Types and Classes

I

- From predefined (simple) and user-defined (composite) types
  - via
- Abstract data types
  - to
- Classes
  - Type compatibility
  - Subtyping <> subclassing
  - Class compatibility
  - Covariance/contravariance
    - Types of parameters of redefined methods

II

- Advanced oo concepts
  - Specialization of behaviour?
  - Multiple inheritance - alternatives
  - Inner classes
- Modularity
  - Packages
  - Interface-implementation
- Generics
- Scandinavian approch to object oriented programming

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Classification of types

- Predefined, simple types (not built from other types)
  - boolean, integer, real, ...
  - pointers, pointers to procedures
  - string
- User-defined types
  - enumerations
- Predefined composite types
  - arrays
- User-defined, composite types
  - Records/structs, unions, abstract data types, classes

- Evolution from simple types, via predefined composite types to user-defined types that reflect parts of the application domain.

Properties of primitive types

- Classifying data of the program
- Well-defined operations on values
- Protecting data from un-intended operations
- Hiding underlying representation

Properties of composite types

- Records, structs (Cartesian products)
  - $(m_1,m_2,...m_n)$ in $M_1xM_2x...xM_n$
  - Assignment, comparison
  - Composite values {3, 3.4}
  - Hiding underlying representation?

```
typedef struct {
   int nEdges;
   float edgeSize;
} RegularPolygon;
RegularPolygon rp={3, 3.4}
rp.nEdges = 4;
```

- Arrays (mappings)
  - domain → range
  - Possible domains, index bound checking, bound part of type definition, static/dynamic?

```
char digits[10]

array [5..95] of integer

array[WeekDay] of T,
where
type WeekDays =enum{
  Monday, Tuesday, ...}
```

Composite types

- Union
  - Run-time type check

```
union address {
  short int offset;
  long int absolute; }
```

```
union bad_idea {
  int int_v;
  int* int_ref; }
```

- Discriminated union
  - Run-time type check

```
address_type = (absolute, offset);
safe_address =
record
  case kind:address_type of
    absolute: (abs_addr: Integer);
    offset: (off_addr: short integer)
end;
```

```
typedef struct {
  address location;
  descriptor kind;
} safe_address;

enum descriptor {abs, rel}
```

Type compatibility (equivalence)

- Name compatible
  - Values of types with the same name are compatible
- Structural compatible
  - Types T1 and T2 are structural compatible
    - If T1 is name compatible with T2, or
    - T1 and T2 are defined by applying the same type constructor to structurally compatible corresponding type components

```
struct Position {int x,y,z;};
struct Position pos;
struct Date {int m,d,y;};
struct Date today;

void show(struct Date d);

...; show(today); ...

...; show(pos); ...
```

```
struct Complex {real x,y; };

struct Point {real x,y; };
```

Abstract datatypes

```
abstype  Complex = C of real * real
   with
        fun complex(x,y: real) = C(x,y)
        fun add(C(x1,y1,C(x2,y2)) = C(x1+x2,y1+y2)
   end

...; add(c1,c2); ...
```

Signature

- Constructor
- Operations

Abstract datatypes versus classes

```
abstype  Complex = C of real * real
   with
        fun complex(x,y:real) = C(x,y)
        fun add(C(x1,y1,C(x2,y2)) = C(x1+x2,y1+y2)
   end

...; add(c1,c2); ...
```

```
class Complex {
   real x,y;
   Complex(real v1,v2) {x=v1; y=v2}
   add(Complex c) {x=x+c.x; y=y+c.y}
}
```

```
...; c1.add(c2); ...
```

With abstract data types:
operation (operands)

$\Rightarrow$ meaning of operation is always the same

With classes
object.operation (arguments)

$\Rightarrow$ code depends on object and operation (dynamic lookup, method dispatch)

Possible to do 'add(c1,c2)' with classes?

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From abstract data types to classes

- Encapsulation through abstract data types
  - Advantage
    - Separate interface from implementation
    - Guarantee invariants of data structure
      - only functions of the data type have access to the internal representation of data
  - Disadvantage
    - Not extensible in the way that OO is

Subtyping (in general)

- Subtype as a subset of the set of values
  - e.g. subrange
- Compatibility rules between subtype and supertype
  - Substitutability principle: a value of a subtype can appear wherever a value of the supertype is expected

Abstract data types argument of Mitchell

```
abstype queue
with
        mk_Queue: unit -> queue
        is_empty: queue -> bool
        insert: queue * elem -> queue
        remove: queue -> elem
is  …
in
                program
end
```

```
abstype pqueue
  with
      mk_Queue: unit -> pqueue
      is_empty: pqueue -> bool
      insert: pqueue * elem -> pqueue
      remove: pqueue -> elem
  is …
  in
      program
  end
```

Cannot apply queue code to pqueue, even though signatures are identical

Point and ColorPoint

```
class Point {
  int x,y;
  move(int dx,dy) {
    x=x+dx; y=y+dy}
}
```

```
class ColorPoint extends Point {
  Color c;
  changeColor(Color nc) {c= nc}
}
```

Point
- x
- y
- move

ColorPoint
- x
- y
- c
- move
- changeColor

- ColorPoint interface contains Point
  - ColorPoint is a *subtype* of Point

Could not form list of points and colored points if done by abstract data types

Object Interfaces - Subtyping

- Interface
  - The operations provided by objects of a certain class
- Example: Point
  - x : returns x-coordinate of a point
  - y : returns y-coordinate of a point
  - move : method for changing location
- The interface of an object is its *type*.

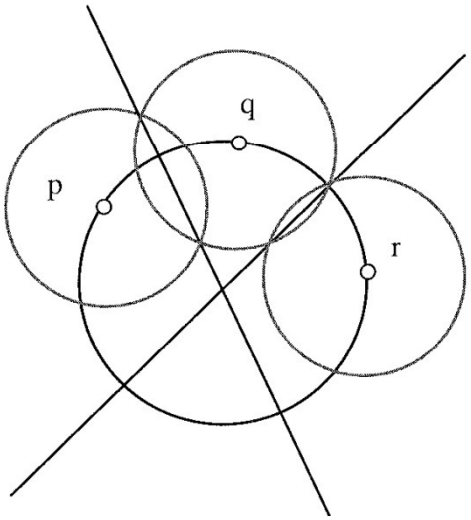
- If interface B contains all of interface A, then B objects can also be used as A objects (substitutability)

- Subclassing <> subtyping

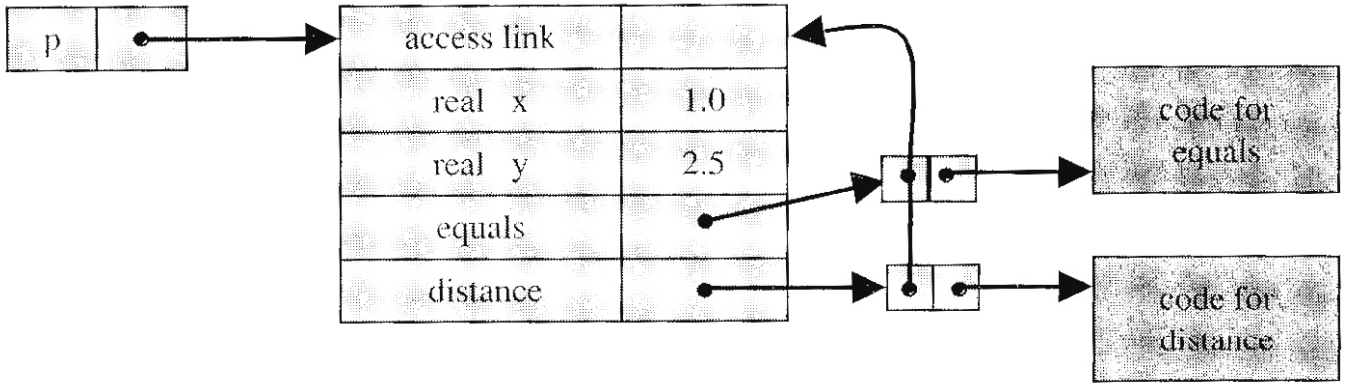
Subclassing

- Two approaches
  - So-called Scandinavian/Modeling Approach
    - Classes represent concepts from the domain
    - Subclasses represent specialized concepts
      - Overriding is specialization/extension
      - Subclass is subtype
    - Reluctant to multiple inheritance (unless it can be understood as multiple specialization)
  - So-called American/Programming Approach
    - Classes represent implementations of types
    - Subclasses inherit code
      - Overriding is overriding
    - Subclassing not necessarily the same as subyping
    - Multiple inheritance as longs as it works

Simula I

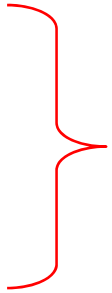



```
class Point(x,y); real x,y;
begin
    boolean procedure equals(p); ref(Point) p;
        if p =/= none then
            equals := abs(x - p.x) + abs(y - p.y) < 0.00001;
    real procedure distance(p); ref(Point) p;
        if p == none then error else
            distance := sqrt(( x - p.x )**2 + (y - p.y) ** 2);
end ***Point***
p :- new Point(1.0, 2.5);
```



Simula II

```
class Line(a,b,c); real a,b,c;
begin
    boolean procedure parallelto(l); ref(Line) l;
        if l =/= none then
            parallelto := abs(a*l.b - b* l.a) < 0.00001;
    ref(Point) procedure meets(l); ref(Line) l;
    begin real t;
        if l =/= none and ~parallelto(l) then
            begin
            t := 1/(l.a * b - l.b * a);
            meets :- new Point(. . . , . . . );
            end;
    end; ***meets***
    real d;
    d := sqrt(a**2 + b**2);
    if d = 0.0 then error else
        begin
        d := 1/d;
        a := a * d; b := b * d; c := c * d;
        end;
end *** Line***
```



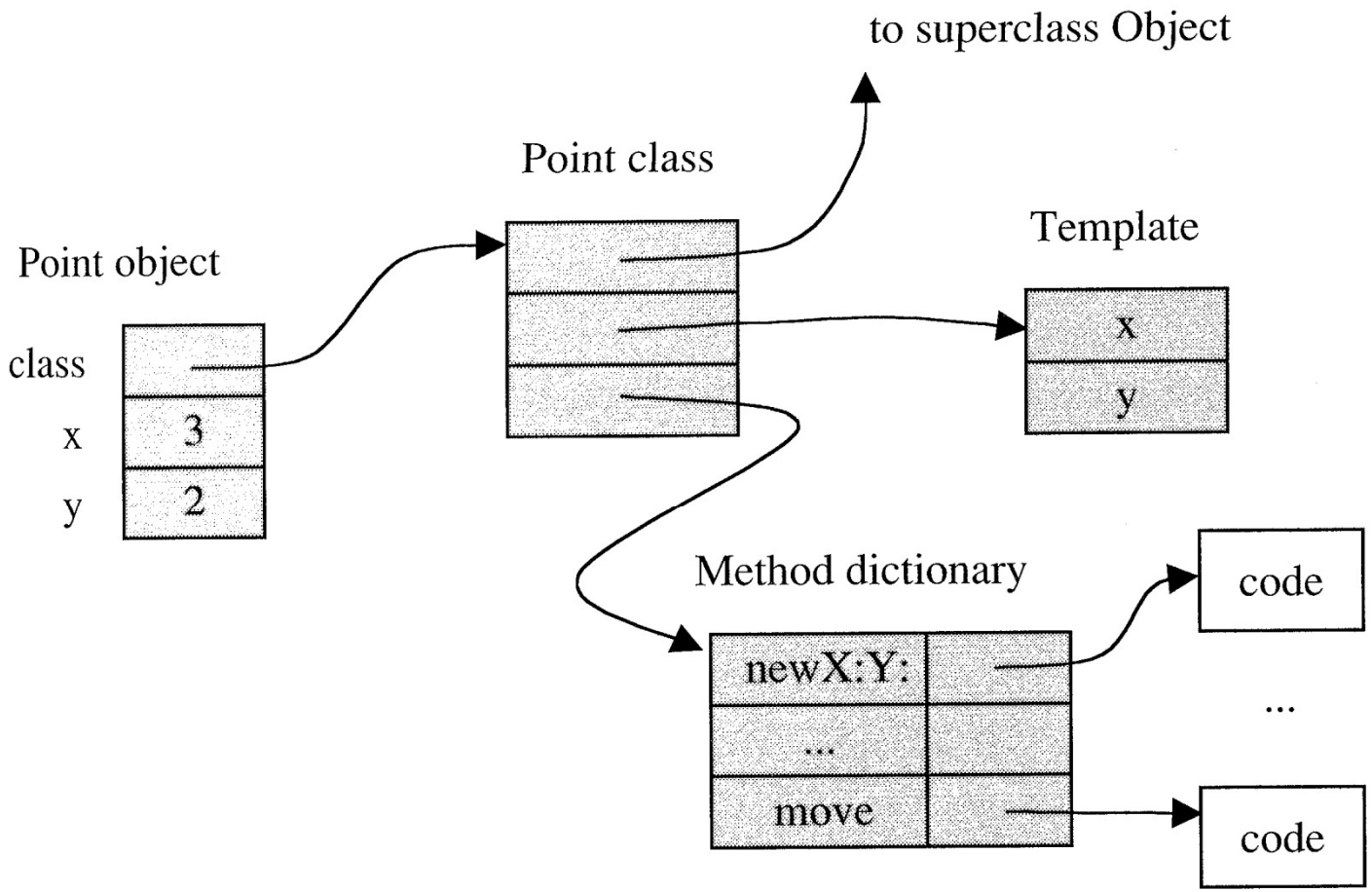
Subclassing in Simula

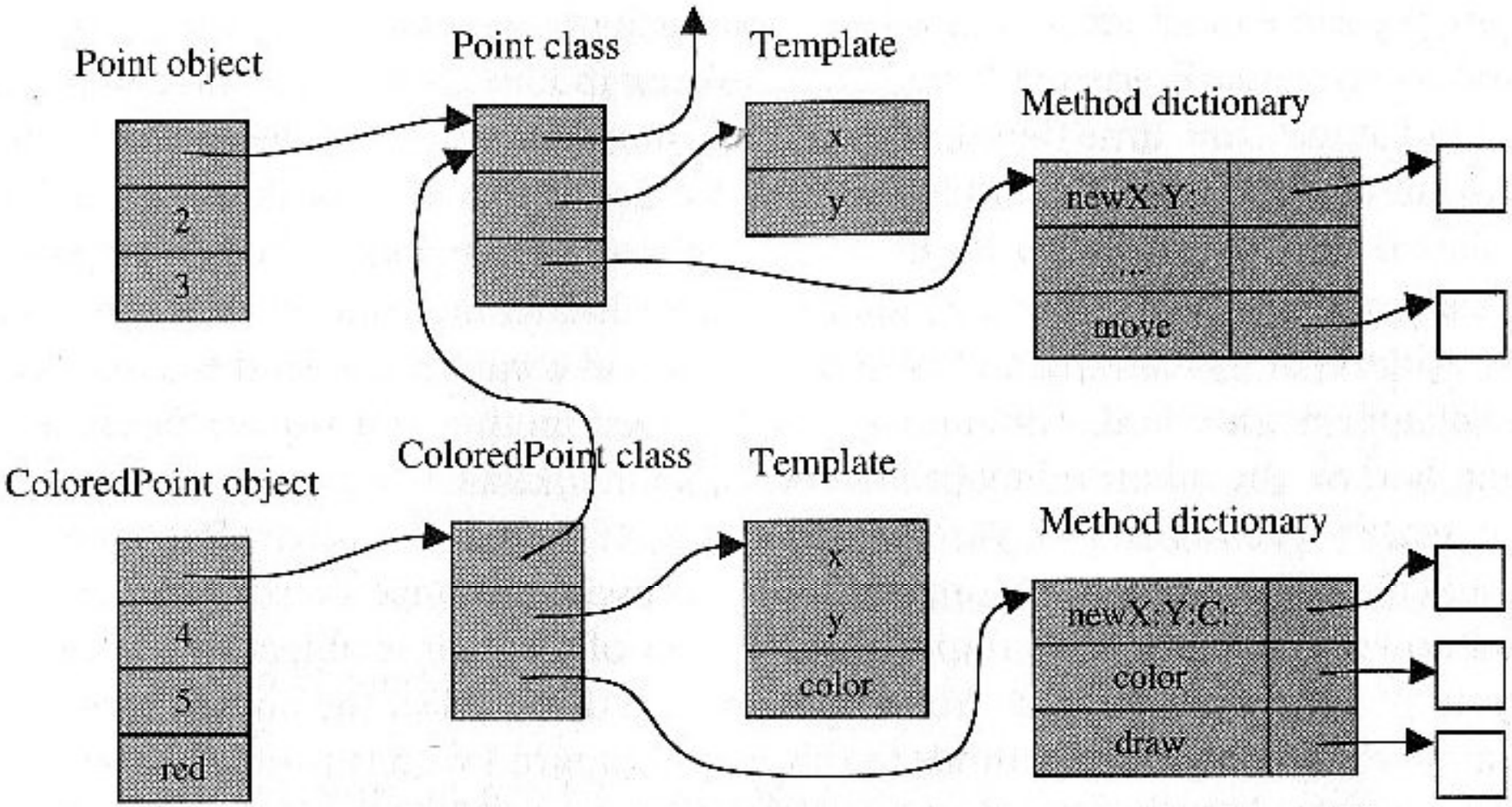
```
Point class ColorPt(c); color c;          ! List new parameter only
begin
    boolean procedure equals(q); ref(ColorPt) q;
        ...;
end ***ColorPt***
ref(Point) p;                             ! Class reference variables
ref(ColorPt) cp;
p :- new Point(2.7, 4.2);
cp :- new ColorPt(3.6, 4.9, red);         ! Include parent class parameters
```

```
class A;
A class B;    /* B is a subclass of A */
ref (A) a;
ref (B) b;
a :- b;       /* legal since B is a subclass of A */
...
b :- a;       /* also legal but checked at run-time to make sure a points to a B
                 object*/
```

```
class A;
A class B; /* B is a subclass of A */
ref (A) a;
ref (B) b;
proc assignA (ref (A) x)
      begin
      x := a
      end;
assignA(b);
```

Smalltalk I

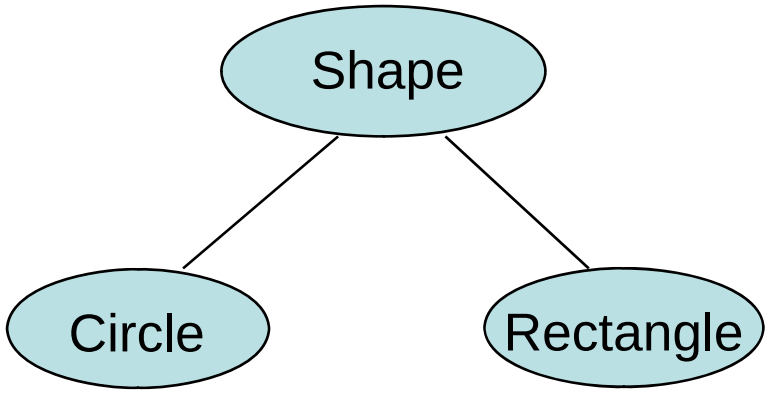

to superclass Object
Point class
Point object
Template
class
x
y
3
2
x
y
Method dictionary
newX:Y:
...
move
code
...
code


Point object
2
3
Point class
Template
x
y
Method dictionary
newX:Y:
...
move
ColoredPoint object
4
5
red
ColoredPoint class
Template
x
y
color
Method dictionary
newX:Y:C:
color
draw

Example: Shapes

Interface of every shape must include center, move, rotate, print

- Programming Approach
  - General interface only in Shape
  - Different kinds of shapes are implemented differently
  - Square: four points, representing corners
  - Circle: center point and radius



- Modeling Approach
  - General interface *and* general implementation in shape
    - Shape has center point
    - Move moves by changing the position of the center point
  - 'To be or not be' virtual
    - e.g. Move should not be redefined in subclasses

In Simula, C++, a method specified as **virtual** may be overridden.

In Java, a method specified as **final** may *not* be overridden.

Subclass compatibility

- *Name compatible*: method with the same name in subclass overrides method in superclass (Smalltalk)
- *Structure compatible*: number and types of method parameters must be compatible (C++, Java)
- *Behavior compatible*: the effect of the subclass method must a specialization of the effect of the superclass method

Types versus classes

- Type as the set of operations on an object
  - Objects of two different classes may have the same type
    - Structural type compatibility
- Type = class (or interface)
  - Type name (e.g. class or interface name)

Example – Structural (sub) typing

- Smalltalk in C-syntax

```
class GraphicalObject  {
   move(dx,dy int) {…}
   draw() {…}
};
...


...; r.draw(); ...; r.draw();
```

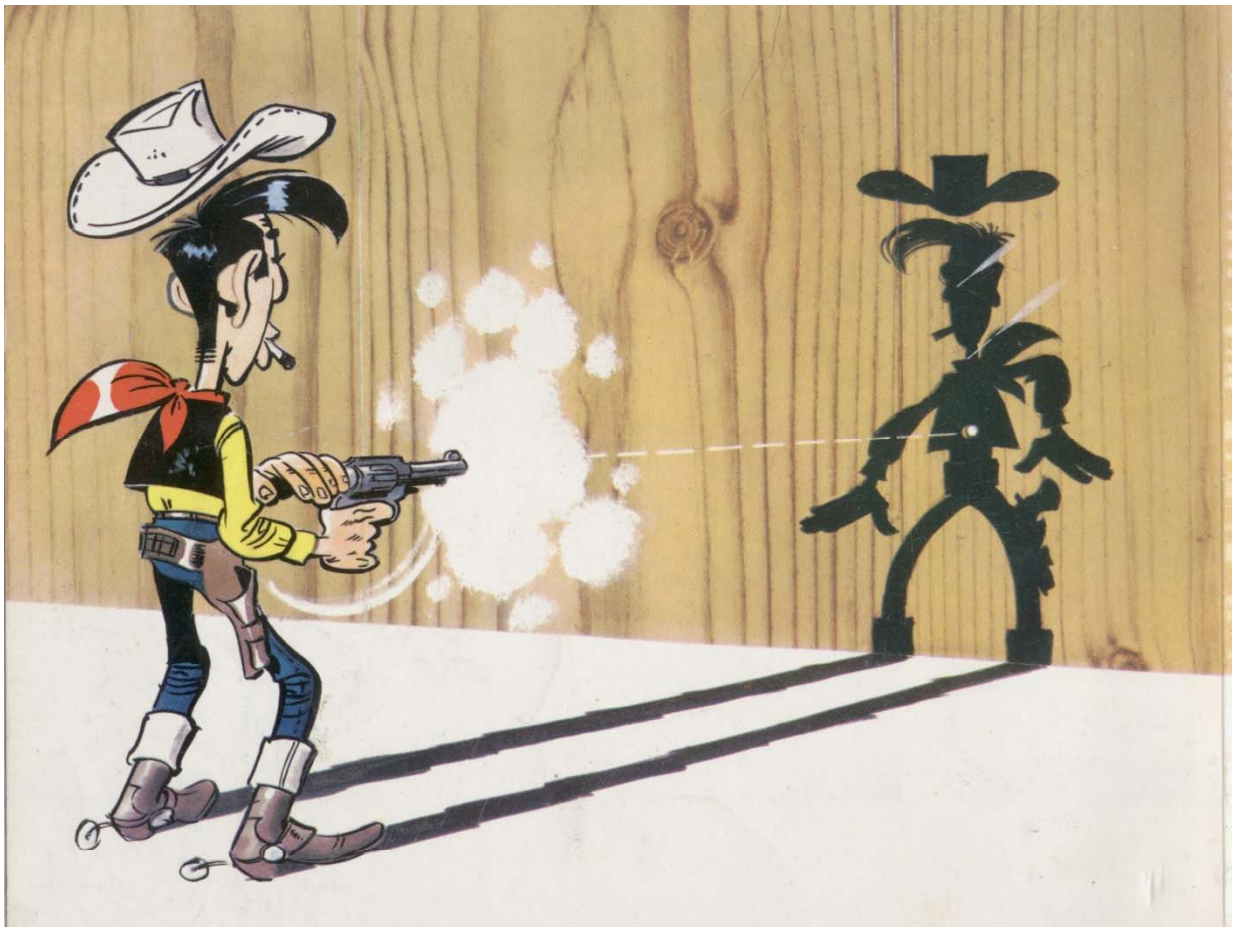
Example

- Two classes with the same structural type

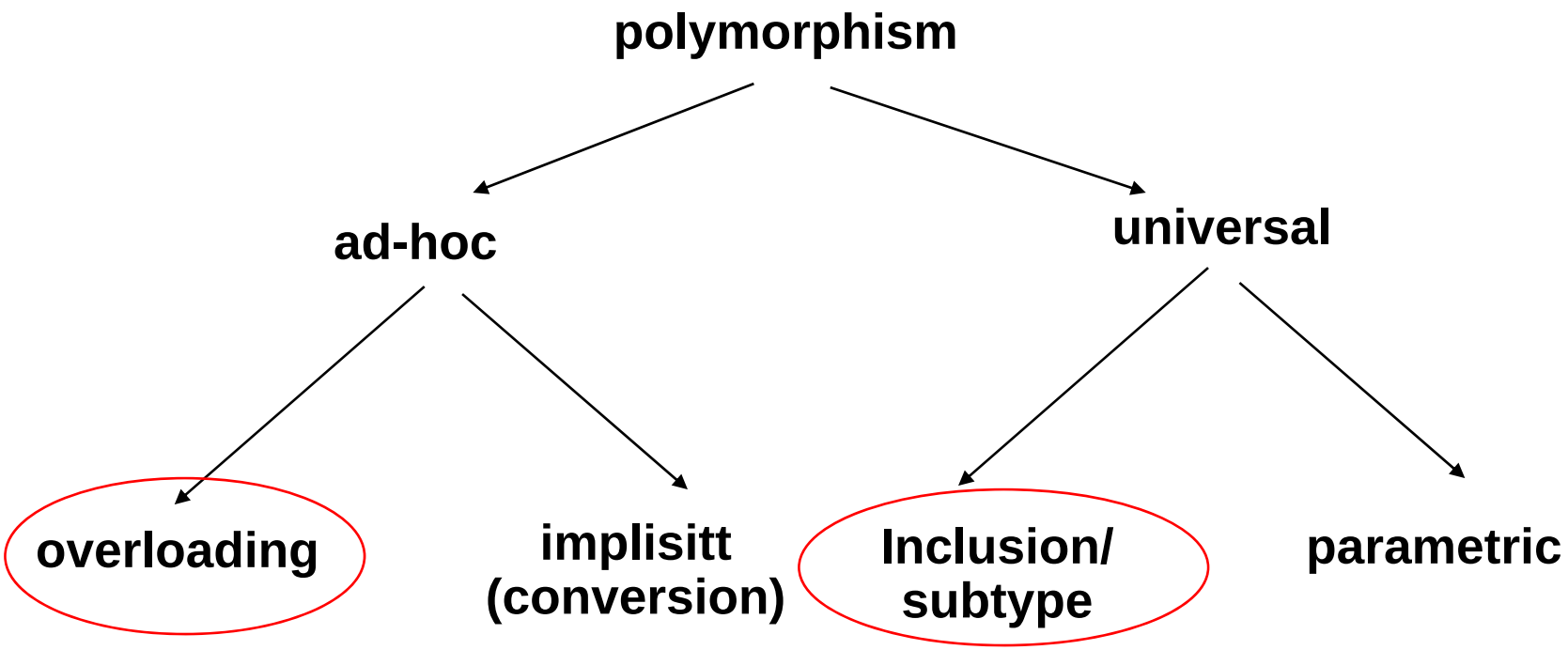
```
class GraphicalObject  {
   move(dx,dy int) {…}
   draw() {…}
};

class Cowboy  {
   move(dx,dy int) {…}
   draw() {…}
};
...


...; r.draw(); ... ; r.draw();
```



Classification of polymorphism



Inclusion/subtype polymorphism

```
Point  p1;
ColorPoint cp1;

…; p1.equals(cp1); …        'equals' works for cp1 because
                            ColorPoint is a subtype of type Point


class Shape {
  void draw() {…}
  …
};
class Circle extends Shape  {
  void draw() {…}
  …
};
...; aShape.draw(); …       will draw a Circle if aShape is a Circle
```

Overriding vs Overloading – I

```
class Shape {
   ...
   bool contains(point pt) {...}
   ...
};


class Rectangle extends Shape {
   ...
   bool contains(int y,y) {...}
   ...
}
```

- Overloading
  - within the same scope {...},
  - crossing superclass boundaries

Overriding vs Overloading - II

```
class C {
   ...
   bool equals(C pC) {
     ...                          // C_equals 1
   }
}

class SC extends C {
   ...
   bool equals(C pC) {
      ...                         // SC_equals 1
   }

   bool equals(SC pSC) {
     ...                          // equals 2
   }
}
```

```
C c       = new C();
SC sc     = new SC();
C c'      = new SC();

c.equals(c)       //1
c.equals(c')      //2
c.equals(sc)      //3

c'.equals(c)      //4
c'.equals(c')     //5
c'.equals(sc)     //6

sc.equals(c)      //7
sc.equals(c')     //8
sc.equals(sc)     //9
```

Covariance/contravariance/novariance

```
class C {
   T1 v;
   T2 m(T3 p) {
     ...
   }
}

class SC extends C {
   T1' v;
   T2' m(T3' p){
      ...
   }
}
```

- Covariance:
  - T1' subtype of T1
  - T2' subtype of T2
  - T3' subtype of T3
- Contravariance:
  - The opposite
- Novariance: same types

- Most languages have no-variance
- Some languages provide covariance on both: most intuitive
- Statically type-safe:
  - Contravariance on parameter types
  - Covariant on result type

Example: Point and ColorPoint – I: no variance

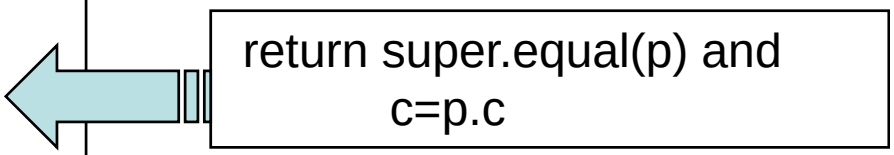
```
class Point {
  int x,y;
  move(int dx,dy) {
    x=x+dx; y=y+dy}

  bool equal(Point p) {
    return x=p.x and y=p.y
  }
}

class ColorPoint
  extends Point {
  Color c;
  bool equal(Point p) {
    return x=p.x and
              y=p.y and
              c=p.c
  }
}
```

```
Point  p1, p2;
ColorPoint c1,c2;
```

1. p2.equal(p1)
2. c2.equal(c1)
3. p1.equal(c1)
4. c1.equal(p1)



Example: Point and ColorPoint – II: covariance

```
class Point {
  int x,y;
  move(int dx,dy) {
    x=x+dx; y=y+dy}

  bool equal(Point p) {
    return x=p.x and y=p.y
  }
}

class ColorPoint
  extends Point {
  Color c;
  bool equal(ColorPoint cp) {
    return super.equal(cp) and
              c=cp.c
  }
}
```

Point p1, p2;

ColorPoint c1,c2;

1.	p2.equal(p1)	OK	run-time
2.	c2.equal(c1)	OK	run-time
3.	p1.equal(c1)	OK	run-time
4.	c1.equal(p1)	NOK	run-time

Example: Point and ColorPoint – III: casting

```
class Point {
  int x,y;
  move(int dx,dy) {
    x=x+dx; y=y+dy}

  bool equal(Point p) {
    return x=p.x and y=p.y
  }
}

class ColorPoint
  extends Point {
  Color c;
  bool equal(Point p) {
    return super.equal(p) and
              c=(ColorPoint)p.c
  }
}
```

Point p1, p2;

ColorPoint c1,c2;

1. p2.equal(p1)
2. c2.equal(c1)
3. p1.equal(c1)
4. c1.equal(p1)

Example: Point and ColorPoint –

```
class Point {
  int x,y;
  virtual class ThisClass < Point;

  bool equal(ThisClass p) {
    return x=p.x and y=p.y
  }
}

class ColorPoint
  extends Point {
  Color c;
  ThisClass:: ColorPoint;
  bool equal(ThisClass p) {
    return super.equal(p) and
              c=p.c
  }
}
```

- Alternative to casting:
  - Virtual classes with constraints (OOPSLA ’89)
  - Still run time type checking

Compile-time vs run-time type checking

- f(x)
  - if f : A $\rightarrow$ B then x : A, but when to check?

- Compile-time (static)
  - Must ensure that x will never have another type then A
- Run-time (dynamic) type checking
  - When calling f(x) – determine the type of x and check if it is A

- Basic tradeoff
  - Both prevent type errors
  - Run-time checking slows down execution
  - Compile-time checking restricts program flexibility

- Combined compile - and run-time checking

Two questions

1. How is the type of an entity (variable, function, …) specified?
2. When is the type determined?

2 \ 1	Explicit declaration	Implicit declaration
Static (compile-time)	Java, C++, Algol, Simula ML, BETA	ML, Perl
Dynamic (run-time)	Simula, BETA, Java (casting) Python, Ruby, Prolog	Smalltalk Python, Ruby