CSE 331
Software Design & Implementation

Spring 2022

Section 10: Review + Design Patterns

Administrivia

- HW9 due tomorrow, Friday 6/3
- Final on Tuesday, June 7
  - A: 4:30pm – 6:20pm @ KNE 220
  - B: 2:30pm – 4:20pm @ KNE 220
- Any questions?

Agenda

- HW9 demos
- Review
  - Reasoning, Specifications, ADTs (RI & AF), Testing, Defensive Programming, Equals and Hash Code, Exceptions, Subtyping, Generics

- Design Patterns

HW9 Demos

- Anyone want to show off their HW9?

Reasoning with `if` (reminders)

```
{{ x < 0}}
↓
if (y > x)
    {{ ? }}
    y = x;
    {{ ? }}
else
    {{ ? }}
    y = y - 1;
    {{ ? }}
↑
{{ x < 0 & y < 0 }}
```

This does not mean you should backwards reason through the **`else`** branch and forward reason through the **`if`** branch

Reasoning with `if` (reminders)

```
{{ x < 0}}
↓
if (y > x)
    {{ x < 0 & y > x }}
    y = x;
    {{ ? }}
else
    {{ x < 0 & y <= x }}
    y = y - 1;
    {{ ? }}
↑
{{ x < 0 & y < 0 }}
```

This does not mean you should backwards reason through the **`else`** branch and forward reason through the **`if`** branch

Forward reason into the precondition of both branches

Reasoning with `if` (reminders)

```
{{ x < 0}}
↓
if (y > x)
    {{ x < 0 & y > x }}
    y = x;
    {{ x < 0 & y < 0 }}
else
    {{ x < 0 & y <= x }}
    y = y - 1;
    {{ x < 0 & y < 0 }}
↑
{{ x < 0 & y < 0 }}
```

This does not mean you should backwards reason through the **`else`** branch and forward reason through the **`if`** branch

Forward reason into the precondition of both branches

Backwards reason into the postcondition of both branches

Reasoning with `if` (reminders)

```
{{ x < 0}}
↓
if (y > x)
    {{ x < 0 & y > x }}
    y = x;
    {{ x < 0 & y < 0 }}
else
    {{ x < 0 & y <= x }}
    y = y - 1;
    {{ x < 0 & y < 0 }}
↑
{{ x < 0 & y < 0 }}
```

Is the code correct?

Yep!

Backwards Reasoning Reminders

What goes here?

```
    {{ ? }}
↑   k = k + 1;
    {{ k = 2 }}
```

Backwards Reasoning Reminders

What goes here?

```
  ✗ {{ k = k + 1 }}
↑   k = k + 1;
    {{ k = 2 }}
```

Remember: An assertion is a true / false claim (proposition) about the **state** at a given point during execution

Assertions like `k = k + 1` make no sense because it is a contradiction and will always evaluate to `false`!

Try putting `assert(k == k + 1);` in your code!

Backwards Reasoning Reminders

What goes here?

✔ `{{ k + 1 = 2 }}` ⇔ `{{ k = 1 }}`

↑ `k = k + 1;`

`{{ k = 2 }}`

Note: single equals

In backwards reasoning, we take the **bottom** assertion and **replace** all instances of the **left-hand** side of the assignment statement with the **right-hand** side of the assignment statement!

Do **NOT** write `k = 2 ∧ k = k + 1`

- `assert(k == 2 && k == k + 1);` will always fail (contradiction!)

Backwards Reasoning Reminders

What goes here?

```
{{ inv: sum = A[0] + ... + A[i-1] }}
while (i != A.length) {
    sum = sum + A[i];
    i = i + 1;
    {{ ? }}
↑
}
```

Backwards Reasoning Reminders

What goes here?

```
{{ inv: sum = A[0] + ... + A[i-1] }}
while (i != A.length) {
    sum = sum + A[i];
    i = i + 1;
  ✗ {{ inv ∧ i ≠ n }}
↑
}
```

When backwards reasoning at the bottom of the loop, we don't know if the loop condition still holds. We only know that the invariant holds. By including that the loop condition holds at the bottom of the loop, you're indicating we never exit the loop!

Backwards Reasoning Reminders

What goes here?

```
{{ inv: sum = A[0] + ... + A[i-1] }}
while (i != A.length) {
    sum = sum + A[i];
    i = i + 1;
  ✔ {{ inv }}
↑
}
```

Reasoning w/ Loops (again!)

We will fill in the implementation for **`runLengthEncode`**:

int runLengthEncode(String str, int n, char[] chars, int[] lens)

- We need to *encode* the first **`n`** characters of **`str`**, writing into **`chars`** and **`lens`**.
- Returns **`t`** such that

  str[0…n-1] = chars[0] * lens[0] + … + chars[t-1] * lens[t-1]

- Ex: after encoding **`"aaabbccccaaddd"`** with **`n = 14`**:
  - **`chars[0…4] = ['a', 'b', 'c', 'a', 'd']`**
  - **`lens[0…4] = [ 3 , 2 , 4 , 2 , 3 ]`**
  - **`returns 5`**

Reasoning w/ Loops (again!)

- Ex: after encoding "**aaabbcccaaddd**" with **n = 14**:
  - **chars[0…4] = ['a', 'b', 'c', 'a', 'd']**
  - **lens[0…4] = [3 , 2 , 4 , 2 , 3]**
  - **returns 5**

- Returns **t** such that

  str[0…n-1] = chars[0] * lens[0] + … + chars[t-1] * lens[t-1]

  - In other words, return **t** = # of chars that we overwrote in **chars**
    = # of ints that we overwrote in **lens**

- Note: can't have two of the same char in a row in **chars**!
- All of **lens[0...t-1]** must be greater than 0!
- You can assume that **str** and both arrays have lengths greater than or equal to **n** and that **str** does not contain **'\0'.**

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
```

How can we make the invariant hold before the loop?
We need to initialize **i**, **j**, and **cur**

```
   {{ inv: pre and
           str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
           chars[0] != chars[1], …, chars[j-1] != chars[j] and
           lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
           (i = 0 or cur = str[i-1])  }}
   while (______) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i =  ;
   int j =   ;
   char cur =   ;
   {{ inv: pre and
           str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
           chars[0] != chars[1], …, chars[j-1] != chars[j] and
           lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
           (i = 0 or cur = str[i-1])  }}
   while (______) {
     ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (______) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (______) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

Does our invariant hold with this **i**, **j**, and **curr**?

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (______) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

pre holds because all the related variables were untouched

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (______) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

The next part holds since there are no indexes **k** such that **0 ≤ k ≤ i-1 = -1**. There are also no such indexes **m** such that **0 ≤ m ≤ j = -1**. This is vacuously true.

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (______) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

The next two parts hold for the same reasoning as previous. This statement is vacuously true since there are no indexes **m** such that **`0 ≤ m ≤ j = -1`**

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (______) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

Finally, this last part holds because we have i = 0.

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (______) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

How can we make the postcondition hold after the loop?

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (i != n) {
      ...
   }

   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (i != n) {
      ...
   }
   {{ inv and i = n }}
   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

Does **{{ inv ∧ i = n }}** imply **post**?

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (i != n) {
      ...
   }
   {{ inv and i = n }}
   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

These two match if we substitute **i = n**.

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (i != n) {
      ...
   }
   {{ inv and i = n }}
   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

These two match exactly.

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1]) }}
   while (i != n) {
     ...
   }
   {{ inv and i = n }}
   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 }}
   return _____;
}
```

The assertion above has additional facts, making it stronger.
Our postcondition is weaker since it excludes those facts!
A stronger assertion implies a weaker one!

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (i != n) {
     ...
   }
   {{ inv and i = n }}
   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

What should we return? Recall:
Returns `t` such that
str[0…n-1] = chars[0] * lens[0] + … + chars[t-1] * lens[t-1]

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (i != n) {
      ...
   }
   {{ inv and i = n }}
   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j]
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return _____;
}
```

What should we return? Recall:
Returns `t` such that
str[0…n-1] = chars[0] * lens[0] + … + chars[t-1] * lens[t-1]

Reasoning w/ Loops (again!)

```
int runLengthEncode(String str, int n, char[] chars, int[] lens){
   {{ pre: 0 < n <= str.length, chars.length, lens.length }}
   int i = 0;
   int j = -1;
   char cur = '\0';
   {{ inv: pre and
            str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
            (i = 0 or cur = str[i-1])  }}
   while (i != n) {
      ...
   }
   {{ inv and i = n }}
   {{ post: str[0…n-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
            chars[0] != chars[1], …, chars[j-1] != chars[j] and
            lens[0] > 0, lens[1] > 0, …, lens[j] > 0  }}
   return j + 1;
}
```

Since we know that `j = t - 1`, we can solve for `t`!
We get `j + 1 = t`.

Reasoning w/ Loops (again!)

```
{{ inv:
```
pre and
str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
chars[0] != chars[1], …, chars[j-1] != chars[j] and
lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
(i = 0 or cur = str[i-1])
```
}}
while (i != n) {
```
We have examined our string through index `i - 1`

What do we need to do next?

```
}
```

Reasoning w/ Loops (again!)

```
{{ inv:
```
pre and
str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
chars[0] != chars[1], …, chars[j-1] != chars[j] and
lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
(i = 0 or cur = str[i-1])
```
}}
while (i != n) {
```
We need to examine the character at index `i`

How do we process a character?

```
}
```

Reasoning w/ Loops (again!)

```
{{ inv:
```
pre and
str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
chars[0] != chars[1], …, chars[j-1] != chars[j] and
lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
(i = 0 or cur = str[i-1])
```
}}
while (i != n) {
```

We need to examine the character at index `i`

How do we process a character?

There are two cases: this character needs a new spot in `chars` and `lens` or it belongs at index `j`

How do we differentiate these two?

```
}
```

Reasoning w/ Loops (again!)

```
{{ inv: pre and
        str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
        chars[0] != chars[1], …, chars[j-1] != chars[j] and
        lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
        (i = 0 or cur = str[i-1])  }}
while (i != n) {
   if (str.charAt(i) == cur) {
      // same as last character, goes into index j

   } else {
      // different from last character, needs new spot




   }

}
```

Reasoning w/ Loops (again!)

```
{{ inv: pre and
        str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
        chars[0] != chars[1], …, chars[j-1] != chars[j] and
        lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
        (i = 0 or cur = str[i-1])  }}
while (i != n) {
   if (str.charAt(i) == cur) {
      // same as last character, goes into index j
      What goes here?
   } else {
      // different from last character, needs new spot




   }

}
```

Reasoning w/ Loops (again!)

```
{{ inv: pre and
        str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
        chars[0] != chars[1], …, chars[j-1] != chars[j] and
        lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
        (i = 0 or cur = str[i-1])  }}
while (i != n) {
   if (str.charAt(i) == cur) {
      // same as last character, goes into index j
      lens[j] = lens[j] + 1;
   } else {
      // different from last character, needs new spot









   }

}
```

Reasoning w/ Loops (again!)

```
{{ inv: pre and
        str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
        chars[0] != chars[1], …, chars[j-1] != chars[j] and
        lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
        (i = 0 or cur = str[i-1])  }}
while (i != n) {
   if (str.charAt(i) == cur) {
      // same as last character, goes into index j
      lens[j] = lens[j] + 1;
   } else {
      // different from last character, needs new spot
      What goes here?




   }

}
```

Reasoning w/ Loops (again!)

```
{{ inv: pre and
        str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
        chars[0] != chars[1], …, chars[j-1] != chars[j] and
        lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
        (i = 0 or cur = str[i-1]) }}
while (i != n) {
   if (str.charAt(i) == cur) {
      // same as last character, goes into index j
      lens[j] = lens[j] + 1;
   } else {
      // different from last character, needs new spot
      j = j + 1;
      cur = str.charAt(i);
      chars[j] = cur;
      lens[j] = 1;
   }

}
```

Reasoning w/ Loops (again!)

```
{{ inv: pre and
        str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
        chars[0] != chars[1], …, chars[j-1] != chars[j] and
        lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
        (i = 0 or cur = str[i-1]) }}
while (i != n) {
   if (str.charAt(i) == cur) {
      // same as last character, goes into index j
      lens[j] = lens[j] + 1;
   } else {
      // different from last character, needs new spot
      j = j + 1;
      cur = str.charAt(i);
      chars[j] = cur;
      lens[j] = 1;
   }
   What's left?
}
```

Reasoning w/ Loops (again!)

```
{{ inv: pre and
        str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
        chars[0] != chars[1], …, chars[j-1] != chars[j] and
        lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
        (i = 0 or cur = str[i-1]) }}
while (i != n) {
   if (str.charAt(i) == cur) {
      // same as last character, goes into index j
      lens[j] = lens[j] + 1;
   } else {
      // different from last character, needs new spot
      j = j + 1;
      cur = str.charAt(i);
      chars[j] = cur;
      lens[j] = 1;
   }
   i = i + 1;
}
```

Reasoning w/ Loops (again!)

```
{{ inv: pre and
        str[0…i-1] = chars[0] * lens[0] + … + chars[j] * lens[j] and
        chars[0] != chars[1], …, chars[j-1] != chars[j] and
        lens[0] > 0, lens[1] > 0, …, lens[j] > 0 and
        (i = 0 or cur = str[i-1])  }}
while (i != n) {
   if (str.charAt(i) == cur) {
      // same as last character, goes into index j
      lens[j] = lens[j] + 1;
   } else {
      // different from last character, needs new spot
      j = j + 1;
      cur = str.charAt(i);
      chars[j] = cur;
      lens[j] = 1;
   }
   i = i + 1;
}
```

Only the invariant must hold at the end of each loop iteration.
Does it hold?

Testing

What would be some good test cases for this method?

Note: @param tags omitted.

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Testing

What would be some good test cases for this method?

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Is `mystery(0, 0)` a good test case?

No. Its behavior is undefined. We cannot test for undefined behavior!

Testing

What would be some good test cases for this method?

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Is `mystery(1, 1)` a good test case?

Yes – we are testing for an IllegalArgumentException being thrown.

Testing

What would be some good test cases for this method?

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Is **`mystery(2, 2)`** a good test case?

We already tested for this with **`mystery(1, 1)`**. This is not testing anything new.

Testing

What would be some good test cases for this method?

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Is `mystery(3, 2)` a good test case?

Yes!

Testing

What would be some good test cases for this method?

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Is `mystery(4, 10)` a good test case?

Yes!

Testing

What would be some good test cases for this method?

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Is `mystery(400000, 1000000)` a good test case?

It's not testing anything new.

Testing

What would be some good test cases for this method?

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Is `mystery(42, -42)` a good test case?

No! It's testing for undefined behavior!

Testing

What would be some good test cases for this method?

```
/** A very mysterious method with a great description
 *  @requires x > 0 and y > 0
 *  @throws IllegalArgumentException if x == y
 */ @return x + y if x > y. x - y if x < y
public int mystery(int x, int y) {
  if (x == y) { throw new IllegalArgumentException(); }
  return (x > y) ? (x + y) : (x - y);
}
```

Is `mystery(null, null)` a good test case?
No! `int` is a primitive, and it cannot be null.

Subtypes & Subclasses

- Subtypes are substitutable for supertypes
- If **`Foo`** is a subtype of **`Bar`**,
  `G<Foo>` is a **NOT** a subtype of **`G<Bar>`**
  - Aliasing resulting from this would let you add objects of type **`Bar`** to **`G<Foo>`**, which would be bad!
  - Example:

```
List<String> ls = new ArrayList<String>();
List<Object> lo = ls;
lo.add(new Object());
String s = ls.get(0);
```

- Subclassing is done to reuse code (extends)
  - A subclass can override methods in its superclass

Typing and Generics

- <?> is a wildcard for unknown
  - Lower bounded wildcard **`<? super SomeClass>`** (superclass)
    - Can only insert items with type **`SomeClass`**, or a type that extends **`SomeClass`**
      - Why? Because we can cast that object into **`SomeClass`**.
    - Illegal to retrieve as type other than **`Object`**.

- What types can you put here?
  - **List<? super Number> lsn = new ArrayList<_____>();**
    - Object
    - Number
  - Number *is* an Object. But an Object might not be a Number.

Typing and Generics

- What types can you put here?
  - **List<? super Number> lsn = new ArrayList<_____>();**
    - Object
    - Number
  - Number *is* an Object. But an Object might not be a Number.

  - Object o = new Object(); lsn.add(o); ✗
  - Number n = 4; lsn.add(n); ✓
  - Integer i = 5; lsn.add(i); ✓

  Remember: ArrayList<Number> must hold Numbers. We cannot add `o` because an Object cannot be cast into a Number. But we can add `i` because an Integer can be cast into a Number.

Typing and Generics

- What types can you put here?
  - **List<? super Number> lsn = new ArrayList<_____>();**
    - Object
    - Number
  - Number *is* an Object. But an Object might not be a Number.

  - Object o = lsn.get(0); ✔
  - Number n = lsn.get(0); ✘
  - Integer i = lsn.get(0); ✘

  Since **`lsn`** *could* be an ArrayList<Object>, we can only pull Objects out of here.

Typing and Generics

- <?> is a wildcard for unknown
  - Upper bounded wildcard: **`<? extends _____>`** (subclass)
    - Safe to read from: result will be the type after **`extends`**
    - Illegal to write into (no calls to add!) because we can't guarantee type safety.
- What types can you put here?
  - **List<? extends Number> lei = new ArrayList<_____>();**
    - Number
    - Integer, Float, Double, Long…
    - Some other class that extends Integer.
    - Some other class that extends the class that extended Integer… (infinitely downwards)
  - Anything that extends Number will still be a Number. But, Number might not be an Integer, or any of its subclasses.

Typing and Generics

- What types can you put here?
  - **List<? extends Number> lei = new ArrayList<_____>();**
    - Number
    - Integer, Float, Double, Long…
    - Some other class that extends Integer.
    - Some other class that extends the class that extended Integer… (infinitely downwards)
  - Anything that extends Number will still be a Number. But, Number might not be an Integer, or any of its subclasses.

- Object o = new Object(); len.add(o); ✗
- Number n = 4; len.add(n); ✗
- Integer i = 5; len.add(i); ✗

We cannot add anything because there is no lower bound on the actual type of the List.

Typing and Generics

- What types can you put here?
  - **List<? extends Number> lei = new ArrayList<_____>();**
    - Number
    - Integer, Float, Double, Long…
    - Some other class that extends Integer.
    - Some other class that extends the class that extended Integer… (infinitely downwards)
  - Anything that extends Number will still be a Number. But, Number might not be an Integer, or any of its subclasses.
  - Object o = len.get(0); ✓
  - Number n = len.get(0); ✓
  - Integer i = len.get(0); ✗

When we retrieve an element, it must be of type Number. A Number is an Object, but a Number might not be an Integer.

Subtypes & Subclasses

Given the below classes which one of the statements in the box are legal?

```
class Student extends Object { ... }
class CSEStudent extends Student { ... }
```

```
List<Student> ls;
List<? extends Student> les;
List<? super Student> lss;
List<CSEStudent> lcse;
List<? extends CSEStudent> lecse;
List<? super CSEStudent> lscse;
Student scholar;
CSEStudent hacker;
```

ls = lcse;

les = lscse;

lcse = lscse;

les.add(scholar);

lscse.add(scholar);

lss.add(hacker);

scholar = lscse.get(0);

hacker = lecse.get(0);

Subtypes & Subclasses

```
class Student extends Object { ... }
class CSEStudent extends Student { ... }
```

```
List<Student> ls;
List<? extends Student> les;
List<? super Student> lss;
List<CSEStudent> lcse;
List<? extends CSEStudent> lecse;
List<? super CSEStudent> lscse;
Student scholar;
CSEStudent hacker;
```

ls = lcse; X

les = lscse;

lcse = lscse;

les.add(scholar);

lscse.add(scholar);

lss.add(hacker);

scholar = lscse.get(0);

hacker = lecse.get(0);

Subtypes & Subclasses

```
class Student extends Object { ... }
class CSEStudent extends Student { ... }
```

```
List<Student> ls;
List<? extends Student> les;
List<? super Student> lss;
List<CSEStudent> lcse;
List<? extends CSEStudent> lecse;
List<? super CSEStudent> lscse;
Student scholar;
CSEStudent hacker;
```

ls = lcse; **X**

les = lscse; **X**

lcse = lscse;

les.add(scholar);

lscse.add(scholar);

lss.add(hacker);

scholar = lscse.get(0);

hacker = lecse.get(0);

Subtypes & Subclasses

```
class Student extends Object { ... }
class CSEStudent extends Student { ... }
```

```
List<Student> ls;
List<? extends Student> les;
List<? super Student> lss;
List<CSEStudent> lcse;
List<? extends CSEStudent> lecse;
List<? super CSEStudent> lscse;
Student scholar;
CSEStudent hacker;
```

ls = lcse; **X**

les = lscse; **X**

lcse = lscse; **X**

les.add(scholar);

lscse.add(scholar);

lss.add(hacker);

scholar = lscse.get(0);

hacker = lecse.get(0);

Subtypes & Subclasses

```
class Student extends Object { ... }
class CSEStudent extends Student { ... }
```

```
List<Student> ls;
List<? extends Student> les;
List<? super Student> lss;
List<CSEStudent> lcse;
List<? extends CSEStudent> lecse;
List<? super CSEStudent> lscse;
Student scholar;
CSEStudent hacker;
```

ls = lcse; X

les = lscse; X

lcse = lscse; X

les.add(scholar); X

lscse.add(scholar);

lss.add(hacker);

scholar = lscse.get(0);

hacker = lecse.get(0);

Subtypes & Subclasses

```
class Student extends Object { ... }
class CSEStudent extends Student { ... }
```

```
List<Student> ls;
List<? extends Student> les;
List<? super Student> lss;
List<CSEStudent> lcse;
List<? extends CSEStudent> lecse;
List<? super CSEStudent> lscse;
Student scholar;
CSEStudent hacker;
```

ls = lcse; **X**

les = lscse; **X**

lcse = lscse; **X**

les.add(scholar); **X**

lscse.add(scholar); **X**

lss.add(hacker);

scholar = lscse.get(0);

hacker = lecse.get(0);

Subtypes & Subclasses

```
class Student extends Object { ... }
class CSEStudent extends Student { ... }
```

```
List<Student> ls;
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List<? super Student> lss;
List<CSEStudent> lcse;
List<? extends CSEStudent> lecse;
List<? super CSEStudent> lscse;
Student scholar;
CSEStudent hacker;
```

ls = lcse; X

les = lscse; X

lcse = lscse; X

les.add(scholar); X

lscse.add(scholar); X

lss.add(hacker); 

scholar = lscse.get(0);

hacker = lecse.get(0);

Subtypes & Subclasses

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class Student extends Object { ... }
class CSEStudent extends Student { ... }
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List<Student> ls;
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Student scholar;
CSEStudent hacker;
```

ls = lcse; X

les = lscse; X

lcse = lscse; X

les.add(scholar); X

lscse.add(scholar); X

lss.add(hacker); 

scholar = lscse.get(0); X

hacker = lecse.get(0);

Subtypes & Subclasses

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class Student extends Object { ... }
class CSEStudent extends Student { ... }
```

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List<Student> ls;
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List<? extends CSEStudent> lecse;
List<? super CSEStudent> lscse;
Student scholar;
CSEStudent hacker;
```

ls = lcse; X

les = lscse; X

lcse = lscse; X

les.add(scholar); X

lscse.add(scholar); X

lss.add(hacker); 

scholar = lscse.get(0); X

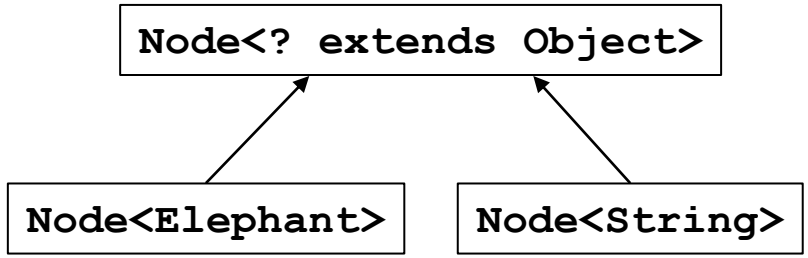
hacker = lecse.get(0); 

equals for a parameterized class

```
class Node<E> {
  …
  @Override
  public boolean equals(Object obj) {
    if (!(obj instanceof Node<?>)) {
      return false;
    }
    Node<?> n = (Node<?>) obj;
    return this.data().equals(n.data());
  }
  …
}
```

Works if the type of obj is **Node<Elephant>** or **Node<String>** or …

Leave it to here to "do the right thing" if **this** and **n** differ on element type



Subclasses & Overriding

```
class Foo extends Object {
      Shoe m(Shoe x, Shoe y){ ... }
}

class Bar extends Foo {...}
```

Overriding a method:

- A method overrides a superclass method only if it has the same name and exact same argument types

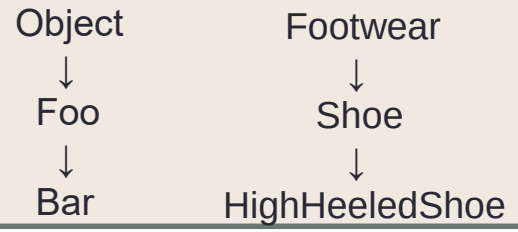
Overloading a method:

- A method overloads a method only if it has the same name and different argument types than another existing method

Method Declarations in Bar

Given the class in the purple box, determine whether the method declarations for the method Shoe() inside **Bar** class are overriding or overloading it?

- The result is method overriding
- The result is method overloading
- The result is a type-error
- None of the above



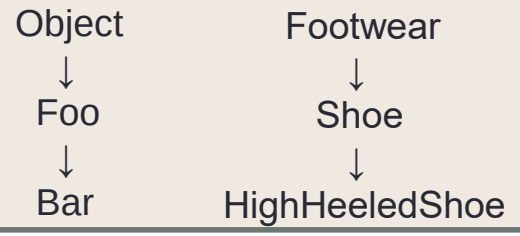
- **FootWear m(Shoe x, Shoe y) { ... }**
- **Shoe m(Shoe q, Shoe z) { ... }**
- **HighHeeledShoe m(Shoe x, Shoe y) { ... }**
- **Shoe m(FootWear x, HighHeeledShoe y) { ... }**
- **Shoe m(FootWear x, FootWear y) { ... }**
- **Shoe m(Shoe x, Shoe y) { ... }**
- **Shoe m(HighHeeledShoe x, HighHeeledShoe y) { ... }**
- **Shoe m(Shoe y) { ... }**
- **Shoe z(Shoe x, Shoe y) { ... }**

```
class Foo extends Object {
        Shoe m(Shoe x, Shoe y){ ... }
}

class Bar extends Foo {...}
```

Method Declarations in Bar

- The result is method overriding
- The result is method overloading
- The result is a type-error
- None of the above



- **FootWear m(Shoe x, Shoe y) { ... }** **type-error**
- **Shoe m(Shoe q, Shoe z) { ... }** **overriding**
- **HighHeeledShoe m(Shoe x, Shoe y) { ... }** **overriding**
- **Shoe m(FootWear x, HighHeeledShoe y) { ... }** **overloading**
- **Shoe m(FootWear x, FootWear y) { ... }** **overloading**
- **Shoe m(Shoe x, Shoe y) { ... }** **overriding**
- **Shoe m(HighHeeledShoe x, HighHeeledShoe y) { ... }** **overloading**
- **Shoe m(Shoe y) { ... }** **overloading**
- **Shoe z(Shoe x, Shoe y) { ... }** **none (new method declaration)**

Subclasses & Method Overriding

```
abstract class Bird {
 public abstract void speak();
 public void move() { System.out.println("flap flap!"); }
 public void move(int n) { move(); speak(); }
}
class Canary extends Bird {
 public void speak() { System.out.println("chirp!"); }
 public void move(int n) { speak(); speak(); }
}
class Duck extends Bird {
 public void speak() { System.out.println("quack!"); }
}
class RubberDuck extends Duck {
 public void speak() { System.out.println("squeak!"); }
 public void move() { speak(); swim(); }
 public void swim() { System.out.println("paddle!"); }
}
```

Given the declarations on the left, determine the outcome of the expressions below.

Bird b = new Bird();
b.move();

Bird b = new Canary();
b.move(17);

Bird b = new Duck();
b.move(42);

Bird b = new RubberDuck();
b.move(3);

Duck donald = new RubberDuck();
donald.swim();

Duck donald = new RubberDuck();
donald.move();

Subclasses & Method Overriding

```
abstract class Bird {
 public abstract void speak();
 public void move() { System.out.println("flap flap!"); }
 public void move(int n) { move(); speak(); }
}
class Canary extends Bird {
 public void speak() { System.out.println("chirp!"); }
 public void move(int n) { speak(); speak(); }
}
class Duck extends Bird {
 public void speak() { System.out.println("quack!"); }
}
class RubberDuck extends Duck {
 public void speak() { Syst                    "); }
 public void move() { spea
 public void swim() { Syst                     ); }
}
```

Compile error: cannot create instances of an abstract class.

Bird b = new Bird();
b.move();

Bird b = new Canary();
b.move(17);

Bird b = new Duck();
b.move(42);

Bird b = new RubberDuck();
b.move(3);

Duck donald = new RubberDuck();
donald.swim();

Duck donald = new RubberDuck();
donald.move();

Subclasses & Method Overriding

```
abstract class Bird {
 public abstract void speak();
 public void move() { System.out.println("flap flap!"); }
 public void move(int n) { move(); speak(); }
}
class Canary extends Bird {
 public void speak() { System.out.println("chirp!"); }
 public void move(int n) { speak(); speak(); }
}
class Duck extends Bird {
 public void speak() { System.out.println("quack!"); }
}
class RubberDuck extends Duck {
 public void speak() { System.out.println("squeak!"); }
 public void move() { speak(); swim(); }
 public void swim() { System.out.println("paddle!"); }
}
```

chirp!
chirp!

Bird
b.mo

Bird b = ne Canary();
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```

```
Bird b = new Bird();
b.move();

Bird b = new Canary();
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Bird b = new Duck();
b.move(42);

Bird b = new RubberDuck();
b.move(3);

Duck();

Duck();
donald.move();
```

flap flap!
quack!

Subclasses & Method Overriding

```
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 public void speak() { System.out.println("squeak!"); }
 public void move() { speak(); swim(); }
 public void swim() { System.out.println("paddle!"); }
}
```

squeak!
paddle!
squeak!

Bi
b.

Bi
b.move(17);

Bird b = new Duck();
b.move(42);

Bird b = new RubberDuck();
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 public void swim() { System.out.println("paddle!"); }
}
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Bird b = new Bird();
b.move();

Bird b = new Canary();
b.move(17);

Compile error: no swim method in class Duck

Duck donald = new RubberDuck();
donald.swim();

Duck donald = new RubberDuck();
donald.move();

b.move(3);

Subclasses & Method Overriding

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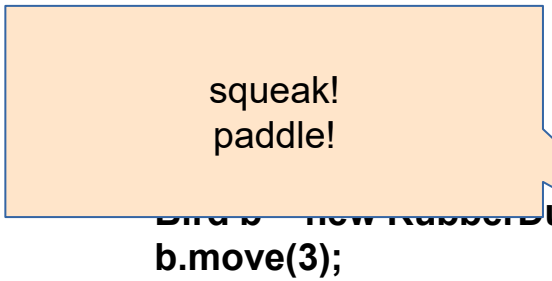
 public void move() { speak(); swim(); }
 public void swim() { System.out.println("paddle!"); }
}
```

Bird b = new Bird();
b.move();

Bird b = new Canary();
b.move(17);



b.move(3);

Duck donald = new RubberDuck();
donald.swim();

Duck donald = new RubberDuck();
donald.move();

Event-Driven Programs

- Sits in an event loop, waiting for events to process
  - often does so until forcibly terminated

- Two common types of event-driven programs:
  - GUIs
  - Web servers

- Where is the event loop in Spark Java?
  - it is created behind the scenes

Design Patterns

- Creational patterns: get around Java constructor inflexibility
  - Sharing: singleton, interning
  - Telescoping constructor fix: builder
  - Returning a subtype: factories
- Structural patterns: translate between interfaces
  - Adapter: same functionality, different interface
  - Decorator: different functionality, same interface
  - Proxy: same functionality, same interface, restrict access
  - All of these are types of **wrappers**

Design Patterns

- Interpreter pattern:
  - Collects code for similar objects, spreads apart code for operations (classes for objects with operations as methods in each class)
  - Easy to add objects, hard to add methods
  - Instance of Composite pattern

- Procedural patterns:
  - Collects code for similar operations, spreads apart code for objects (classes for operations, method for each operand type)
  - Easy to add methods, hard to add objects
  - Ex: Visitor pattern

Design Patterns

Adapter, Builder, Composite, Decorator, Factory, Iterator, Intern, Interpreter, Model-View-Controller (MVC), Observer, Procedural, Prototype, Proxy, Singleton, Visitor, Wrapper

- What pattern would you use to…
  - Remove the addNode/addEdge functionality from your Graph class (throw an UnsupportedOperationException when those methods are called), in order to create an UnmodifiableGraph?

  - We have an existing object that controls a communications channel. We would like to provide the same interface to clients but transmit and receive encrypted data over the existing channel.

  - When the user clicks the "find path" button in the Campus Maps application (HW9), the path appears on the screen.

Design Patterns

Adapter, Builder, Composite, Decorator, Factory, Iterator, Intern, Interpreter, Model-View-Controller (MVC), Observer, Procedural, Prototype, Proxy, Singleton, Visitor, Wrapper

- What pattern would you use to…
  - Remove the addNode/addEdge functionality from your Graph class (throw an UnsupportedOperationException when those methods are called), in order to create an UnmodifiableGraph?
    - **Decorator**
  - We have an existing object that controls a communications channel. We would like to provide the same interface to clients but transmit and receive encrypted data over the existing channel.
    - **Proxy**
  - When the user clicks the "find path" button in the Campus Maps application (HW9), the path appears on the screen.
    - **MVC**
    - **Observer**

Design Patterns

- We have a worksheet with additional practice problems on the website!

Stronger vs Weaker (one more time!)

- In each case, what is the effect of changing the amount of information required about the input?

- Requires more about inputs?

- Promises more about behavior?

Stronger vs Weaker (one more time!)

- In each case, what is the effect of changing the amount of information required about the input?

- Requires more about inputs?

  weaker

- Promises more about behavior?

  stronger

Stronger vs Weaker

Compared to the spec in the box, what is the effect of using specs A,B,C in terms of our statement's strength (weaker/stronger/neither)?

```
@requires key is a key in this
@return the value associated with key
@throws NullPointerException if key is null
```

A.
```
@requires that key is a key in this and key != null
  @return the value associated with key
```

B.
```
@return the value associated with key if key is a
      key in this, or null if key is not associated
      with any value
```

C.
```
@return the value associated with key
  @throws NullPointerException if key is null
  @throws NoSuchElementException if key is not a
          key this
```

Stronger vs Weaker

Compared to the spec in the box, what is the effect of using specs A,B,C in terms of our statement's strength (weaker/stronger/neither)?

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A.
```
@requires that key is a key in this and key != null
  @return the value associated with key
```
WEAKER

B.
```
@return the value associated with key if key is a
      key in this, or null if key is not associated
      with any value
```
NEITHER

C.
```
@return the value associated with key
  @throws NullPointerException if key is null
  @throws NoSuchElementException if key is not a
          key this
```
STRONGER

Exceptions

- Unchecked exceptions are ignored by the compiler.
- If a method throws a checked exception or calls a method that throws a checked exception, then it must either:
  - catch the exception
  - declare it in `@throws`

Exceptions Examples

Should these be checked or unchecked?

- Attempt to write an invalid type into an array
  E.g., write **`Double`** into **`Integer[]`** cast to **`Number[]`**

- Attempt to open a file that does not exist

- Attempt to create a URL from invalidly formatted text
  E.g., “http:/foo” (only one “/”)

Exceptions Examples

Should these be checked or unchecked?

- Attempt to write an invalid type into an array
  E.g., write **`Double`** into **`Integer[]`** cast to **`Number[]`**

  unchecked

- Attempt to open a file that does not exist

  checked

- Attempt to create a URL from invalidly formatted text
  E.g., "http:/foo" (only one "/")

  debatable – could see either one