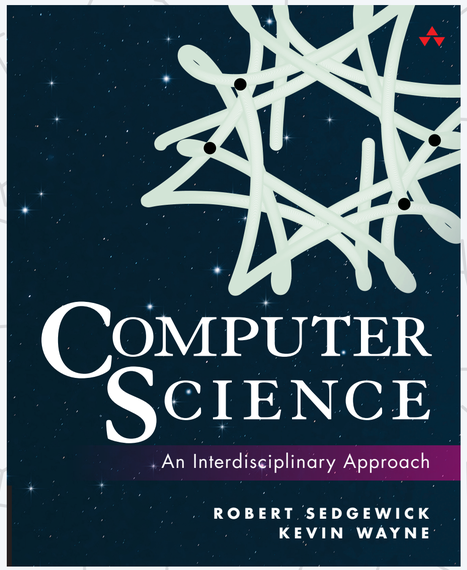
Robert Sedgewick | Kevin Wayne



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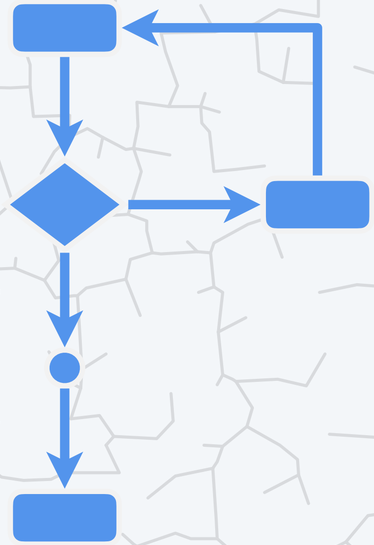
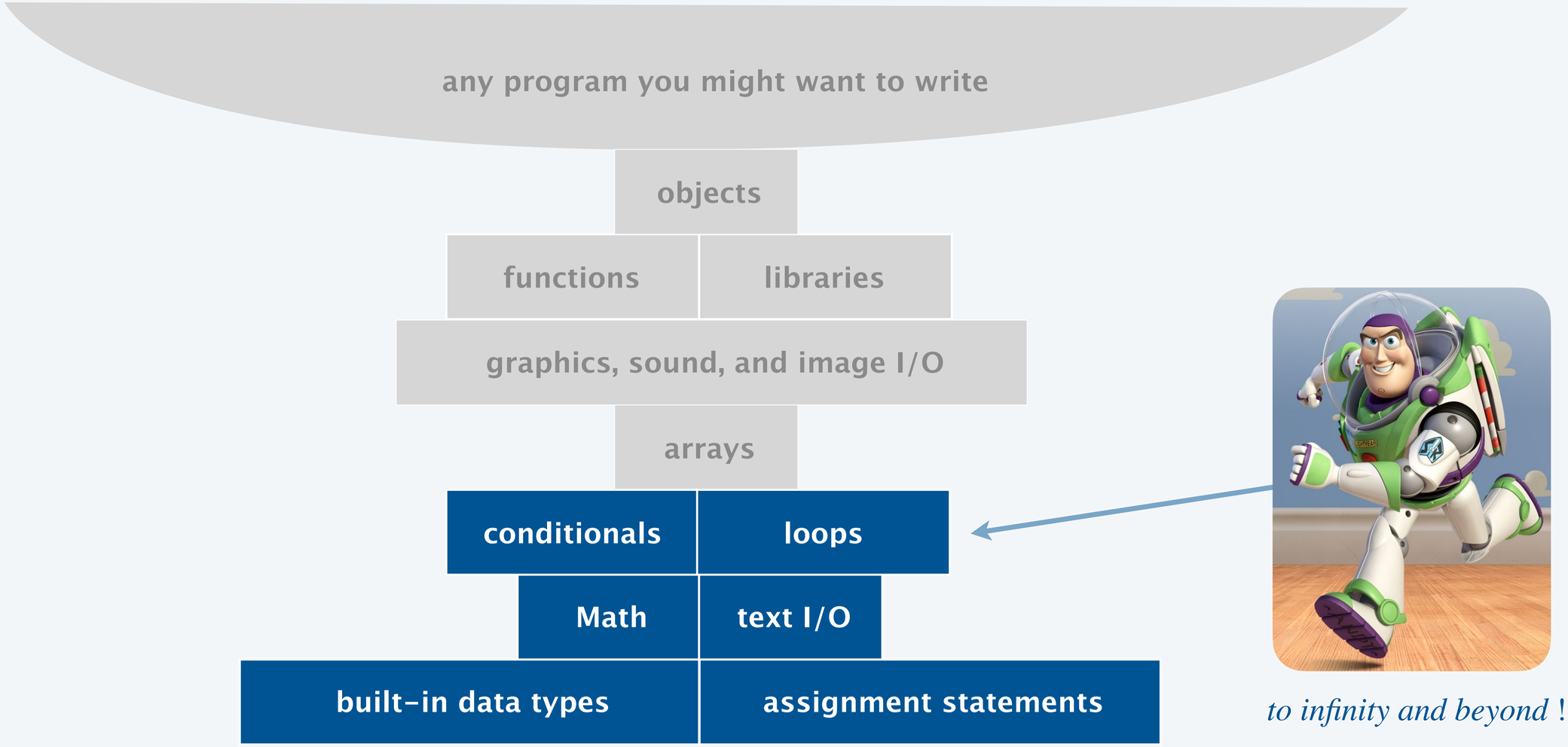
1.3 Loops

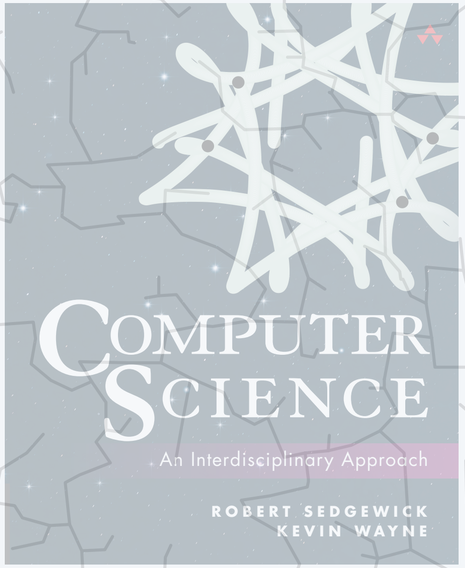
- *while loops*
- *for loops*
- *nested loops*
- *image processing*



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

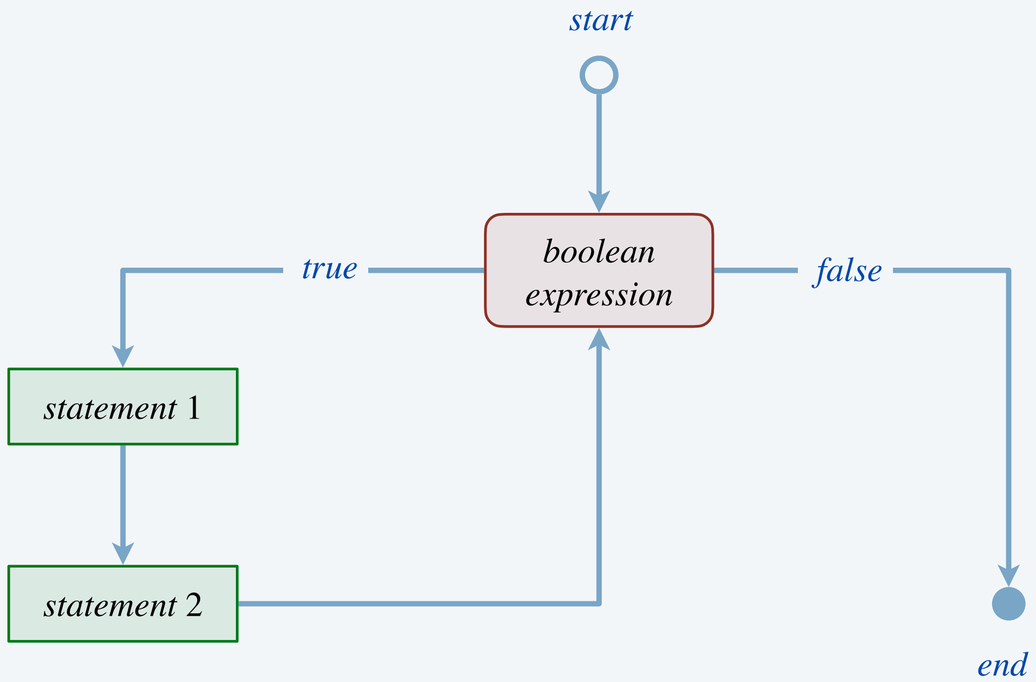
Goal. Repeat a certain statement (or statements).

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

loop-continuation condition

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

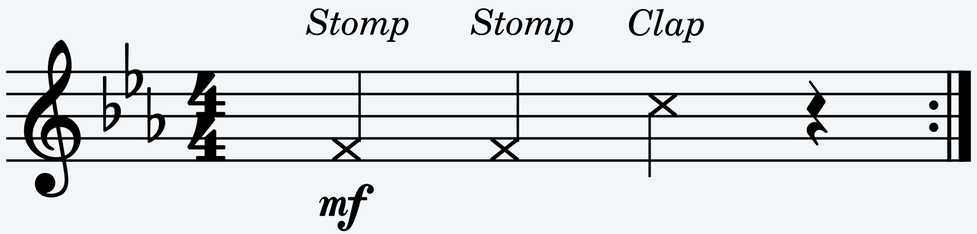
while loop template



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. Prints 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--;`
	`}`

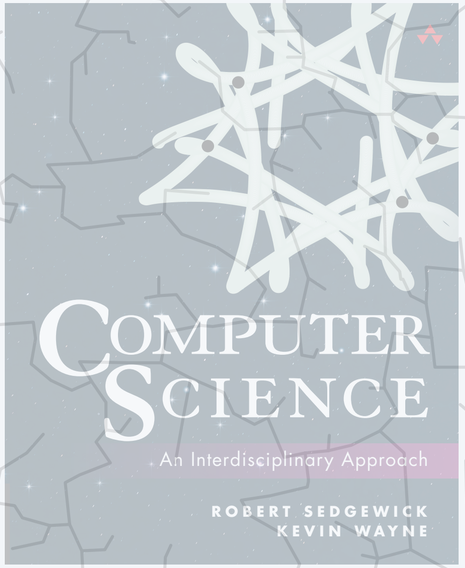
infinite loop	`while (true) {`
	`  StdAudio.play("heartbeat.wav");`
	`}`

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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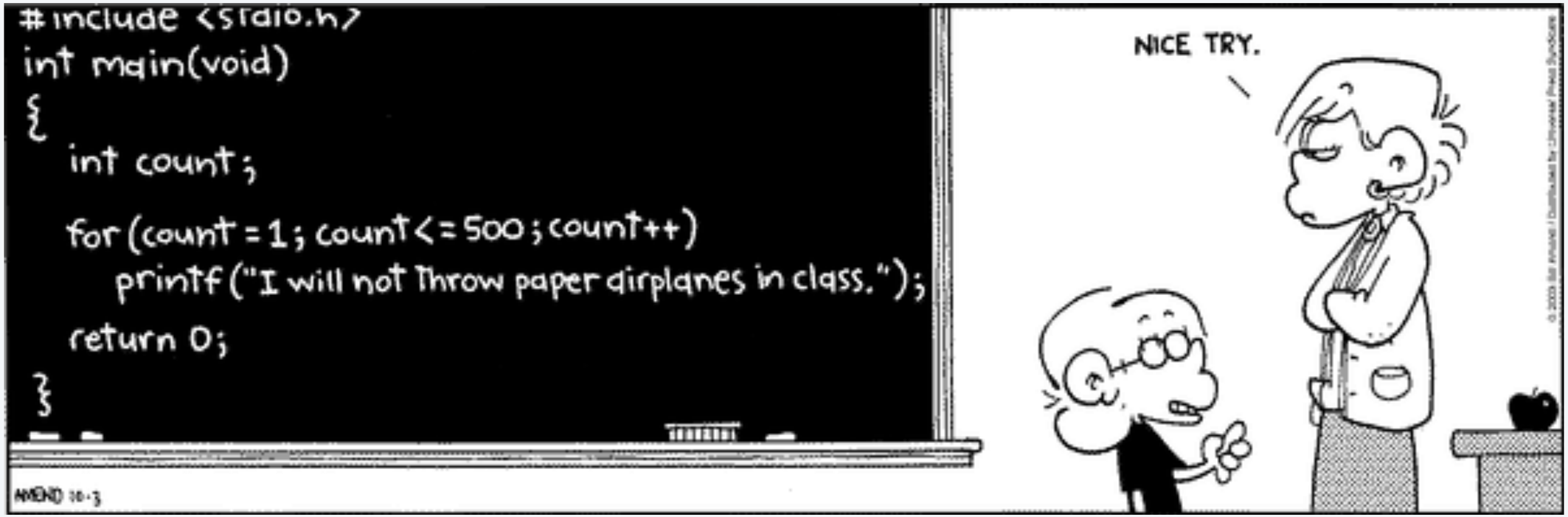
LOOPS

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

A *for* loop (in C)



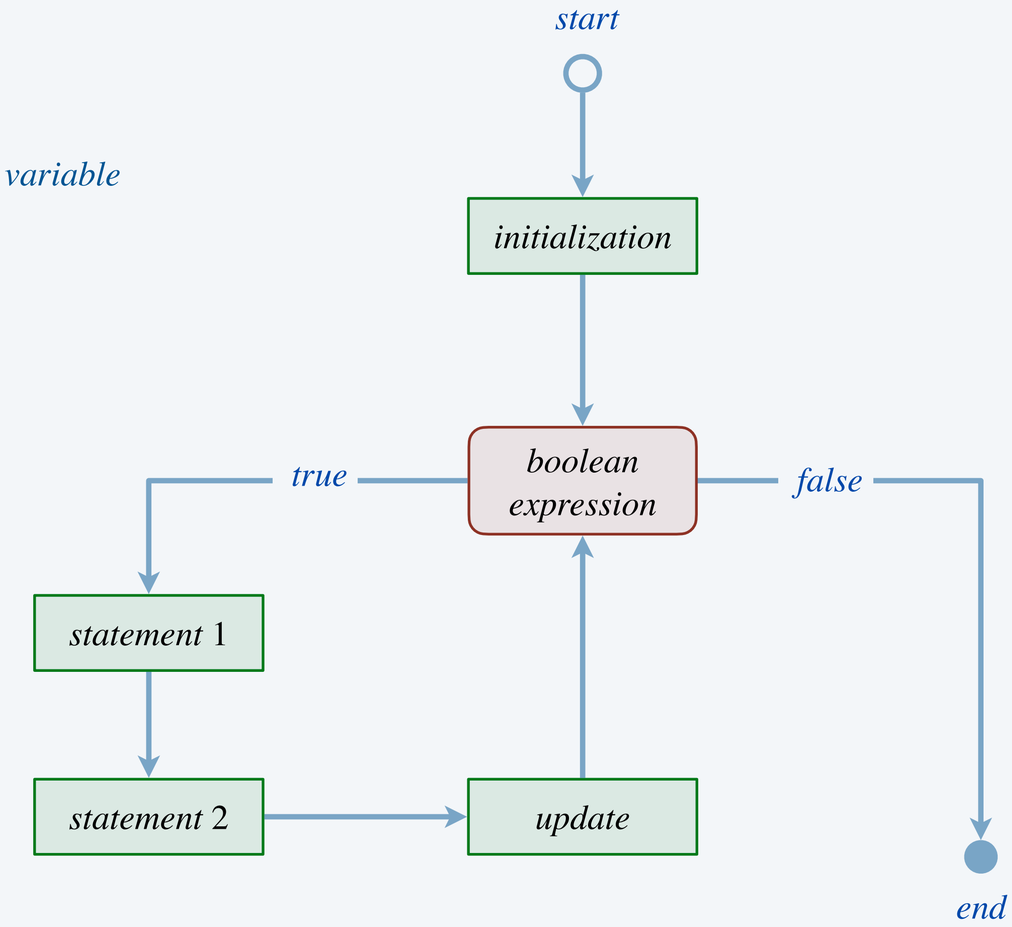
The *for* loop

An alternative repetition structure.

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

Examples of *for* loops

computation	for loop

factorial $(1 \times 2 \times 3 \times \ldots \times n)$	`int product = 1;`
	`for (int i = 1; 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 `if` body consists of only one statement (but better style to include)

empty initialization and update (but 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.

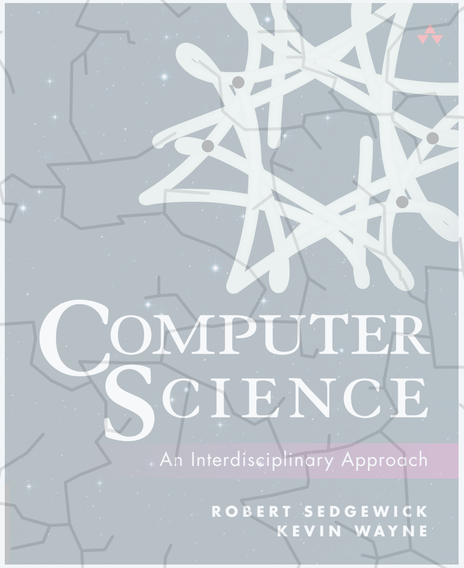
```
int i = 1;
while (i <= n) {
   StdAudio.play(filename);
   i++;
}
```

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

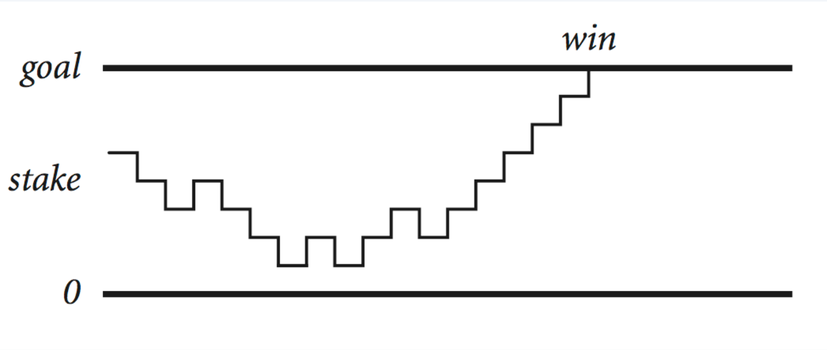
```
public class Mystery {
   public static void main(String[] args) {
      int m = Integer.parseInt(args[0]);
      int n = Integer.parseInt(args[1]);

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

   }
}
```

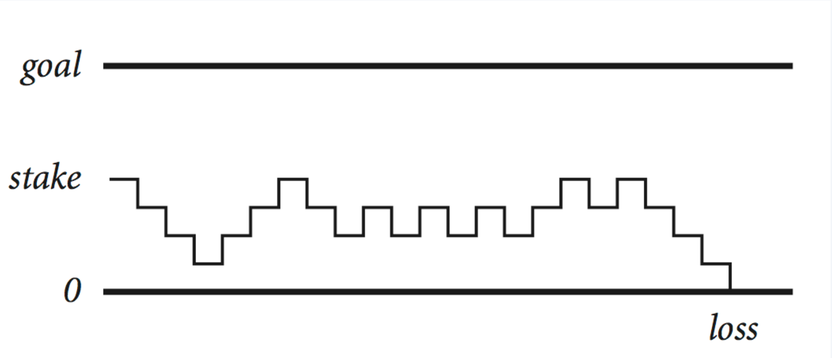
for loop nested within a for loop

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);
   }
}
```

do `trials` *experiments*

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

do one experiment

make one bet

if goal met, count as a win

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

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

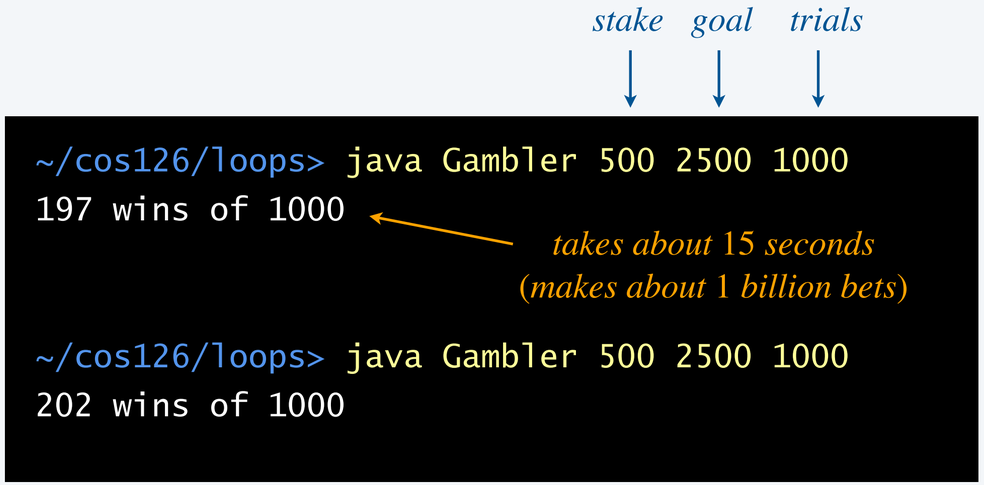
Digression: simulation vs. mathematical analysis

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

if d is a divisor, factor it out

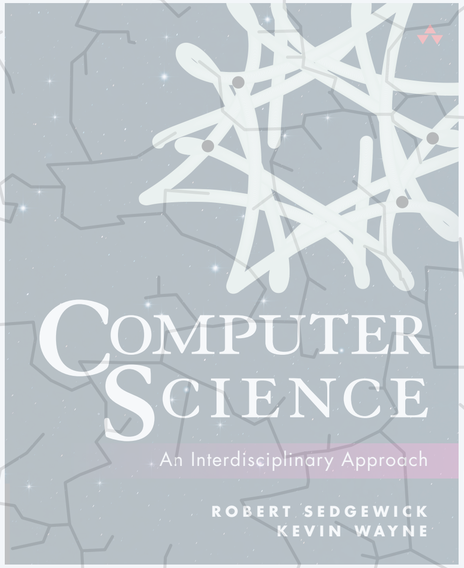
```
~/cos126/loops> java Factors 98
2 7 7

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

~/cos126/loops> java Factors 97
97

~/cos126/loops> java Factors 11111111111111111
2071723 536322235
```

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

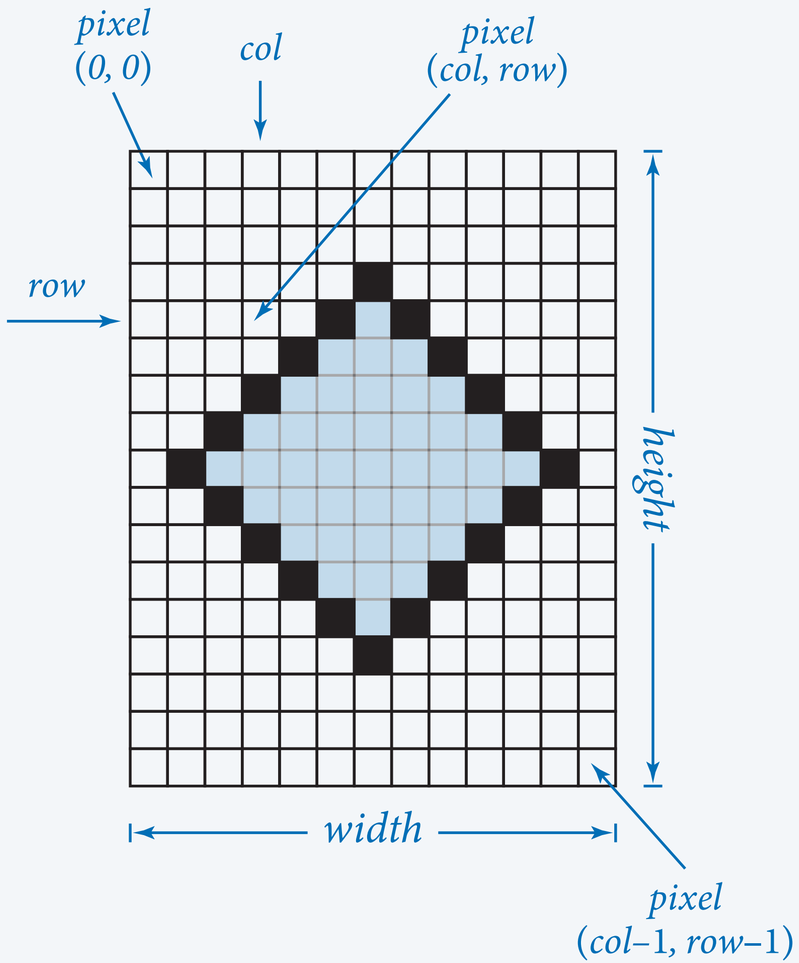


Image-processing conventions.

- 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

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

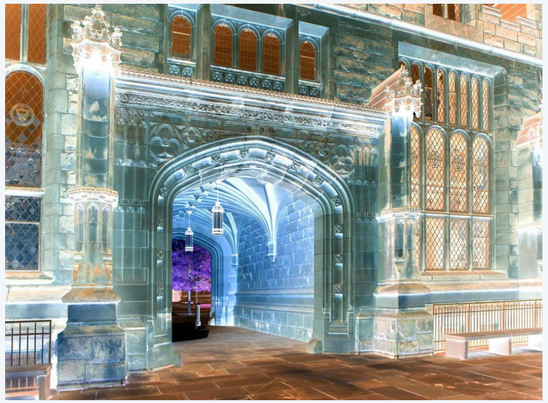
sepia

duotone

brighter

darker

RGB layers



negative

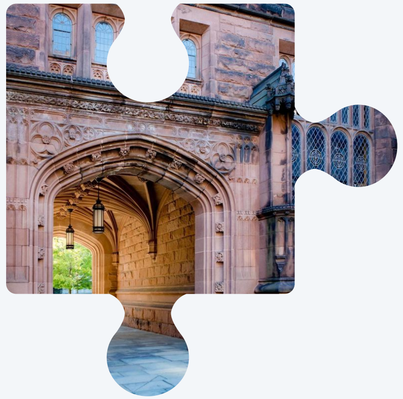
Image processing: shape masks

original

rounded rectangle

oval

heart

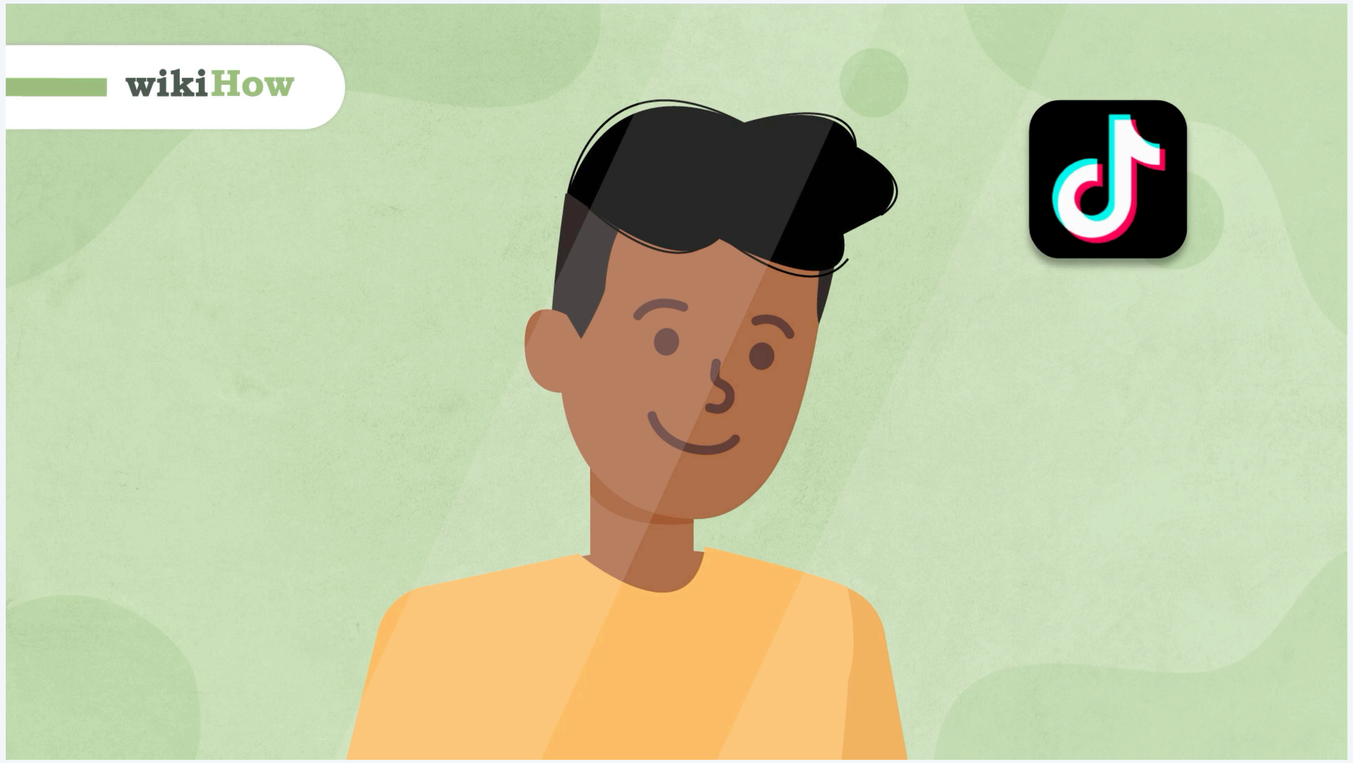


puzzle piece

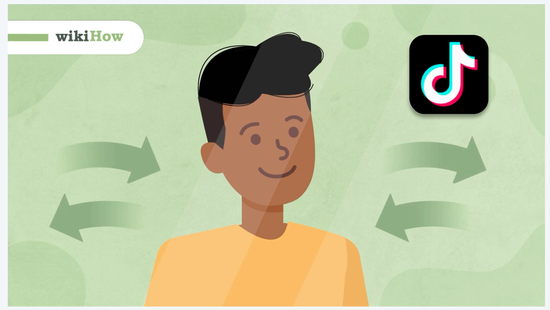
tiger

Flip an image horizontally

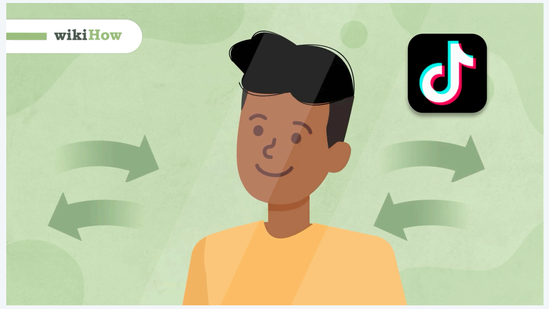
Goal. Flip an image horizontally, like looking into a mirror. ⟵ *on Zoom, Instagram, TikTok, …*



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



original



Tik Tok inverted filter

Deja Vu challenge

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

VICE

I Tried The Inverted Filter on TikTok to Find Out Why It's Messing With People's Self-Esteem

TikTokers are having meltdowns seeing their faces inverted. I tried the cursed filter out myself.

COSMOPOLITAN Celebs Style Beauty Lifestyle Shopping

OPINION

Beauty & Style > Beauty

You Realize That TikTok's Inverted Filter Is Designed to Destroy Our Self-Esteem, Right?

I would love an app that DIDN'T make me feel terrible, thanks.

CNET Join/Login

Tech Money Home Wellness Home Internet Energy Deals Sleep Price Finder More

Culture > Internet Culture

Why TikTok's inverted filter is turning people's self-esteem upside down

Commentary: The Deja Vu challenge is all fun and games until it warps your self-image.

4 min read

Why Are TikTok Users Inverting Their Faces & What's The Deja Vu Challenge?

TikTok users have popularized Olivia Rodrigo's new song, Deja Vu, by using the inverted filter to create a cool effect, but reactions have been mixed.

BY ANNIKA SANTHANAM PUBLISHED APR 26, 2021

Flip an image horizontally: demo

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

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

(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

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

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();
```

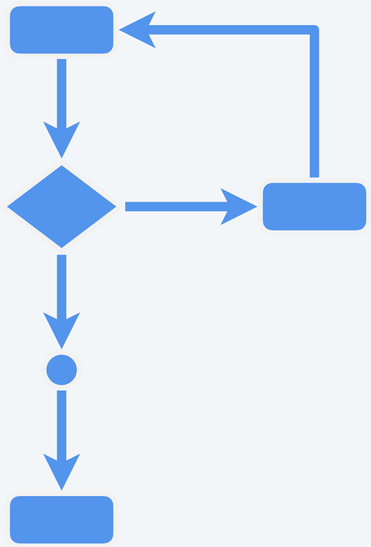
switched order of two `for` *loops*

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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