cs205: engineering software
university of virginia
fall 2006

Substitution Principle

David Evans
www.cs.virginia.edu/cs205

How do we know if saying *B* is a subtype of *A* is safe?

Substitution Principle: If *B* is a subtype of *A*, everywhere the code expects an *A*, a *B* can be used instead *and* the program still satisfies its specification

---

Subtype Condition 1: Signature Rule

We can use a subtype method where a supertype methods is expected:

- Subtype must implement all of the supertype methods
- Argument types must not be more restrictive
- Result type must be at least as restrictive
- Subtype method must not throw exceptions that are not subtypes of exceptions thrown by supertype

---

Signature Rule

```
class A {
   public R_A m (P_A p) ;
}
                    class B extends A {
                       public R_B m (P_B p) ;
                    }
```

R_B must be a subtype of R_A: $R_B <= R_A$

P_B must be a ***super***type of P_A: $P_B >= P_A$

*co*variant for results, *contra*variant for parameters

Subtype Condition 2: Methods Rule

- Precondition of the subtype method must be *weaker* than the precondition of the supertype method.

  $m_A.\text{pre} \Rightarrow m_B.\text{pre}$

- Postcondition of the subtype method must be *stronger* than the postcondition of the supertype method.

  $m_B.\text{post} \Rightarrow m_A.\text{post}$

```
                              public int f (a A, x X) {
                                 // REQUIRES: a is initialized
                                 // EFFECTS: returns a.value * x.value
                                 return a.m (x);
public class A {              }
   // An A may be initialized or uninitialized.
   // An initialized A has an associated int value.
   public int m (x X) {
      // REQUIRES: this is initialized
}
             public class B extends A {
                // A B may be initialized or uninitialized.
                // A B may be awake or asleep.
                // An initialized B has an associated int value.
                public int m (x X) {
                   // REQUIRES: this is initialized and awake
                }
```

Can't make the precondition stronger! The callsite might not satisfy it.

```
public int f (a A, x X) {
   // REQUIRES: a is initialized
   // EFFECTS: returns a.value * x.value
   return a.m (x);
}
```

```
public class A {
   // An A may be initialized or uninitialized.
   // An initialized A has an associated int value.
   public int m (x X) {
     // REQUIRES: this is initialized
}
```

```
public class B extends A {
   // A B may be initialized or uninitialized.
   // A B may be awake or asleep.
   // An initialized B has an associated int value.
   public int m (x X) {
     // REQUIRES: nothing
   }
```

Okay, precondition is *weaker*

Subtype Condition 3: Properties

Subtypes must preserve all properties described in the overview specification of the supertype.

Properties Example

```
public class StringSet {
   // Overview: An immutable set of Strings.
```

public class MutStringSet ~~extends StringSet~~ {
   // Overview: A mutable set of Strings.

MutStringSet cannot be a subtype of StringSet, since it does not satisfy unchangable property.

Properties Example

```
public class StringSet extends MutStringSet {
   // Overview: An immutable set of Strings.

public class MutStringSet {
   // Overview: A mutable set of Strings.
```

StringSet could be a subtype of MutStringSet according to the properties rule.

...but couldn't satisfy methods rule

Substitution Principle Summary

- Signatures: subtype methods must be type correct in supertype callsites: result is a subtype (covariant), parameters are supertypes (contravariant)
- Methods: subtype preconditions must be weaker than supertype preconditions (covariant); subtype postconditions must be stronger than supertype postconditions (contravariant)
- Properties: subtype must preserve all properties specified in supertype overview

Substitution Mystery

```
…    (in client code)
MysteryType1 mt1;
MysteryType2 mt2;
MysteryType3 mt3;
…    (anything could be here)
mt1 = mt2.m (mt3);
```

If the Java compiler accepts this code, which of these are *guaranteed* to be true:

a. The apparent type of mt2 is MysteryType2
b. At the last statement, the actual type of mt2 is MysteryType2
c. MysteryType2 has a method named m
d. The MysteryType2.m method takes a parameter of type MysteryType3
e. The MysteryType2.m method returns a subtype of MysteryType1
f. After the last statement, the actual type of mt1 is MysteryType1

```
…         (in client code)
MysteryType1 mt1;
MysteryType2 mt2;
MysteryType3 mt3;
…         (anything could be here)
mt1 = mt2.m (mt3);
```

a. The apparent type of mt2 is MysteryType2
   TRUE: the apparent type is obvious from the declaration.
b. At the last statement, the actual type of mt2 is MysteryType2
   FALSE: we only know the actual type <= MysteryType2
c. MysteryType2 has a method named m
   TRUE
d. The MysteryType2.m method takes a parameter of type MysteryType3
   FALSE: we only know it takes a parameter >= MysteryType3
e. The MysteryType2.m method returns a subtype of MysteryType1
   TRUE: the assignment type checking depends on this
f. After the last statement, the actual type of mt1 is MysteryType1
   FALSE: we only know that the actual type <= MysteryType1

Demystifying Subtyping

```
class A {
   public RA m (PA p) ;
}
```

```
…         (in client code)
MysteryType1 mt1;
MysteryType2 mt2;
MysteryType3 mt3;
…
mt1 = mt2.m (mt3);
```

If A is MysteryType2, what do we know about RA and PA?

RA must be a subtype of MysteryType1:
RA <= MysteryType1
MysteryType3 must be a subtype of PA:
PA >= MysteryType3

Subtyping Rules

```
class A {
   public RA m (PA p) ;
}
class B extends A {
   public RB m (PB a);
}
```

```
…         (in client code)
MysteryType1 mt1;
MysteryType2 mt2;
MysteryType3 mt3;
…
mt1 = mt2.m (mt3);
```

If B <= A, what do we know about RB and PB?

RB must be a subtype of RA: RB <= RA

PA must be a subtype of PB: PB >= PA

Substitution Principle Summary

Param Types Preconditions	Psub $\geq$ Psuper pre_sub $\Rightarrow$ pre_super	contravariant for inputs
Result Type Postconditions	Rsub $\leq$ Rsuper post_sub $\Rightarrow$ post_super	covariant for outputs
Properties	properties_sub $\Rightarrow$ properties_super	

These properties ensure if sub is a subtype of super, code that is correct using an object of supertype is correct using an object of subtype.

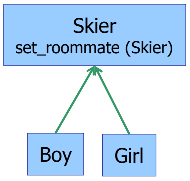
Substitution Principle

Is this the only way?

Eiffel's Rules

(Described in Bertrand Meyer paper out today)

Eiffel Rules



The types of the parameters in the subtype method may be subtypes of the supertype parameters.

How can Girl override set_roomate?
set_roommate (Girl g)
set_roommate (Boy b)

Opposite of substitution principle!

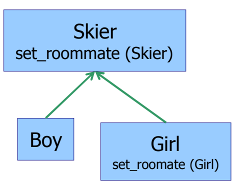
Substitution Principle / Eiffel

```
class A {
   public RA m (PA p) ;
}
class B extends A {
   public RB m (PB a);
}
```

```
…        (in client code)
MysteryType1 mt1;
MysteryType2 mt2;
MysteryType3 mt3;
…
mt1 = mt2.m (mt3);
```

	Substitution Principle	Eiffel
Parameters	Psub ≥ Psuper	Psub ≤ Psuper
Preconditions	pre_sub ⇒ pre_super	**pre_sub ⇒ pre_super**
Result	Rsup ≤ Rsuper	
Postconditions	post_sup ⇒ post_super	

Eiffel and I Can't Get Up?



s: skier; g: girl; b: boy;
s := g;
...
s.set_roommate (b);

Meyer's paper is all about the contortions Eiffel needs to deal with non-substitutable subtypes

Charge

Must it be assumed that because we are engineers beauty is not our concern, and that while we make our constructions robust and durable we do not also strive to make them elegant?

Is it not true that the genuine conditions of strength always comply with the secret conditions of harmony?

Gustav Eiffel