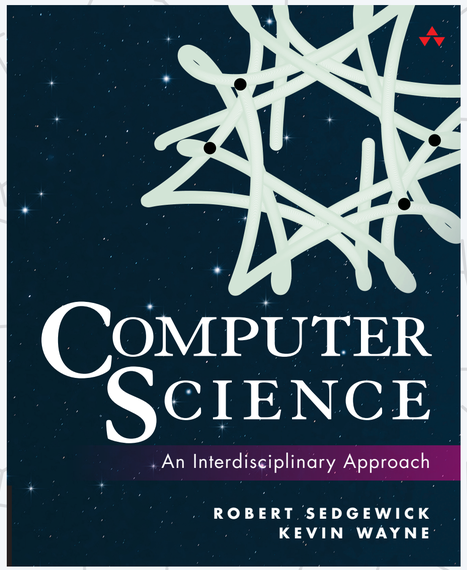

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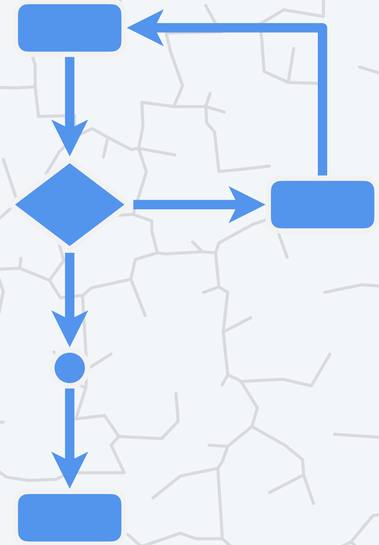
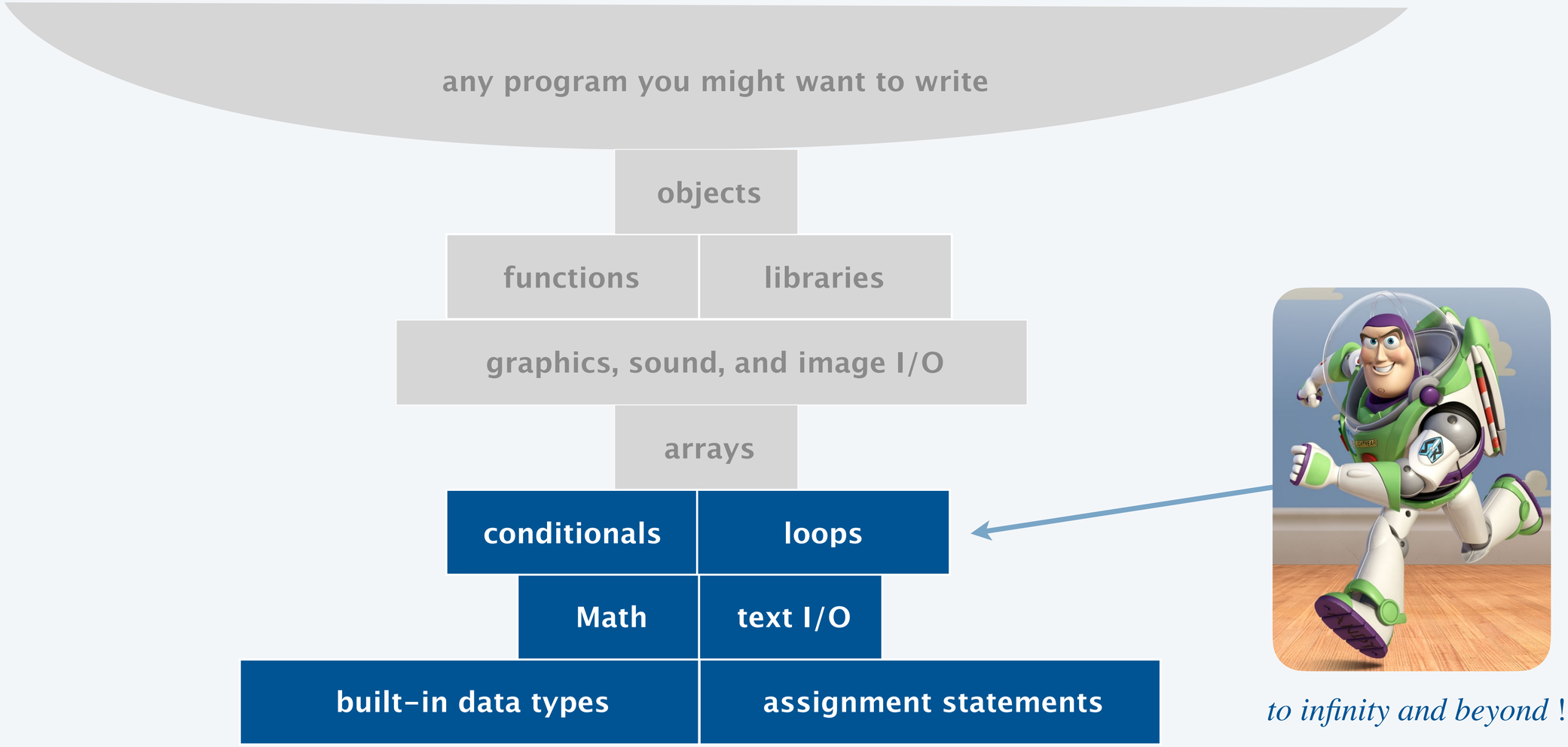
1.3 Loops

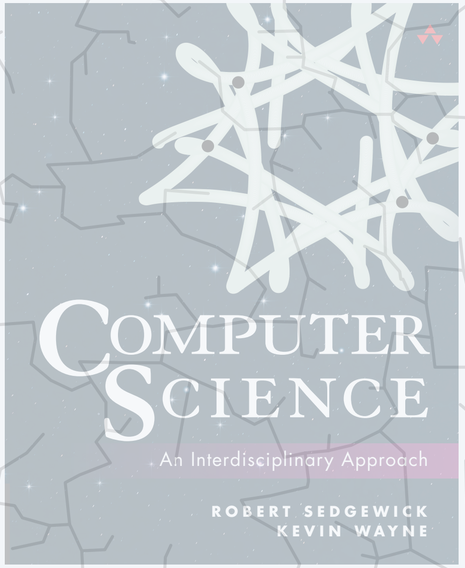
- *while loops*
- *for loops*
- *nested loops*
- *image processing*



Basic building blocks for programming



to infinity and beyond !



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1.3 Loops

- *while loops*
- *for loops*
- *nested loops*
- *image processing*

The *while* loop

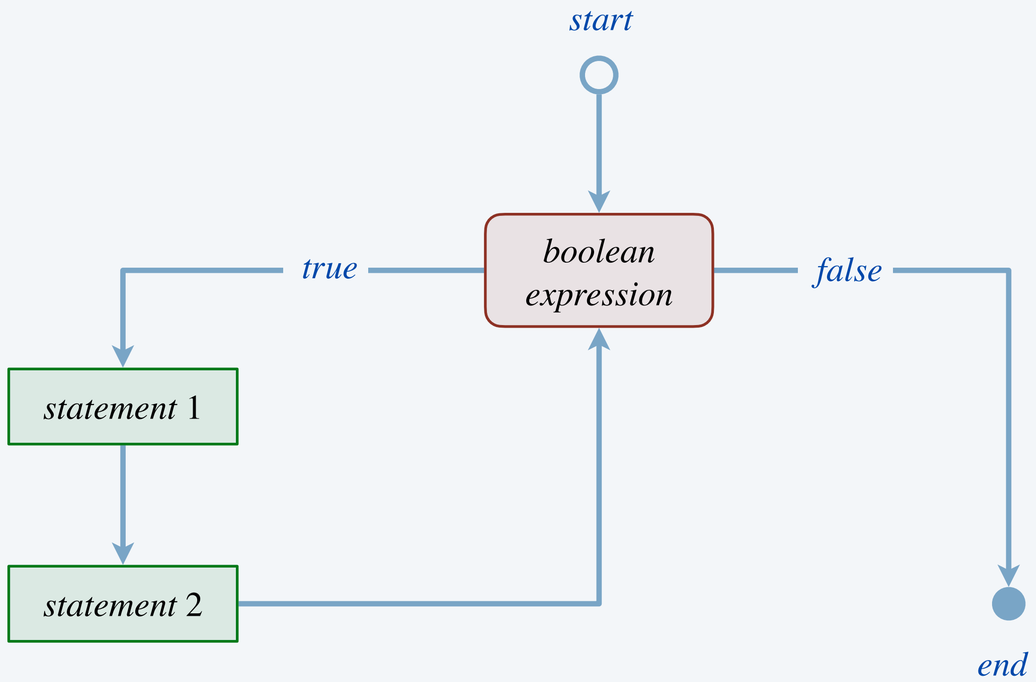
Goal. Repeat a certain statement (or statements).

- Evaluate a boolean expression. If *true*,
  - execute sequence of statements in code block
  - repeat

loop-continuation condition

```
while (<boolean expression>) {
   <statement 1>
   <statement 2>
}
```

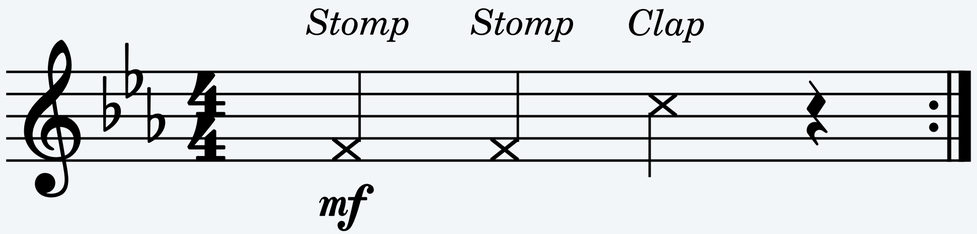
while loop template



while loop flow chart

An infinite *while* loop

Goal. Recreate percussive beat from Queen's *"We Will Rock You."*



effect	audio file	sound
stomp	stomp.wav	
clap	clap.wav	
silence	rest.wav	

```
public class StompStompClap {
   public static void main(String[] args) {
      while (true) {
         StdAudio.play("stomp.wav");
         StdAudio.play("stomp.wav");
         StdAudio.play("clap.wav");
         StdAudio.play("rest.wav");
      }
   }
}
```

an infinite loop

```
~/cos126/loops> java-introcs StompStompClap
[plays stomp-stomp-clap beat]
```

<Ctrl–C> *to break out of infinite loop*

Counting from 1 to n

Goal. Repeat a ringtone n times.

```
public class Ringtone {
   public static void main(String[] args) {
      String filename = args[0];
      int n = Integer.parseInt(args[1]);

      int i = 1;
      while (i <= n) {
         StdAudio.play(filename);
         i++;
      }

   }
}
```

repeat n *times*

shorthand for

```
i = i + 1;
```

```
~/cos126/loops> java-introcs Ringtone marimba.wav 1
[plays marimba ringtone once]

~/cos126/loops> java-introcs Ringtone marimba.wav 3
[plays marimba ringtone three times]

~/cos126/loops> java-introcs Ringtone sonar.wav 2
[plays sonar ringtone twice]
```

Counting from 1 to n

Goal. Repeat a ringtone n times.

Trace. Show values of variables at end of each iteration of *while* loop.

```
public class Ringtone {
   public static void main(String[] args) {
      String filename = args[0];
      int n = Integer.parseInt(args[1]);

      int i = 1;
      while (i <= n) {
         StdAudio.play(filename);
         i++;
      }

   }
}
```

filename	*n*	*i*	
"marimba.wav"	3	1	← *before loop*
"marimba.wav"	3	2	
"marimba.wav"	3	3	
"marimba.wav"	3	4	← *after loop*

a trace of variables
(values at end of each loop iteration)

Loops: quiz 1

What does the following program do when *n* is 10?

A. Print 0 to 10.

B. Print powers of 2, from 2^0 to 2^9.

C. Print powers of 2, from 2^0 to 2^{10}.

D. Print powers of 2, from 2^0 to 2^{11}.

E. Print powers of 2, from 2^1 to 2^{10}.

```
public class Mystery {
   public static void main(String[] args) {
      int n = Integer.parseInt(args[0]);
      int i = 0;
      int value = 1;

      while (i <= n) {
         System.out.println(value);
         i++;
         value = value * 2;
      }

   }
}
```

Examples of *while* loops

computation	while loop

print integers from n down to 1	`int i = n;`
	`while (i >= 1) {`
	`  System.out.println(i);`
	`  i--;`
	`}`

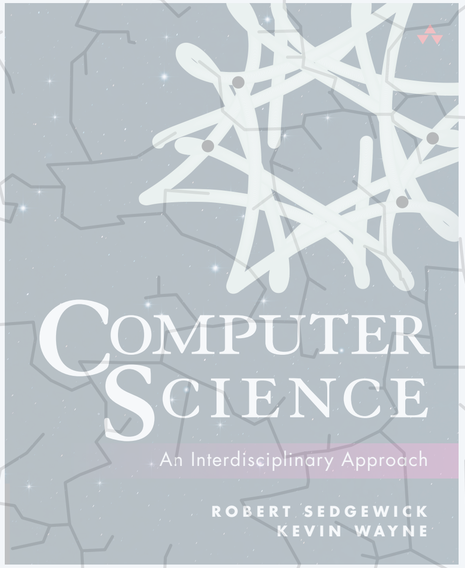
infinite loop	`while (true) {`
	`  StdAudio.play("clap.wav");`
	`}`

number of decimal digits in positive integer x	`int digits = 0;`
	`while (x > 0) {`
	`  x = x / 10;`
	`  digits++;`
	`}`

shorthand for `i = i - 1`

integer division

curly braces are optional here since only one statement in body of loop (but better style to use curly braces)



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LOOPS

- *while loops*
- *for loops*
- *nested loops*
- *image processing*

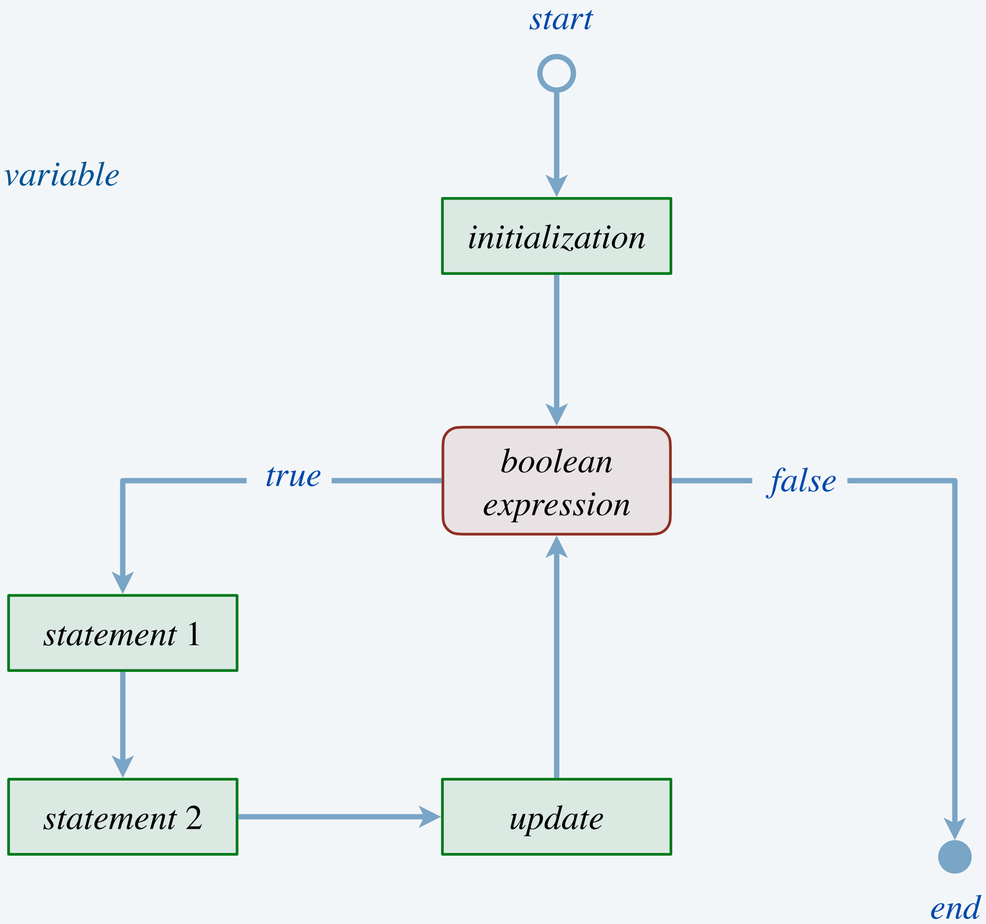
The *for* loop

An alternative repetition structure.

- Perform an initialization step. ← *typically, declaring and initializing a variable*
- Evaluate a boolean expression. If *true*,
  - execute sequence of statements in code block
  - perform an update step ← *typically, updating the value of the variable*
  - repeat

```
for (<init>; <boolean expression>; <update>) {
   <statement 1>
   <statement 2>
}
```

for loop template



for loop flowchart

Counting from 1 to n

Goal. Play a WAV file n times. ← *identical behavior as* `Ringtone.java`

```
public class MusicLoop {
   public static void main(String[] args) {
      String filename = args[0];
      int n = Integer.parseInt(args[1]);

      for (int i = 1; i <= n; i++) {
         StdAudio.play(filename);
      }

   }
}
```

repeat `n` *times*

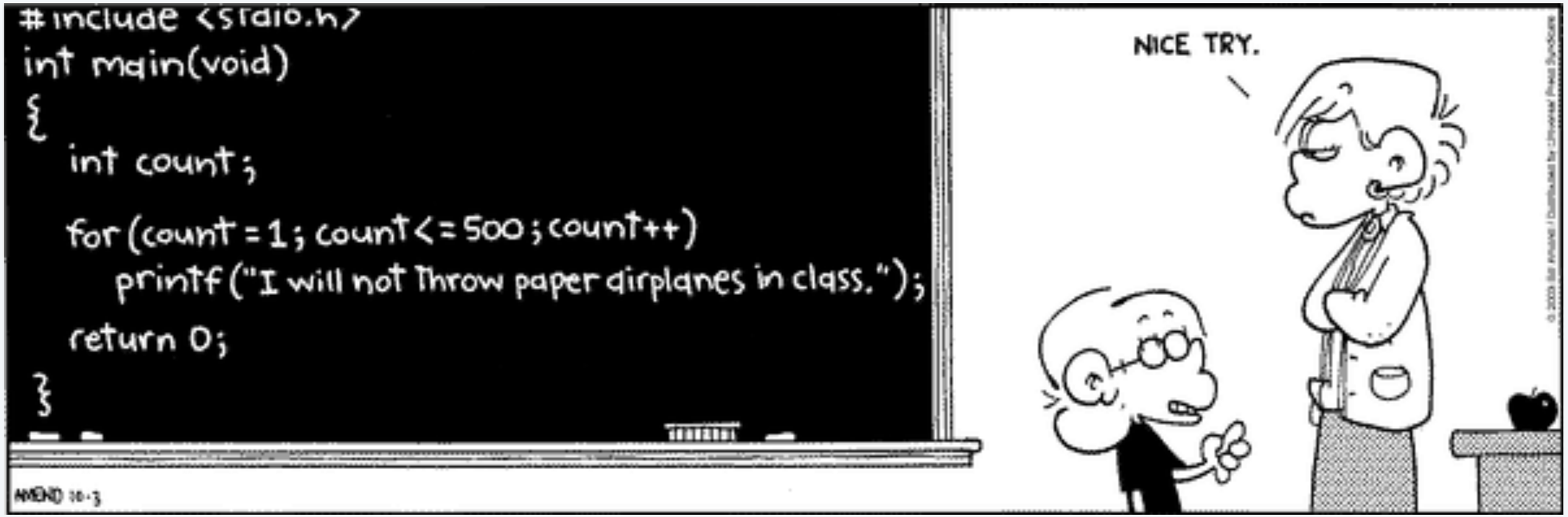
```
~/cos126/loops> java-introcs MusicLoop heartbeat.wav 1
[plays heartbeat once]

~/cos126/loops> java-introcs MusicLoop heartbeat.wav 9999999
[plays heartbeat repeatedly]

~/cos126/loops> java-introcs MusicLoop AmenBreak.wav 10
[plays The Winstons "Amen Break" drum break 10 times]
```

among most sampled tracks in music history

A *for* loop (in C)



Examples of *for* loops

computation	for loop

factorial $(1 \times 2 \times 3 \times \ldots \times n)$	`int product = 1;`
	`for (int i = 2; i <= n; i++) {`
	`  product = product * i;`
	`}`

print integers from n down to 1	`for (int i = n; i >= 1; i--) {`
	`  System.out.println(i);`
	`}`

infinite loop	`for (;;) {`
	`  StdAudio.play("heartbeat.wav");`
	`}`

curly braces are optional since only one statement in body of loop (but better style to include)

empty initialization and update (⟹ better style to use `while` *loop)*

Loops: quiz 2

Q. Which value does the following program print when n is 3?

A. 0 1 2 3 2 1 0

B. 0 1 0 2 0 1 0

C. 0 1 0 2 0 1 0 3

D. 0 1 0 2 0 1 0 3 0 1 0 2 0 1 0

```
public class Ruler {
   public static void main(String[] args) {
      int n = Integer.parseInt(args[0]);

      String ruler = "0";
      for (int i = 1; i <= n; i++) {
         ruler = ruler + " " + i + " " + ruler;
      }

      System.out.println(ruler);
   }
}
```

While loop vs. for loop

Fact. Any *while* loop can be replaced with a *for* loop, and vice versa.

Q. Which one should I use?

A. Guiding principle: use loop construct that leads to clearer code.

Rule-of-thumb. Use a *for* loop when you know the number of iterations ahead of time.

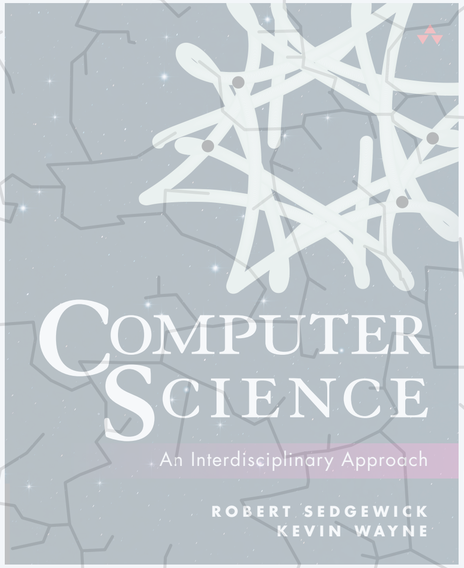
```
int i = 1;
while (i <= n) {
   StdAudio.play(filename);
   i++;
}
```

while loop

```
for (int i = 1; i <= n; i++) {
   StdAudio.play(filename);
}
```

code controlling loop localized to one place

equivalent for loop
(except i not accessible after loop)



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LOOPS

- *while loops*
- *for loops*
- *nested loops*
- *image processing*

Loops: quiz 3

Suppose m = 10 and n = 5. How many lines of output does the following program produce?

A. 10

B. 15

C. 50

D. 55

E. 60

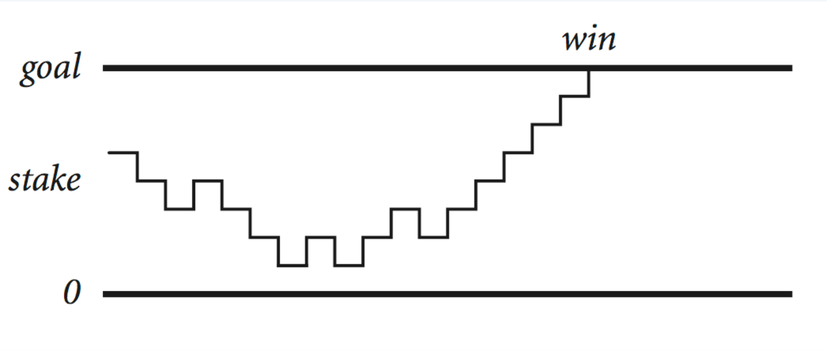
```
public class Mystery {
   public static void main(String[] args) {
      int m = Integer.parseInt(args[0]);
      int n = Integer.parseInt(args[1]);

      for (int i = 1; i <= m; i++) {
         for (int j = 1; j <= n; j++) {
            System.out.println(i + "-" + j);
         }
      }

   }
}
```

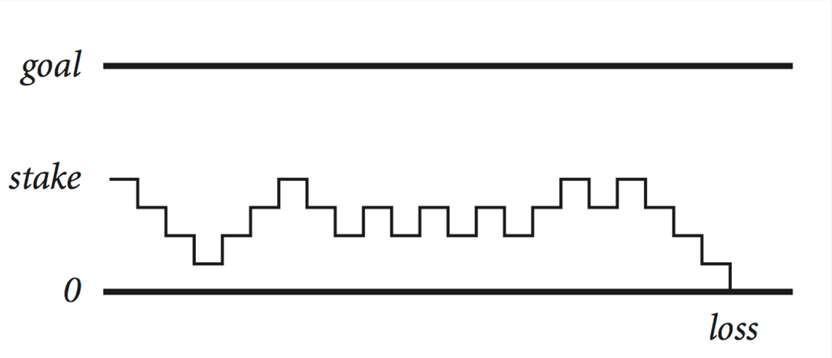
`for` *loop nested within a* `for` *loop*

Gambler's ruin problem

Gambler's ruin. A gambler starts with $\$stake$ and places $\$1$ fair bets.

- Outcome 1 (win): gambler reaches $\$goal$.
- Outcome 2 (loss): gambler goes broke with $\$0$.





Q1. What are the chances of winning?

Q2. How many bets until win or loss?

One approach. [Monte Carlo simulation]

- Perform one experiment using simulated coin flips.
- Repeat experiment many times and collect statistics.

Gambler's ruin problem: one experiment

Warmup. Simulate one experiment. ← *use* `while` *loop* (*don't know how many iterations*)

```
public class GamblerWarmup {
   public static void main(String[] args) {
      int stake = Integer.parseInt(args[0]);
      int goal  = Integer.parseInt(args[1]);

      int cash = stake;
      System.out.println(cash);
      while ((cash > 0) && (cash < goal)) {
         if (Math.random() < 0.5) cash++;
         else                     cash--;
         System.out.println(cash);
      }
   }
}
```

← `if-else` *statement nested within a* `while` *loop*

print trace (*for debugging only*)

```
~/loops> java GamblerWarmup 4 10
4
5
4
3
4
3
2
1
2
1
0
```

Monte Carlo simulation of gambler's ruin problem

```
public class Gambler {
   public static void main(String[] args) {
      int stake  = Integer.parseInt(args[0]);
      int goal   = Integer.parseInt(args[1]);
      int trials = Integer.parseInt(args[2]);

      int wins = 0;
      for (int t = 1; t <= trials; t++) {
         int cash = stake;
         while ((cash > 0) && (cash < goal)) {
            if (Math.random() < 0.5) cash++;
            else                     cash--;
         }
         if (cash == goal) wins++;
      }

      System.out.println(wins + " wins of " + trials);
   }
}
```

```
~/cos126/loops> java Gambler 5 25 1000
191 wins of 1000

~/cos126/loops> java Gambler 5 25 1000
183 wins of 1000
```

do `trials` *experiments*

initialize `cash` *to* `stake` *for each experiment*

do one experiment

make one bet

if goal met in experiment `t`*,*
record as a win

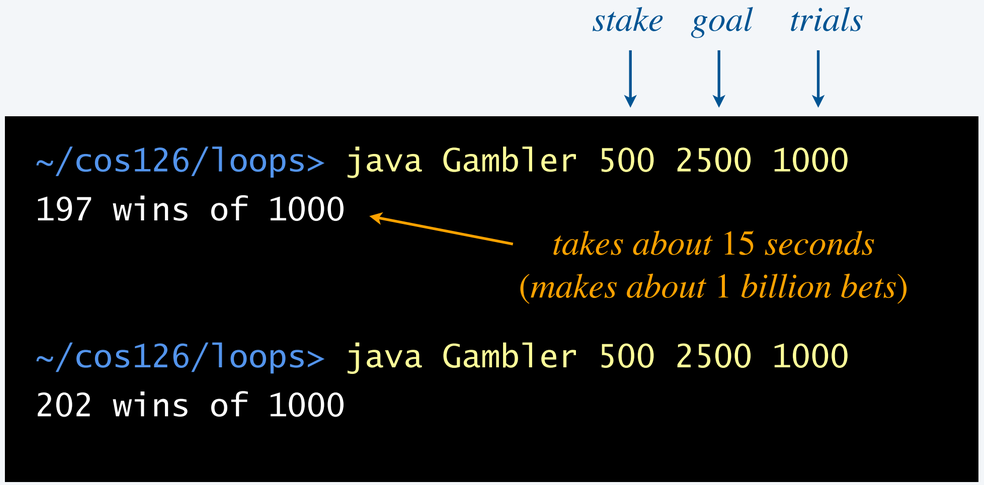
Digression: simulation vs. mathematical analysis

Facts. [known via probability theory]

- Probability of winning = $stake \div goal$.
- Expected number of bets = $stake \times (goal - stake)$.

Ex. [$stake = 500, goal = 2500$]

- 20% chance of winning.
- Expect to make 1 million bets per experiment.



Remarks.

- For gambler's ruin, mathematical analysis is well known.
- Computer simulation agrees with math.
- For more complicated variants, math may be beyond reach.
- Monte Carlo simulations widely used in STEM.

Integer factorization

Goal. Given a positive integer n, find its prime factorization.

$$98 = 2 \times 7 \times 7$$

$$3{,}757{,}208 = 2 \times 2 \times 2 \times 7 \times 13 \times 13 \times 397$$

$$11{,}111{,}111{,}111{,}111{,}111 = 2{,}071{,}723 \times 5{,}363{,}222{,}357$$

Grade-school factoring algorithm.

FACTOR(n)

Consider each potential divisor d between 2 and n:

- ***while*** d is a divisor of n:
  - ***print*** d
  - $n \leftarrow n / d$

Critical application. Cryptography.

security of internet commerce relies on difficulty of factoring very large integers

Integer factorization

```
public class Factors {
   public static void main(String[] args) {
      long n = Long.parseLong(args[0]);

      for (long d = 2; d <= n; d++) {
         while (n % d == 0) {
            System.out.print(d + " ");
            n = n / d;
         }
      }
      System.out.println();

   }
}
```

try all possible divisors d

d is a divisor, so factor it out

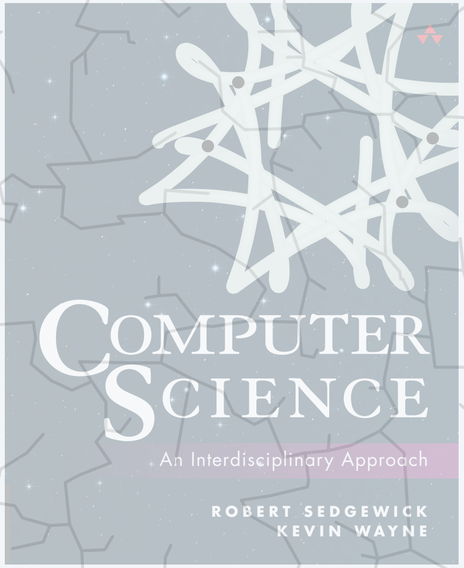
```
~/cos126/loops> java Factors 98
2 7 7

~/cos126/loops> java Factors 3757208
2 2 2 7 13 13 397

~/cos126/loops> java Factors 97
97

~/cos126/loops> java Factors 11111111111111111
2071723 5363222357
```

takes a few seconds

Remark 1. Uses *long* instead of *int* to support integers between -2^{63} and $2^{63} - 1$.

Remark 2. Way too slow to break cryptography.

can be sped up substantially by stopping when $d > \sqrt{n}$ (but still way too slow)



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LOOPS

- *while loops*
- *for loops*
- *nested loops*
- *image processing*

Image processing

A picture is a *width*-by-*height* grid of pixels; each pixel has a color.

mandrill.jpg

arch.jpg

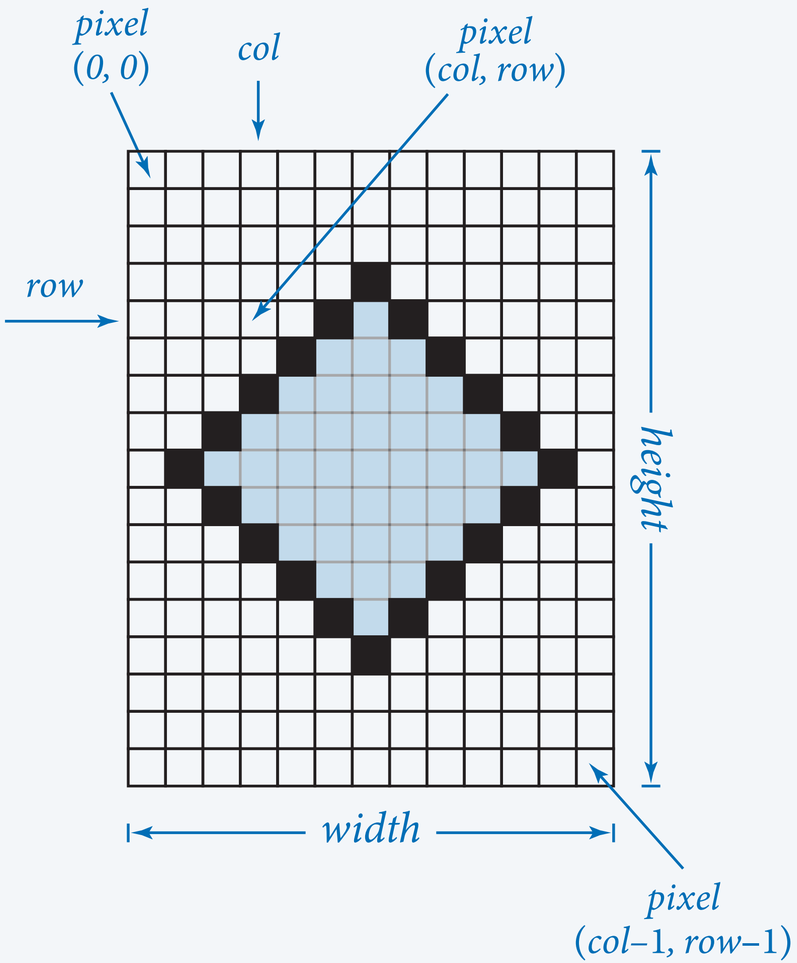


Image-processing conventions.

- Pixel (i, j) means column i and row j.
- Pixel $(0, 0)$ is upper-left.

warning: different conventions from matrices and Cartesian coordinates

RGB color model

Color is a sensation in the eye from electromagnetic radiation.

RGB color model. Popular format for representing color on digital displays.

- Color is composed of red, green, and blue components.
- Each color component is an integer between 0 to 255.

name	red	green	blue	color
red	255	0	0	
green	0	255	0	
blue	0	0	255	
black	0	0	0	
white	255	255	255	
yellow	255	255	0	
magenta	255	0	255	
cyan	0	255	255	
book blue	0	64	128	

Grayscale

Goal. Convert color image to grayscale. ← *fundamental operation in computer graphics and vision*

- RGB color is a shade of gray when $R = G = B$.
- To convert RGB color to grayscale, use luminance for R, G, and B values:

$$Y = 0.299\,R + 0.587\,G + 0.114\,B$$

name	red	green	blue	color	lum	gray
red	255	0	0		76	
green	0	255	0		150	
blue	0	0	255		29	
black	0	0	0		0	
white	255	255	255		255	
yellow	255	255	0		226	
magenta	255	0	255		105	
cyan	0	255	255		179	
book blue	0	64	128		52	

$$Y = 0.299\,R + 0.587\,G + 0.114\,B$$
$$= 0.299\,(0) + 0.587\,(64) + 0.114\,(128)$$
$$= 52.16$$

Standard picture library

StdPicture. Our library for manipulating images. ← *available with* `javac-introcs` *and* `java-introcs` *commands*

`public class StdPicture`

`static void read(String filename)`	*initialize picture from* `filename`
`static void save(String filename)`	*save picture to* `filename`
`static int width()`	*width of picture*
`static int height()`	*height of picture*
`static int getRed(int col, int row)`	*red component of pixel* (`col`, `row`)
`static int getGreen(int col, int row)`	*green component of pixel* (`col`, `row`)
`static int getBlue(int col, int row)`	*blue component of pixel* (`col`, `row`)
`static void setRGB(int col, int row, int r, int g, int b)`	*set color of pixel* (`col`, `row`) *to* (`r`, `g`, `b`)
⋮	⋮

← *supported file formats: JPEG, PNG, GIF, TIFF, BMP*

Grayscale filter

```
public class Grayscale {
   public static void main(String[] args) {
      String filename = args[0];
      StdPicture.read(filename);
      int width = StdPicture.width();
      int height = StdPicture.height();

      for (int col = 0; col < width; col++) {
         for (int row = 0; row < height; row++) {
            int r = StdPicture.getRed(col, row);
            int g = StdPicture.getGreen(col, row);
            int b = StdPicture.getBlue(col, row);
            int y = (int) (Math.round(0.299*r + 0.587*g + 0.114*b));
            StdPicture.setRGB(col, row, y, y, y);
         }
      }

      StdPicture.show();
   }
}
```

read picture from file and get dimensions

iterate over all pixels

get RGB values

red green blue

luminance formula

$(Y = 0.299\,R + 0.587\,G + 0.114\,B)$

display picture in window

```
~/> java-introcs Grayscale arch.jpg
```

Image processing: color image filters

original

grayscale

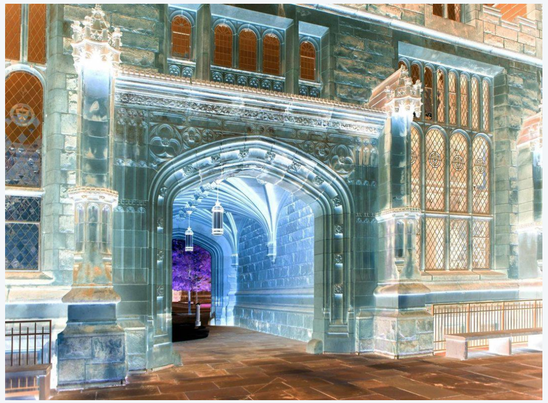
sepia

duotone

brighter

darker

RGB layers



negative

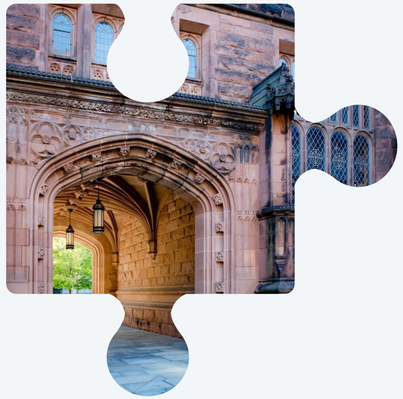
Image processing: shape masks

original

rounded rectangle

oval

heart

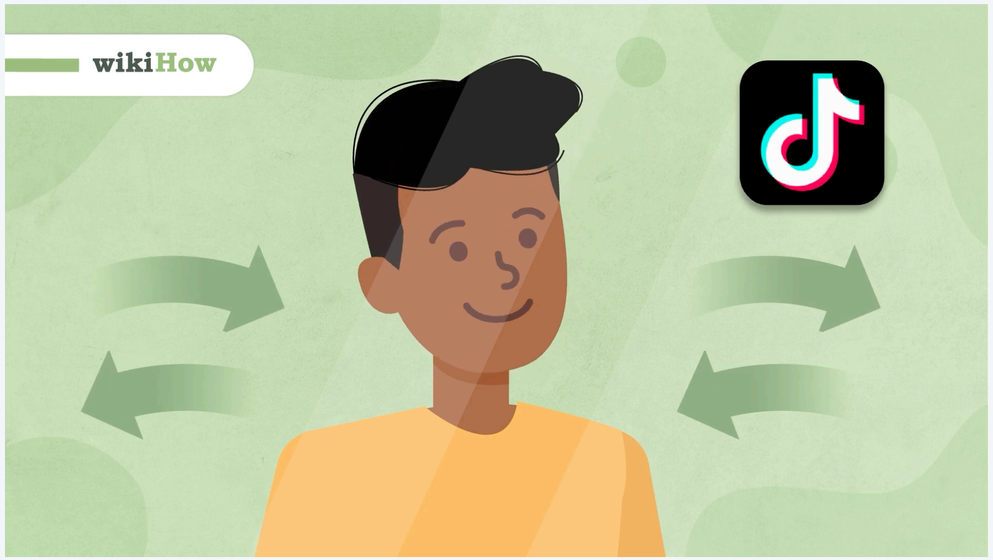


puzzle piece

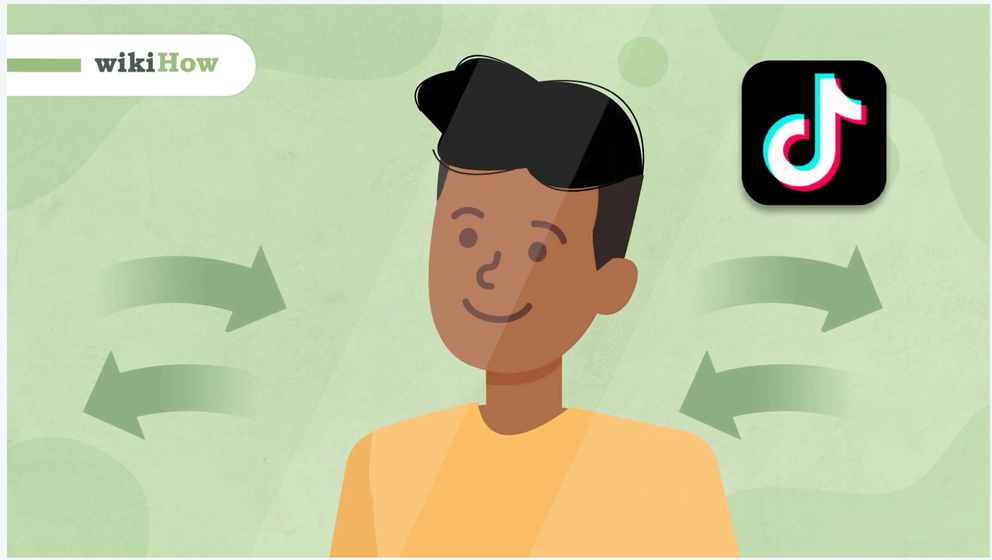
tiger

Flip an image horizontally (inverted filter)

Goal. Flip an image horizontally, like looking into a mirror. ⟵ *on Zoom, Instagram, TikTok, …*



original



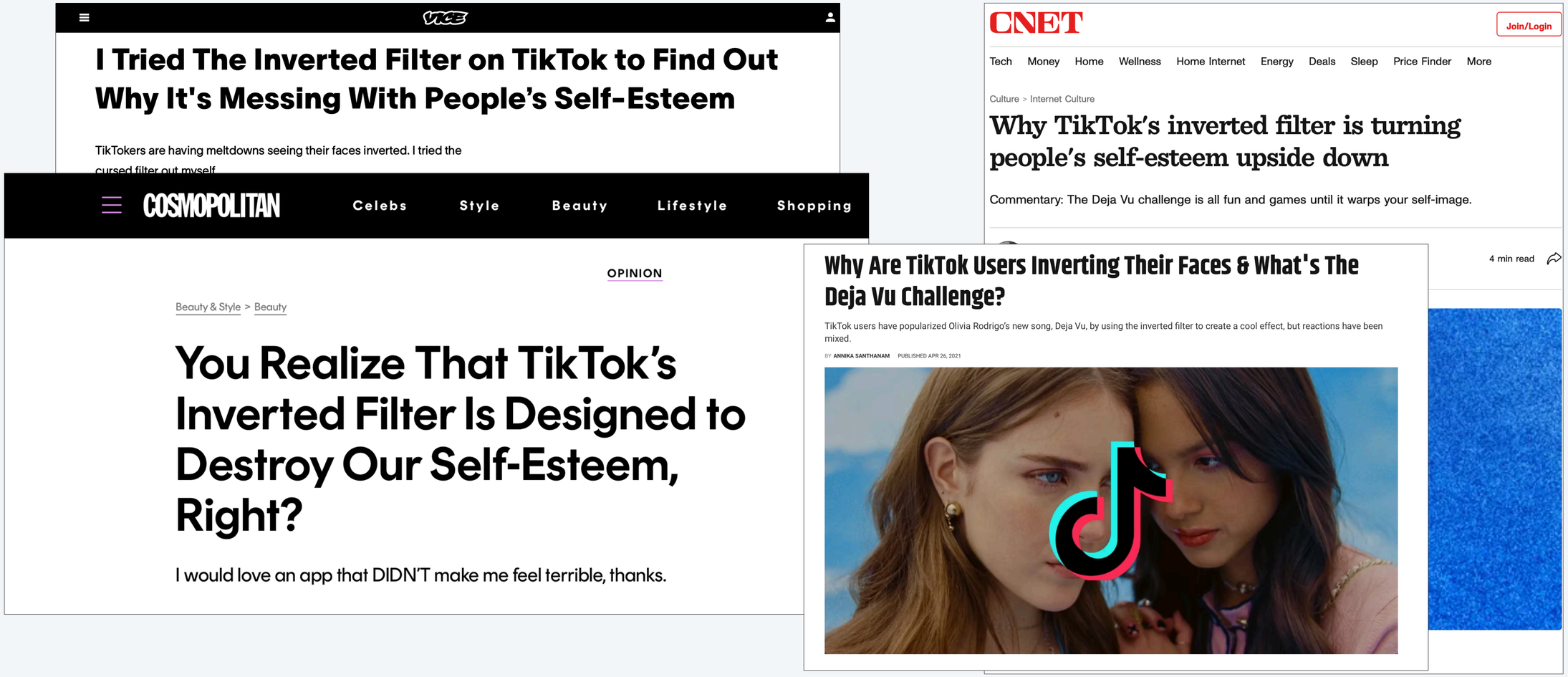
Tik Tok inverted filter

https://www.wikihow.com/Inverted-Filter

Deja Vu challenge

Deja Vu challenge. Record video of face while repeatedly turning on/off inverted filter.

Disclaimer. COS 126 is not liable for damage to self-esteem.



Flip an image horizontally: demo

Goal. Flip an image horizontally, like looking into a mirror.

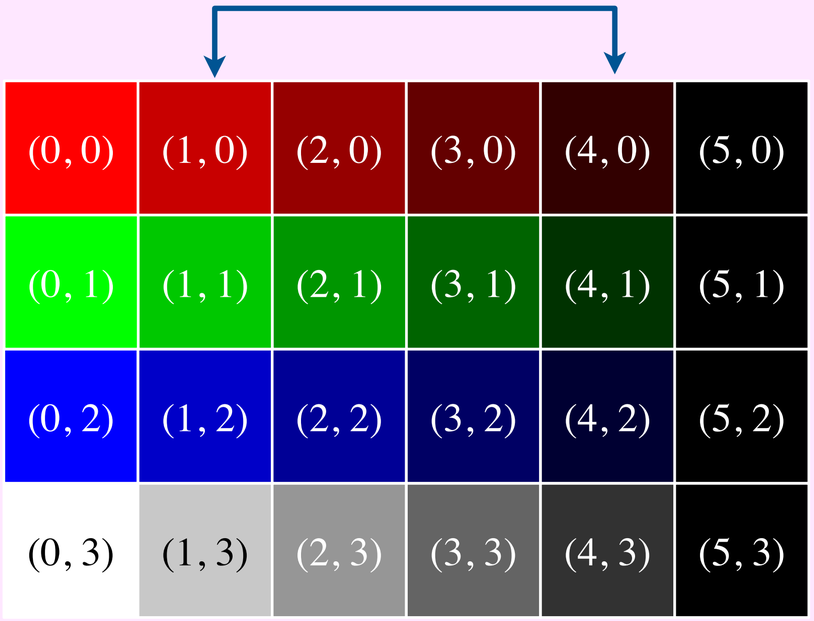
(0, 0)	(1, 0)	(2, 0)	(3, 0)	(4, 0)	(5, 0)
(0, 1)	(1, 1)	(2, 1)	(3, 1)	(4, 1)	(5, 1)
(0, 2)	(1, 2)	(2, 2)	(3, 2)	(4, 2)	(5, 2)
(0, 3)	(1, 3)	(2, 3)	(3, 3)	(4, 3)	(5, 3)

original image

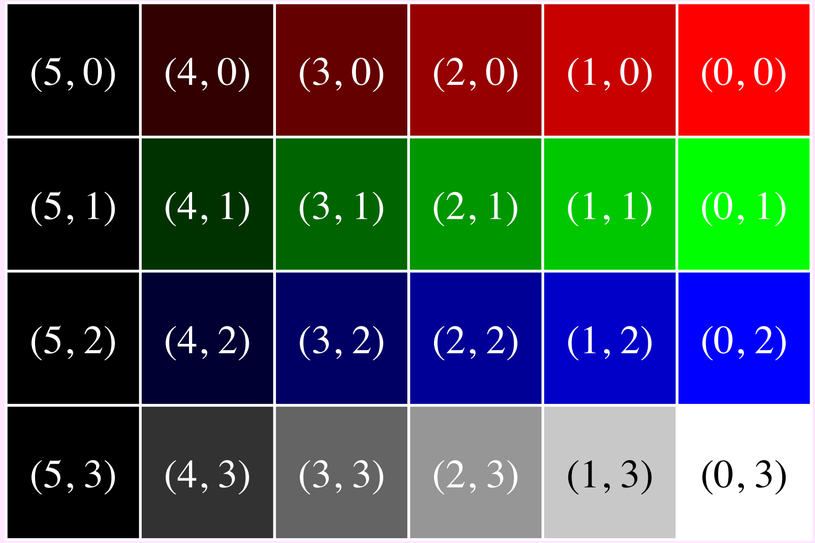
Flip an image horizontally: demo

Goal. Flip an image horizontally, like looking into a mirror.

Algorithm. For each pixel (col, row), swap with pixel $(width - col - 1, row)$.



original image



flipped image

Flip an image horizontally: implementation

Goal. Flip an image horizontally, like looking into a mirror.

Algorithm. For each pixel (col, row), swap with pixel $(width - col - 1, row)$.

why not `width` ?

```
for (int col = 0; col < width / 2; col++) {
   for (int row = 0; row < height; row++) {
      int r1 = StdPicture.getRed(col, row);
      int g1 = StdPicture.getGreen(col, row);
      int b1 = StdPicture.getBlue(col, row);
      int r2 = StdPicture.getRed(width - col - 1, row);
      int g2 = StdPicture.getGreen(width - col - 1, row);
      int b2 = StdPicture.getBlue(width - col - 1, row);
      StdPicture.setRGB(col, row, r2, g2, b2);
      StdPicture.setRGB(width - col - 1, row, r1, g1, b1);
   }
}
StdPicture.show();
```

```
~/> java-introcs FlipHorizontal arch.jpg
```

Loops: quiz 4

What image does the following code fragment produce?

A. Original image.

B. Horizontal flip.

C. Vertical flip.

```
for (int row = 0; row < height; row++) {
   for (int col = 0; col < width / 2; col++) {
      int r1 = StdPicture.getRed(col, row);
      int g1 = StdPicture.getGreen(col, row);
      int b1 = StdPicture.getBlue(col, row);
      int r2 = StdPicture.getRed(width - col - 1, row);
      int g2 = StdPicture.getGreen(width - col - 1, row);
      int b2 = StdPicture.getBlue(width - col - 1, row);
      StdPicture.setRGB(col, row, r2, g2, b2);
      StdPicture.setRGB(width - col - 1, row, r1, g1, b1);
   }
}
StdPicture.show();
```

switched order of two `for` *loops*

Live coding (Deja Vu challenge)

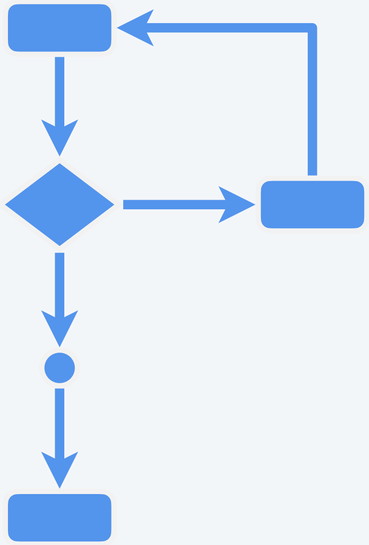
```
public class DejaVuChallenge {
    public static void main(String[] args) {
        // read file
        String filename = args[0];
        StdPicture.read(filename);

        // get dimensions
        int width = StdPicture.width();
        int height = StdPicture.height();

        while (true) {

            // flip image horizontally
            for (int col = 0; col < width / 2; col++) {
                for (int row = 0; row < height; row++) {
                    int r1 = StdPicture.getRed(col, row);
                    int g1 = StdPicture.getGreen(col, row);
                    int b1 = StdPicture.getBlue(col, row);
                    int r2 = StdPicture.getRed(width - col - 1, row);
                    int g2 = StdPicture.getGreen(width - col - 1, row);
                    int b2 = StdPicture.getBlue(width - col - 1, row);
                    StdPicture.setRGB(col, row, r2, g2, b2);
                    StdPicture.setRGB(width - col - 1, row, r1, g1, b1);
                }
            }

            // display image and pause
            StdPicture.show();
            StdPicture.pause(100);
        }
    }
}
```

Summary

Iteration. Use *while* and *for* loops to repeat code in a program.

Nested iteration. Body of loop contains another loop.

Image processing. An image is a 2D grid of pixels, each of which has a color.



control flow with loops

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