1.3 Conditionals and Loops
A Foundation for Programming

any program you might want to write

objects

functions and modules

graphics, sound, and image I/O

arrays

conditionals and loops

Math

text I/O

primitive data types

assignment statements

last lecture: equivalent to a calculator
A Foundation for Programming

any program you might want to write

objects

functions and modules

graphics, sound, and image I/O

arrays

conditionals and loops

Math  text I/O

primitive data types  assignment statements

to infinity and beyond!
Control Flow

Control flow

- Sequence of statements that are actually executed in a program
- Conditionals and loops: enable us to choreograph control flow

straight-line control flow

control flow with conditionals and loops
Conditionals
If Statement

The if statement  A common branching structure

- Evaluate a boolean expression
- If true, execute some statements
- If false, execute other statements

```java
if (boolean expression) {
    statement T;
} else {
    statement F;
}
```
The **if** statement  A common branching structure

- Evaluate a **boolean** expression
- If **true**, execute some statements
- If **false**, execute other statements

```java
if (x < 0) x = -x;
```

```java
if (x > y) max = x;
else max = y;
```

![Diagram of the if statement with flowchart](image)
If Statement

Ex. Take different action depending on value of variable.

```java
public class Flip {
    public static void main(String[] args) {
        if (Math.random() < 0.5) System.out.println("Heads");
        else System.out.println("Tails");
    }
}
```

% java Flip
Heads
% java Flip
Heads
% java Flip
Tails
% java Flip
Heads
# If Statement Examples

<table>
<thead>
<tr>
<th>Description</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>absolute value</td>
<td><code>if (x &lt; 0) x = -x;</code></td>
</tr>
</tbody>
</table>
| put x and y into sorted order        | `if (x > y) {
  int t = x;
  x = y;
  y = t;
}`                                                               |
| maximum of x and y                   | `if (x > y) max = x;
else max = y;`                                                   |
| error check for division operation   | `if (den == 0) System.out.println("Division by zero");
else System.out.println("Quotient = " + num/den);`                |
| error check for quadratic formula    | `double discriminant = b*b - 4.0*c;
if (discriminant < 0.0) {
  System.out.println("No real roots");
}
else {
  System.out.println((-b + Math.sqrt(discriminant))/2.0);
  System.out.println((-b - Math.sqrt(discriminant))/2.0);
}`               |
The For Loop

```c
#include <stdio.h>
int main(void)
{
    int count;
    for (count = 1; count <= 500; count++)
        printf("I will not throw paper airplanes in class.\n");
    return 0;
}
```
For Loops

The for loop  A common repetition structure

- Execute initialization statement
- Evaluate a boolean expression
- If true, execute some statements
- And then the increment statement
- Repeat

```
for (init; boolean expression; increment) {
    statement 1;
    statement 2;
}
```

![Diagram of for loop structure]

- **init**: initialization statement
- **boolean expression**: condition for loop continuation
- **increment**: update statement
- **true**: continue loop
- **false**: exit loop
Anatomy of a For Loop

Q. What does it print?
A.
Ex. Print powers of 2 that are $\leq 2^N$

- Increment $i$ from 0 to $N$
- Double $v$ each time

```java
int v = 1;
for (int i = 0; i <= N; i++) {
    System.out.println(i + " " + v);
    v = 2 * v;
}
```

<table>
<thead>
<tr>
<th>$i$</th>
<th>$v$</th>
<th>$i \leq N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>true</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>true</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>true</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>true</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>true</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>true</td>
</tr>
<tr>
<td>6</td>
<td>64</td>
<td>true</td>
</tr>
<tr>
<td>7</td>
<td>128</td>
<td>false</td>
</tr>
</tbody>
</table>

$N = 6$
For Loops: Subdivisions of a Ruler

Create subdivision of a ruler

- Initialize ruler to " "
- For each value i from 1 to N:
  - sandwich two copies of ruler on either side of i

```java
public class RulerN {
    public static void main(String[] args) {
        int N = Integer.parseInt(args[0]);
        String ruler = " ";
        for (int i = 1; i <= N; i++) {
            ruler = ruler + i + ruler;
        }
        System.out.println(ruler);
    }
}
```

<table>
<thead>
<tr>
<th>i</th>
<th>ruler</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&quot; 1 &quot;</td>
</tr>
<tr>
<td>2</td>
<td>&quot; 1 2 1 &quot;</td>
</tr>
<tr>
<td>3</td>
<td>&quot; 1 2 1 3 1 2 1 &quot;</td>
</tr>
</tbody>
</table>
For Loops: Subdivisions of a Ruler

% java RulerN 1
1

% java RulerN 2
1 2 1

% java RulerN 3
1 2 1 3 1 2 1

% java RulerN 4
1 2 1 3 1 2 1 4 1 2 1 3 1 2 1

% java RulerN 5
1 2 1 3 1 2 1 4 1 2 1 3 1 2 1 5 1 2 1 3 1 2 1 4 1 2 1 3 1 2 1

% java RulerN 100
Exception in thread "main"
java.lang.OutOfMemoryError

Observation  Loops can produce a huge amount of output!
The While Loop
The **while** loop. Another common repetition structure

- Evaluate a **boolean expression**
- If **true**, execute some statements
- Repeat

```
while (boolean expression) {
    statement 1;
    statement 2;
}
```
While Loop: Powers of Two

Ex. Print powers of 2 that are $\leq 2^N$

- Increment $i$ from 0 to $N$
- Double $v$ each time

```java
int i = 0;
int v = 1;
while (i <= N) {
    System.out.println(i + " " + v);
    i++;
    v = 2 * v;
}
```

<table>
<thead>
<tr>
<th>i</th>
<th>v</th>
<th>i &lt;= N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>true</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>true</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>true</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>true</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>true</td>
</tr>
<tr>
<td>5</td>
<td>32</td>
<td>true</td>
</tr>
<tr>
<td>6</td>
<td>64</td>
<td>true</td>
</tr>
<tr>
<td>7</td>
<td>128</td>
<td>false</td>
</tr>
</tbody>
</table>

$N = 6$

Click for demo
Powers of Two

```java
public class PowersOfTwo {
    public static void main(String[] args) {

        // last power of two to print
        int N = Integer.parseInt(args[0]);

        int i = 0;  // loop control counter
        int v = 1;  // current power of two
        while (i <= N) {
            System.out.println(i + " " + v);
            i = i + 1;
            v = 2 * v;
        }
    }
}
```

% java PowersOfTwo 3
0 1
1 2
2 4
3 8

% java PowersOfTwo 6
0 1
1 2
2 4
3 8
4 16
5 32
6 64
Q. Anything wrong with the following code for printing powers of 2?

```java
int i = 0;
int v = 1;
while (i <= N)
    System.out.println(i + " " + v);
i = i + 1;
v = 2 * v;
```
Q. Anything wrong with the following code for printing powers of 2?

```java
int i = 0;
int v = 1;
while (i <= N)
    System.out.println(i + " " + v);
    i = i + 1;
    v = 2 * v;
```

A. Need curly braces around statements in while loop; otherwise it enters an infinite loop, printing "0 1".

Moment of panic. How to stop infinite loop?
Goal. Implement `Math.sqrt()`

Newton-Raphson method to compute the square root of \( c \):

- Initialize \( t_0 = c \)
- Repeat until \( t_i = c / t_i \), up to desired precision:
  - set \( t_{i+1} \) to be the average of \( t_i \) and \( c / t_i \)

\[
\begin{align*}
  t_0 &= 2.0 \\
  t_1 &= \frac{1}{2} (t_0 + \frac{2}{t_0}) = 1.5 \\
  t_2 &= \frac{1}{2} (t_1 + \frac{2}{t_1}) = 1.416666666666665 \\
  t_3 &= \frac{1}{2} (t_2 + \frac{2}{t_2}) = 1.4142156862745097 \\
  t_4 &= \frac{1}{2} (t_3 + \frac{2}{t_3}) = 1.4142135623746899 \\
  t_5 &= \frac{1}{2} (t_4 + \frac{2}{t_4}) = 1.414213562373095
\end{align*}
\]

computing the square root of 2

% java Sqrt 2.0
1.414213562373095

15 decimal digits of accuracy in 5 iterations

"A wonderful square root. Let's hope it can be used for the good of mankind."
Goal. Implement `Math.sqrt()`.

Newton-Raphson method to compute the square root of \( c \):
- Initialize \( t_0 = c \).
- Repeat until \( t_i = c / t_i \), up to desired precision:
  - set \( t_{i+1} \) to be the average of \( t_i \) and \( c / t_i \).

```java
public class Sqrt {
    public static void main(String[] args) {
        double epsilon = 1e-15;
        double c = Double.parseDouble(args[0]);
        double t = c;
        while (Math.abs(t - c/t) > t*epsilon) {
            t = (c/t + t) / 2.0;
        }
        System.out.println(t);
    }
}
```

% java Sqrt 2.0  
1.414213562373095  

15 decimal digits of accuracy in 5 iterations
Newton-Raphson Method

Square root method explained

- **Goal**: find root of any function \( f(x) \)
- **Start with estimate** \( t_0 \)
- **Draw line tangent to curve at** \( x = t_i \)
- **Set** \( t_{i+1} \) **to be** \( x \)-coordinate where line hits \( x \)-axis
- **Repeat until desired precision**

**Technical conditions.** \( f(x) \) is smooth; \( t_0 \) is good estimate

\[
t_{i+1} = t_i - \frac{f(t_i)}{f'(t_i)}
\]
## Loop Examples

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Code Snippet</th>
</tr>
</thead>
</table>
| Print largest power of two less than or equal to \( N \) | ```
int v = 1;
while (v <= N/2)
   v = 2*v;
System.out.println(v);
``` |
| Compute a finite sum \((1 + 2 + \ldots + N)\) | ```
int sum = 0;
for (int i = 1; i <= N; i++)
   sum += i;
System.out.println(sum);
``` |
| Compute a finite product \((N! = 1 \times 2 \times \ldots \times N)\) | ```
int product = 1;
for (int i = 1; i <= N; i++)
   product *= i;
System.out.println(product);
``` |
| Print a table of function values | ```
for (int i = 0; i <= N; i++)
   System.out.println(i + " " + 2*Math.PI*i/N);
``` |
Nesting
Nested If Statements

**Ex.** Pay a certain tax rate depending on income level

<table>
<thead>
<tr>
<th>Income</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 47,450</td>
<td>22%</td>
</tr>
<tr>
<td>47,450 - 114,650</td>
<td>25%</td>
</tr>
<tr>
<td>114,650 - 174,700</td>
<td>28%</td>
</tr>
<tr>
<td>174,700 - 311,950</td>
<td>33%</td>
</tr>
<tr>
<td>311,950 -</td>
<td>35%</td>
</tr>
</tbody>
</table>

5 mutually exclusive alternatives

double rate;
if (income < 47450) rate = 0.22;
else if (income < 114650) rate = 0.25;
else if (income < 174700) rate = 0.28;
else if (income < 311950) rate = 0.33;
else rate = 0.35;

graduated income tax calculation
Nested If Statements

Use nested if statements to handle multiple alternatives

```java
if (income < 47450) rate = 0.22;
else {
    if (income < 114650) rate = 0.25;
    else {
        if (income < 174700) rate = 0.28;
        else {
            if (income < 311950) rate = 0.33;
            else rate = 0.35;
        }
    }
}
```
Nested If Statements

Need all those braces? Not always

if (income < 47450) rate = 0.22;
else if (income < 114650) rate = 0.25;
else if (income < 174700) rate = 0.28;
else if (income < 311950) rate = 0.33;
else rate = 0.35;

is shorthand for

if (income < 47450) rate = 0.22;
else {
  if (income < 114650) rate = 0.25;
  else {
    if (income < 174700) rate = 0.28;
    else {
      if (income < 311950) rate = 0.33;
      else rate = 0.35;
    }
  }
}

but be careful when nesting if-else statements. [See Q+A on p. 75.]
**Nested If Statement Challenge**

**Q.** What's wrong with the following for income tax calculation?

```java
double rate = 0.35;
if (income < 47450) rate = 0.22;
if (income < 114650) rate = 0.25;
if (income < 174700) rate = 0.28;
if (income < 311950) rate = 0.33;
```

*wrong* graduated income tax calculation
Monte Carlo Simulation
**Gambler's Ruin**

**Gambler's ruin** Gambler starts with $stake and places $1 fair bets until going broke or reaching $goal

- What are the chances of winning?
- How many bets will it take?

**One approach** Monte Carlo simulation

- Flip digital coins and see what happens
- Repeat and compute statistics
public class Gambler {
    public static void main(String[] args) {
        int stake = Integer.parseInt(args[0]);
        int goal = Integer.parseInt(args[1]);
        int T = Integer.parseInt(args[2]);
        int wins = 0;

        // repeat experiment T times
        for (int t = 0; t < T; t++) {
            // do one gambler's ruin experiment
            int cash = stake;
            while (cash > 0 && cash < goal) {
                // flip coin and update
                if (Math.random() < 0.5) cash++;
                else cash--;
            }

            if (cash == goal) wins++;
        }

        System.out.println(wins + " wins of " + T);
    }
}
Digression: Simulation and Analysis

<table>
<thead>
<tr>
<th>Stake</th>
<th>Goal</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>25</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>191 wins of 1000</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>203 wins of 1000</td>
</tr>
<tr>
<td>500</td>
<td>2500</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>197 wins of 1000</td>
</tr>
</tbody>
</table>

**Fact** Probability of winning = stake ÷ goal

**Fact** Expected number of bets = stake × desired gain

**Ex.** 20% chance of turning $500 into $2500, but expect to make one million $1 bets

\[
\frac{500}{2500} = 20\%
\]

\[
500 \times (2500 - 500) = 1 \text{ million}
\]

**Remark** Both facts can be proved mathematically; for more complex scenarios, computer simulation is often the best (only) plan of attack
**Control Flow**

- Sequence of statements that are actually executed in a program
- Conditionals and loops: enable us to choreograph the control flow

<table>
<thead>
<tr>
<th>Control Flow</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>straight-line</td>
<td>all statements are executed in the order given</td>
<td></td>
</tr>
<tr>
<td>programs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>conditionals</td>
<td>certain statements are executed depending on the values of certain variables</td>
<td>if, if-else</td>
</tr>
<tr>
<td>loops</td>
<td>certain statements are executed repeatedly until certain conditions are met</td>
<td>while, for do-while</td>
</tr>
</tbody>
</table>