

Classes and Types in an Ideal Object-Oriented Programming Language

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Motivation: the good news

Object-orientation

is now universal for programming, modelling, ..

Mature theory and technology

- ≈ 24 centuries after Aristotle (350 BC),
- ≈ half a century after Simula (1967),
- ≈ 3 decades ago: first *mainstream* languages (Eiffel, C++)
- ≈ 2 decades ago: Java, then C# and Scala

👉 Likely the greatest success of the last century!

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The greatest failure of the last century?

The object-oriented programming languages!

- Each one, individually!
- All together!

The same features

- are specified differently,
- as if programming languages were works of art!

👉 The Babel Tower!

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My thesis



Plato's ideals

- apply to Circle, Tree, ..
- apply to Programming Languages, too

☞ The ideal Object-Oriented Programming Language exists

My thesis



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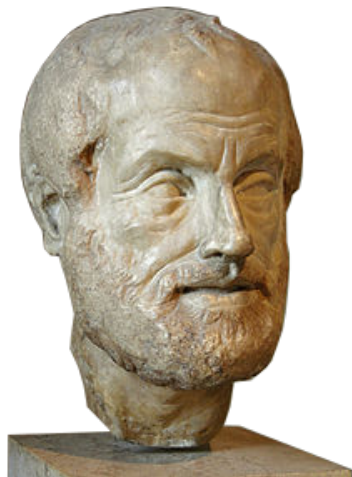


Arguments taken from ...

- philosophy (Aristotle)
- ontology (object metamodel)
- necessity (Occam's razor)
- mathematics (type and set theory, logic)
- empiricism
- common sense

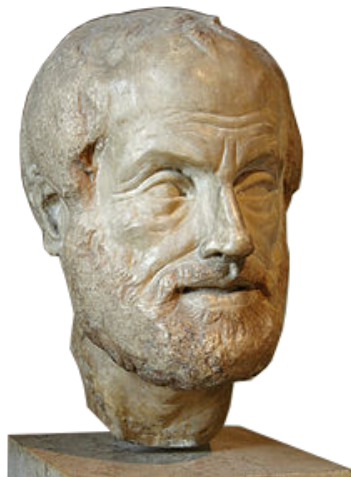
Plan

- 1 **Classes and inheritance**
- 2 **Types and subtyping**
- 3 **Genericity**
- 4 **Conclusions and projects**



Plan

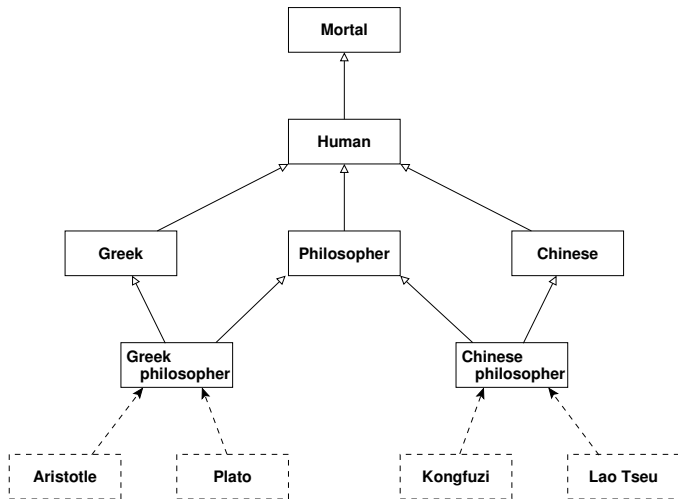
- 1 **Classes and inheritance**
 - Aristotelian semantics
 - Class and property metamodel
 - Multiple inheritance conflicts
 - Method combination
 - About existing languages
- 2 Types and subtyping
- 3 Genericity
- 4 Conclusions and prospects



Object-orientation vs knowledge representation

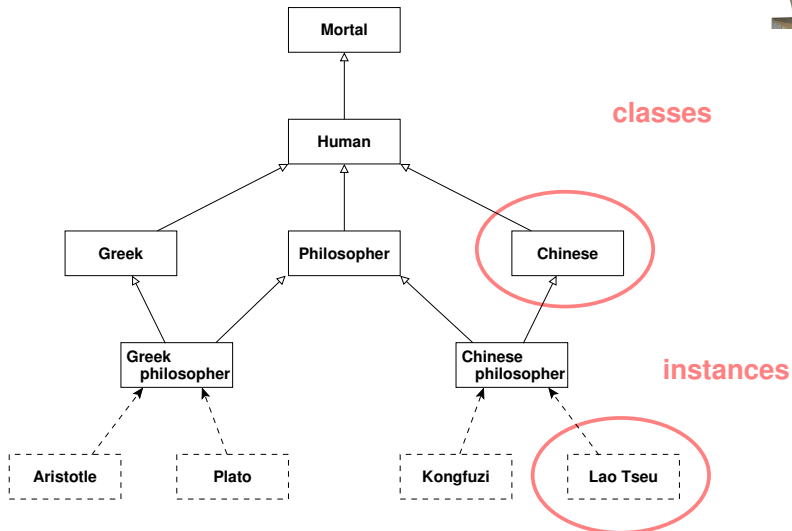
• an object-oriented model is a representation of the **real-world**TM

OO vs KR: Philosophers



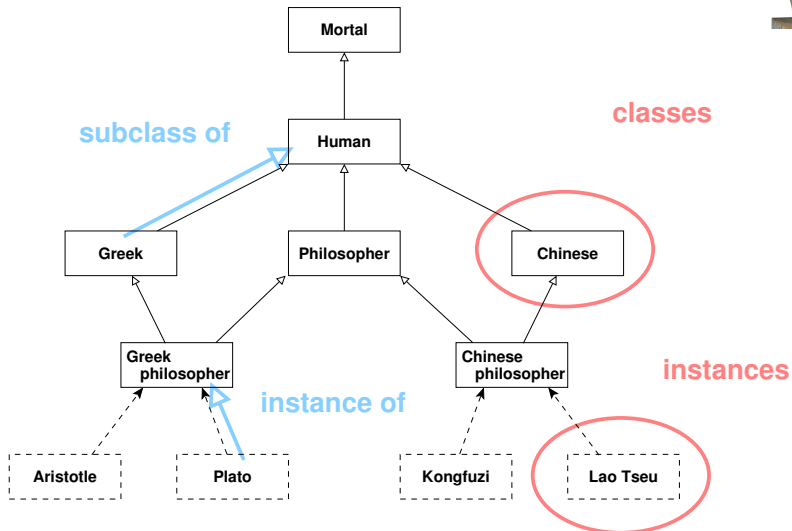


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Philosophers



Aristotle (Ἀριστοτέλης , 384-322 BC) founded **logic**

Plato (Πλάτων , 427-348 BC) promoted the existence of **ideas**

孔子 (Kongfuzi, 551-479 BC)

老子 (Lao Tseu)

庄子 (Zhuangzi) a butterfly dream

👉 in the XX^o century jargon, **ideas** are **first-class objects**

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Aristotelian semantics (1/3)



The **extension** of a **class** is the set of its **instances**

Foundation syllogism

Humans are Mortals

孔子 is a Human

孔子 is a Mortal

Human \prec Mortal

孔子 \in Ext(Human)

孔子 \in Ext(Mortal)

Subclassing = specialization = inclusion of extensions

Instances of the subclass are instances of the superclass

$$B \prec A \Rightarrow \text{Ext}(B) \subset \text{Ext}(A)$$

Aristotelian semantics (1/3)



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Aristotelian semantics (2/3)



The **intension** of a class is a set of **properties** declared for its **instances**

Inheritance of properties

- an instance of a class has all the properties declared by the class
- as a **Human**, 孔子 is a **Mortal**
- ☞ 孔子 has all the properties declared by **Mortal**

Inheritance is implied by specialization

- ☞ The subclass inherits the properties declared in the superclass

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Aristotelian semantics (2/3)



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Aristotelian semantics (3/3)



My answers to objections

- in Logo, a **Turtle** is a **Point**
there is no specialization in the **real world**TM
- ☞ but specialization is in the artefact
- so-called **implementation inheritance**
- ☞ a bad practice resulting from an erroneous model

An object model of the object model (1/3)

Object-orientation is part of the **real world**TM

☞ object-orientation can be used for representing object-orientation

An object meta-model

- a UML model
- modelling the entities of object-orientation,
i.e. **classes**, **associations**, **attributes**, **methods**, ...
- with **classes**, **associations**, **attributes**, **methods**, ...

An object model of the object model (2/3)

Motivations

- mandatory for all **metaprograms** (e.g. compilers, VMs, IDEs)
- provides an ontology of object orientation
- with unambiguous specifications
- by **getting rid of names**

An object model of the object model (3/3)

Language ambiguities

- natural languages are inherently ambiguous
 - ☞ plays on words
- programming languages, although formal, are ambiguous, too
 - because they serve as **man-machine interfaces**
 - through various **names**
- ☞ compilers don't joke!

Foundation requirement

☞ in the modelled program, each occurrence of the name of a modelled entity must denote a single instance of the metamodel

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Foundation requirement

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```

1 class A {
2     foo() {...}
3 }

```

a **class**, named **A**

a **method** named **foo()**, defined in **A**

```

3 class B extends A {
4     foo() {...}
5     bar() {...}
6 }

```

a class named **B**, subclass of **A**

a method named **foo()**, defined in **B**

redefining **foo()** of **A**

a method named **bar()**, defined in **B**

```

1 A x;
3 B y;
6 x.foo();
7 y.bar();

```

a type annotation with class **A**

a type annotation with class **B**

a **message** **foo()** introduced in **A**

sent to **x** with late binding

a message **bar()** introduced in **B**

1	class A {	a class , named A
2	foo() {...}	a method named foo() , defined in A
	}	
3	class B extends A {	a class named B , subclass of A
4	foo() {...}	a method named foo() , defined in B redefining foo() of A
5	bar() {...}	a method named bar() , defined in B
	}	
1	A x;	a type annotation with class A
3	B y;	a type annotation with class B
6	x.foo();	a message foo() introduced in A sent to x with late binding
7	y.bar();	a message bar() introduced in B

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An object model of the object model (3/3)

A single class for classes

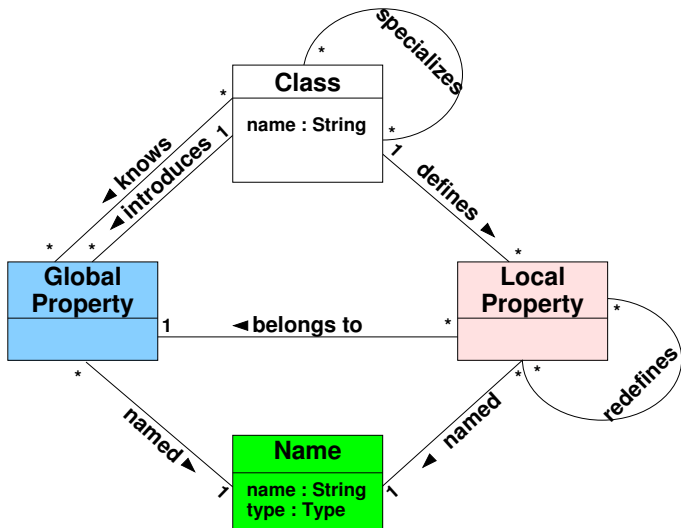
- for all usages: declarations, type annotations and **new**

Two classes for properties

- a class for **local** properties, implementations **defined** in a class
- a class for **global** properties, messages **invoked** from the code

What are properties?

- methods, attributes
- formal type parameters, virtual types, ...




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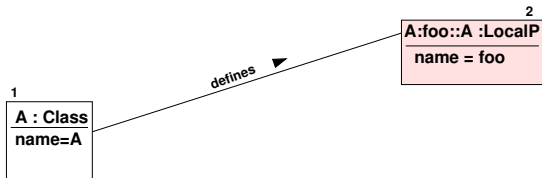
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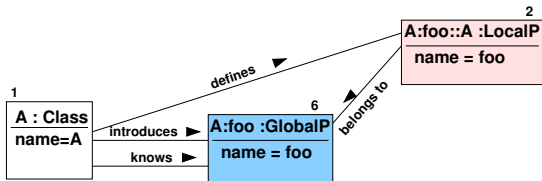
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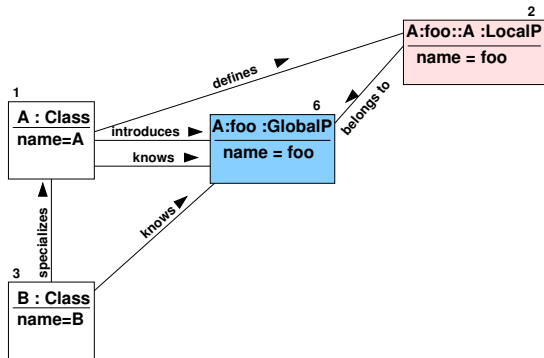
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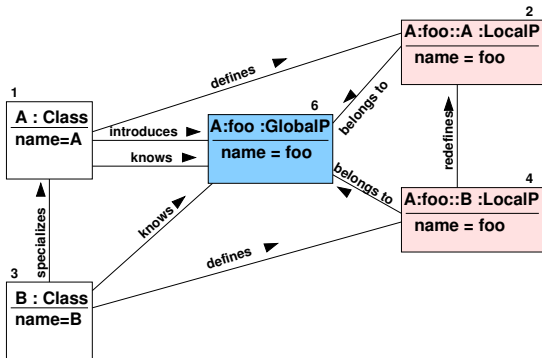
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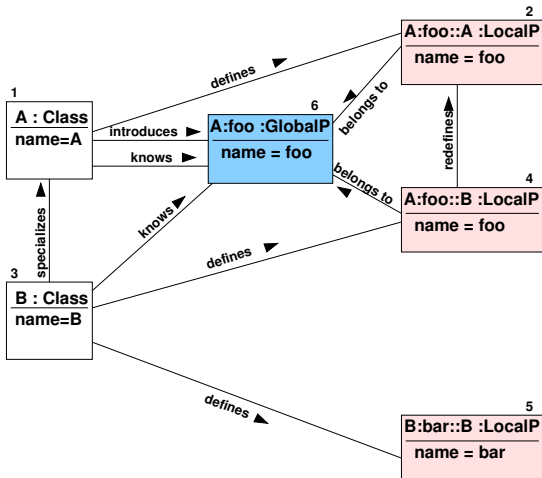
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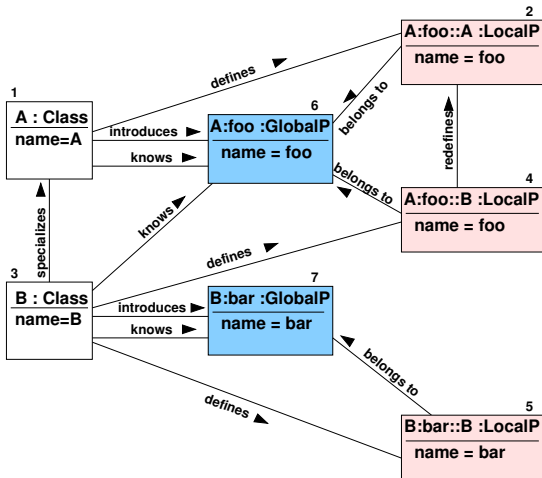
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Metamodeling semantics

Disambiguating name conflicts

In two situations

- with **multiple inheritance**
- with **static overloading**
- by substituting an instance of **local/global property** to each property name, even when it seems ambiguous

Actual ambiguities = compiler errors

When this substitution is not possible (several candidates)

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Motivation for multiple inheritance (1/2)

Multiple inheritance provides

- increased expressivity
 - improved reuse
-
- given a class **A** providing a service **foo**
 - and a class **B** providing a service **bar**
 - both developed independently of each other (apart from common superclasses)
 - ➡ define a common subclass **C** providing both services

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Motivation for multiple inheritance (2/2)

In static typing

There is no language without

- full multiple inheritance (C++, Eiffel),
- or mixins (Scala),
- or at least multiple subtyping (Java, C#, Ada 2005)

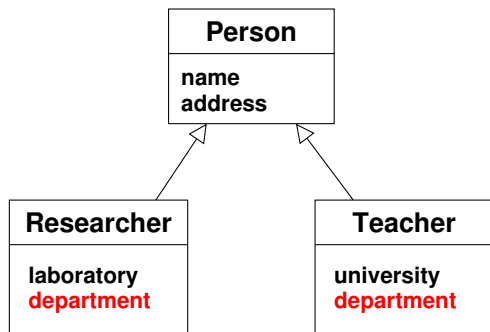
Multiple inheritance conflicts (1/5)

Conflicts of two kinds

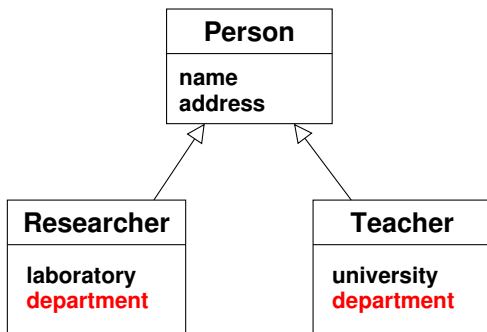
- between two **global** properties with the **same name**
- between two **local** properties of the **same global property**

➡ plus the **method combination** case

Multiple inheritance conflicts (2/5)



Multiple inheritance conflicts (2/5)



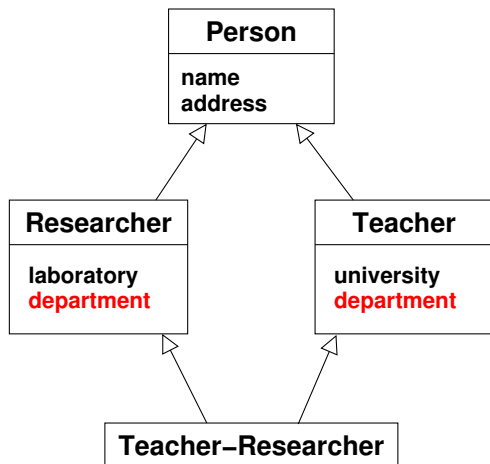
```

Researcher x;
x.department; // OK
  
```

```

Teacher y;
y.department // OK
  
```

Multiple inheritance conflicts (2/5)



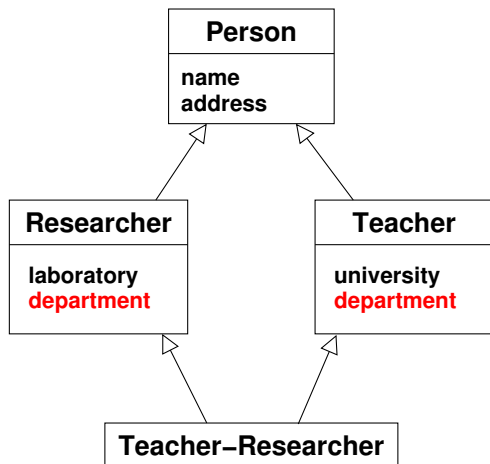
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Multiple inheritance conflicts (2/5)



Teacher-Researcher z;

Researcher x=z;

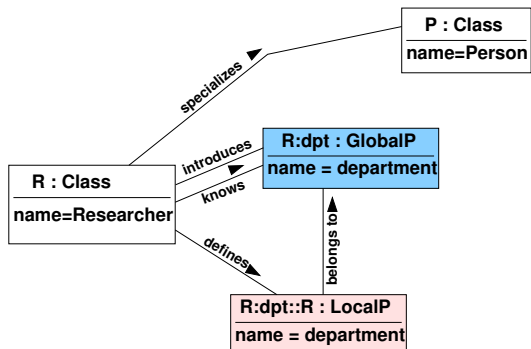
x.department; // OK

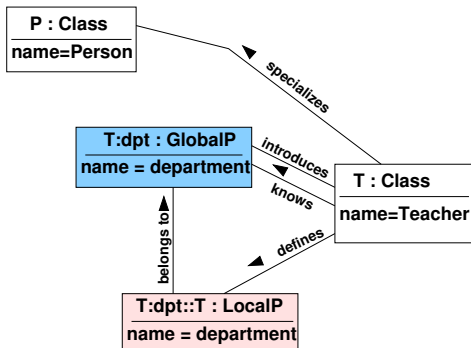
Teacher y=z;

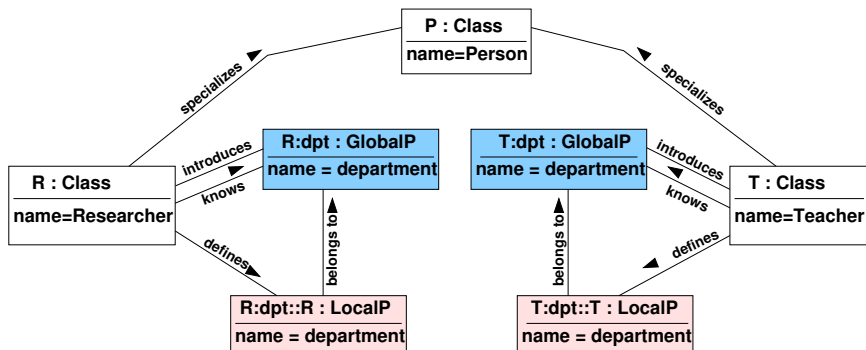
y.department // OK

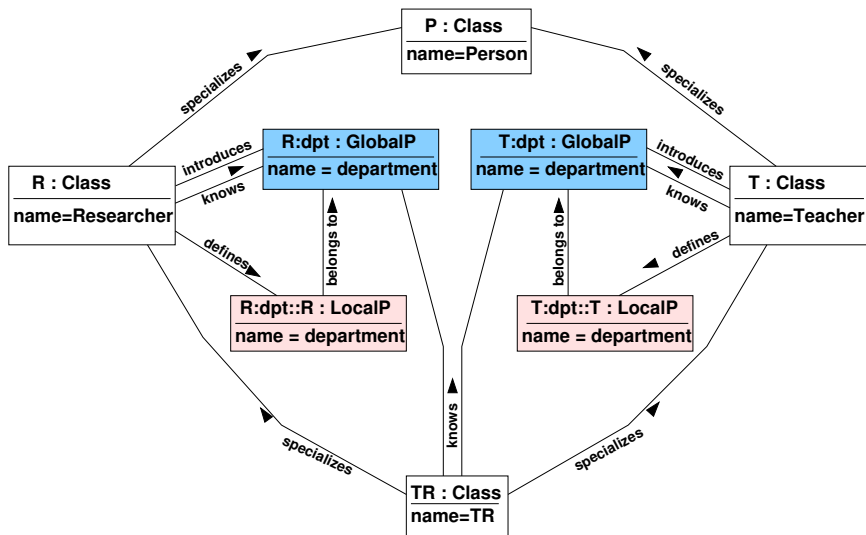
z.department // KO

P : Class
name=Person









Multiple inheritance conflicts (3/5)

Diagnosis

- conflict between two **global** properties with the **same name**

Solution: Fully Qualified Names

- short names are used in most situations
- names qualified with the **introduction class** used when a conflict occurs
- a global property is introduced by a single class
static typing required

short names

```
Teacher-Researcher z;
```

```
Researcher x=z;
```

```
x.department; // OK
```

```
Teacher y=z;
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```
y.department // OK
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```
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short names

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```

fully qualified names

means `x.Researcher:department`

means `y.Teacher:department`

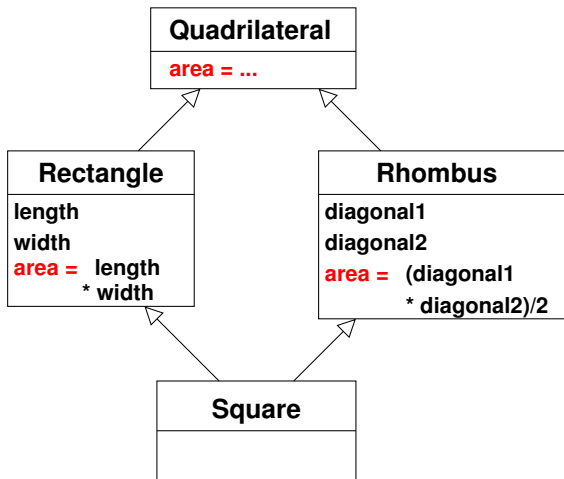
must be disambiguated with

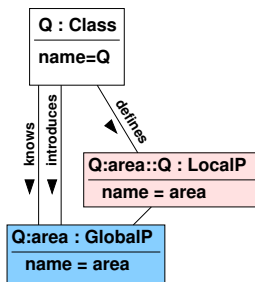
`z.Teacher:department`

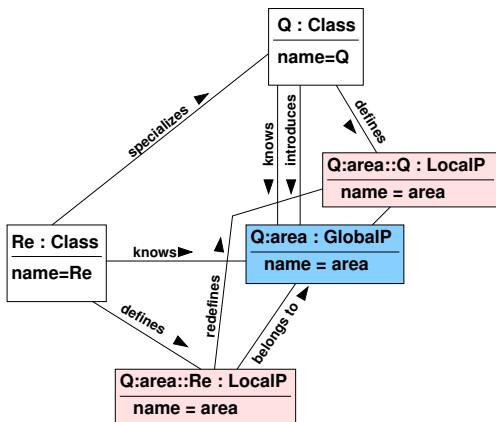
or `z.Researcher:department`

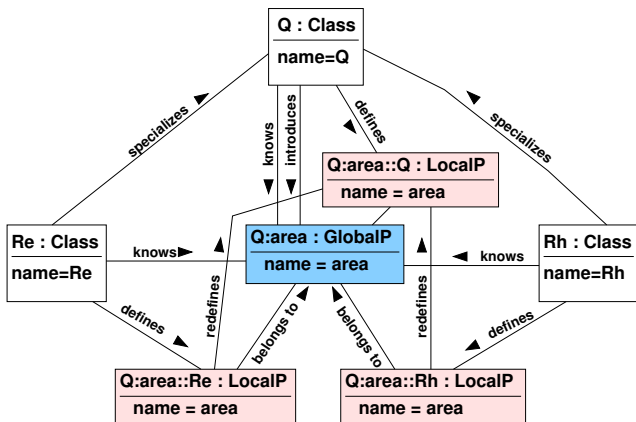
the programmer should know!

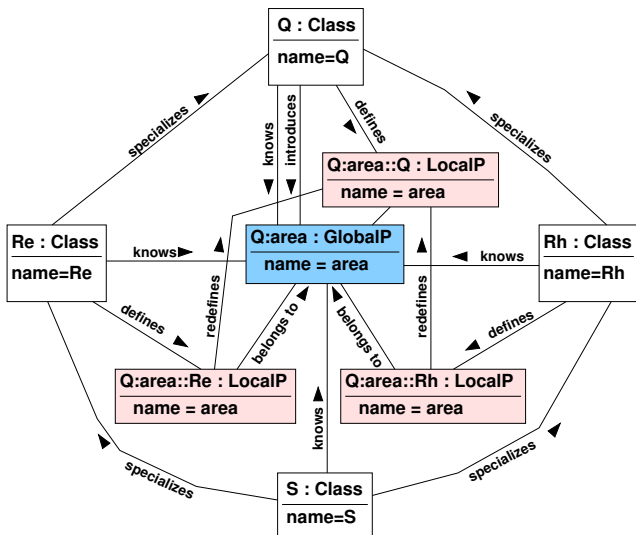
Multiple inheritance conflicts (4/5)











Multiple inheritance conflicts (5/5)

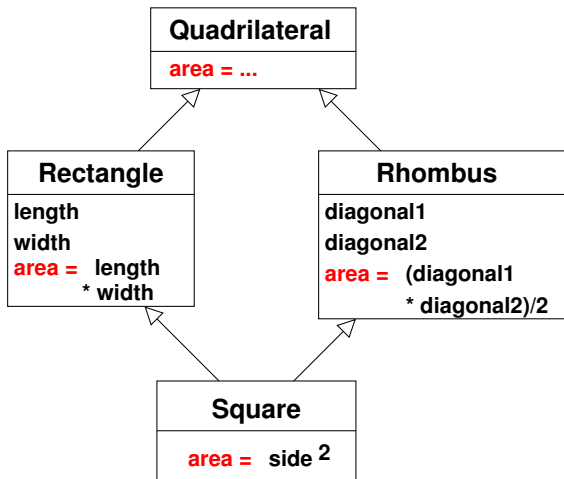
Diagnosis

- conflict between two **local** properties of the **same global property**
- none **more specific** than the other

Solution

- **redefinition** in the class where the conflict occurs

Multiple inheritance conflicts (5/5)



Monotonicity vs redefinition

Aristotelian logic is monotonic

☞ a **Human** must behave like a **Mortal**

Redefinition is non-monotonic

☞ redefining a method yields non-monotonicity

Method combination = Call to **super**

- a way to recover monotonicity

☞ a **Human** behaves like a **Mortal**, with extra behaviour

Monotonicity vs redefinition

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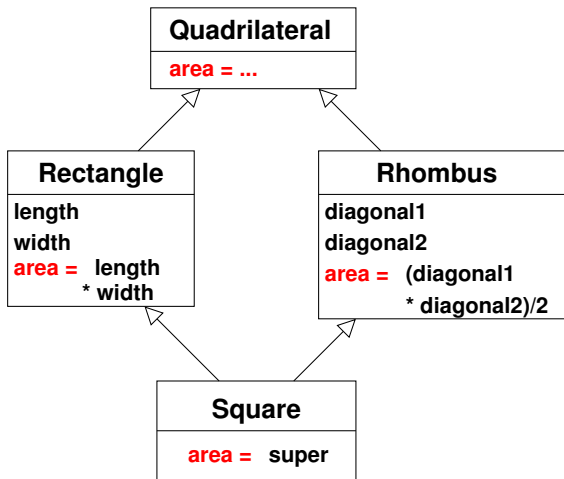
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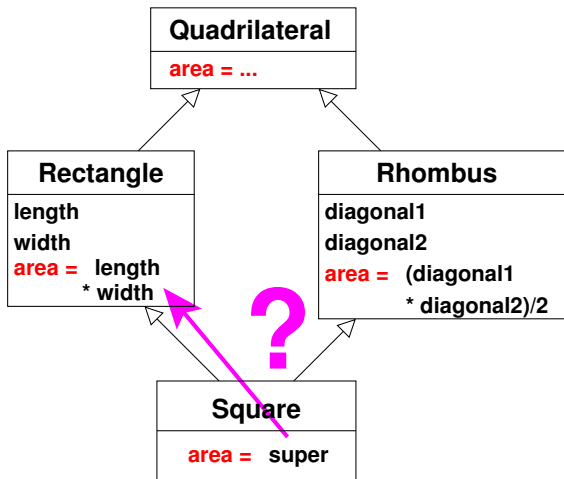
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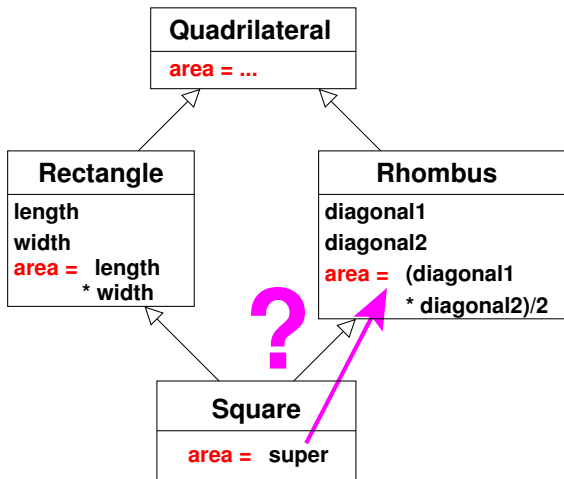
Method combination conflicts



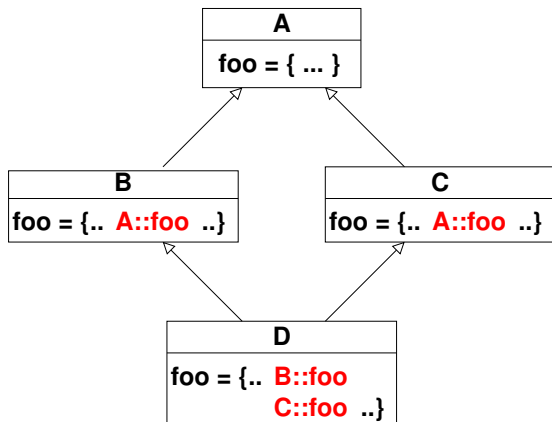
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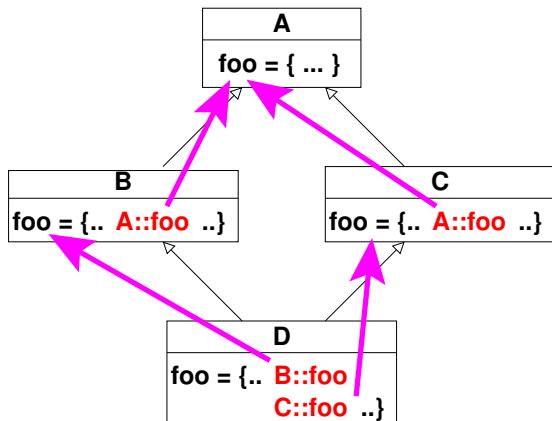



A wrong solution: static super calls



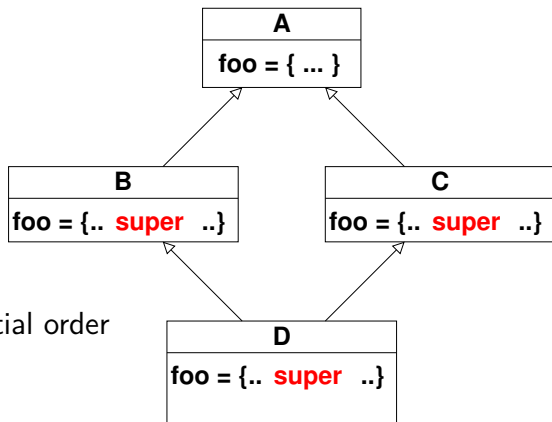
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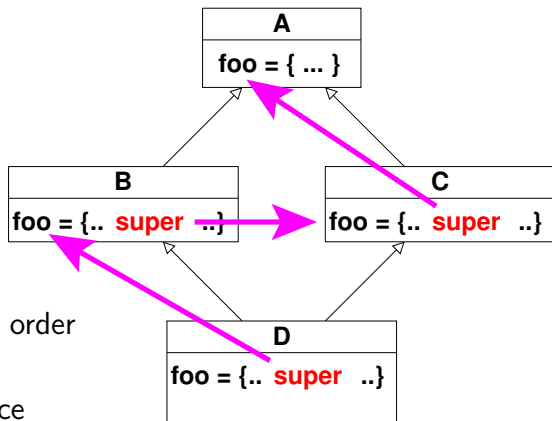
- like C++ or Eiffel
-  `A::foo` evaluated twice
repeated inheritance

The right solution: linearization (1/2)



- Specialization = a partial order

The right solution: linearization (1/2)



- Linearization = a total order
- ☞ `A::foo` evaluated once
non-repeated inheritance

The right solution: linearization (2/2)

Principle

- **linear extension** of the specialization partial order
- **monotonic**
- order preserved by specialization
- an algorithm called **C3** (used in Python)

With restricted multiple inheritance (1/3)

Multiple subtyping (Java, C#)

- no problem with **local** property conflicts, nor method combination
- except with **default methods** in Java 8
- ad hoc solution for **global** property conflicts in C#
- no solution for **global** property conflicts in Java

Multiple subtyping could be well-specified

With restricted multiple inheritance (1/3)

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Multiple subtyping could be well-specified

With restricted multiple inheritance (2/3)

Mixins/Traits

- same problems as with full multiple inheritance
 - **global** property conflicts
 - **method combination**
- ☞ if mixins were the answer, what was the question?
- ☞ just add unnecessary **asymmetry** between classes and traits

With restricted multiple inheritance (3/3)

The Scala case

- no solution for **global** property conflicts (like in Java)
- linearization-based method combination, but not **C3**

The question

How to easily implement “multiple inheritance” in multiple-subtyping runtime systems?

With restricted multiple inheritance (3/3)

The Scala case

- no solution for **global** property conflicts (like in Java)
- linearization-based method combination, but not **C3**

The question

How to easily implement “multiple inheritance” in multiple-subtyping runtime systems?

With full multiple inheritance (1/2)

C++ virtual inheritance

- right solution for **global attribute** conflicts
- no solution for **global method** conflicts
- ☞ two distinct attributes for a single accessor!
- method combination with static calls and repeated inheritance
- linearization used for **constructor/destructor** combination but not **C3**

C++ non-virtual inheritance

- repeated inheritance for non-conflicting **global attributes**
- ☞ an abomination

With full multiple inheritance (1/2)

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With full multiple inheritance (2/2)

Eiffel

- ad hoc solution for **global** property conflicts, with **renaming**
- method combination with static calls and repeated inheritance

With dynamic typing (CLOS, Python)

- no solution for **global** property conflicts
- linearization-based method combination
- **C3** default linearization only in Python
- possibility to define metaclasses using **C3** in CLOS

The ideal of multiple inheritance



- fully **symmetric**
 - no distinction between classes and traits
 - the same for methods, attributes, virtual types, type parameters
- **metamodeling** semantics
 - with **fully qualified names** for global properties
 - without any repetition
- local property conflicts solved by redefinition
- method combination using the **C3 linearization**

References on multiple inheritance



- with Jean Privat: Meta-Modeling Semantics of Multiple Inheritance
Science of Computing Programming, 2011.
- with Michel Habib, Marianne Huchard and Marie-Laure Mugnier:
Proposal for a monotonic multiple inheritance linearization.
In Proc. OOPSLA'94. 1994.
- Monotonic conflict resolution mechanisms for inheritance.
In Proc. OOPSLA'92, 1992

Plan

- 1 Classes and inheritance
- 2 Types and subtyping**
 - Classes vs types
 - Specialization vs subtyping
 - Static overloading
- 3 Genericity
- 4 Conclusions and projects



Classes vs types (1/2)

Different roles

- **classes** declare **properties** and create **instances**
- **types** serve as **annotations** in the code
- allow the compiler to ensure the code is **type safe**

Nominal vs structural types

- a **nominal type** is a **symbol** with **explicit subtyping**
- a **structural type** is a **record** of named signatures, with **implicit subtyping**

Classes vs types (2/2)

Mainstream position (C++, Java, C#, Scala, Eiffel, ..)

Besides higher-order types:

- classes are nominal types
- subtyping is implied by class specialization

The OCAML exception

☞ types are purely structural

Specialization vs subtyping (1/5)

Subtyping is substitutability (B. Liskov)

Specialization implies subtyping

IFF redefinition satisfies the **contravariance rule**

- **return type** must be redefined **covariantly**
- **parameter types** must be redefined **contravariantly**
- **type safe**

Specialization vs subtyping (2/5)

Mainstream position (C++, Java, Scala, ...)

- return types are **covariant**
- parameter types are **invariant**

Exceptions

- C# & Java 1.4: return types are **invariant**
 - ☞ no reason at all
- Eiffel: parameter types are **covariant**
 - ☞ **type unsafe**
- OCAML: parameter types are **contravariant**

Specialization vs subtyping (3/5)

Motivations of the choice

- **covariance** because of the **mad cow** example
- **invariance** because
 - contravariance is useless in practice
 - static overloading was preexisting object-orientation
- **contravariance** because of structural types

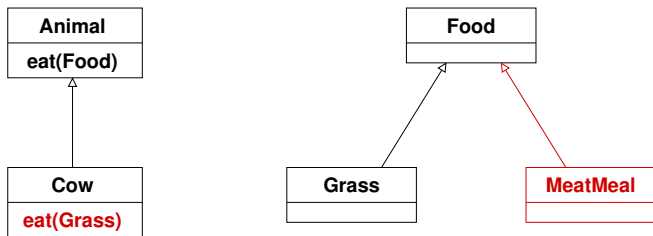
Specialization vs subtyping (4/5)



```
Animal x ;  
Food y ;  
x.eat(y);
```

👉 don't panic, but type errors are in the **real world**TM

Specialization vs subtyping (4/5)



```
Animal x = new Cow();
Food y = new MeatMeal();
x.eat(y); // runtime type error
```

☞ don't panic, but type errors are in the **real world**TM

Specialization vs subtyping (5/5)

What is my ideal?

- **invariance** of both parameter and return types
- **covariance** through **virtual types**

Static overloading (1/3)

When parameter types are **invariant**,
☞ there is room for **static overloading**

Principle

- a **name** denoting different entities in a common context
- **disambiguated with static types**
- originates in pre-object languages like PL/1 and C

Static overloading (1/3)

When parameter types are **invariant**,
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Principle

- a **name** denoting different entities in a common context
- **disambiguated with static types**
- originates in pre-object languages like PL/1 and C

*Mal nommer les choses,
c'est ajouter au malheur du monde*

Misnaming things adds to the world's misfortunes
(Albert Camus)

Albert Camus a French writer and philosopher (1913-60)

Peyo a Belgian author of comic strips (1928-92)
creator of the **Schtroumpfs**

Schtroumpfs small characters whose language
has a single noun and verb: "**schtroumpf**"

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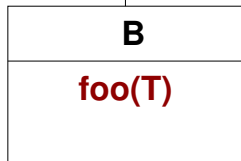
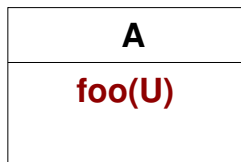
in the context of a picture, even small children can understand!

Schtroumpfing schtroumpfs schtroumpfs
to the schtroumpf's schtroumpfs



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Static overloading (2/3)

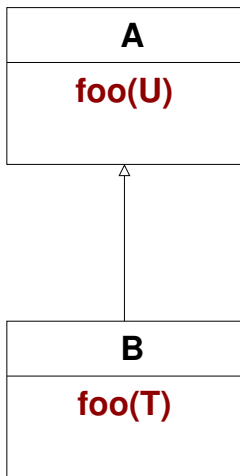


$U <: T$ $B \ x$
 $U \ y$

	x.foo(y)
C++	
Java 1.4	
Java 1.5	
Scala	
C#	



Static overloading (2/3)

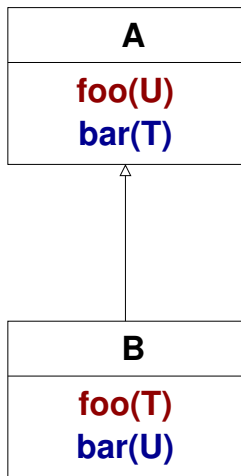


$U <: T$ $B \times$
 $U \ y$

	$x.foo(y)$
C++	$foo(T)$
Java 1.4	error
Java 1.5	$foo(U)$
Scala	error
C#	$foo(T)$



Static overloading (2/3)

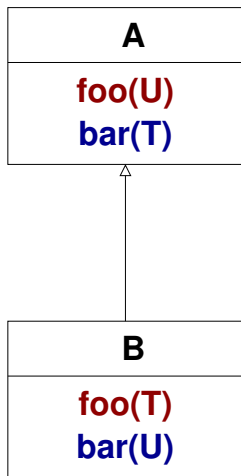


$U <: T$


$B \ x$
 $U \ y$
 $T \ z = \text{new } U$

	$x.foo(y)$	$x.bar(z)$
C++	<code>foo(T)</code>	<code>error</code>
Java 1.4	<code>error</code>	<code>bar(T)</code>
Java 1.5	<code>foo(U)</code>	<code>bar(T)</code>
Scala	<code>error</code>	<code>bar(T)</code>
C#	<code>foo(T)</code>	<code>bar(T)</code>

Static overloading (2/3)



$U <: T$ $B \ x$
 $U \ y$
 $T \ z = \text{new } U$

Confusion with **covariance** 
contravariance or **multiple selection**

	<code>x.foo(y)</code>	<code>x.bar(z)</code>
Eiffel	error	error
OCAML	<code>foo(T)</code>	error
<i>intuition</i>	—	<code>bar(U)</code>

Static overloading (3/3)



6 languages

☞ 6 different specifications + the intuition

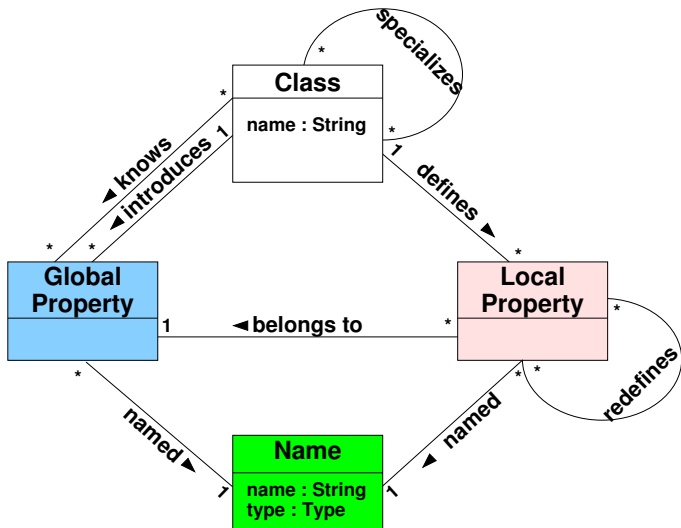
☞ it cannot be a sane language feature

Static overloading (3/3)



6 languages

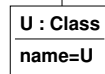
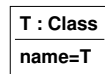
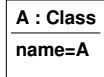
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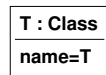
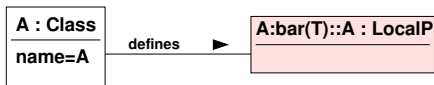
Static overloading in the metamodel



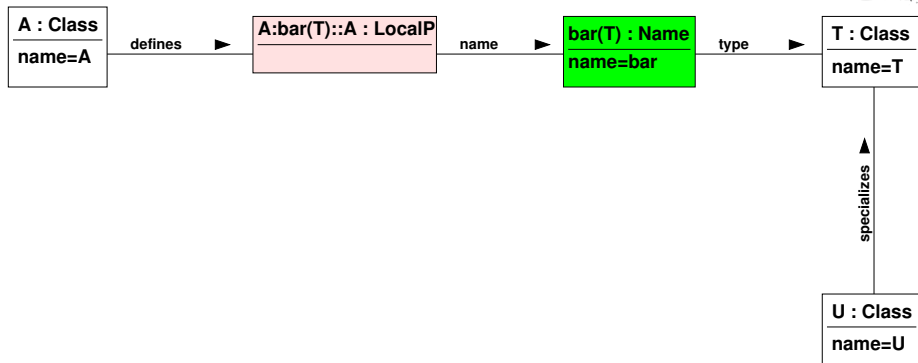
Static overloading in the metamodel



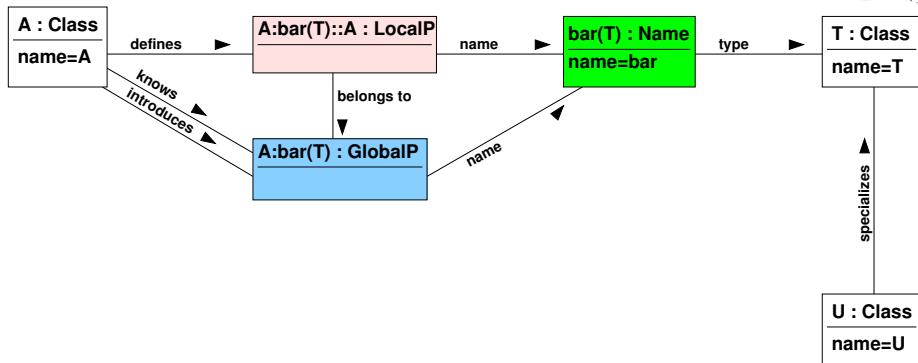
Static overloading in the metamodel



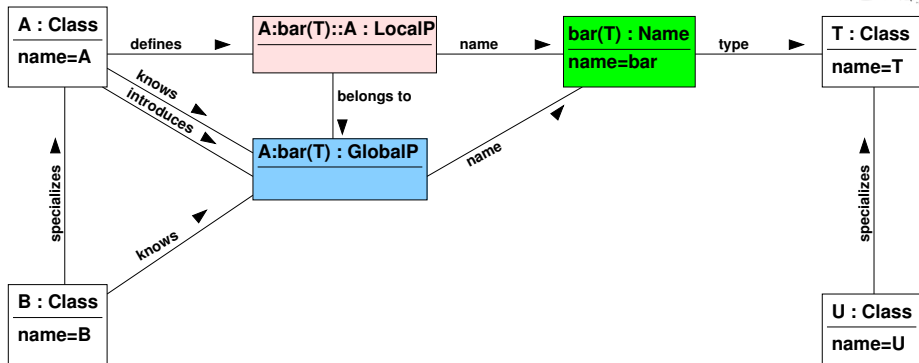
Static overloading in the metamodel



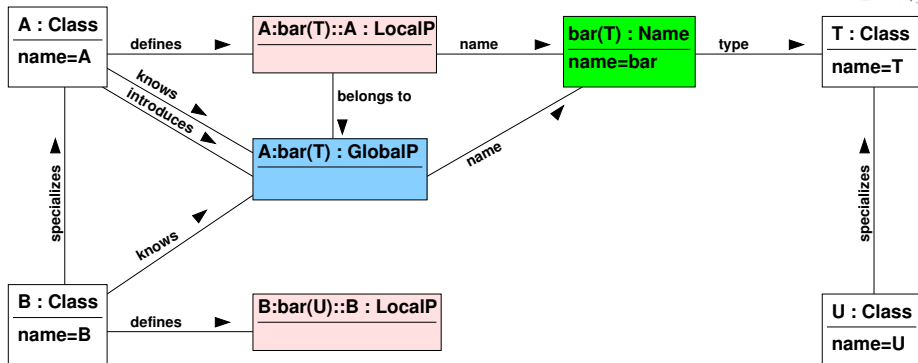
Static overloading in the metamodel



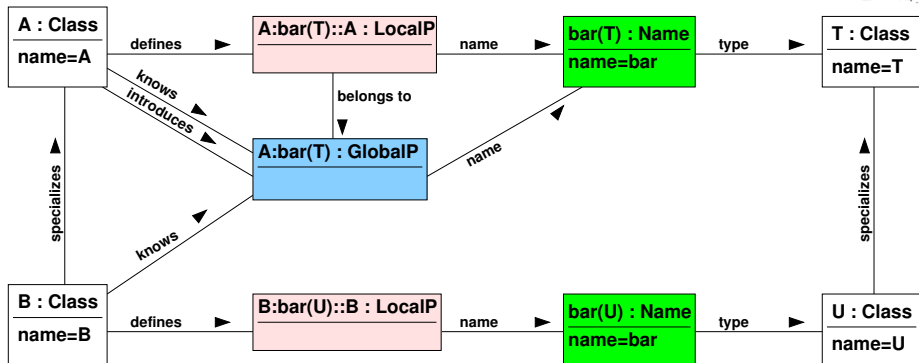
Static overloading in the metamodel



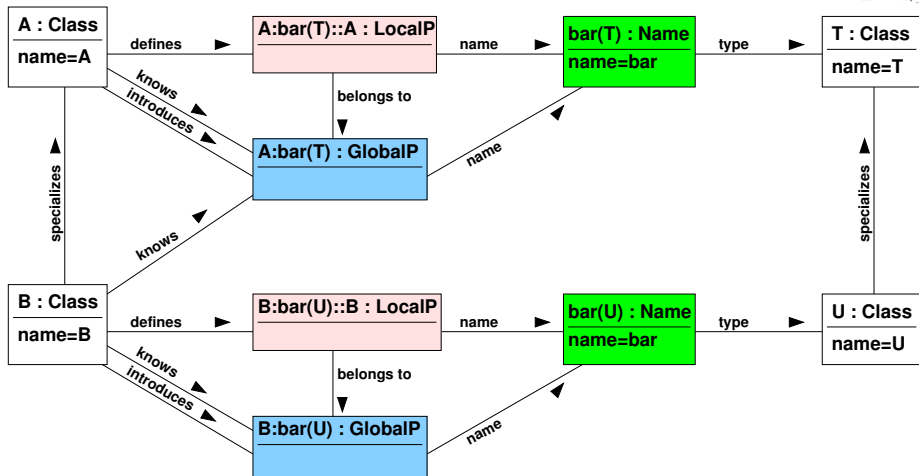
Static overloading in the metamodel



Static overloading in the metamodel



Static overloading in the metamodel





The right semantics (1/2)

At compile-time

- 1 select all the **global methods**, known by the **receiver's static type**, with **parameter static types** compatible with the call
say $\text{foo}(T)$ and $\text{foo}(U)$
- 2 select among them **the single most specific**
if $U <: T$, $\text{foo}(U)$ is more specific than $\text{foo}(T)$
- 3 compilation error when there are several most specific
eg $\text{baz}(T,U)$ and $\text{baz}(U,T)$

At run-time = late binding

- select in the **global property** the most specific **local property**
for the **receiver's dynamic type**

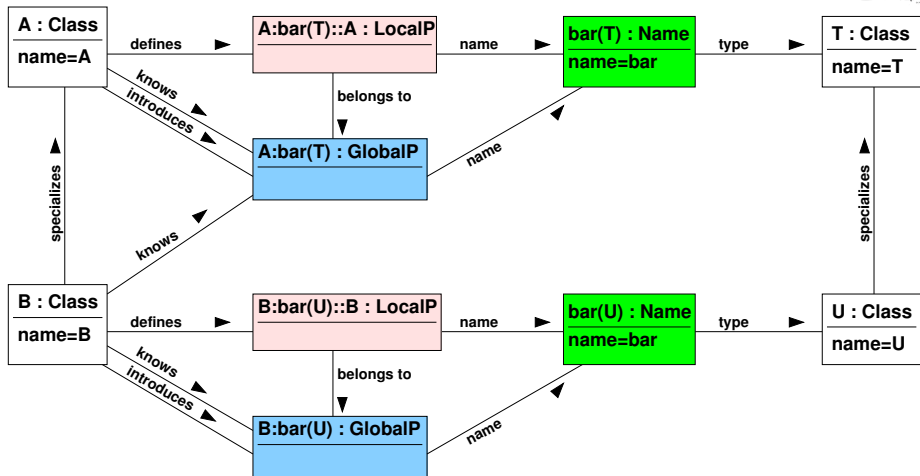
The right semantics (2/2)



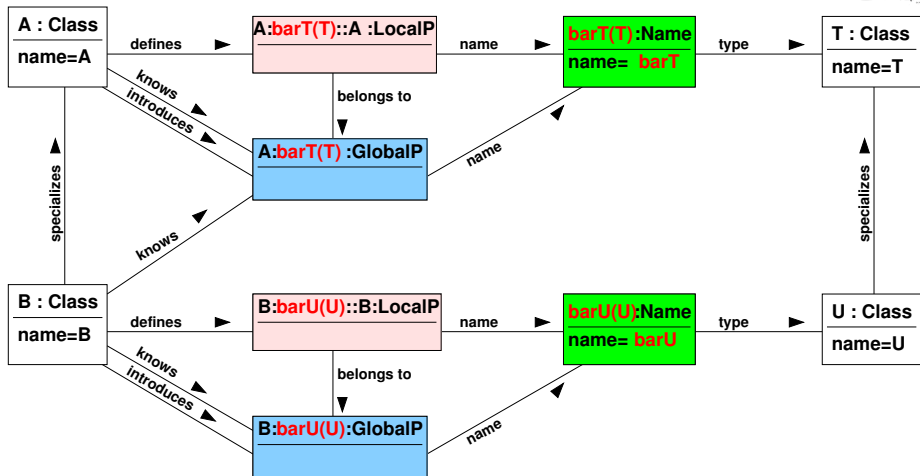
That of Java 1.5

- **specificity** does not involve the **introduction** or **definition** classes (as in Java 1.4 or Scala)
- a **local property** of a given **global property** doesn't **mask** a **local property** of another **global property**, as in C++ and C#
eg $\text{foo}(T)$ in B doesn't mask $\text{foo}(U)$ in A

Avoid overloading by renaming



Avoid overloading by renaming



The right specifications



- exclude overloading from the language specifications (as in Eiffel or Nit),
- otherwise, apply the right semantics (Java 1.5)
- but don't use it
- instead, **rename!**

The Schtroumpf project



Reductio ad absurdum

- select some mainstream language with static overloading
 - C++, Java, C#, Scala, not Eiffel
- select some large-scale project written in this language
- **rename** all methods in the project classes as either **foo** or **bar**
- in case of conflict, add an extra, unused parameter

Variant

- develop an Eclipse plugin that does this renaming, automatically

Plan

- 1 Classes and inheritance
- 2 Types and subtyping
- 3 Genericity**
 - Genericity vs subtyping
 - Variance annotations
- 4 Conclusions and projects



Generic vs object-oriented programming



Genericity is not object-oriented

- two almost orthogonal constructs

Genericity is now universal

In static typing

- object-oriented languages are now generic (Eiffel, C++, Java, C#, ...)
- generic languages (Ada) are now object-oriented

Generic vs object-oriented programming



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Generic vs object-oriented programming



Genericity + subtyping \Rightarrow troubles

- hard to **specify**
- hard to **understand** and **use**
- hard to **implement** efficiently

Specifications **by** implementation



At least 3 versions

heterogeneous pure **textual substitution** (C++)

- no recursive types + code explosion

homogeneous **type erasure** and code sharing (Java 1.5, Scala)

- limited expressivity, unsafe *casts*, inefficient **boxing**

mixed code shared or specialized, with runtime types (C#)

- best tradeoff expressivity-efficiency-safety

Constrained genericity



At least 3 specifications of constraints

- none (C++)
 - ☞ no checking before instantiation
 - ☞ (recently) notion of **concept**
- formal type parameters **bounded by subtyping**
 - ☞ simple to understand and use
- **recursive bound** (*F-bounded*) (Java, C#, Scala, Eiffel, ...)
 - ☞ powerful but harder to understand
 - allows to clone isomorphic structures

Genericity and (co)variance



Principle

Cup<茶> is not a subtype of **Cup<Drink>**

But many unsafeties ...

- generalized covariance (Eiffel)
- covariance of arrays (Java, C#)
- casts with type erasure (Java, Scala)



Safe variance annotations

- at definition-time (Scala, C# only for interfaces)
- at use-time (*wildcards* Java, Scala)



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Array covariance



Cats are not dogs

```
Cat[] x;
```

```
...
```

```
Animal[] y;
```

```
y = x; // dangerous but compiled
```

```
y[i] = new Dog(); // compiled but runtime exception
```



Type erasure = Alzheimer



Cats are not dogs (re)

```
Stack<Cat> x;
```

```
...
```

```
Stack<Dog> y;
```

```
y = (Stack<Dog>)x; // stupid but compiled
```

```
y.push(new Dog); // type is erased! Alzheimer
```

```
...
```

```
Cat z = x.pop(); // late exception
```



☞ bad traceability of errors

Type erasure = Alzheimer



Cats are not dogs (re)

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```
...
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☞ bad traceability of errors

Variance



Variance positions

```
class Stack<T> {  
    T pop () {...} // covariant position  
    push(T t) {...} // contravariant position  
}
```

☞ more complex rules when **T** is nested

Variance

-variance can be considered

- if **T** does not occur in a -variant position
- if such occurrences are excluded from the type interface

Variance



Variance positions

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```

☞ more complex rules when **T** is nested

Variance

Co-variance can be considered

- if **T** does not occur in a **contra**-variant position
- if such occurrences are excluded from the type interface

Variance



Variance positions

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☞ more complex rules when **T** is nested

Variance

Contra-variance can be considered

- if **T** does not occur in a **co**-variant position
- if such occurrences are excluded from the type interface

Variance annotations (1/3)



Use-site covariance

```
Stack<? extends Animal> s = new Stack<Cat>();
```

```
Animal a = s.pop();           // OK
```

```
s.push(a);                    // KO
```

- ☞ interface restricted to methods where the type parameter is **not in a contravariant position**

- ☞ useful for exporting “almost read-only” collections

Variance annotations (1/3)



Use-site covariance

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Variance annotations (2/3)



Use-site **contravariance**

```
Stack<? super Cat> s = new Stack<Animal>();
```

```
Animal a = s.pop(); // KO
```

```
Object o = s.pop(); // OK
```

```
s.push(new Cat()); // OK
```

- ☞ interface restricted to methods where the type parameter is **not in a covariant position** or is replaced by the parameter **bound**

- ☞ counter-intuitive and rarely used, apart from **Comparable**

Variance annotations (2/3)



Use-site **contravariance**

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- ☛ counter-intuitive and rarely used, apart from **Comparable**

Variance annotations (3/3)



Definition-site variance

- class ImmutableContainer<+ T>
 { T get() ;}
- class Container<T> inherit ImmutableContainer<T>
 { put(T) ;}

- with + the type parameter is **covariant**
and cannot be used in a **contravariant** position
useful for exporting “actual read-only” collections

Variance annotations (3/3)



Definition-site variance

- class ImmutableContainer<**+** T>
 { T get() ;}
 - class Container<T> inherit ImmutableContainer<T>
 { put(T) ;}
- ☞ with – the type parameter is **contra**variant and cannot be used in a **cova**riant position
- counter-intuitive and rarely used

Contravariance and recursive bound



- interface Comparable<**T** extends Comparable<**T**>>
- class OrderedSet<**T** extends Comparable<**T**>>
- class **A** implements Comparable<**A**>
- OrderedSet<**A**> // OK

- class B extends A
 // **B** implements Comparable<**A**>
- OrderedSet<**B**> //
 // **B** doesn't implement Comparable<**B**>

Contravariance and recursive bound



- interface Comparable<**T** extends Comparable<**T**>>
 - class OrderedSet<**T** extends Comparable<**T**>>
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-
- class B extends A // OK
// **B** implements Comparable<**A**>
 - OrderedSet<**B**> // KO
// **B** doesn't implement Comparable<**B**>

Contravariance and recursive bound



- interface Comparable<**T** extends Comparable<**T**>>
 - class OrderedSet<**T** extends Comparable<**T**>>
 - class **A** implements Comparable<**A**>
 - OrderedSet<**A**> // OK
-
- class B extends A implements Comparable<**B**> // KO
// B cannot implement both
 - OrderedSet<**B**> // KO

Contravariance and recursive bound



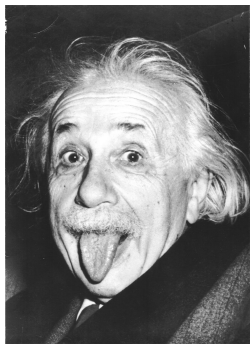
- interface Comparable<**T** extends Comparable<**T**>>
 - class OrderedSet<**T** extends Comparable<? **super T**>> Java
 - class **A** implements Comparable<**A**>
 - OrderedSet<**A**> // OK
-
- class B extends A
// **B** implements Comparable<A> <: Comparable<? **super B**>
 - OrderedSet<**B**> // OK

Contravariance and recursive bound



- interface Comparable<**T** extends Comparable<**-T**>> Scala
 - class OrderedSet<**T** extends Comparable<**T**>>
 - class **A** implements Comparable<**A**>
 - OrderedSet<**A**> // OK
-
- class B extends A
 - // **B** implements Comparable<A> <: Comparable<**B**>
 - OrderedSet<**B**> // OK

A programmer hierarchy



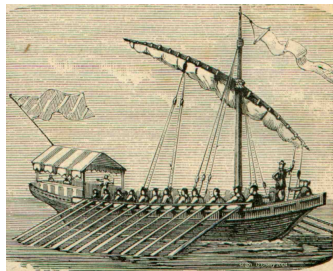
language or library
implementer

an ingenious engineer



language designer

a Pure Light of
programming



base programmer

an obscure rower

Variance annotations



Use-site variance more general than definition-site

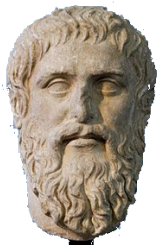
- instead of defining $A<+T>$ once,
 - use $A<? \text{ extends } T>$ everywhere!
 - ☞ It's unfair to impose to the **base programmer** the difficulties that could have been adressed by **language designers** or **implementers**
-
- **using** classes, especially generics, is easier that **defining** them
 - **definition-site** variance should be added to Java and enlarged to all classes in $C\#$
 - most of the burden of **use-site** variance would be avoided

Genericity (the end)



Ideal specifications

- no type erasure
- mixed implementation à la C#
- definition- and use-site variance (Scala)
- array invariance
- recursive bound (*F-bounded*)
- no specialization of multiple generic instances
- no static overloading on the formal type
- better support of the IDEs



Plan

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- 4 **Conclusions and projects**



Ideal specifications of OO languages



In static typing

- metamodeling semantics of multiple inheritance
- generics with variance and runtime types
- without overloading

Ideal specifications of OO languages



Why static typing?

because

- dynamic typing is unsafe
- dynamic typing is too difficult for most programmers
- programming in dynamic typing is an **art**, not an industry
- static typing allows for **exoskeletons** like **Eclipse**

Before boarding an aircraft,
be sure that all the avionics is statically typed!



a programmer dreams that he commands Eclipse,
is it not Eclipse dreaming it is a programmer? (after 庄子)

Ideal specifications for other features



Constructors, i.e. initialization methods

- an open problem
- no satisfying specification

Reflection

- first-class metaclasses, based on variant generics
- as an extension of Java `Class` class
- language-level UML associations
- ... and certainly a few other object-oriented features

Ideal specifications for other features



Constructors, i.e. initialization methods

- an open problem
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- first-class metaclasses, based on variant generics
- as an extension of Java `Class` class
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- ... and certainly a few other object-oriented features

What about existing languages?



Marginal evolution in Java and C#

- global property conflicts (Java)
- covariant return types (C#)
- definition-site variance (both)

Too many backwards incompatibilities

- ☞ type erasure seems to be definitive (Java, Scala)
- ☞ a complete solution involves new languages

Just do it!

- the specifications are state-of-the-art
- solutions exist for implementing it (another story...)



末尾