Integrating Nominal and Structural Subtyping

Donna Malayeri
Jonathan Aldrich

Structural vs. nominal subtyping

Nominal Subtyping

- A type *T* is a subtype of *U* only if *T* has been *declared* as a subtype of *U*
- The norm in mainstream languages like Java

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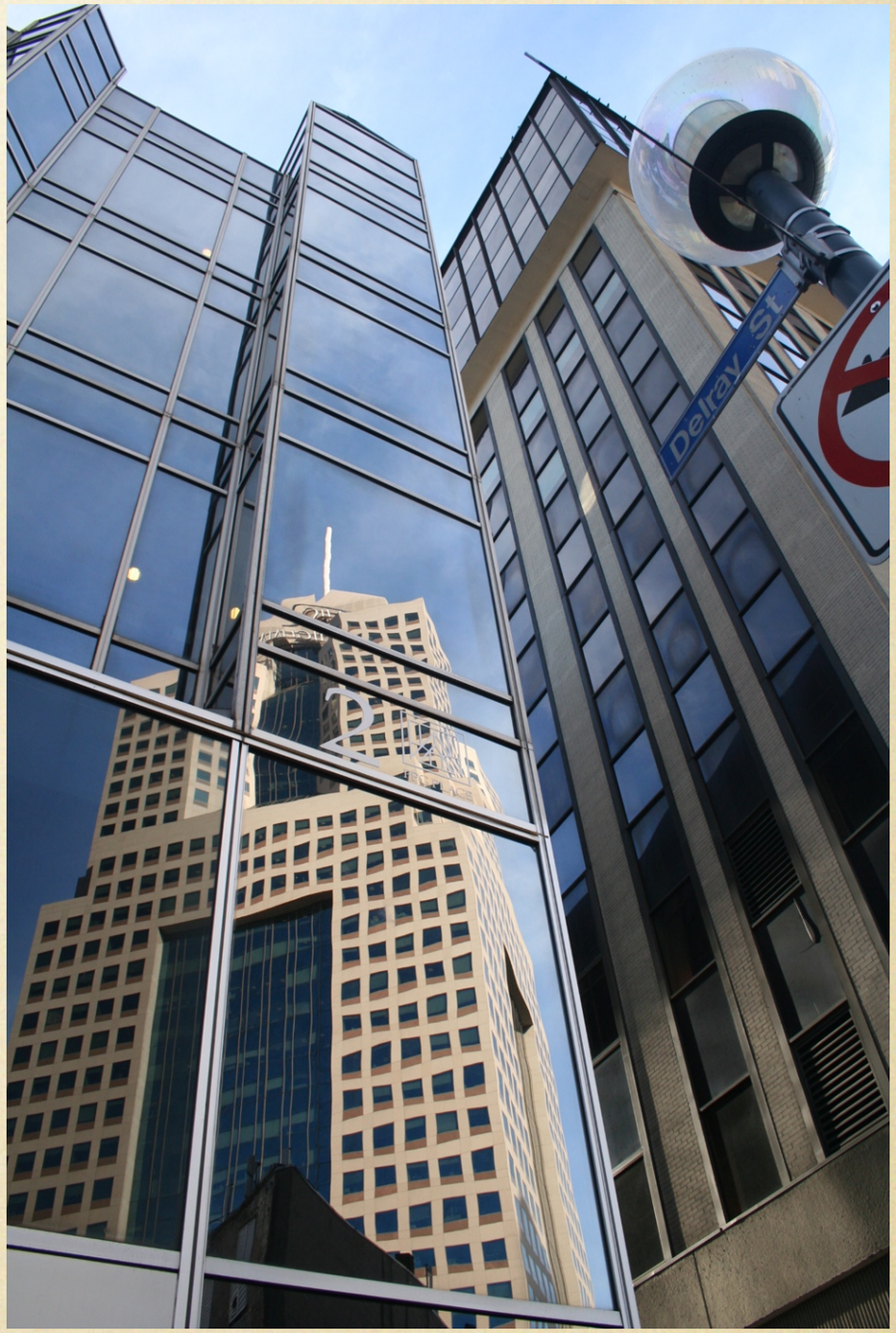
Structural subtyping

- a type *T* is a subtype of *U* if *T has at least U's methods and fields*—possibly more, possibly with more refined types
  - So, any class with an `iterator()` method would automatically be a subtype of `Iterable`

Our language: Unity

- A type has:
  - a nominal component (a brand)
  - a structural component (its fields and methods)
- Subtyping takes both components into account
- Allows structural subtyping to co-exist with external dispatch
  - Combination is novel

Why structural subtyping?



A motivating example (Java)

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interface Drawable {
    void draw();
    void setBounds(Rect bounds);
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void centerAndDraw(____ item)  {
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    item.setBounds(rect);
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Our solution: Unity

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 Object (
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- Structural subtyping: Drawable ≤ Bitmap
  Circle ≤ Bitmap
  Circle ≤ Drawable
  Icon ≤ Bitmap

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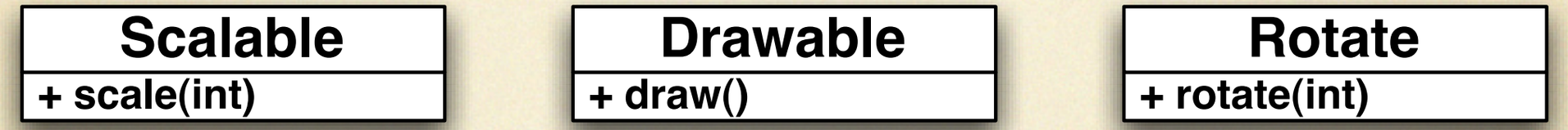
Example 2: composing interfaces



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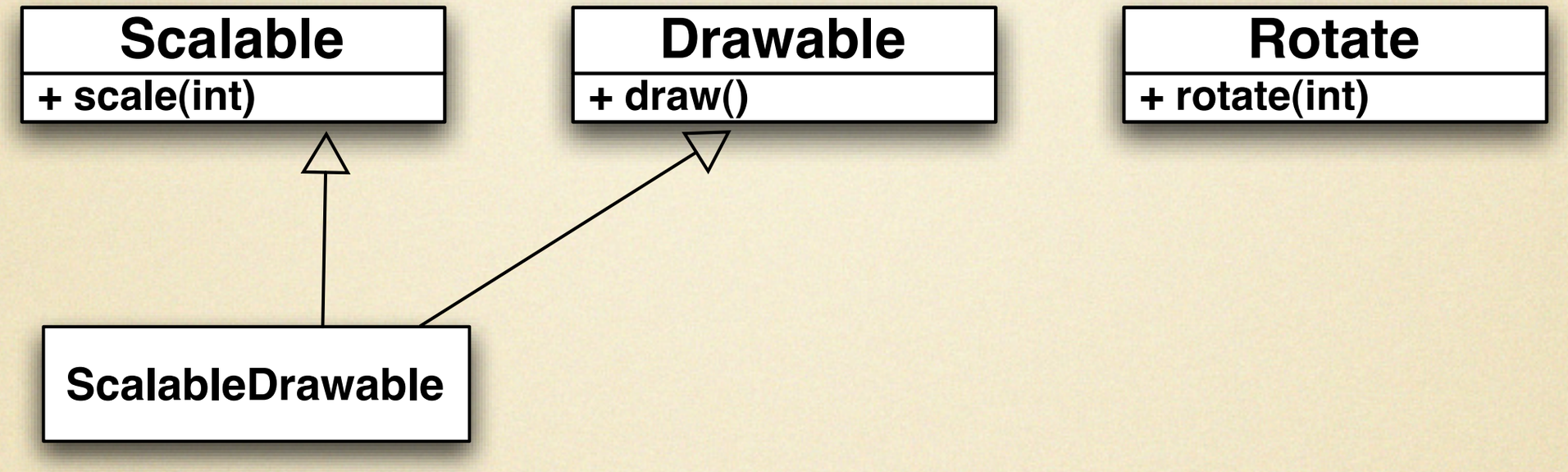

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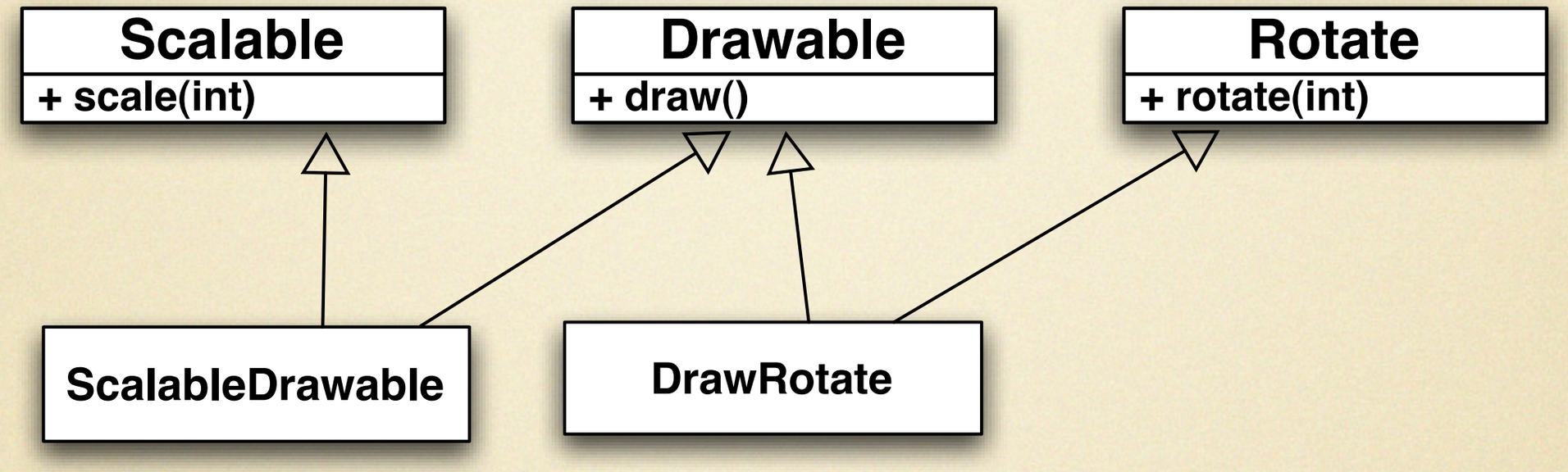

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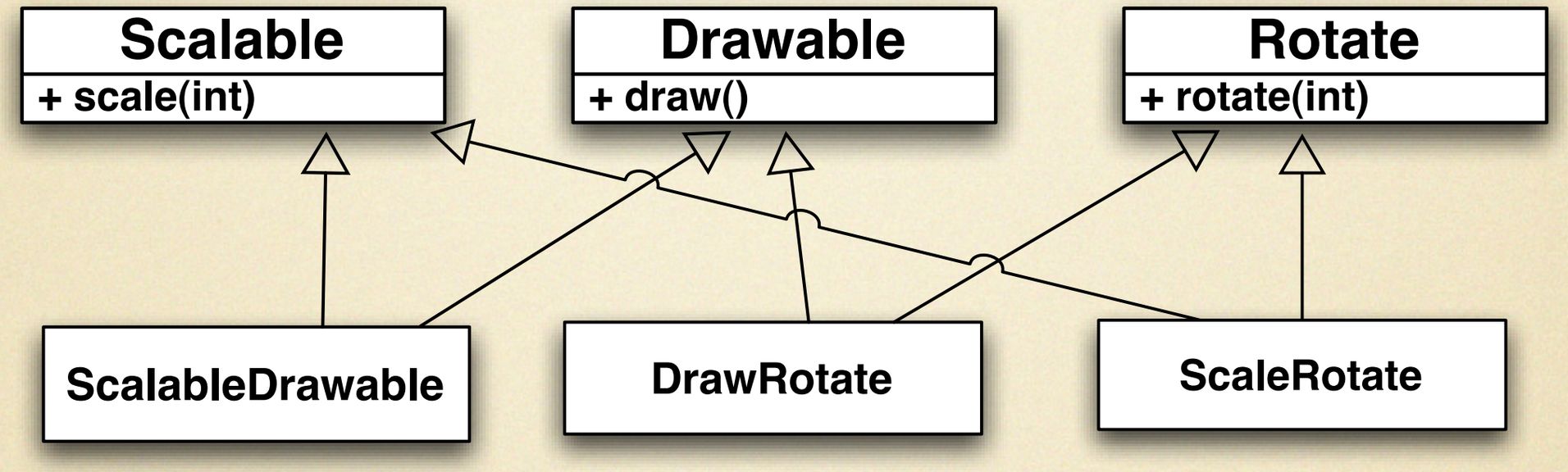

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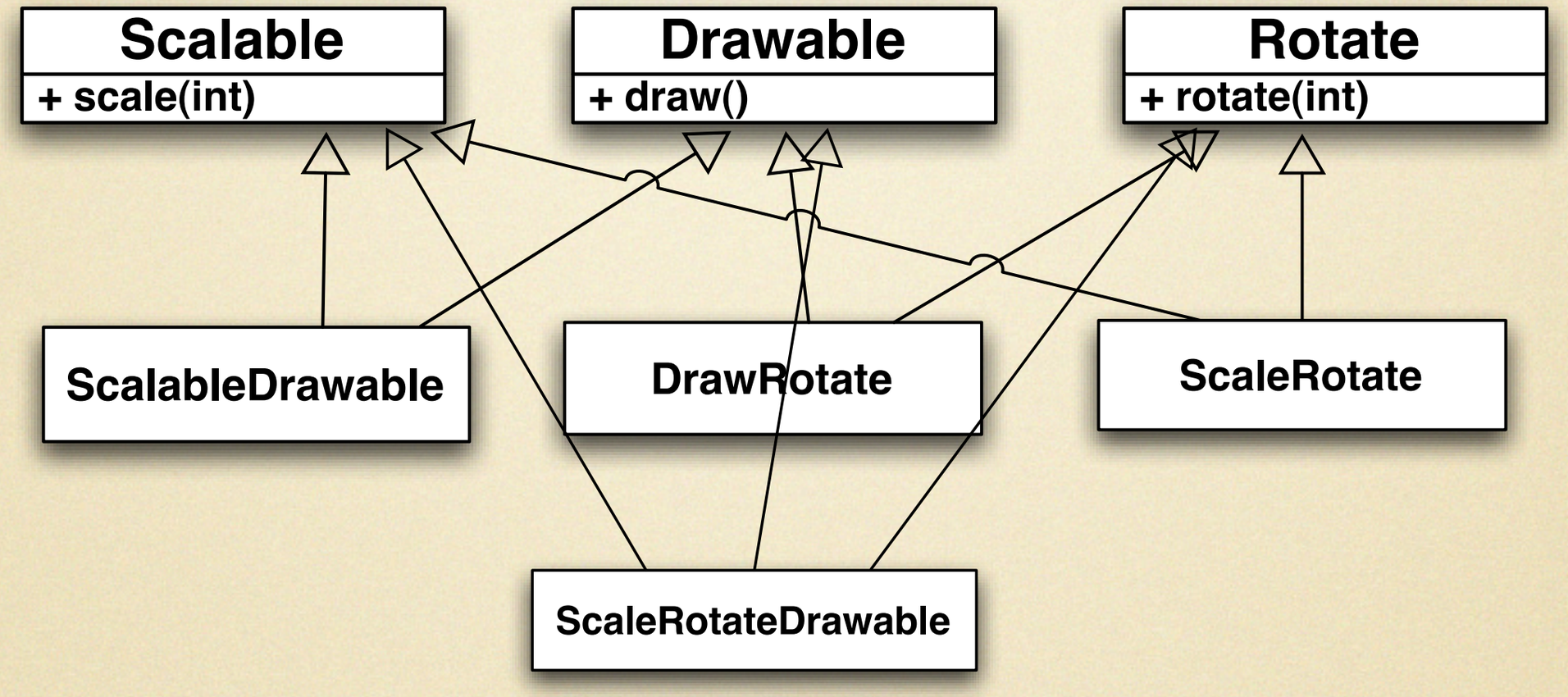

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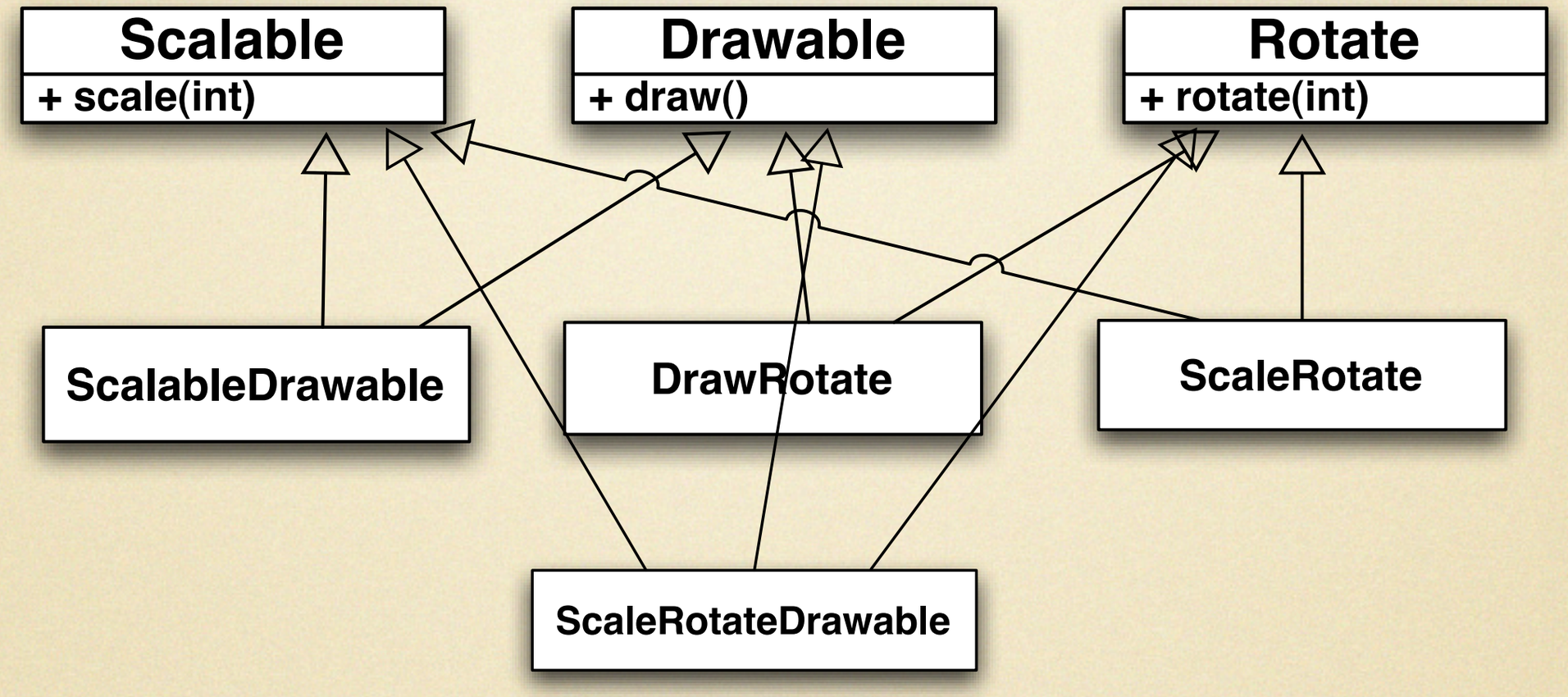


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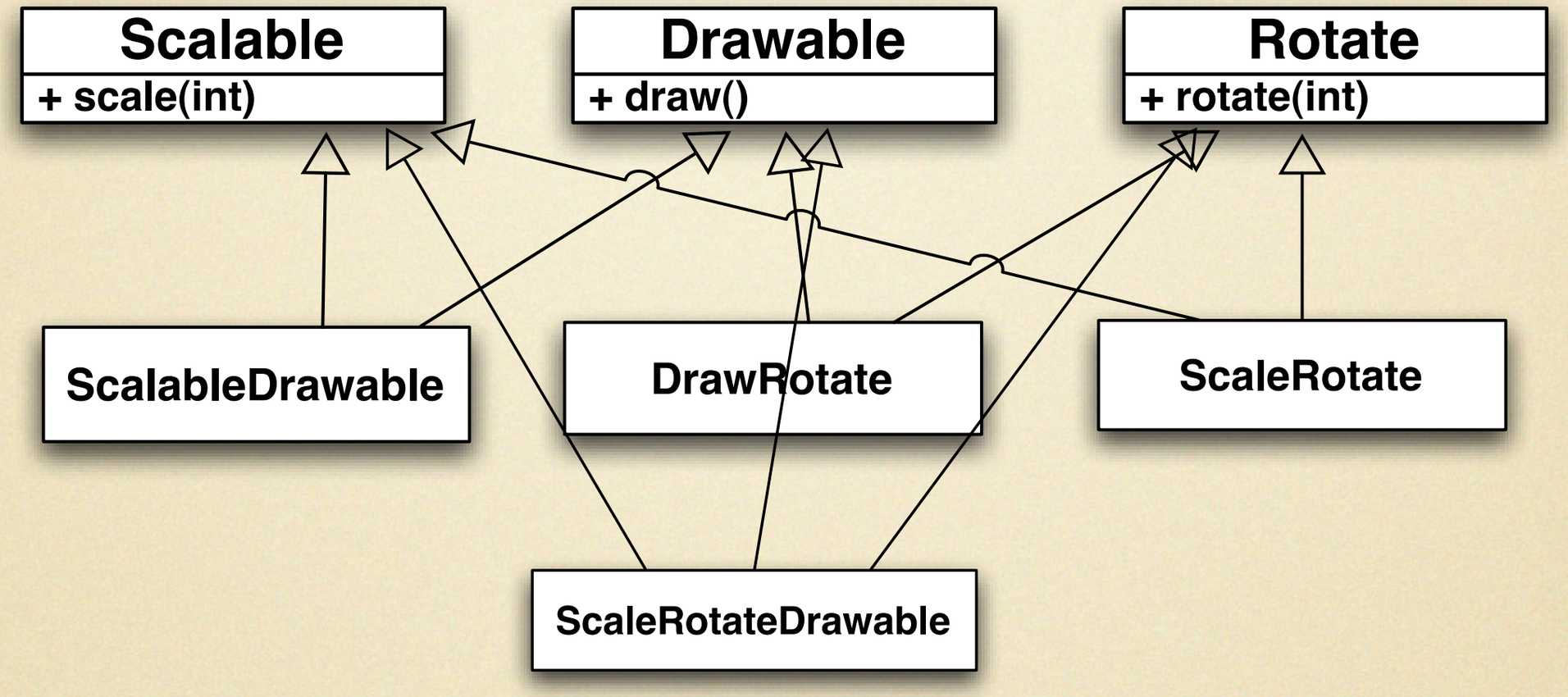


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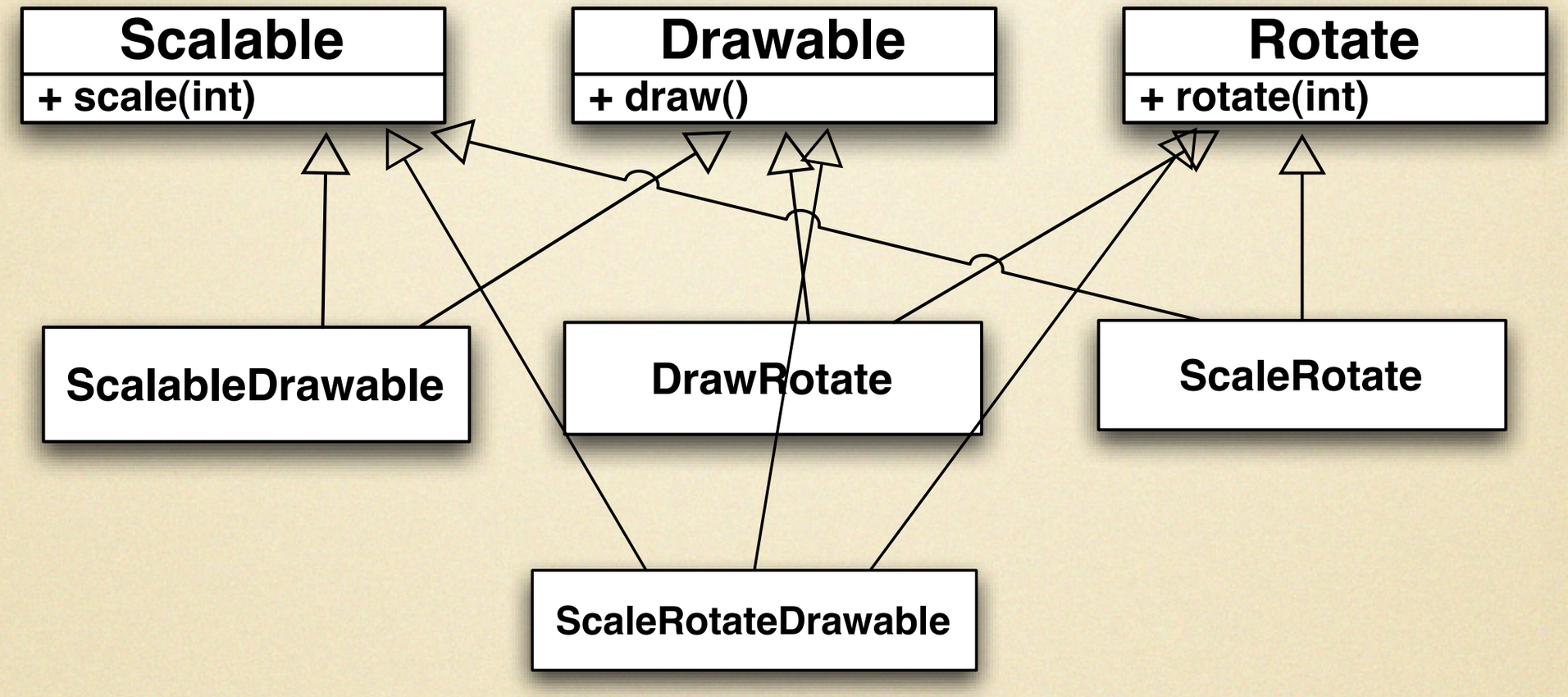


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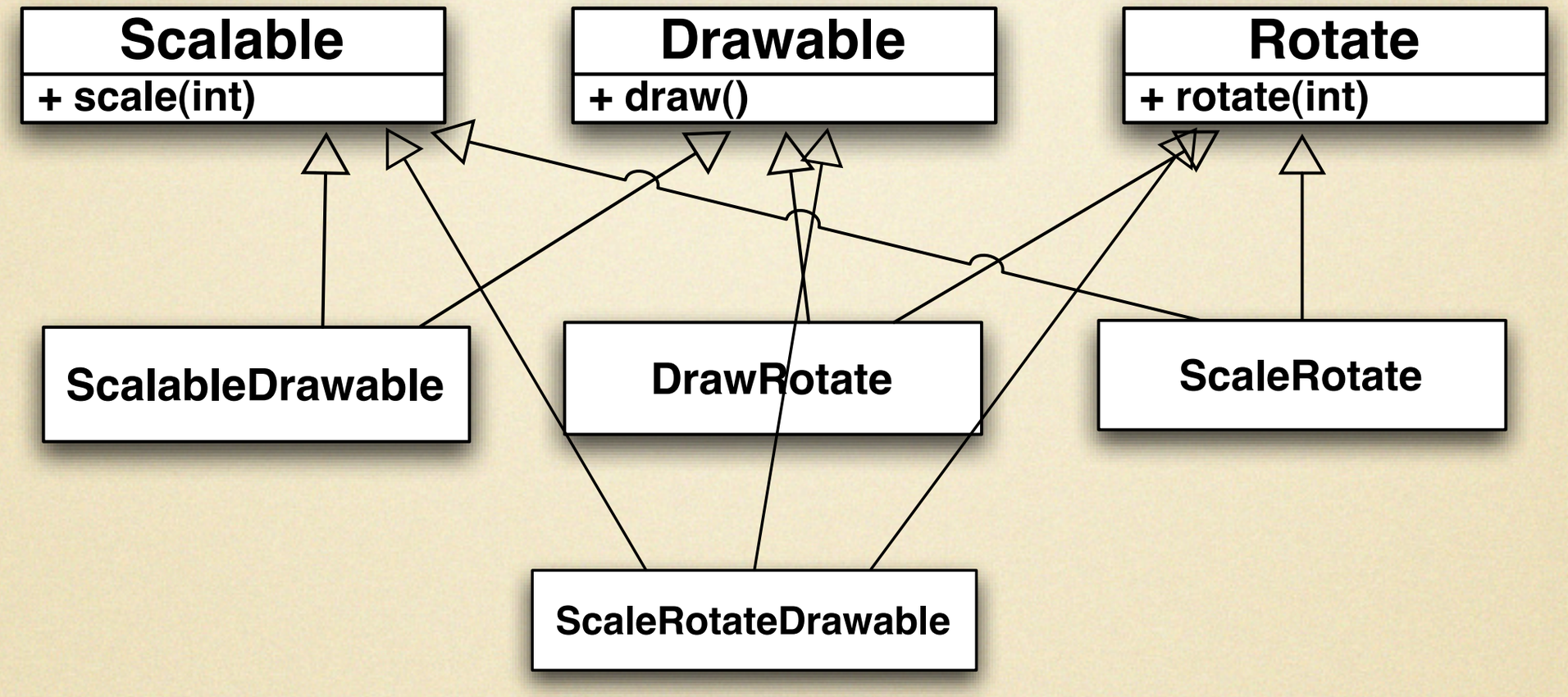


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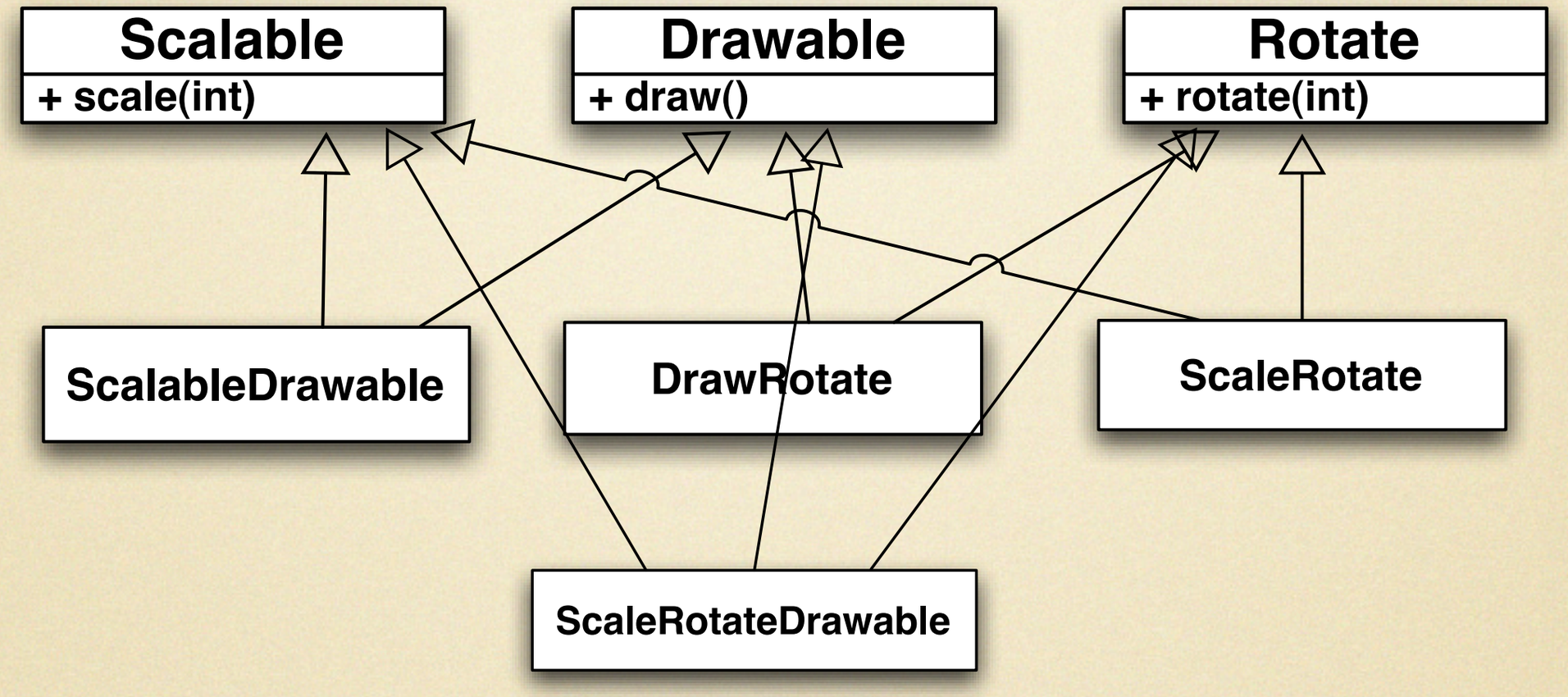


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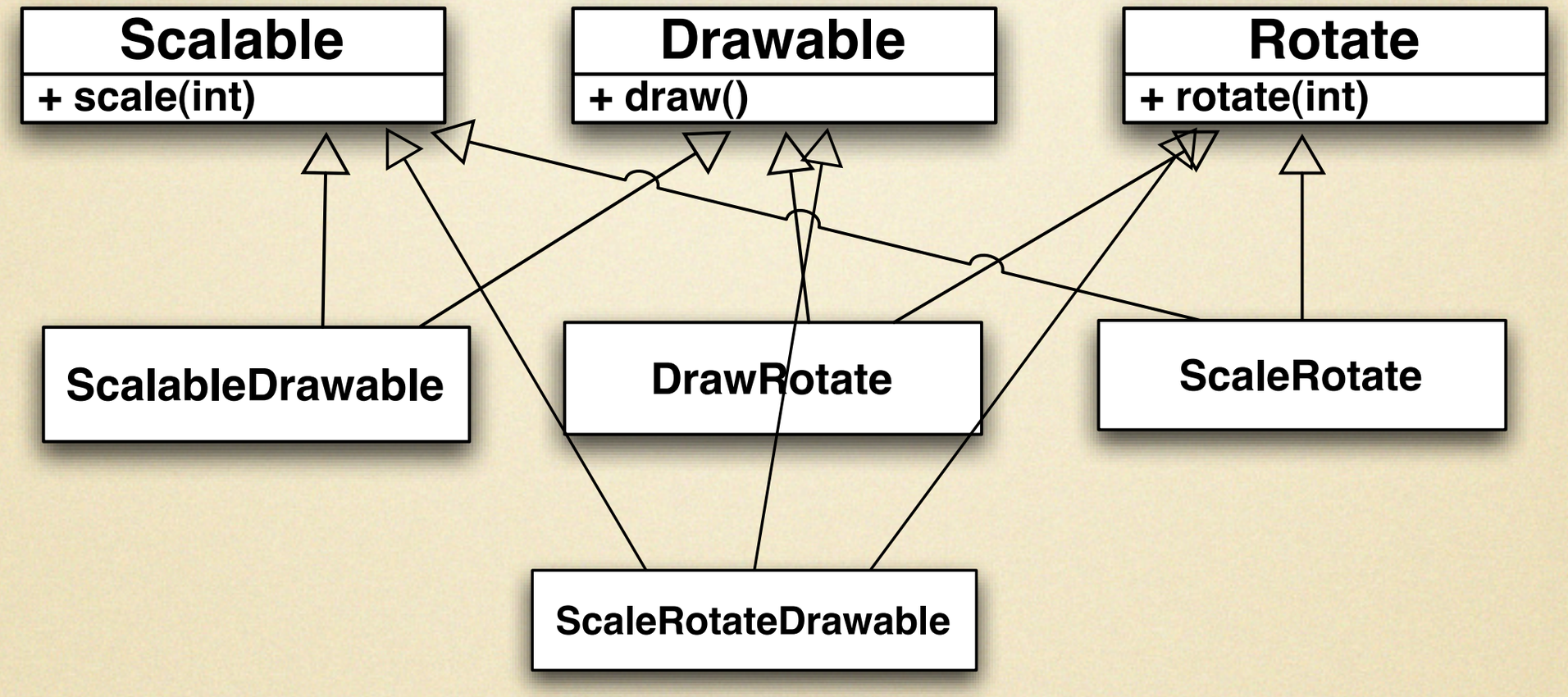


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Method call fails!

How to solve this problem?

- Problem: nominal subtyping doesn't compose
  - types `Scalable` and `Movable` do not compose to `ScalableMovable`
- But types DO compose in structural subtyping!
  - `{scale()}` and `{move()}` compose naturally to `{scale(), move()}`
- No need to manually define all combinations of types!

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- Allows unanticipated reuse
- No unnecessary proliferation of declared types
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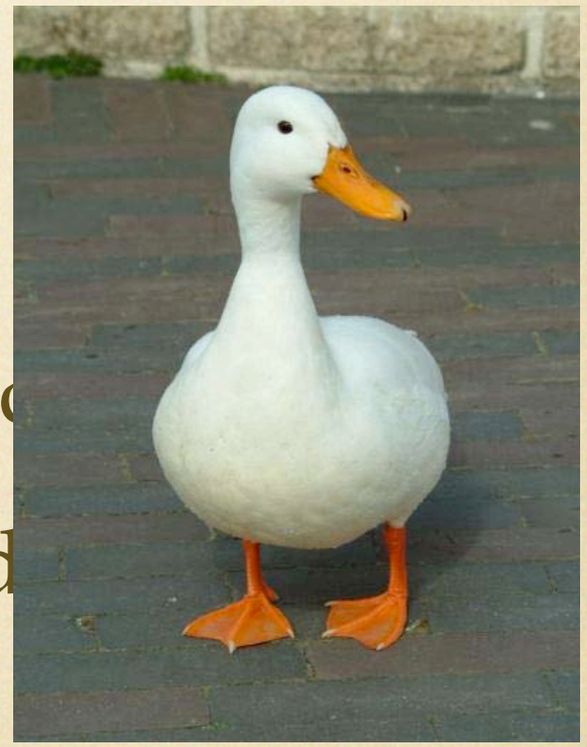

Why nominal subtyping?

Expressing intent

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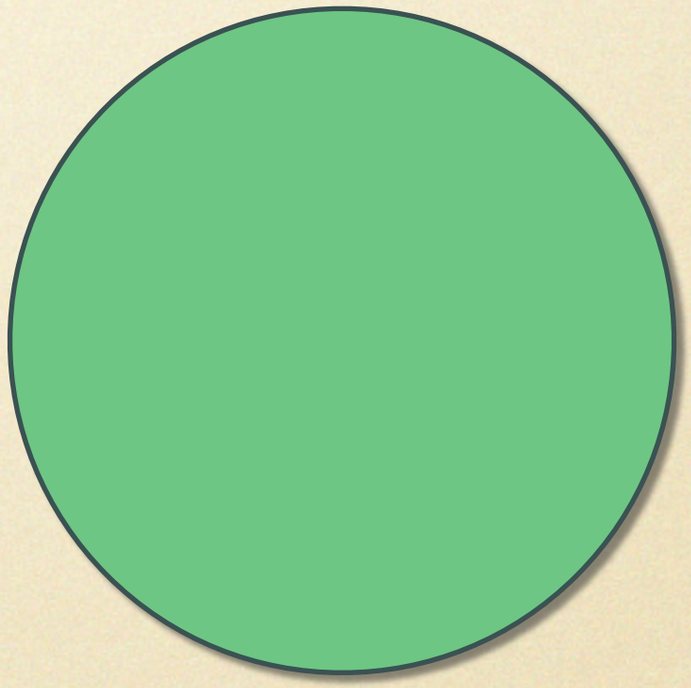

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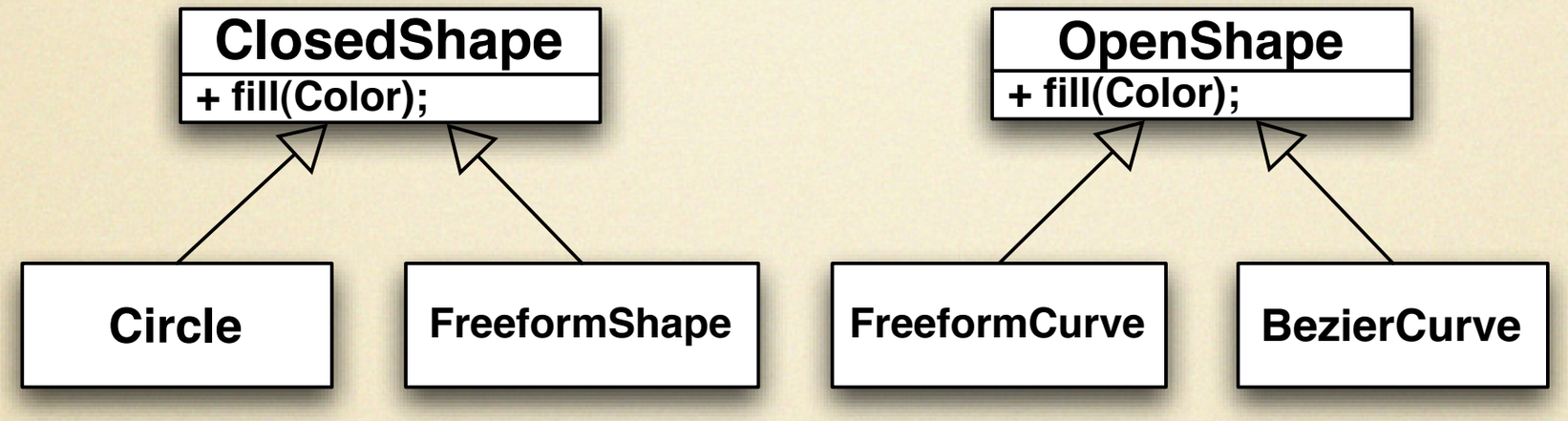

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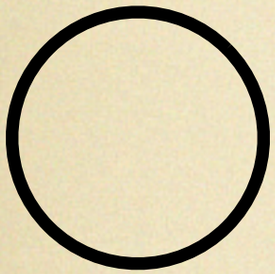

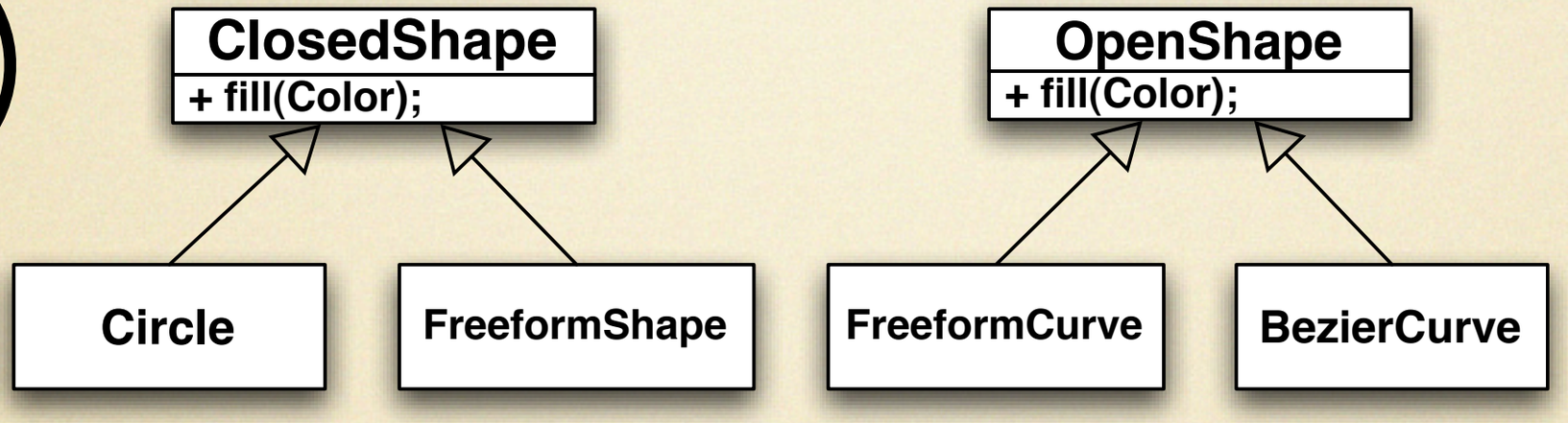

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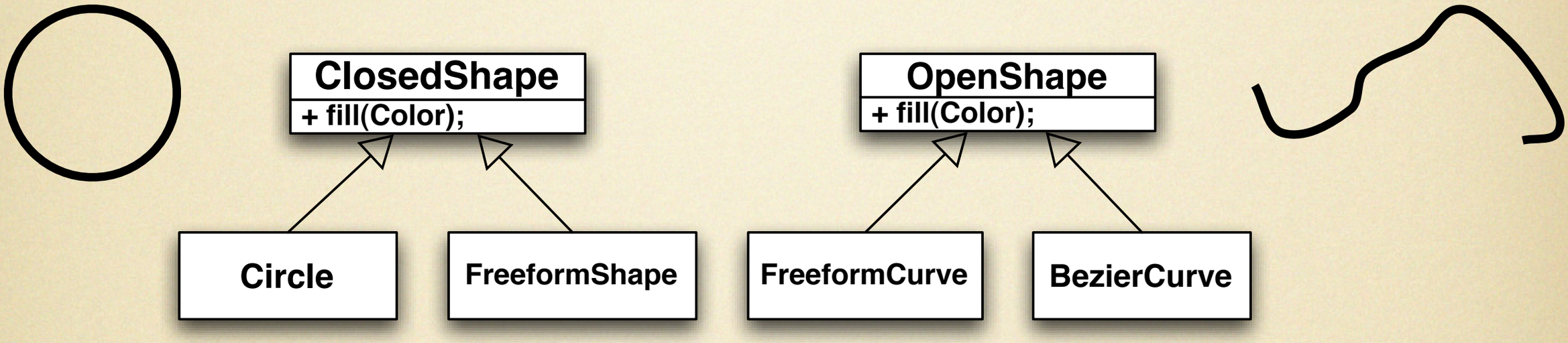

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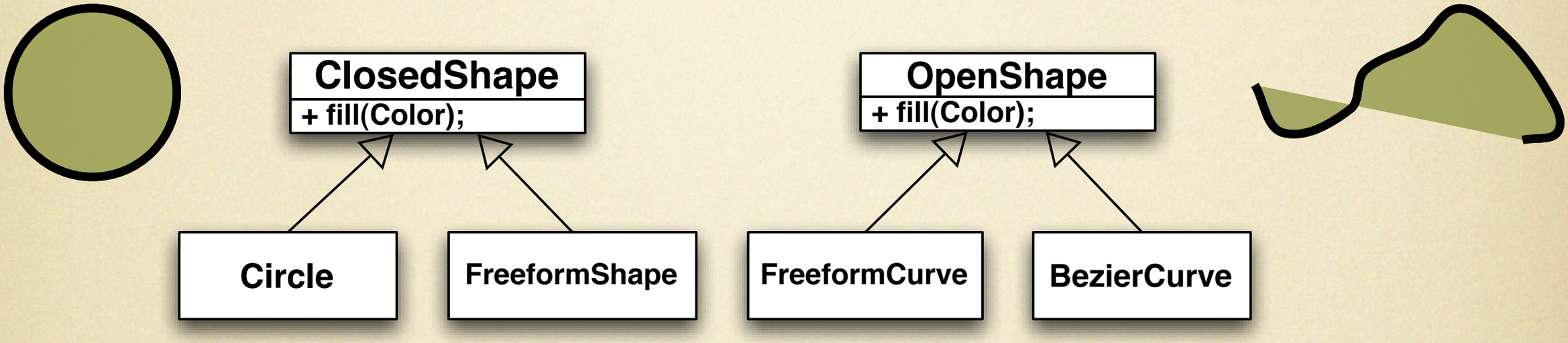

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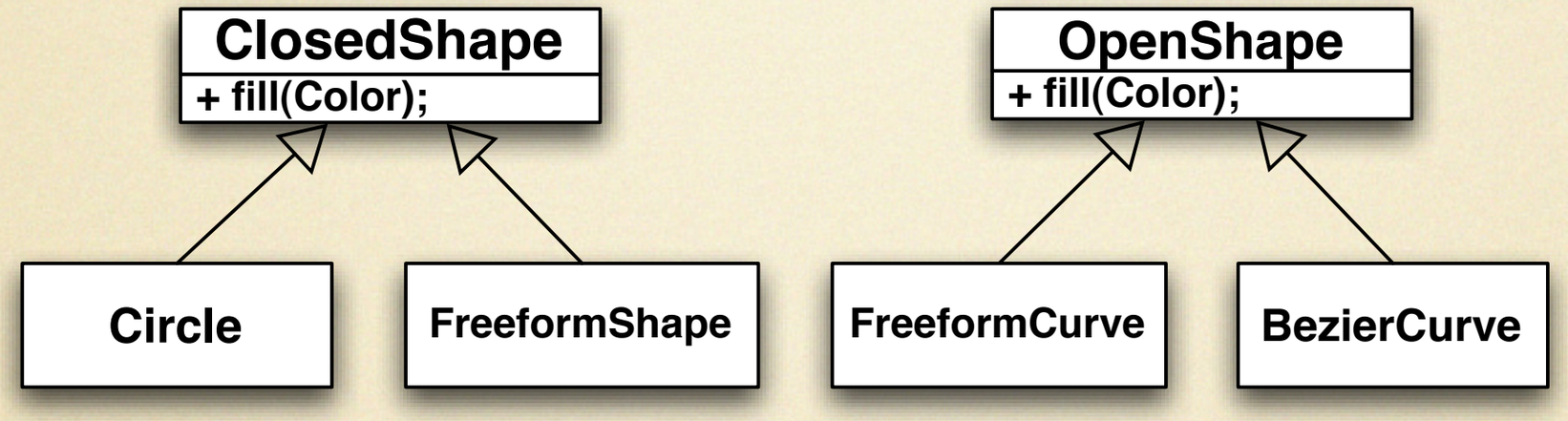

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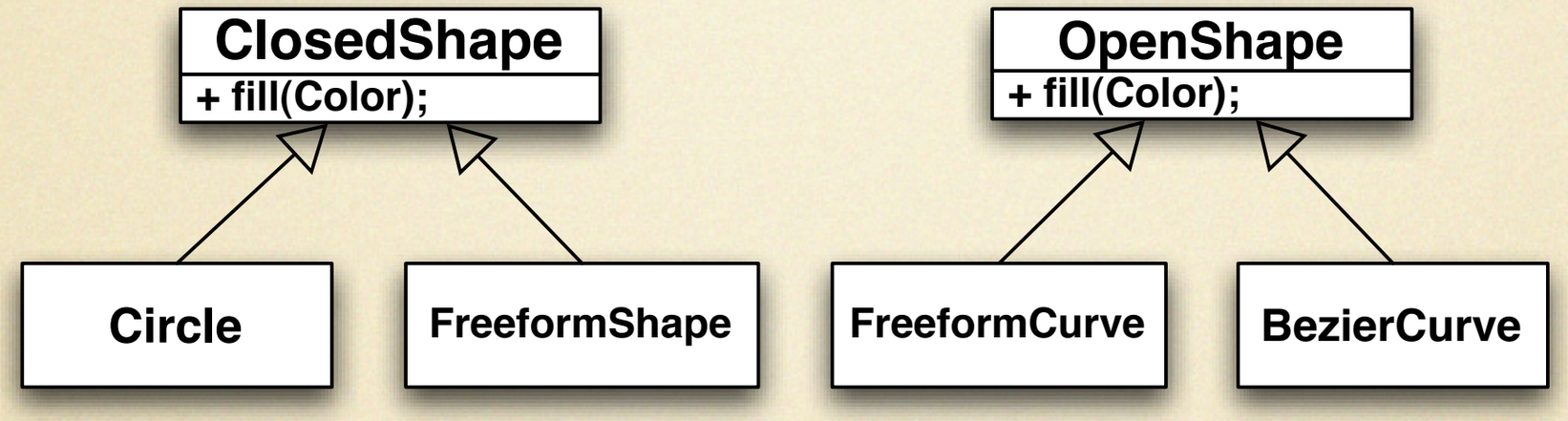

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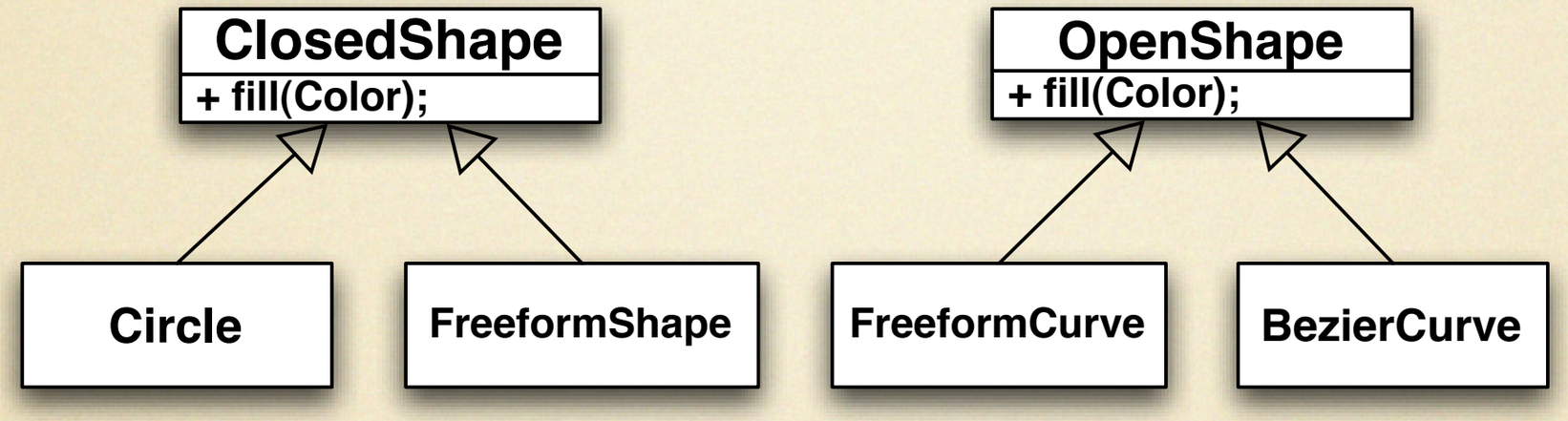

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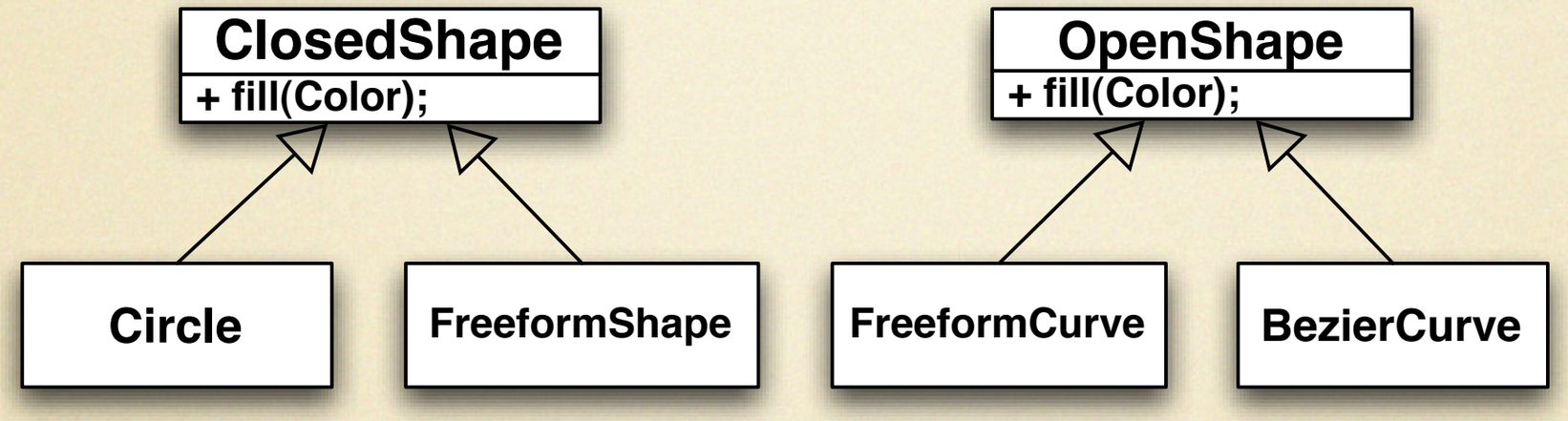

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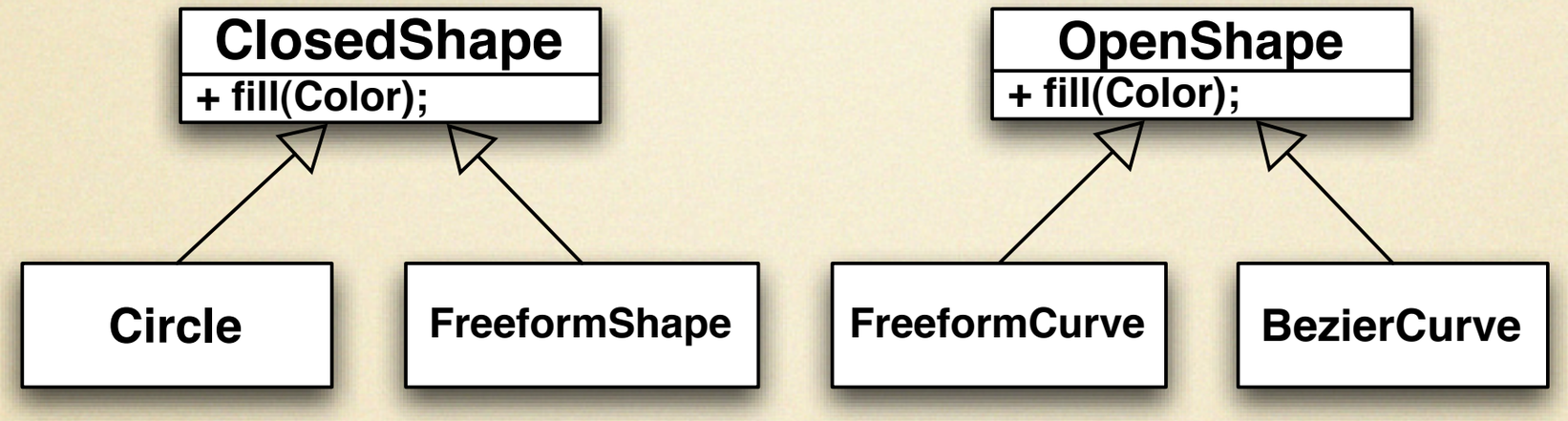

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void Image.mask(ClosedShape shape) { ... }

myimage.mask(freeformCurve);  // type error
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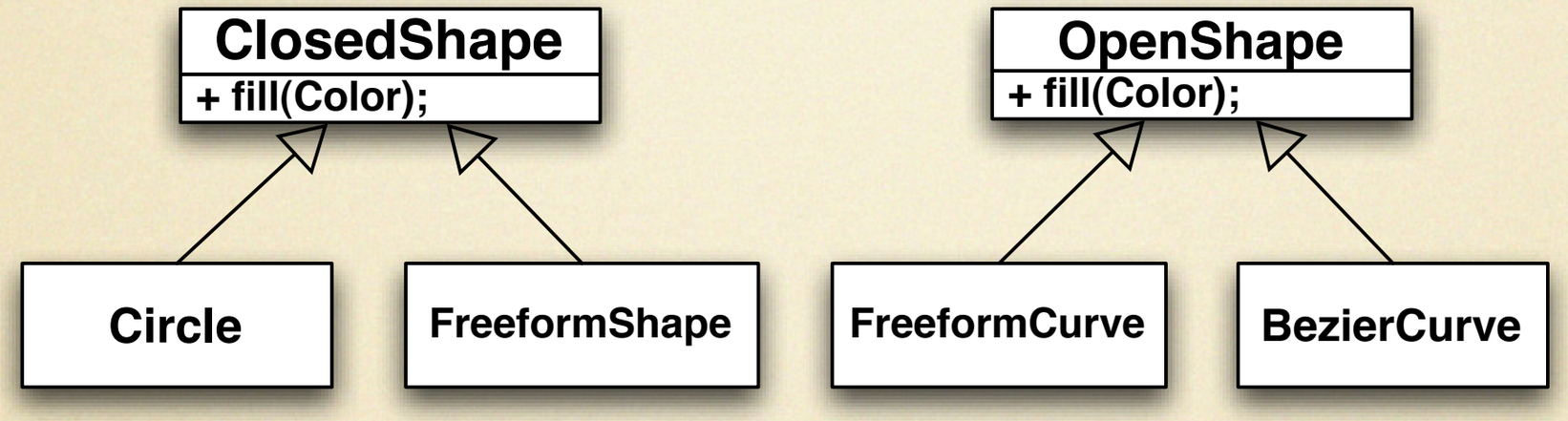

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- Provides better error messages
- Facilitates natural and efficient external methods
  - More on this later
- Languages: Java, C#, C++, VB, Modula-3, etc.

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- Along with the *design intent* of nominal subtyping
- Types have ***both*** a nominal and structural component
- $A \leq B$ iff

  $A \leq_{\text{nominal}} B$ and $A \leq_{\text{structural}} B$

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brand ClosedShape extends Object (...)
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myimage.mask(circle);         // type error, Circle lacks getArea() method
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Adding methods to implement an interface

```
brand Circle extends ClosedShape
  (method fill() : unit = …
   ...
  )
```

```
type EnhancedClosedShape =
  ClosedShape(getArea():int)
```

Adding methods to implement an interface

```
brand Circle extends ClosedShape
  (method fill() : unit = …
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type EnhancedClosedShape =
  ClosedShape(getArea():int)
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  - But, can't change `Circle` directly

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- Solution: structural subtyping & external methods

Structural subtyping + external methods

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```
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myimage.mask(circle);
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typechecks!

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External dispatch may cause ambiguity

- Non-example, structural dispatch:

```
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What are we dispatching on?

```
brand Circle extends ClosedShape
  (method fill() : unit = …
   method scale(int) : unit = …
   method draw() : unit = … )
```

```
method Circle.getArea()
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Nominal types

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Nominal types

- Dispatch on *nominal* types (i.e. brands)
- Another reason to combine structural and nominal subtyping: external dispatch depends on nominal types!

External methods in Unity

- Conceptually part of an existing brand/class
- Performs dispatch on objects of that brand's type
- Dispatch: method is selected based on the run-time type of the object
- Doesn't have to be in the same compilation unit as the brand

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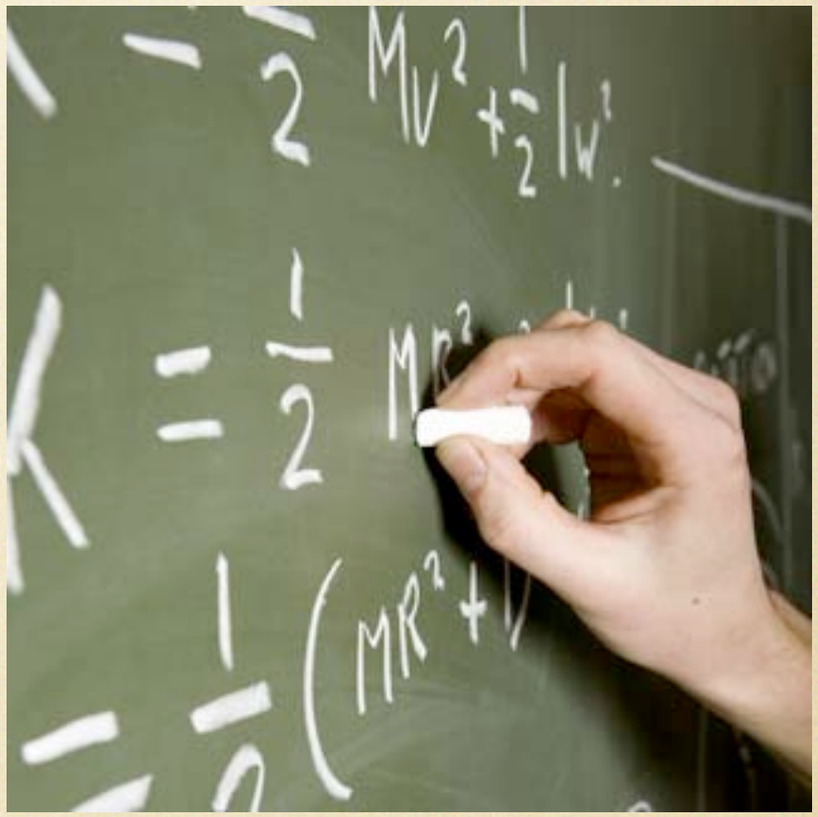
Unity benefits

- Makes it easier to maintain software, both in terms of ***interfaces*** and ***code***
- Structural subtyping eases the task of ***expressing an interface***
  - An interface is just a type and does not need to be declared in advance
- Nominal subtyping ***captures intent***
- External dispatch eases the task of ***conforming to an interface***

Examples



Eclipse JDT: example 1

- All of these classes have method `IBinding resolveBinding()`

- But there's no `HasBinding` interface with a `resolveBinding()` method
- Structural subtyping would solve this problem—just declare the interface after-the-fact

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  Type
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- But there's no `HasBinding` interface with a `resolveBinding()` method
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Eclipse JDT: example 2

- All of these classes have method `SimpleName getName()`

```
AbstractTypeDeclaration
AnnotationTypeMemberDeclaration
EnumConstantDeclaration
FieldAccess
MemberRef
MemberValuePair
MethodDeclaration
MethodInvocation
```

… plus 8 more

- But there's no `HasName` interface with a `getName()` method

Displaying elements in a tree view: Java

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```
class MyLabelProvider extends LabelProvider
{
  String getText(Object element) {
     String label;
     if (element instanceof AbstractTypeDeclaration)
      label = ((AbstractTypeDeclaration) element).
                  getName().toString();
     else if (element instanceof EnumConstantDeclaration)
      label = ((EnumConstantDeclaration) element).
                  getName().toString();
     else if (element instanceof FieldAccess)
      label = ((FieldAccess) element).
                  getName().toString();
     else if (element instanceof MemberRef)
      label = ((MemberRef) element).
                  getName().toString();
  ...

     return label;
   }
}
```

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Displaying elements in a tree view: Unity

```
brand MyLabelProvider extends LabelProvider (
    method getText(element : Object(getName() : SimpleName)) : String =
    element.getName().toString()
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  - Range from 164 to 24,500 methods in application
  - Example: 5 iterator decorators in Apache Collections have methods `getIterator` and `setIterator`

Summary of results

	Total methods	%common methods
Tomcat	14678	28.4%
Ant	9178	28.1%
JHotDraw	5149	23.2%
Smack	3921	22.5%
Struts	3783	20.4%
Apache Forrest	164	17.1%
Cayenne	9243	16.7%
Log4j	1950	16.0%
OpenFire	8135	16.0%
Apache Collections	3762	15.5%
Derby	24521	14.6%
Lucene	2472	13.4%
jEdit	5845	12.0%
Apache HttpClient	1818	11.9%
Areca	3565	11.9%

Type soundness proof

$\Sigma \vdash \tau_1 \leq \tau_2$

$$\frac{}{\Sigma \vdash \tau \leq \tau} \qquad \frac{\Sigma \vdash \tau_1 \leq \tau_2 \qquad \Sigma \vdash \tau_2 \leq \tau_3}{\Sigma \vdash \tau_1 \leq \tau_3} \qquad \frac{\Sigma \vdash \beta_1 \sqsubseteq \beta_2 \qquad \Sigma \vdash M_1 \leq M_2 \qquad \Sigma \vdash \beta_1(M_1)\ \textbf{type} \qquad \Sigma \vdash \beta_2(M_2)\ \textbf{type}}{\Sigma \vdash \beta_1(M_1) \leq \beta_2(M_2)}$$

$$\frac{\Sigma \vdash \sigma_1 \leq \tau_1 \qquad \Sigma \vdash \tau_2 \leq \sigma_2}{\Sigma \vdash \tau_1 \to \tau_2 \leq \sigma_1 \to \sigma_2} \qquad \frac{\Sigma \vdash \tau \leq \sigma_1 \qquad \Sigma \vdash \tau \leq \sigma_2}{\Sigma \vdash \tau \leq \sigma_1 \wedge \sigma_2} \qquad \frac{}{\Sigma \vdash \tau_1 \wedge \tau_2 \leq \tau_1}$$

$$\frac{}{\Sigma \vdash \tau_1 \wedge \tau_2 \leq \tau_2} \qquad \frac{\{\ell_i : \tau_i\ ^{i \in 1..n}\} \text{ is a permutation of } \{\ell_j : \tau_j\ ^{j \in 1..n}\}}{\Sigma \vdash \{\ell_i : \tau_i\ ^{i \in 1..n}\} \leq \{\ell_j : \tau_j\ ^{j \in 1..n}\}}$$

$$\frac{n > m}{\Sigma \vdash \{\ell_i : \tau_i\ ^{i \in 1..n}\} \leq \{\ell_j : \tau_j\ ^{j \in 1..m}\}} \qquad \frac{\Sigma \vdash \tau_i \leq \sigma_i\ (i \in 1..n)}{\Sigma \vdash \{\ell_i : \tau_i\}_{i \in 1..n} \leq \{\ell_i : \sigma_i\}_{i \in 1..n}}$$

$$\frac{\Sigma \vdash \beta_1 \sqsubseteq \beta_2}{\Sigma \vdash \beta_1(M_1) \wedge \beta_2(M_2) \leq \beta_1(M_1 \wedge M_2)}$$

$$\frac{\Sigma \vdash \beta_1 \sqsubseteq \beta_2 \qquad \Sigma \vdash M_2 \leq M_1 \qquad \Sigma \vdash \sigma_1 \leq \sigma_2}{\Sigma \vdash \beta_1(M_1) \Rightarrow \sigma_1 \ \leq\ \beta_2(M_2) \Rightarrow \sigma_2} \qquad \frac{\Sigma \vdash \{\overline{m : \tau}\} \leq \{\overline{n : \sigma}\}}{\Sigma \vdash \overline{m : \tau} \leq \overline{n : \sigma}}$$

- Proved the usual progress and preservation theorems
- Type safety implies that no method-not-found or method-ambiguous errors will occur during evalution

Selected Related Work

- Similar approaches after our initial proposal:
  - Scala [Odersky '07], Whiteoak [Gil and Maman '08] *not formalized*

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- Similar approaches after our initial proposal:
  - Scala [Odersky '07], Whiteoak [Gil and Maman '08] *not formalized*
  - External methods: MultiJava [Clifton et al '00]
  - Only structural *typing*, not subtyping: Modula-3

Summary

- Unity combines structural and nominal subtyping
- Allows structural subtyping to co-exist with external dispatch
  - Each adds flexibility to the language
  - Combination is novel
- Evidence that existing programs could benefit