Concepts of Object-Oriented Programming
Recall...

- **Standard**
- **NaturalNumber-Kernel**
- **NaturalNumber**
  - implements **NaturalNumber1L**
  - implements **NaturalNumber2**

The diagram shows the inheritance hierarchy with **Standard** extending **NaturalNumber-Kernel**, and **NaturalNumber** implementing both **NaturalNumber1L** and **NaturalNumber2**.
The “Implements” Relation

• The *implements* relation may hold between a class and an interface
• If C *implements* I then class C contains code for the behavior specified in interface I
  – This means C has method bodies for instance methods whose contracts are specified in I
  – The code for C looks like this:

```java
class C implements I {
    // bodies for methods specified in I
}
```
The “Implements” Relation

• The implements relation may hold between a class and an interface.

• If \( C \) implements \( I \) then class \( C \) contains code for the behavior specified in interface \( I \).

  – This means \( C \) has method bodies for instance methods whose contracts are specified in \( I \).

  – The code for \( C \) looks like this:

```java
class C implements I {
    // bodies for methods specified in I
}
```
The "Implements" Relation

- The `implements` relation may hold between a class and an interface.
- If `C implements I`, then class `C` contains code for the behavior specified in `I`.
  - This means `C` has method bodies for instance methods whose contracts are specified in `I`.
  - The code for `C` looks like this:
    ```java
class C implements I {
    // bodies for methods specified in I
}
```

The Java compiler checks that `C` contains bodies for the methods in `I`, but does not check that those bodies correctly implement the method contracts!
The “Extends” Relation

• The *extends* relation may hold between:
  – Two interfaces (as on the earlier slide), or
  – Two classes

• In either case, if $B$ *extends* $A$ then $B$ *inherits* all the methods of $A$
  – This means $B$ implicitly *starts out* with all the method contracts (for an interface) or all the method bodies (for a class) that $A$ has
  – $B$ can then *add more* method contracts (for an interface) or method bodies (for a class)
Caveats About Java Interfaces

• “If $B$ extends $A$ then $B$ inherits all the methods of $A$”
  – Interfaces cannot have constructors
    • So there is no good place to write separate contracts for the constructors of classes that implement an interface
  – Interfaces cannot have static method contracts without also providing corresponding method bodies
    • So there is no good place to write separate contracts for public static methods of classes that implement an interface
Caveats About Java Classes

• “If \textbf{B extends A} then \textbf{B inherits} all the methods of \textbf{A}”
  – Constructors \textit{are not} inherited
    • So in the situation above, the class \textbf{B} must include bodies for any constructors that are expected, even if they would be identical to those of \textbf{A}
    • The bodies of the constructors in \textbf{B} generally would simply invoke the constructors of \textbf{A}, which is done using the special notation \texttt{super(...)}
  – Static methods \textit{are} inherited
“Implements” May Be Inferred

I1

extends

I2

implements

C3

extends

C4
We may infer in this case that C3 implements I1.
We may also infer in this case that $C_4$ implements $I_2$. 
Interface Extension

• If \( I_1 \) and \( I_2 \) are interfaces and \( I_2 \) extends \( I_1 \), then the code for \( I_2 \) looks like this:

```java
interface I2 extends I1 {
    // contracts for methods added in I2
}
```

```
I1

extends

I2
```
If $I_1$ and $I_2$ are interfaces and $I_2$ extends $I_1$, then the code for $I_2$ looks like this:

```java
interface I2 extends I1 {
    // contracts for methods added in I2
}
```

Remember, for interfaces all such methods are instance methods!
Interface Extension

- If \( I_1 \) and \( I_2 \) are interfaces and \( I_2 \) extends \( I_1 \), then the code for \( I_2 \) looks like this:

```java
interface I2 extends I1 {
    // contracts for methods added in I2
}
```

Other terminology for this situation:
- \( I_2 \) is a subinterface of \( I_1 \)
- \( I_2 \) is a derived interface of \( I_1 \)
- \( I_2 \) is a child interface of \( I_1 \)
Interface Extension

- If \( I_1 \) and \( I_2 \) are interfaces and \( I_2 \) extends \( I_1 \), then the code for \( I_2 \) looks like this:

```java
interface I2 extends I1 {
    // contracts for methods added in I2
}
```

Other terminology for this situation:
- \( I_1 \) is a superinterface of \( I_2 \)
- \( I_1 \) is a base interface of \( I_2 \)
- \( I_1 \) is a parent interface of \( I_2 \)
Example: Interface Extension

```
clear
newInstance
transferFrom
+
multiplyBy10
divideBy10
isZero
=
clear
newInstance
transferFrom
multiplyBy10
divideBy10
isZero
```
Example: Interface Extension

*NaturalNumberKernel* actually has all these methods, even though their contracts are in two separate interfaces.

```java
NaturalNumberKernel
```

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Example: Interface Extension

The extends relation for interfaces allows you to separate contracts into smaller chunks — arguably a **best practice** for component design.

```java
// NaturalNumber-Kernel
NaturalNumber-Kernel
  clear
  newInstance
  transferFrom
  multiplyBy10
  divideBy10
  isZero
  =
  clear
  multiplyBy10
  newInstance
  divideBy10
  isZero
```
Class Extension

• For classes, extension can serve two different purposes:
  – To add method bodies that are not already in the class being extended (similar to the use of extension for interfaces)
  – To override methods that are already implemented in the class being extended, by providing new method bodies for them
Class Extension

- For classes, extension can serve two different purposes:
  - To add method bodies that are not already in the class being extended (similar to the use of extension for interfaces)
  - To **override** methods that are already implemented in the class being extended, by providing new method bodies for them

When pronounced, this may sound like “overwrite”, but that is not a correct interpretation!
Class Extension

• For classes, extension can serve two different purposes:
  – To add method bodies that are not already in the class being extended (similar to the use of extension for interfaces)
  – To *override* methods that are already implemented in the class being extended, by providing *new* method bodies for them

For now, we are concerned only with this use of class extension.
• For classes, extension can serve two different purposes:
  – To add method bodies that are not already in the class being extended (similar to the use of extension for interfaces)
  – To override methods that are already implemented in the class being extended, by providing new method bodies for them

Important note: **Overriding** a method is different from **overloading** a method! A method (name) is **overloaded** when two or more methods have the same name, in which case the methods must differ in the number and/or types of their formal parameters (which the compiler uses to disambiguate them).
Class Extension

- If \( C_1 \) and \( C_2 \) are classes and \( C_2 \) extends \( C_1 \), then the code for \( C_2 \) looks like this:

```java
class C2 extends C1 {
    // code for methods added or overridden in C2
}
```

![Diagram of class inheritance](image)
If $C_1$ and $C_2$ are classes and $C_2$ extends $C_1$, then the code for $C_2$ looks like this:

```java
class C2 extends C1 {
    // code for methods added or overridden in C2
}
```

Remember, for classes these may be either static methods or instance methods.
Class Extension

• If \( C_1 \) and \( C_2 \) are classes and \( C_2 \) \textbf{extends} \( C_1 \), then the code for \( C_2 \) looks like this:

```java
class C2 extends C1 {
    // code for methods added or overridden
}
```

Other terminology for this situation:
- \( C_2 \) is a \textit{subclass} of \( C_1 \)
- \( C_2 \) is a \textit{derived class} of \( C_1 \)
- \( C_2 \) is a \textit{child class} of \( C_1 \)
Class Extension

- If C1 and C2 are classes and C2 extends C1, then the code for C2 looks like this:

  ```java
  class C2 extends C1 {
    // code for methods added or overridden
  }
  ```

Other terminology for this situation:

- C1 is a **superclass** of C2
- C1 is a **base class** of C2
- C1 is a **parent class** of C2
Example: Overriding a Method

NaturalNumber2

NaturalNumber2-Override

extends

... power ...

power
Example: Overriding a Method

There is a method body for `power` in `NaturalNumber2` ...

\[ \text{extends} \]

\[ \begin{align*}
\text{NaturalNumber2} \\
\text{NaturalNumber2-Override}
\end{align*} \]
Example: Overriding a Method

\[\text{NaturalNumber2} \quad \text{extends} \quad \text{NaturalNumber2-Override}\]

\[\text{... \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot\]

\[\text{... power ... power...} \]

\[\ldots \text{and there is another method body for power in NaturalNumber2Override.}\]
“@Override” Annotation

• When writing the code for the body of either a method
  – whose contract is from an interface being implemented, or
  – that overrides a method in a class being extended

you preface the method body with an @Override annotation
Example of "@Override"

```java
@Override
public void power(int p) {
    ...
}
```
Which Method Body Is Used?

This raises the question: Which method body for `power` is used when `power` is called in a client program?
Interface as Declared Type

• When a variable is declared using the name of an *interface* as its type, e.g.:
  
  ```
  NaturalNumber k = new NaturalNumber2();
  ```
  
  then its *declared type* (or *static type*) is said to be an *interface type*
Interface as Declared Type

• When a variable is declared using the name of an interface as its type, e.g.:

```java
NaturalNumber k = new NaturalNumber2();
```

then its declared type (or static type) is said to be an interface.

Here, the declared type of `k` is `NaturalNumber`. 

Interface as Declared Type

• When a variable is declared using the name of an *interface* as its type, e.g.:

```java
NaturalNumber k = new NaturalNumber2();
```

then its *declared type* (or *static type*) is said to be an *interface type*. A *Best practice* is for variables to be declared using an *interface* type, as shown here.
Class as Declared Type

• When a variable is declared using the name of a class as its type, e.g.:

```
NaturalNumber2 k =
    new NaturalNumber2();
```

then its declared type (or static type) is said to be a class type
Class as Declared Type

• When a variable is declared using the name of a `class` as its type, e.g.:

```java
NaturalNumber2 k = new NaturalNumber2();
```

then its `declared type` (or `static type`) is said to be a `class` type.

Here, the declared type of `k` is `NaturalNumber2`. 
Class as Declared Type

• When a variable is declared using the name of a **class** as its type, e.g.:

```java
NaturalNumber2 k = new NaturalNumber2();
```

then its **declared type** (or **static type**) is said to be a **class type**.

Best practice is for variables to be declared using an **interface type**, but Java will let you use a **class type**, as shown here.
Object Type

• When a variable is *instantiated* (an object for it to reference is constructed), e.g.:

  `NaturalNumber k = new NaturalNumber2();`

  then its *object type* (or *dynamic type*) is the class type from which the constructor comes
Object Type

• When a variable is instantiated (an object for it to reference is constructed), e.g.:
  
  ```java
  NaturalNumber k = new NaturalNumber2();
  ```

  then its **object type** (or **dynamic type**) is the class type from which the constructor comes

Here, the object type of \( k \) is \( \text{NaturalNumber2} \).
Declared/Object Type Rule

• Suppose we follow best practices, and:
  – The *declared type* of some variable is the interface type $I$
  – The *object type* of that variable is the class type $C$

• Then the relation $C$ *implements* $I$ must hold
  – Java enforces this rule!
Polymorphism

• Finally, back to overriding... Java and other object-oriented languages decide which method body to use for any call to an instance method based on the **object type** of the **receiver**
  – This type, because it is the **class** of the constructor, is always a **class** type

• This behavior for calling methods is known as **polymorphism**: “having many forms”
Example of Polymorphism

NaturalNumber k =
    new NaturalNumber2();
NaturalNumber n =
    new NaturalNumber2Override();
...

k.power(2);
n.power(2);
...
Example of Polymorphism

NaturalNumber k =
    new NaturalNumber2();
NaturalNumber n =
    new NaturalNumber2Override();

...  
k.power(2);
    n.power(2);
...  

This call of power uses the method body for power from NaturalNumber2 (which is the object type of k).
Example of Polymorphism

NaturalNumber k =
    new NaturalNumber2();
NaturalNumber n =
    new NaturalNumber2Override();
...
 k.power(2);
n.power(2);
...

This call of `power` uses the method body for `power` from `NaturalNumber2Override` (which is the object type of `n`).
Example of Polymorphism

NaturalNumber k =
    new NaturalNumber2();
NaturalNumber n =
    new NaturalNumber2Override();
...
k.power(2);
n.power(2);
...

Note that the declared type of both k and n is NaturalNumber, and it does not determine which method body is used.
Another Example

NaturalNumber k = new NaturalNumber2();
NaturalNumber n = new NaturalNumber2Override();
NaturalNumber j = k;
...
j.power(2);
...
Another Example

NaturalNumber \( k = \)
\[
\text{new NaturalNumber2();}
\]
NaturalNumber \( n = \)
\[
\text{new NaturalNumber2Override();}
\]
NaturalNumber \( j = k; \)

\[
\ldots
\]
\[
 j.\text{power}(2);
\]
\[
\ldots
\]

This call of \texttt{power} uses the method body for \texttt{power} from \texttt{NaturalNumber2} (which is the object type of \( j \)) ...
Another Example

NaturalNumber k =
    \textbf{new} \texttt{NaturalNumber2}();
NaturalNumber n =
    \textbf{new} \texttt{NaturalNumber2Override}();
NaturalNumber j = n;

\ldots
j.power(2);
\ldots

\ldots but this call of \texttt{power} uses the method body for \texttt{power} from \texttt{NaturalNumber2Override} (which is the object type of j).