Polymorphism

Introduction

- Compare these function types
- The ML function is more flexible, since it can be applied to any pair of the same (equality-testable) type

C:

```
int f(char a, char b) {
  return a==b;
}
```

ML:

```
- fun f(a, b) = (a = b);
val f = fn : ''a * ''a -> bool
```

Polymorphism

- Functions with that extra flexibility are called *polymorphic*
- A difficult word to define:
  - Applies to a wide variety of language features
  - Most languages have at least a little
  - We will examine four major examples, then return to the problem of finding a definition that covers them

Outline

- Overloading
- Parameter coercion
- Parametric polymorphism
- Subtype polymorphism
- Definitions and classifications

Overloading

- An *overloaded* function name or operator is one that has at least two definitions, all of different types
- Many languages have overloaded operators
- Some also allow the programmer to define new overloaded function names and operators

Predefined Overloaded Operators

ML:

```
val x = 1 + 2;
val y = 1.0 + 2.0;
```

Pascal:

```
a := 1 + 2;
b := 1.0 + 2.0;
c := "hello " + "there";
d := ['a'..'d'] + ['f']
```

Adding to Overloaded Operators

- Some languages, like C++, allow additional meanings to be defined for operators

```
class complex {
  double rp, ip; // real part, imaginary part
public:
  complex(double r, double i) {rp=r; ip=i;}
  friend complex operator+(complex, complex);
  friend complex operator*(complex, complex);
};

void f(complex a, complex b, complex c) {
  complex d = a + b * c;
  …
}
```

Operator Overloading In C++

- C++ allows virtually all operators to be overloaded, including:
  - the usual operators (+,-,*,/,%,^,&,|,~,!,=,<,>, +=,-=,=,*=,/=,%=,^=,&=,|=,<<,>>,>>=,<<=,==, !=,<=,>=,&&,||,++,--,->*,,)
  - dereferencing (`*p` and `p->x`)
  - subscripting (`a[i]`)
  - function call (`f(a,b,c)`)
  - allocation and deallocation (`new` and `delete`)

Defining Overloaded Functions

- Some languages, like C++, permit the programmer to overload function names

```
int square(int x) {
  return x*x;
}

double square(double x) {
  return x*x;
}
```

To Eliminate Overloading

```
int square(int x) {          square_i
  return x*x;
}

double square(double x) {    square_d
  return x*x;
}

void f() {
  int a = square(3);
  double b = square(3.0);
}
```

You could rename each overloaded definition uniquely…

How To Eliminate Overloading

```
int square_i(int x) {
  return x*x;
}

double square_d(double x) {
  return x*x;
}

void f() {
  int a = square_i(3);
  double b = square_d(3.0);
}
```

Then rename each reference properly (depending on the parameter types)

Implementing Overloading

- Compilers usually implement overloading in that same way:
  - Create a set of monomorphic functions, one for each definition
  - Invent a *mangled* name for each, encoding the type information
  - Have each reference use the appropriate mangled name, depending on the parameter types

Example: C++ Implementation

C++:
```
int shazam(int a, int b) {return a+b;}
double shazam(double a, double b) {return a+b;}
```

Assembler:
```
shazam__Fii:
        lda $30,-32($30)
        .frame $15,32,$26,0
        …
shazam__Fdd:
        lda $30,-32($30)
        .frame $15,32,$26,0
        …
```

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Coercion

- A coercion is an implicit type conversion, supplied automatically even if the programmer leaves it out

Explicit type conversion in Java:

```
double x;
x = (double) 2;
```

Coercion in Java:

```
double x;
x = 2;
```

Parameter Coercion

- Languages support different coercions in different contexts: assignments, other binary operations, unary operations, parameters…
- When a language supports coercion of parameters on a function call (or of operands when an operator is applied), the resulting function (or operator) is polymorphic

Example: Java

```
void f(double x) {
   …
}

f((byte) 1);
f((short) 2);
f('a');
f(3);
f(4L);
f(5.6F);
```

This **`f`** can be called with any type of parameter Java is willing to coerce to type **`double`**

Defining Coercions

- Language definitions often take many pages to define exactly which coercions are performed
- Some languages, especially some older languages like Algol 68 and PL/I, have very extensive powers of coercion
- Some, like ML, have none
- Most, like Java, are somewhere in the middle

Example: Java

Some operators apply *unary numeric promotion* to a single operand, which must produce a value of a numeric type:

If the operand is of compile-time type **`Byte`**, **`Short`**, **`Character`**, or **`Integer`** it is subjected to unboxing conversion. The result is then promoted to a value of type **`int`** by a widening conversion or an identity conversion. Otherwise, if the operand is of compile-time type **`Long`**, **`Float`**, or **`Double`** it is subjected to unboxing conversion. Otherwise, if the operand is of compile-time type **`byte`**, **`short`**, or **`char`**, unary numeric promotion promotes it to a value of type **`int`** by a widening conversion. Otherwise, a unary numeric operand remains as is and is not converted. In any case, value set conversion is then applied.

Unary numeric promotion is performed on expressions in the following situations:

- Each dimension expression in an array creation expression
- The index expression in an array access expression
- The operand of a unary plus operator **`+`**
- The operand of a unary minus operator **`-`**
- The operand of a bitwise complement operator **`~`**
- Each operand, separately, of a shift operator **`>>`**, **`>>>`**, or **`<<`**; therefore a long shift distance (right operand) does not promote the value being shifted (left operand) to **`long`**…

The Java Language Specification, Third Edition
James Gosling, Bill Joy, Guy Steele, and Gilad Bracha

Coercion and Overloading: Tricky Interactions

- There are potentially tricky interactions between overloading and coercion
  - Overloading uses the types to choose the definition
  - Coercion uses the definition to choose a type conversion

Example

- Suppose that, like C++, a language is willing to coerce **`char`** to **`int`** or to **`double`**
- Which **`square`** gets called for **`square('a')`** ?

```
int square(int x) {
  return x*x;
}
double square(double x) {
  return x*x;
}
```

Example

- Suppose that, like C++, a language is willing to coerce **`char`** to **`int`**
- Which **`f`** gets called for **`f('a', 'b')`** ?

```
void f(int x, char y) {
  …
}
void f(char x, int y) {
  …
}
```

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Parametric Polymorphism

- A function exhibits *parametric polymorphism* if it has a type that contains one or more type variables
- A type with type variables is a *polytype*
- Found in languages including ML, C++, Ada, and Java

Example: C++ Function Templates

```
template<class X> X max(X a, X b) {
  return a>b ? a : b;
}

void g(int a, int b, char c, char d) {
  int m1 = max(a,b);
  char m2 = max(c,d);
}
```

Note that **>** *can be overloaded, so* **X** *is not limited to types for which* **>** *is predefined.*

Example: ML Functions

```
- fun identity x = x;
val identity = fn : 'a -> 'a
- identity 3;
val it = 3 : int
- identity "hello";
val it = "hello" : string
- fun reverse x =
=   if null x then nil
=   else (reverse (tl x)) @ [(hd x)];
val reverse = fn : 'a list -> 'a list
```

Implementing Parametric Polymorphism

- One extreme: many copies
  - Create a set of monomorphic implementations, one for each type parameter the compiler sees
    - May create many similar copies of the code
    - Each one can be optimized for individual types
- The other extreme: one copy
  - Create one implementation, and use it for all
    - True universal polymorphism: only one copy
    - Can’t be optimized for individual types
- Many variations in between

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Subtype Polymorphism

- A function or operator exhibits *subtype polymorphism* if one or more of its parameter types have subtypes
- Important source of polymorphism in languages with a rich structure of subtypes
- Especially object-oriented languages: we'll see more when we look at Java

Example: Pascal

```
type
  Day = (Mon, Tue, Wed, Thu, Fri, Sat, Sun);
  Weekday = Mon..Fri;

function nextDay(D: Day): Day;
  begin
    if D=Sun then nextDay:=Mon else nextDay:=D+1
  end;

procedure p(D: Day; W: Weekday);
  begin
    D := nextDay(D);
    D := nextDay(W)
  end;
```

Subtype polymorphism: **`nextDay`** *can be called with a subtype parameter*

Example: Java

```
class Car {
  void brake() { … }
}

class ManualCar extends Car
{
  void clutch() { … }
}

void g(Car z) {
  z.brake();
}

void f(Car x, ManualCar y) {
  g(x);
  g(y);
}
```

A subtype of **`Car`** *is* **`ManualCar`**

Function **`g`** *has an unlimited number of types—one for every class we define that is a subtype of* **`Car`**

That's subtype polymorphism

More Later

- We’ll see more about subtype polymorphism when we look at object-oriented languages

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Polymorphism

- We have seen four kinds of polymorphic functions
- There are many other uses of *polymorphic*:
  - Polymorphic variables, classes, packages, languages
  - Another name for runtime method dispatch: when **`x.f()`** may call different methods depending on the runtime class of the object **`x`**
  - Used in many other sciences
- No definition covers all these uses, except the basic Greek: *many forms*
- Here are definitions that cover our four…

Definitions For Our Four

- A function or operator is *polymorphic* if it has at least two possible types
  - It exhibits *ad hoc polymorphism* if it has at least two but only finitely many possible types
  - It exhibits *universal polymorphism* if it has infinitely many possible types

Overloading

- Ad hoc polymorphism
- Each different type requires a separate definition
- Only finitely many in a finite program

Parameter Coercion

- Ad hoc polymorphism
- As long as there are only finitely many different types can be coerced to a given parameter type

Parametric Polymorphism

- Universal polymorphism
- As long as the universe over which type variables are instantiated is infinite

Subtype Polymorphism

- Universal
- As long as there is no limit to the number of different subtypes that can be declared for a given type
- True for all class-based object-oriented languages, like Java