Interface Inheritance: Behavioral Subtyping

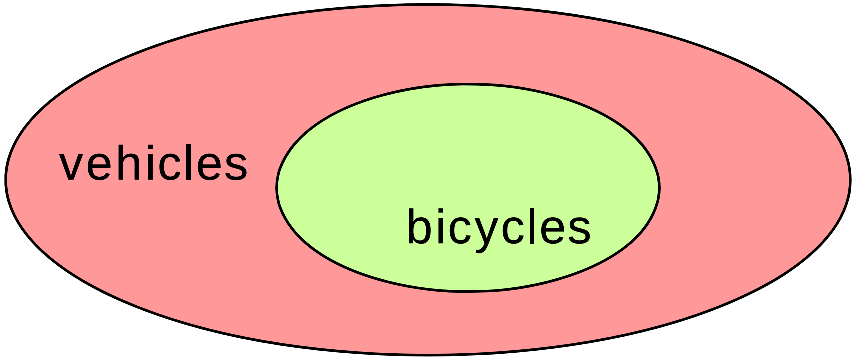
Computer Science and Engineering ■ College of Engineering ■ The Ohio State University

Lecture 11

Intuition

- Some interfaces have significant overlap in functionality
  - bicycles and vehicles
    - both have owners and both can move
  - students and persons
    - both have names and both can be selected for juries
  - rectangles and shapes
    - both have a color
- These are all examples of an "is a" relationship
  - This is a common (but poor) intuitive litmus test
- Interfaces define types, ie *sets* of possible values

Every bicycle is a vehicle

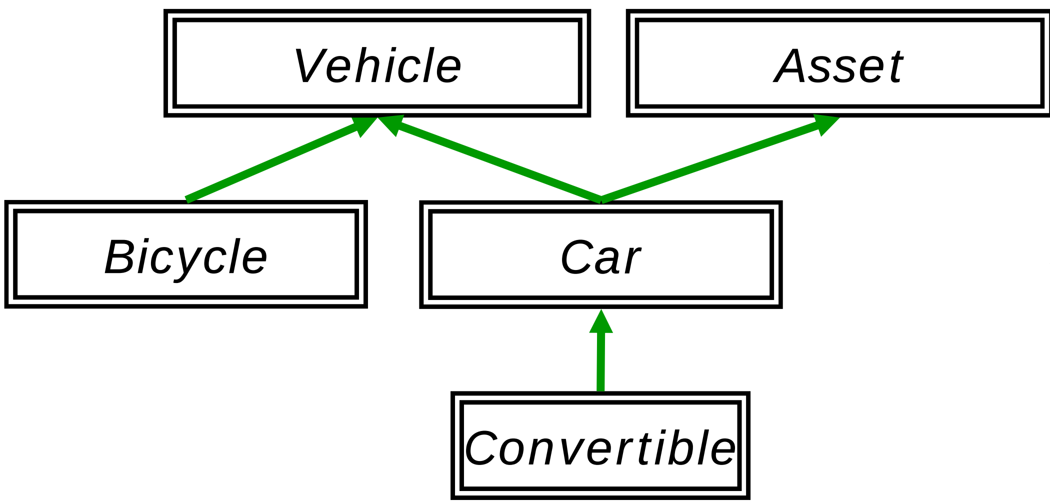


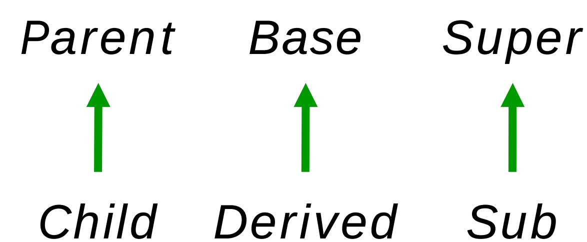
Extending Interfaces

- One interface can extend another

```
interface X extends A, B { . . . }
```

  - X implicitly includes all methods declared in A, B, and transitively above A and B





Recall: Narrowing vs Widening

- Recall primitive types (eg long, int)
- Widening
  - Assign a “small” value to a variable of “big” type
  - This is always ok and so can be done implicitly

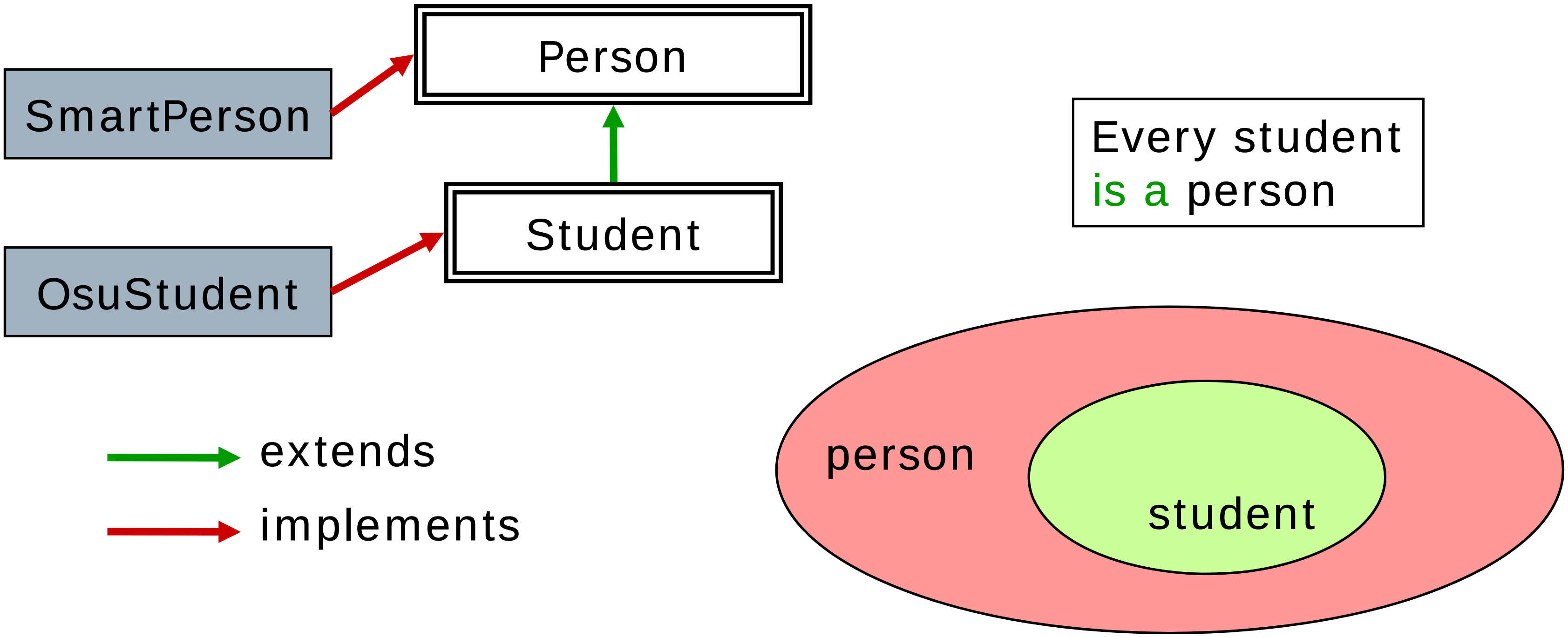
```
void f(int i) {
  long x = i; //widening: always ok
```

- Narrowing
  - Assign a “big” value to a variable of “small” type
  - The correctness of this cannot be checked by compiler and so requires an explicit cast

```
void f(long x) {
  int i = x;  //narrowing: compile error
  int j = (int)x; //ok? programmer promise!
```

Narrowing and Widening Objects

- Subinterfaces are "smaller" types than superinterfaces



Narrowing and Widening Objects

- Widening
  - Assign a *subinterface* (declared type) to a variable of *superinterface* (declared) type
  - This is always ok and so can be done implicitly

```
void f(Student s) {
  Person p = s; //widening: always ok
```

- Narrowing
  - Assign a *superinterface* (declared type) to a variable of *subinterface* (declared) type
  - This can not be checked by the compiler and so requires an explicit cast

```
void f(Person p) {
  Student s = p; //compiler complains
  Student s = (Student)p; //ok? prg promise!
```

Argument Passing

- Method argument declared types must match signature

```
interface Course {
  void enroll(Student s) { . . . }
}
interface Jury {
  void select(Person p) { . . . }
}
```

- Automatic (implicit) widening

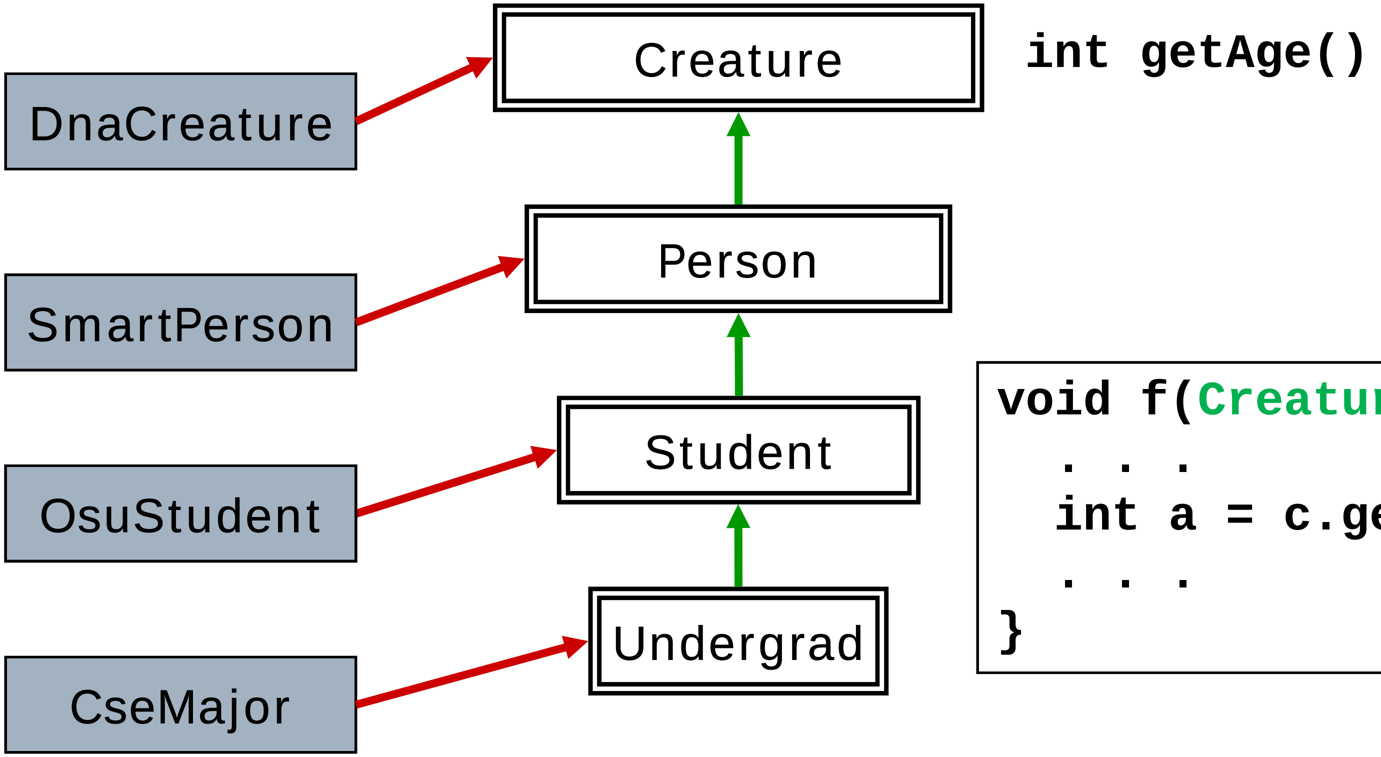
```
Student s = …;
cse421.enroll(s);   //ok (exact match)
someJury.select(s); //ok (automatic widening)
```

- Cast for (explicit) narrowing

```
Person p = …;
someJury.select(p); //ok (exact match)
cse421.enroll(p);   //compiler complains (narrowing)
cse421.enroll((Student)p); //ok? programmer promise!
```

Simple Rule

- A variable / parameter of declared type T can refer to an object of dynamic type "at or below" T



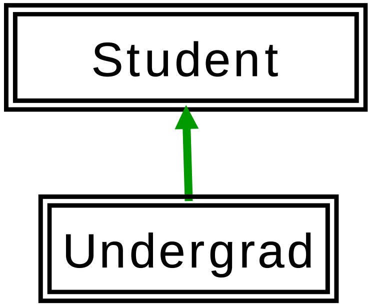

```
void f(Creature c) {
  . . .
  int a = c.getAge();
  . . .
}
```

Behavioral Subtyping

- Informally, A is a *behavioral subtype* of B when it does everything B does (and maybe more)
  - Everywhere a B is expected, an A can be used instead
- Must satisfy the Substitution Principle:
  - *Any* correct client that uses a B is *still correct* when given an A instead
- Example:
  - A class uses Creature (eg void f(Creature c))
  - Actual argument might be a Creature, Person, Student, or Undergrad
  - Implementation of f() should still be correct!
- Note: This is a requirement on the component provider (of A), *not* on the client

Substitution Principle

- If Undergrad is a subtype of Student
  - *Any* correct client of Student is still correct when given an Undergrad
- If Undergrad not a subtype of Student
  - There exists *some* correct client of Student that is no longer correct when given an Undergrad



Behavioral Subtyping Rules

- Subtype constraint $\Rightarrow$ supertype constraint
  - Hence the informal "is a" litmus test
  - This condition alone, however, is not sufficient
- Each method in subinterface:
  - Requires *less* than in superinterface
    - Add disjuncts (or) to requires clause
    - Must work under more conditions
    - Contravariance of argument types
  - Ensures *more* than in superinterface
    - Add conjuncts (and) to the ensures clause
    - Must guarantee more to client
    - Covariance of return types

A is Narrower than B (A is-a B)

- A's invariant is "stronger"
  - Inv_A ==> Inv_B
- For each method, A "requires less"
  - Pre^m_A <== Pre^m_B
  - Pre^n_A <== Pre^n_B
- For each method, A "ensures more"
  - $Post^m_A$ ==> $Post^m_B$
  - $Post^n_A$ ==> $Post^n_B$
- Aside:
  - Omitted requires/ensures stands for true
  - Anything ==> true

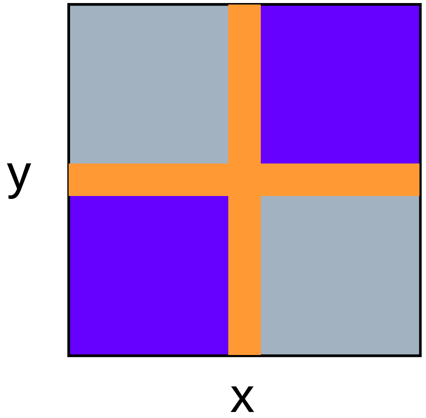
A is Narrower than B


```
//@mathmodel M                      //@mathmodel M
//@constraint Inv_A           ==>   //@constraint Inv_B
interface A {                       interface B {

  //@requires Pre^m_A         <==     //@requires Pre^m_B
  //@ensures Post^m_A         ==>     //@ensures Post^m_B
  int m(int x, int y);                int m(int x, int y);

  //@requires Pre^n_A         <==     //@requires Pre^n_B
  //@alters this              ==>     //@alters this
  //@ensures Post^n_A         ==>     //@ensures Post^n_B
  void n(String s);                   void n(String s);
}                                   }
```

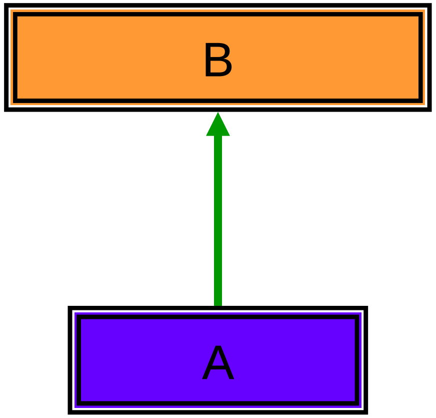
Visualization: Spec of m()

Requires

(x==0) || (y==0)

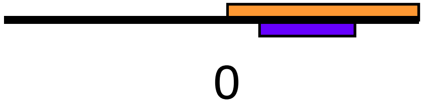


x*y >= 0



Ensures

0 < m



10 < m < 100

Example: BigNatural & BigInteger

- Should BigNatural extend BigInteger?
- For behavioral subtyping, ask:
  - Is BigNatural's invariant *stronger*?
  - Do all BigNatural methods *require less*?
  - Do all BigNatural methods *ensure more*?

BigNatural Extends BigInteger?


```
//@mathmodel n integer
//@constraint n >= 0
interface BigNatural {

  //@alters n
  //@ens n = #n+1
  void increment();

  //@alters n
  //@ens n=max(0,#n-1)
  void decrement();
}
```

```
//@mathmodel n integer
//@constraint
interface BigInteger {

  //@alters n
  //@ens n = #n+1
  void increment();

  //@alters n
  //@ens n = #n-1
  void decrement();
}
```

Example: BigNatural & BigInteger

- Should BigNatural extend BigInteger?
- Is invariant stronger? **Yes!**
  - BigNatural invariant is n >= 0
  - BigInteger invariant is true
- Do methods require less? **Yes!**
  - increment() requires the same (true) in both
  - decrement() requires the same (true) in both
- Do methods ensure more? **No!**
  - BigNatural decrement() ensures #n>0 ==> n=#n-1
  - BigInteger decrement() ensures n=#n-1
- Example client code that illustrates the problem

```
BigInteger noop(BigInteger i) {
  i.decrement();
  i.increment();
  return i;
}
```

  - noop() is correct for BigInteger, but not for BigNatural

Example: Square & Rectangle

- These interfaces have similar abstract state (mathematical model)
  - two components: length, width
- These interfaces have similar public behavior (methods)
  - getArea(): returns the area (ie length * width)
  - widthStretch(): changes width of figure
  - lengthStretch(): changes length of figure
- Should we use inheritance?
  - Square extends Rectangle?
  - Rectangle extends Square?

Square Extends Rectangle?


```
//@mathmodel l,w
//@constraint l = w
interface Square {

  //@ens getArea=l*w
  float getArea();

  //@alters l,w
  //@ens w = i*#w
  // (&& l = i*#l)
  void widthStretch
       (int i);
}
```

```
//@mathmodel l,w
//@constraint
interface Rectangle {

  //@ens getArea=l*w
  float getArea();

  //@alters w
  //@ens w = i*#w
  // (&& l = #l)
 void widthStretch
       (int i);
}
```

Example: Square is a Rectangle?

- Is invariant stronger? **Yes!**
  - Square invariant is length = width and both are >= 0
  - Rectangle invariant is length and width both >= 0
- Do methods require less? **Yes!**
  - all methods require true in both classes
- Do methods ensure more? **No!**
  - Square widthStretch(s) ensures length = #length * s
  - Rectangle widthStretch() ensures length = #length
- Example client code that illustrates the problem

```
Rectangle alwaysTrue(Rectangle r) {
  double intialArea = r.getArea();
  double finalArea = r.widthStretch(2).getArea();
  return(finalArea == 2*initialArea);
}
```

  - alwaysTrue is correct for Rectangle, but not for Square

Rectangle Extends Square?


```
//@mathmodel l,w
//@constraint
interface Rectangle {

  //@ens getArea=l*w
  float getArea();

  //@alters w
  //@ens w = i*#w
  // (&& l = #l)
  void widthStretch
       (int i);
}
```

```
//@mathmodel l,w
//@constraint l = w
interface Square {

  //@ens getArea=l*w
  float getArea();

  //@alters l,w
  //@ens w = i*#w
  // (&& l = i*#l)
 void widthStretch
       (int i);
}
```

Example: Rectangle is a Square?

- Is invariant stronger? **No!**
  - Square invariant is length = width and both are >= 0
  - Rectangle invariant is length and width both >= 0
- Do methods require less? **Yes!**
  - all methods require true in both classes
- Do methods ensure more? **No!**
  - Square widthStretch(s) ensures length = #length * s
  - Rectangle widthStretch() ensures length = #length
- Example client code that illustrates the problem

```
Square alwaysTrue(Square s) {
  double intialArea = s.getArea();
  double finalArea = s.widthStretch(2).getArea();
  return(finalArea == 4*initialArea);
}
```

  - alwaysTrue is correct for Square, but not for Rectangle

Java Support for Subtyping

- Java does not enforce behavioral contracts
- Support for behavioral subtyping limited to very weak promises, such as:
  - If B has a visible method m(), A has a visible method m() with same signature
    - A can not *decrease* visibility of m()
    - Parameter types must match exactly
      - Real contravariance would allow A.m's parameter types to be supertypes of B.m's parameter types
    - Return type *can be* a subtype (covariance)
  - If B's method m() can not throw an exception of type E, neither can A's m()
    - A can not *increase* the list of possible exceptions (we'll talk about exceptions later...)

Summary

- Interface extensions
  - Declaration syntax
  - Vocabulary: super/sub, base/derived, parent/child
  - Widening (up) is automatic
  - Narrowing (down) requires explicit cast
- Behavioral subtyping
  - Substitution principle
- Subtyping rules
  - Strengthen the constraint
  - Weaken the requires of each method
  - Strengthen the ensures of each method
- Java rules (syntax)
  - Does not allow contravariance of argument types
  - Does allow covariance of return type