Principles of Software Construction: Objects, Design, and Concurrency

Part 4: et cetera

A puzzling finale: What you see is what you get?

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Administrivia

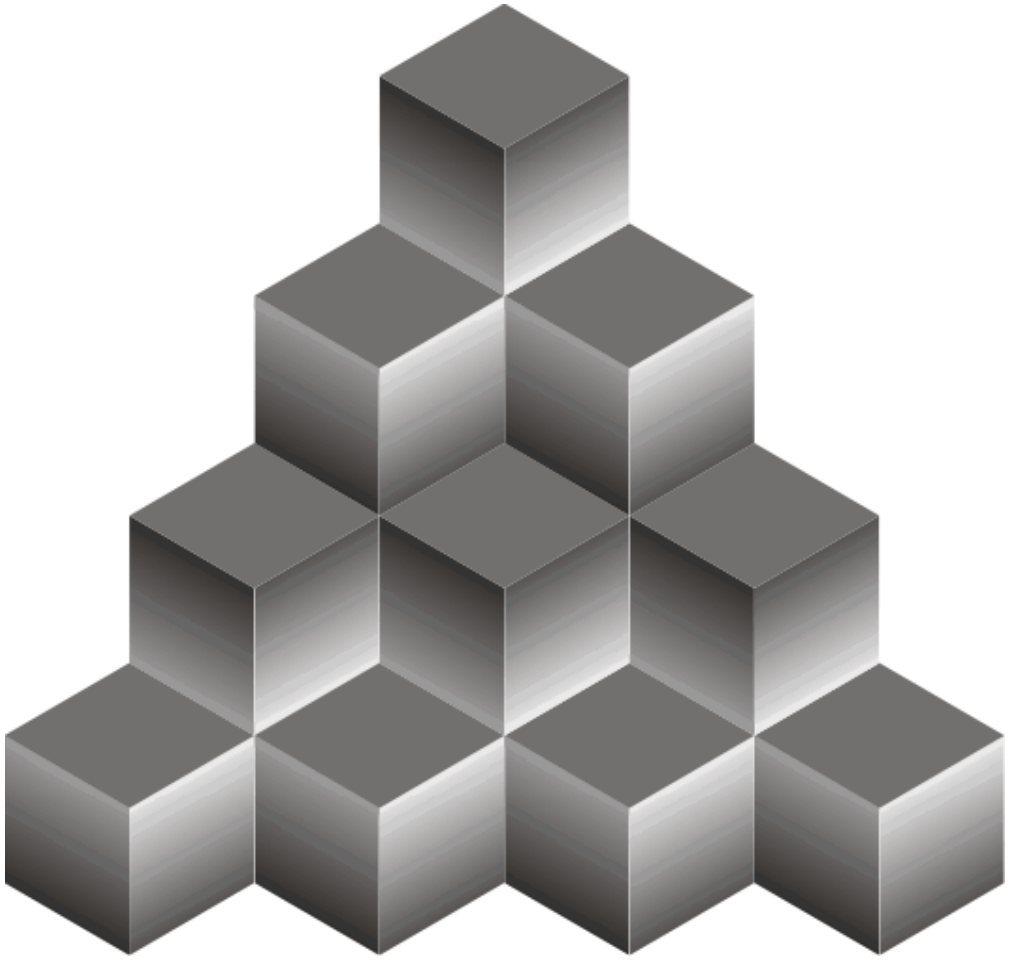
- Homework 6 available
  - Due last night
- Final exam review session Sunday noon - 2 p.m. EDT
  - https://cmu.zoom.us/j/447863845
- Final exam
  - Will be released on Gradescope, Monday 5 p.m. EDT
  - Due Tuesday 8:30 p.m. EDT
  - Designed to take 3 hrs.
  - Open book, open notes
  - Closed person, no interaction with others about the exam
- Evaluate us: https://cmu.smartevals.com/
- Evaluate our TAs: https://www.ugrad.cs.cmu.edu/ta/S20/feedback/

Key concepts from Tuesday

Today: A finale of puzzlers

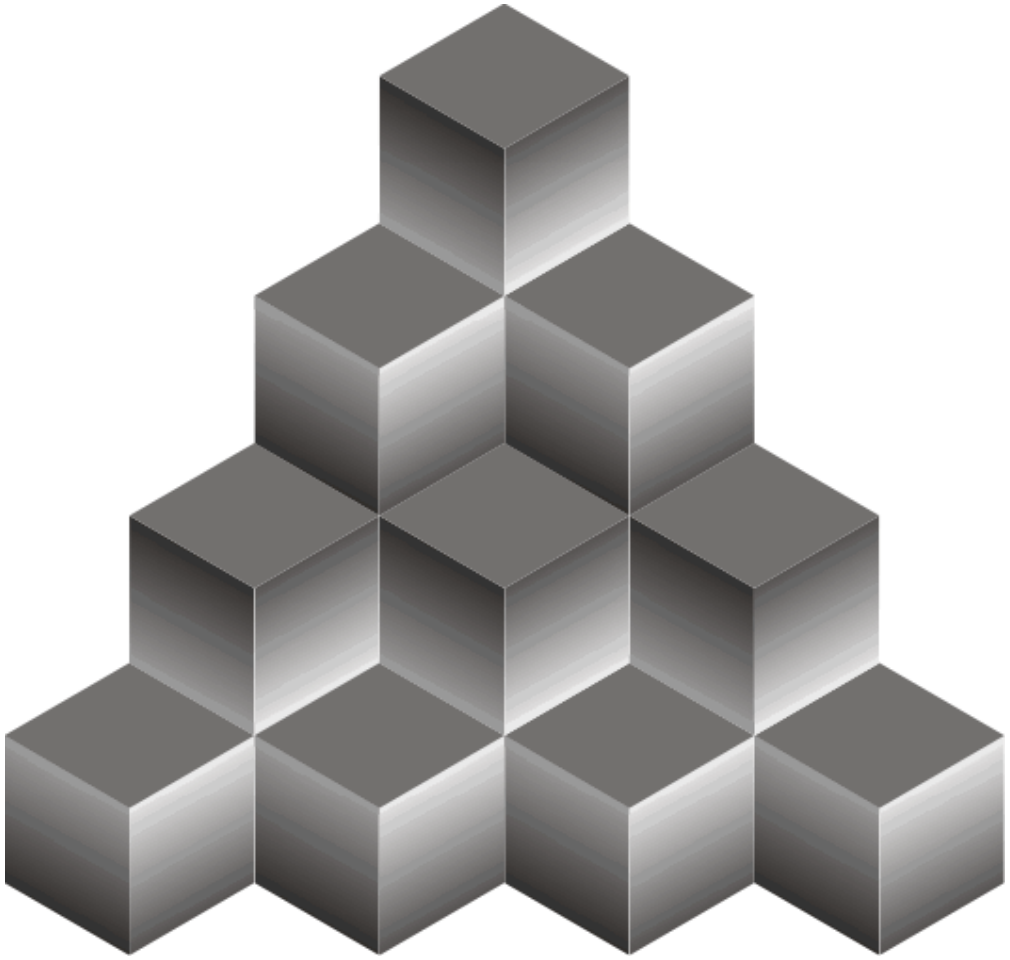
A quick challenge: Implement binary search

```
/**
 * 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);
```

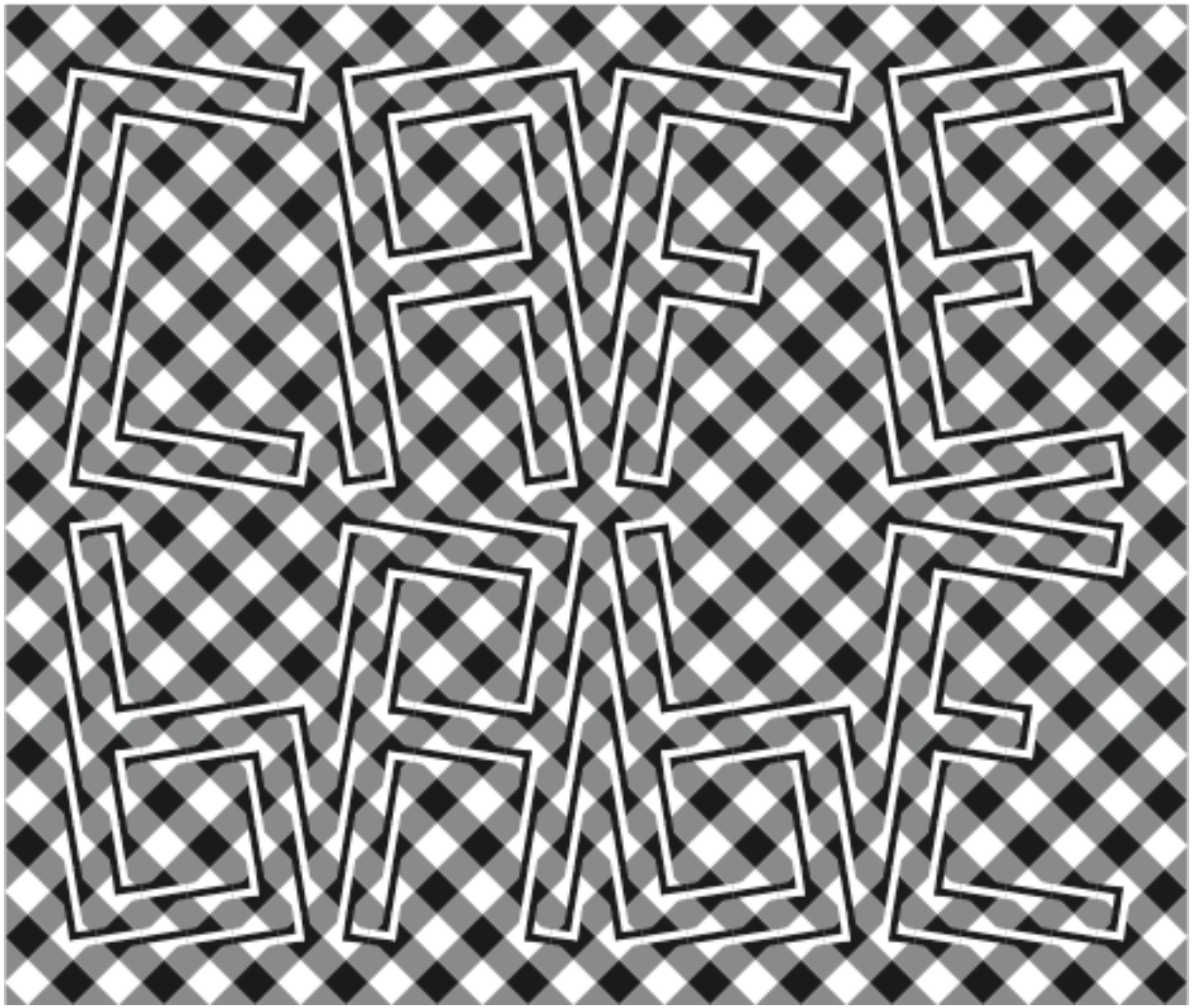


Logvinenko 1999

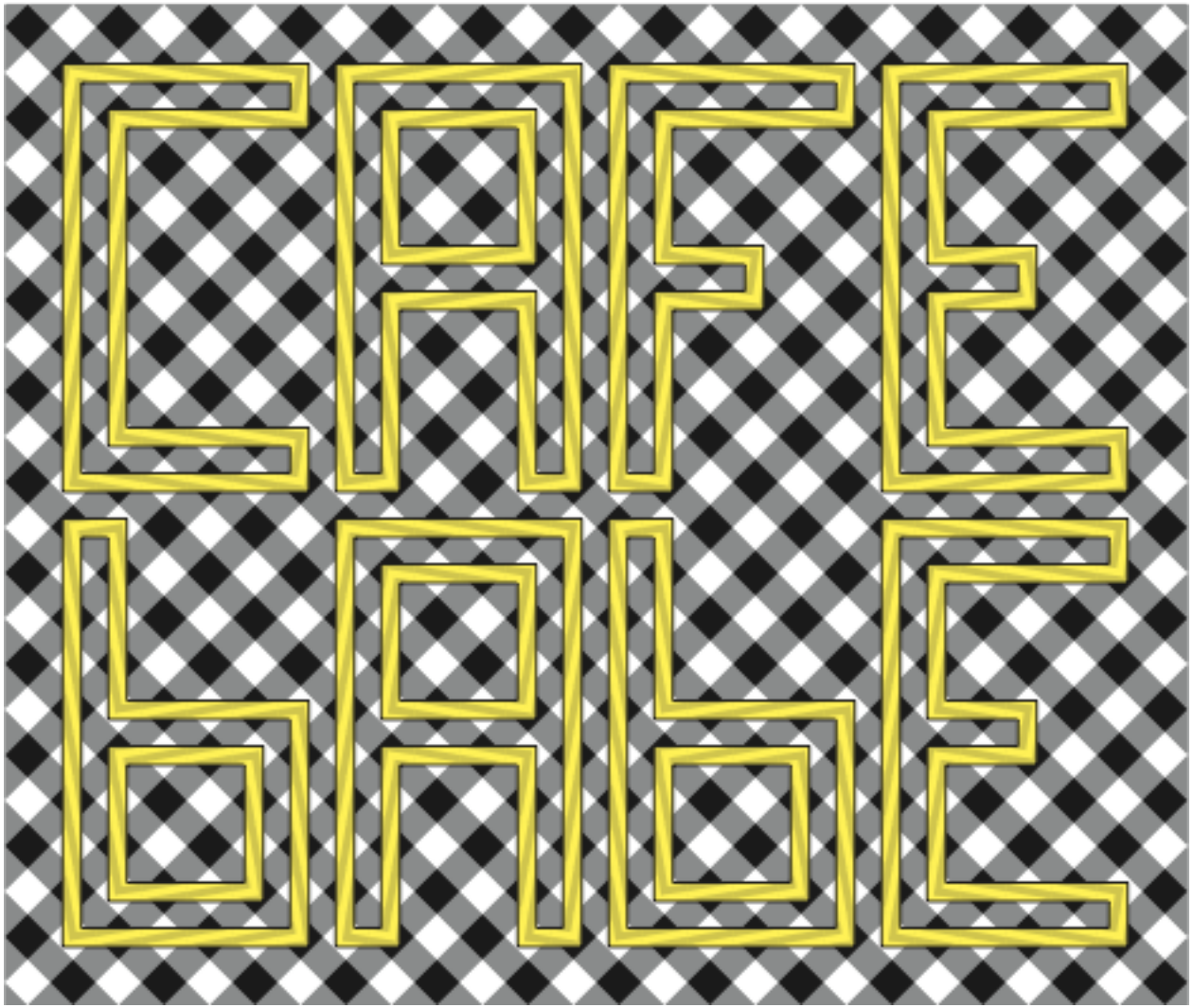
Logvinenko 1999



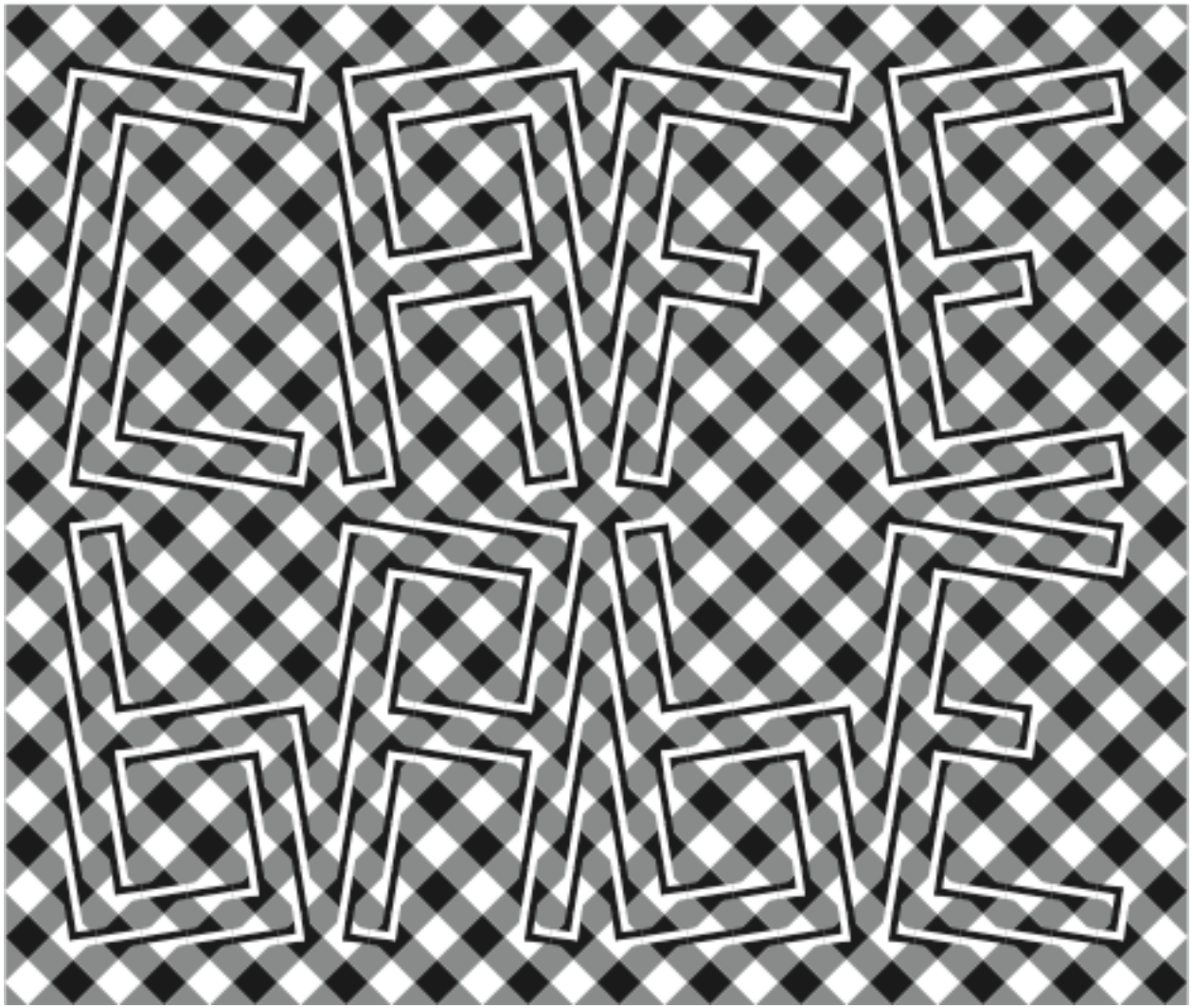
Logvinenko 1999



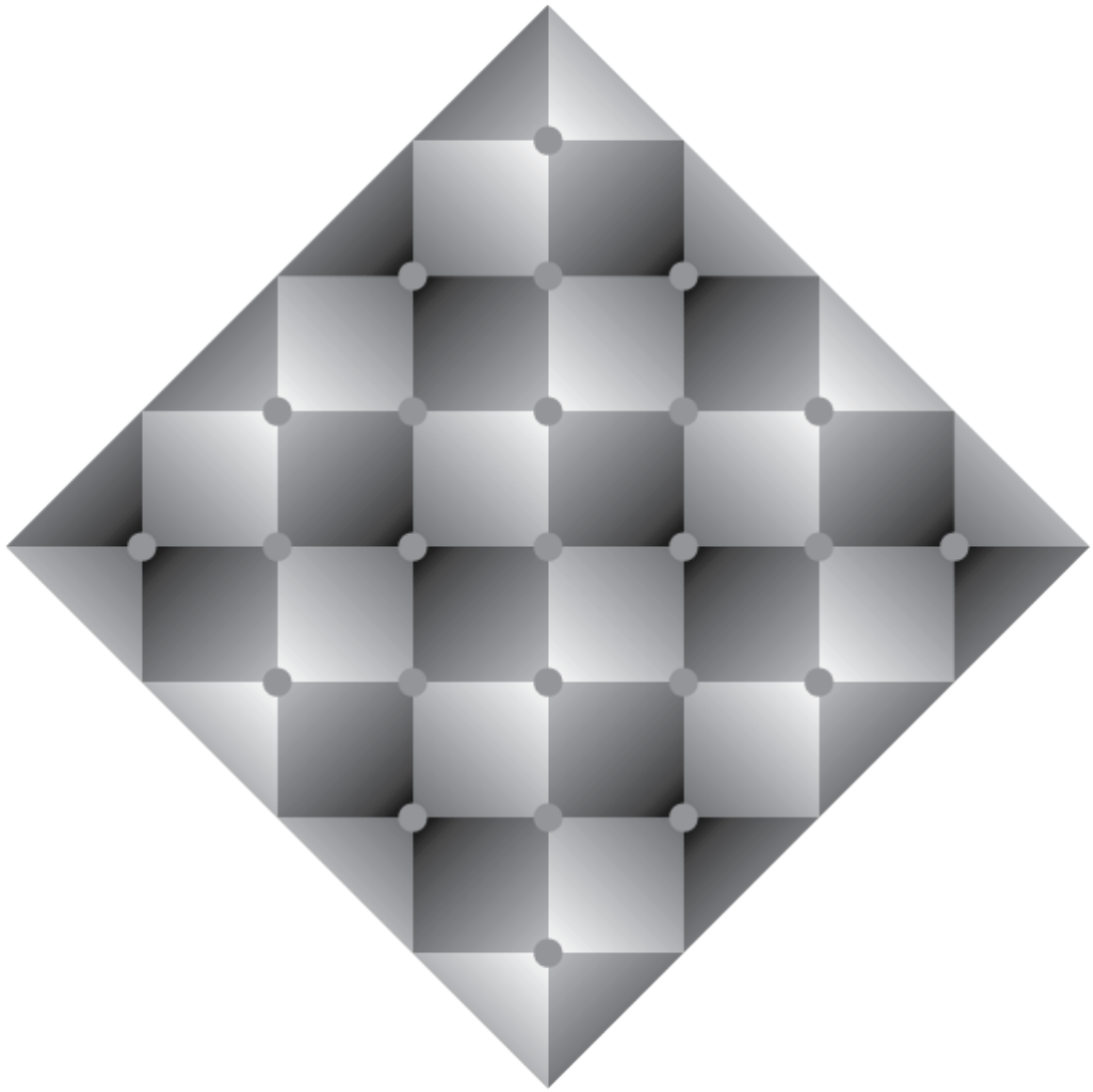
Fraser 1908



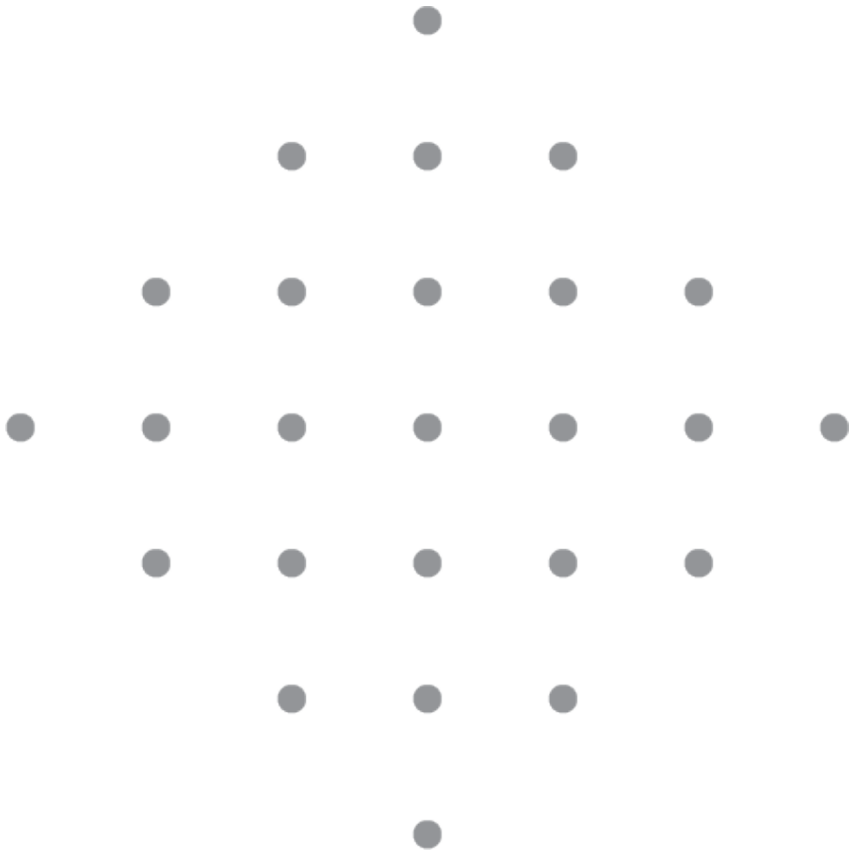
Fraser 1908



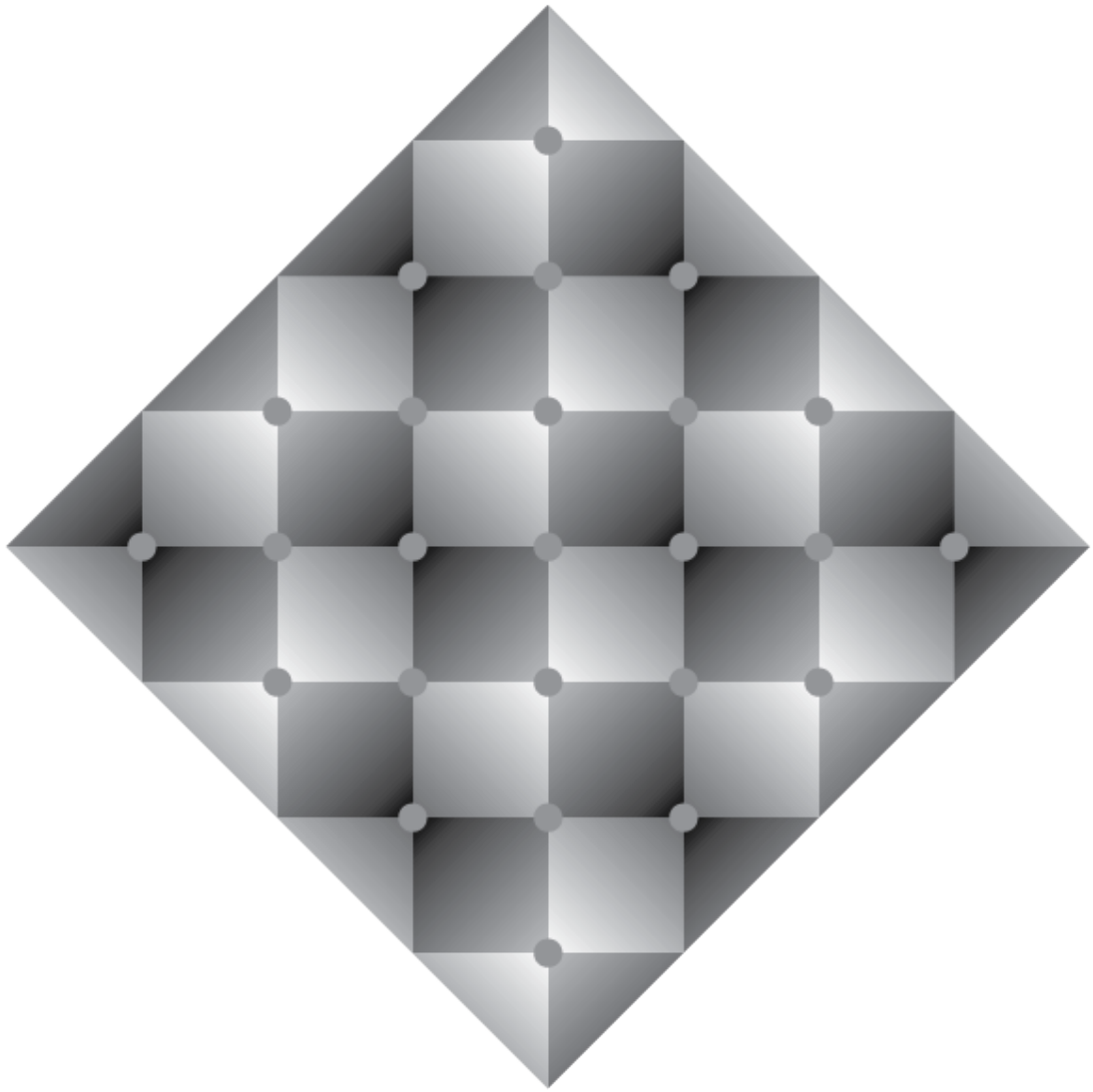
Fraser 1908



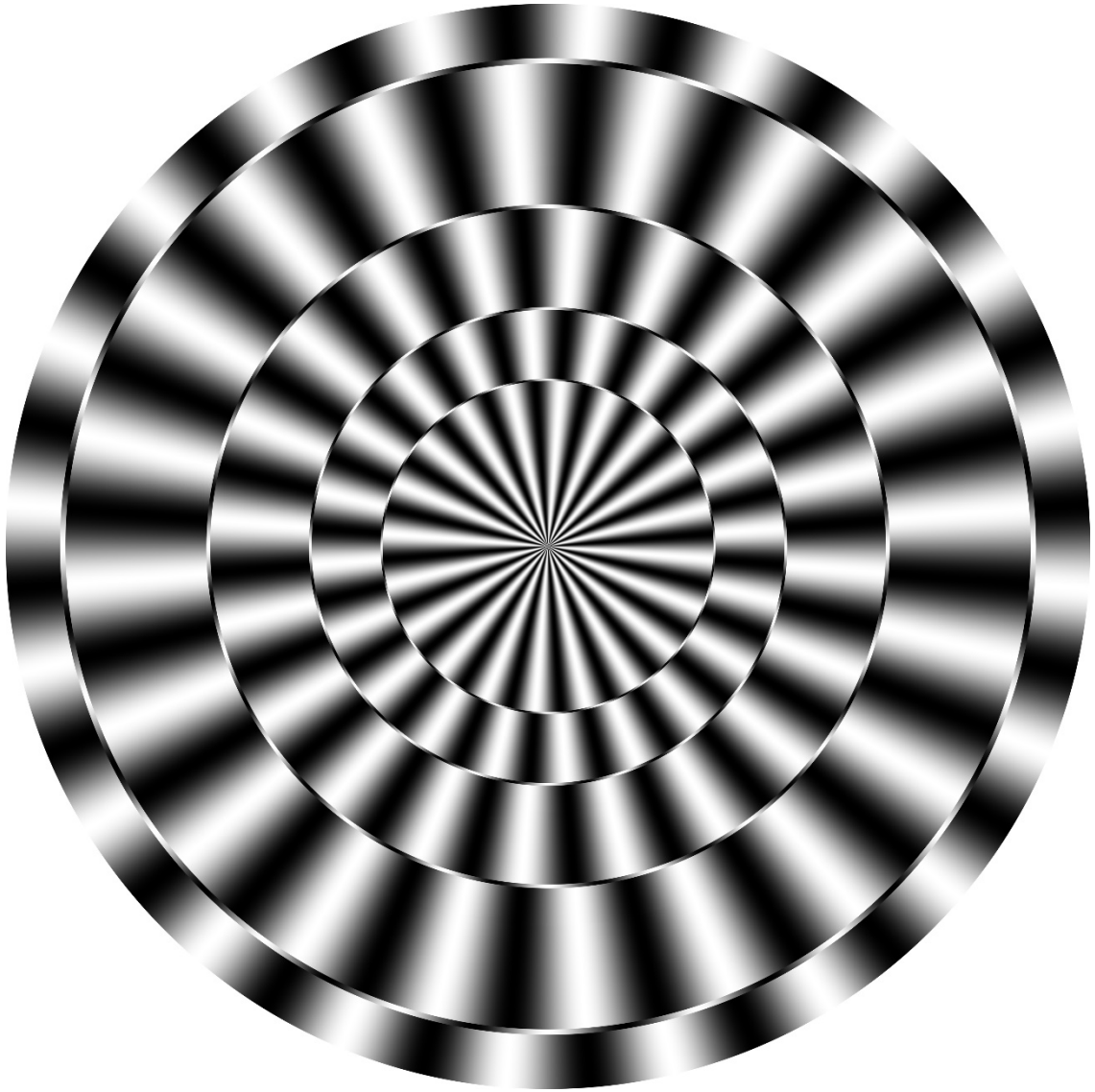
Todorovic 1997



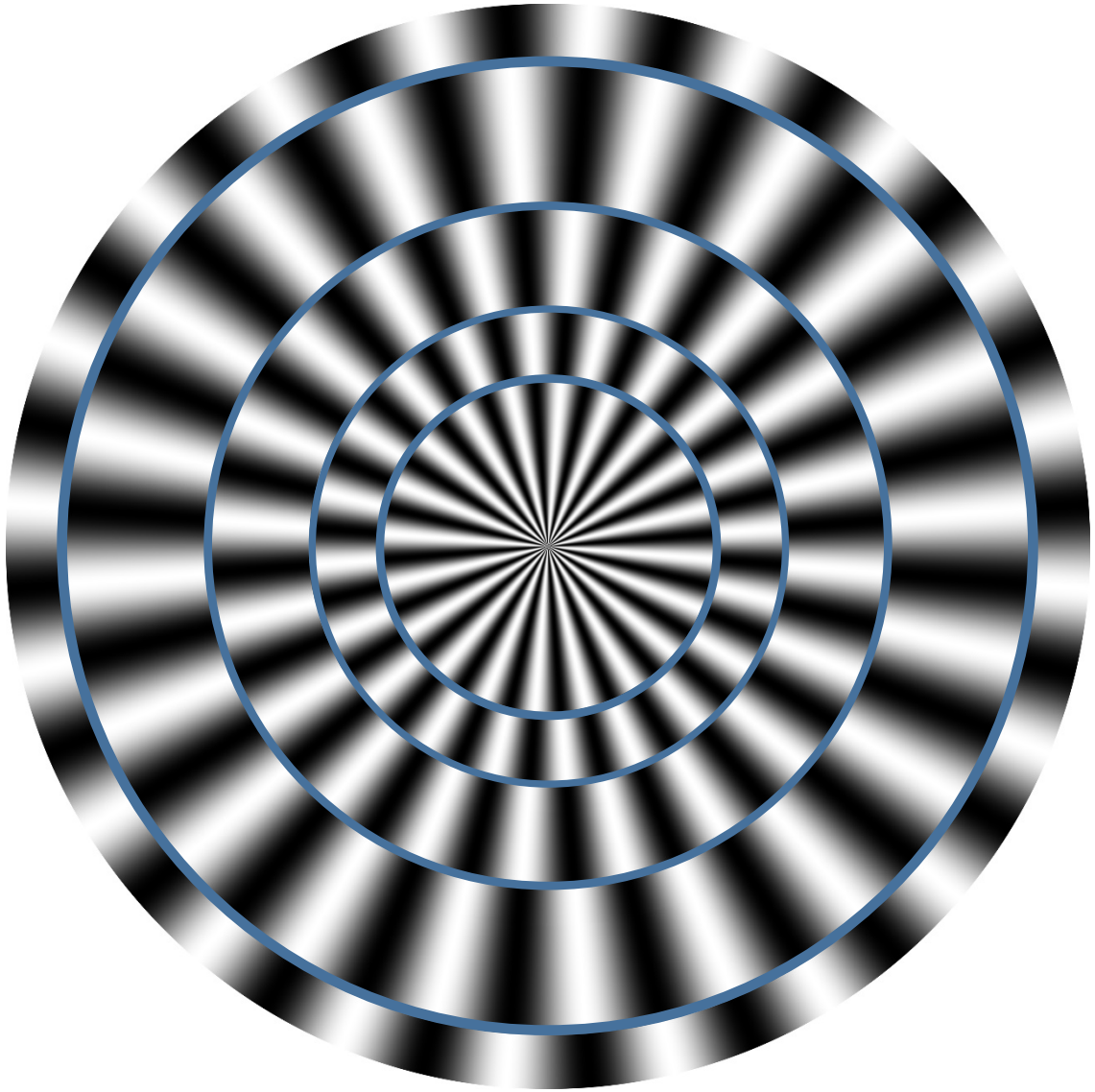
Todorovic 1997



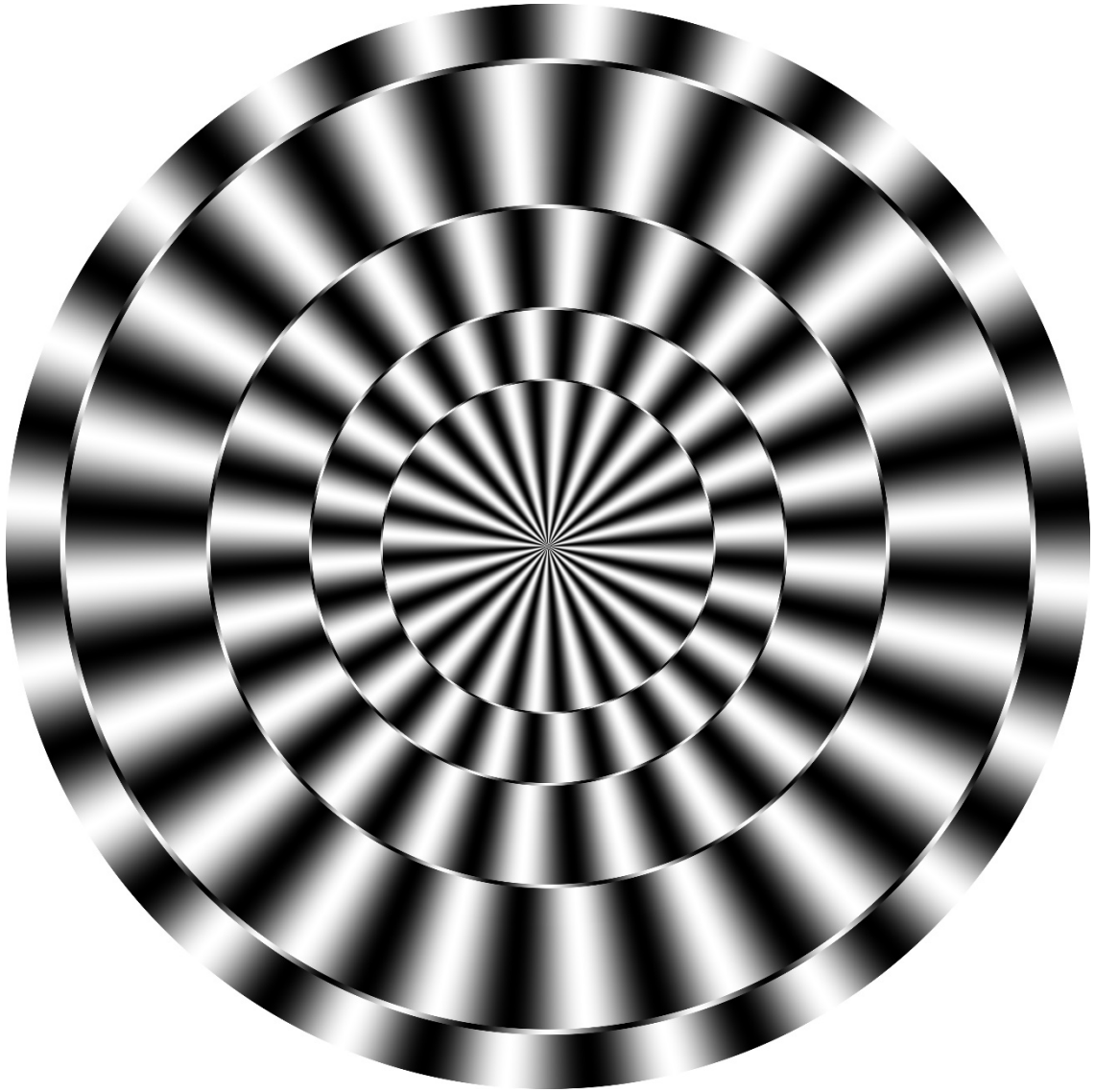
Todorovic 1997



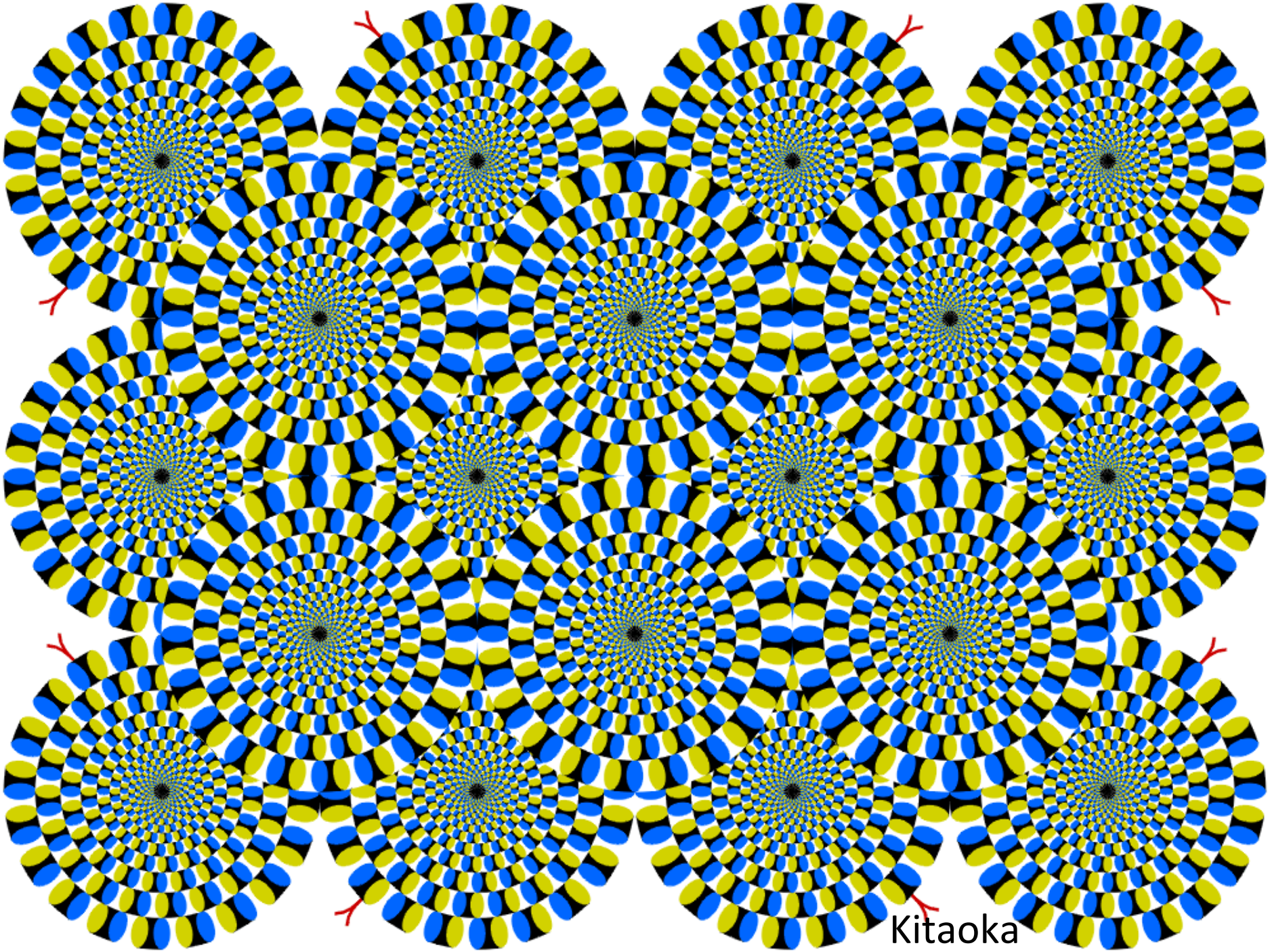
Kitaoka 2020



Kitaoka 2020



Kitaoka 2020


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

“A Big Delight in Every Byte”

```
class Delight {
    public static void main(String[] args) {
        for (byte b = Byte.MIN_VALUE;
             b < Byte.MAX_VALUE; b++) {
            if (b == 0x90)
                System.out.print("Joy! ");
        }
    }
}
```

What Does It Print?

```
class Delight {
    public static void main(String[] args) {
        for (byte b = Byte.MIN_VALUE;
             b < Byte.MAX_VALUE; b++) {
            if (b == 0x90)
                System.out.print("Joy! ");
        }
    }
}
```

(a) `Joy!`
(b) `Joy! Joy!`
(c) **Nothing**
(d) **None of the above**

What Does It Print?

(a) `Joy!`
(b) `Joy!  Joy!`
(c) Nothing
(d) None of the above

Program compares a `byte` with an `int`;
`byte` is *promoted* with surprising results

Another Look

bytes are signed; range from -128 to 127

```
class Delight {
    public static void main(String[] args) {
        for (byte b = Byte.MIN_VALUE;
             b < Byte.MAX_VALUE; b++) {
            if (b == 0x90)  // (b == 144)
                System.out.print("Joy! ");
        }
    }
}



// (byte)0x90 == -112
// (byte)0x90 != 0x90
```

You Could Fix it Like This…

- Cast `int` to `byte`

```
if (b == (byte)0x90)
    System.out.println("Joy!");
```

- Or convert `byte` to `int`, suppressing sign extension with mask

```
if ((b & 0xff) == 0x90)
    System.out.println("Joy!");
```

…But This is Even Better

```
 public class Delight {
    private static final byte TARGET = 0x90; // Won't compile!
    public static void main(String[] args) {
        for (byte b = Byte.MIN_VALUE; b < Byte.MAX_VALUE; b++)
            if (b == TARGET)
                System.out.print("Joy!");
    }
}
```

```
 Delight.java:2: possible loss of precision
found   : int
required: byte
    private static final byte TARGET = 0x90; // Won't compile!
                                       ^
```

The Best Solution, Debugged

```
public class Delight {
    private static final byte TARGET = (byte) 0x90; // Fixed
    public static void main(String[] args) {
        for (byte b = Byte.MIN_VALUE; b < Byte.MAX_VALUE; b++)
            if (b == TARGET)
                System.out.print("Joy!");
    }
}
```

The Moral

- **byte values are signed ☹**
- Be careful when mixing primitive types
- **Compare like-typed expressions**
  - Cast or convert one operand as necessary
  - Declared constants help keep you in line
- For language designers
  - Don't violate principle of least astonishment
  - Don't make programmers' lives miserable

“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 references!

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)

- `int`s 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)

- `int`s aren't `Integer`s
  - 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) It varies
(d) None of the above

What does it print?

(a) `true`
(b) `false`
(c) It varies
(d) None of the above
(e) Who cares?!?

What does it print?

(a) `true`

(b) `false`

(c) It varies

(d) 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;
        }
    }
}
```

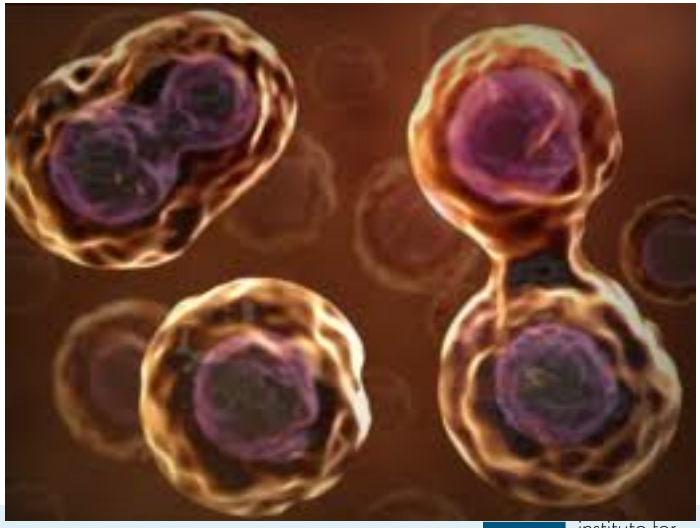
The moral

- Don't rely on obscure language or library details
- Here: Avoid abrupt completion of `finally` blocks
  - Don't return or throw exception from `finally`
  - 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);
    }
}
```

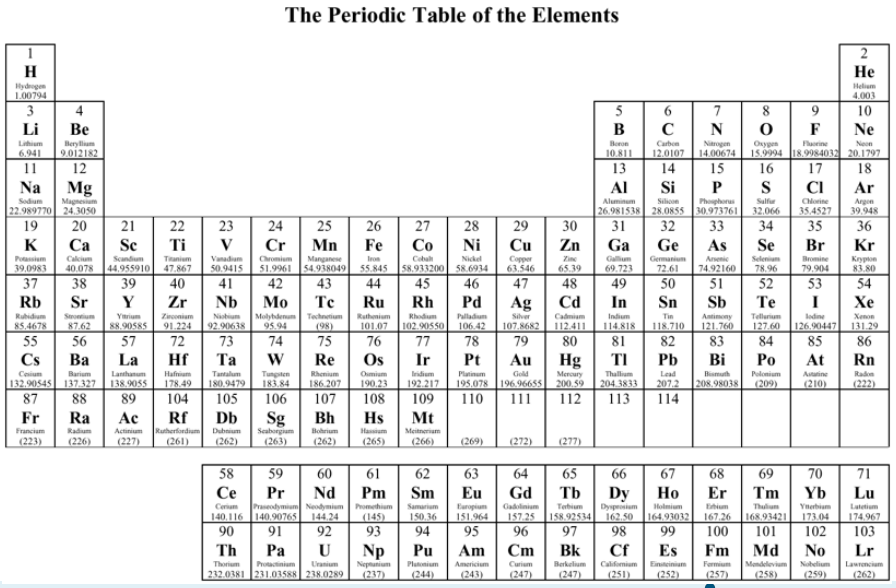
Prints 1000

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 + 54321);
        System.out.println(01234 + 43210);
    }
}
```



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 + 5432l);
        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 (reprised)

- 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