INF3110 – Programming Languages
Object orientation and types, part I

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Slides adapted from previous years' slides made by Birger Møller-Pedersen

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Follow-up from last time

- What is the difference between a Context-Free Grammar (CFG) and BNF?
  - A CFG is (informally) a grammar where all the rules are one-to-one, one-to-many or one-to-none.
  - The left hand side of a rule in a CFG contains one (and only one) non-terminal symbol, and no terminal symbols (thus, no *context* → *context-free)*
  - This is the way rules are expressed in BNF too!
- Thus, BNF is a *notation* for CFGs.
  - Other notations are possible
  - Notably «Van Wijngaarden form»

Object orientation and types

Lecture I (today)

- 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

Lecture II

- Advanced oo concepts
  - Specialization of behaviour?
  - Multiple inheritance - alternatives
  - Inner classes
- Modularity
  - Packages
  - Interface-implementation
- Generics

Why should we care?

Remember from last time: *syntax* (program text) and *semantics* (meaning) are two separate things.

Types and type systems help to ascribe meaning to programs:

- What does `"Hello" + " World"` mean?
- Which operation is called when you write `System.out.println("INF3110")`?
- What does the concept of a `Student` entail?

What is a type?

- A set of values that have a set of operations in common
  - 32 bit integers, and the arithmetic operations on them
  - Instances of a Person class, and the methods that operate on them

- How is a type *identified*?
  - By its *name* (e.g. Int32, Person, Stack)*:* nominal type checking
  - By its *structure* (fields, operations): structural type checking

- Does this cover everything a type might be? No.
  - Alternative definition of “type”: *A piece of the program to which the type system is able to assign a label.*
  - *(but don’t worry too much about this now)*

Classification of types

- Predefined, simple types (not built from other types)
  - boolean, integer, real, ...
  - pointers, pointers to procedures
  - string
- User-defined simple types
  - enumerations, e.g. `enum WeekDay { Mon, Tue, Wed, … }`
- Predefined composite types
  - Arrays, lists/collections (in some languages)
- 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
  - E.g. this is a string, this is an integer, etc
- Well-defined operations on values
  - Arithmetic operations
  - String concatenation
  - Etc
- Protecting data from un-intended operations
  - Cannot subtract an integer from a string (in most languages!)
- Hiding underlying representation
  - Does not allow manipulation of individual bits
  - Are ints big or small endian?
  - Are strings represented as a character array in memory?

Properties of composite types

- Records, structs
  - $(m_1,m_2,...m_n)$ in $M_1 x M_2 x ... x M_n$
  - 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 WeekDay =
  enum{Monday, Tuesday, ...}
```

Composite types

- Union
  - Run-time type check
- Discriminated union
  - Run-time type check
    - Or compile time!
  - Additional discriminator aids checking

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

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

enum descriptor {abs, rel}
```

```
typedef union {
    struct {
        unsigned char byte1;
        unsigned char byte2;
        unsigned char byte3;
        unsigned char byte4;
    } bytes;
    unsigned int dword;
} HW_Register;

HW_Register reg;
reg.dword = 0x12345678;
reg.bytes.byte3 = 4;
```

```
address_type = (absolute, offset);

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

TypeScript 2.0 - 2016

```
interface Square {
    kind: "square";
    size: number;
}
interface Circle {
    kind: "circle";
    radius: number;
}
```

```
interface Rectangle {
    kind: "rectangle";
    width: number;
    height: number;
}
```

```
type Shape = Square | Rectangle |
Circle;
```

```
function area(s: Shape) {
    switch (s.kind) {
        case "square": return s.size * s
        case "rectangle": return s.width
        case "circle": return Math.PI * s.radius * s.radius;
    }
}
```

Type of s is narrowed base on «kind» in union type

Type compatibility (equivalence)

- Nominally compatible
  - Values of types with the same name are compatible
- Structurally compatible
  - Types T1 and T2 are compatible
    - If T1 is nominally compatible with T2, or
    - T1 and T2 have the same signature (functions, variables, including names of such)

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

void show(Date d);

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

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

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

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

Subtyping

- Types can be related through *subtyping*
  - Relationships can, again, be defined nominally or structurally
- A variable of a supertype can at runtime hold a value of a subtype
  - *Without introducing type errors*
  - Enables polymorphism, dynamic dispatch
  - However, *behavioral subtyping* (Liskov) cannot, in general, be enforced by a compiler/type system
- How to best facilitate creation of such hierarchies are subject to much research and debate
  - Single/multiple inheritance
  - Traits/mixins
  - Structural/nominal subtyping
  - etc

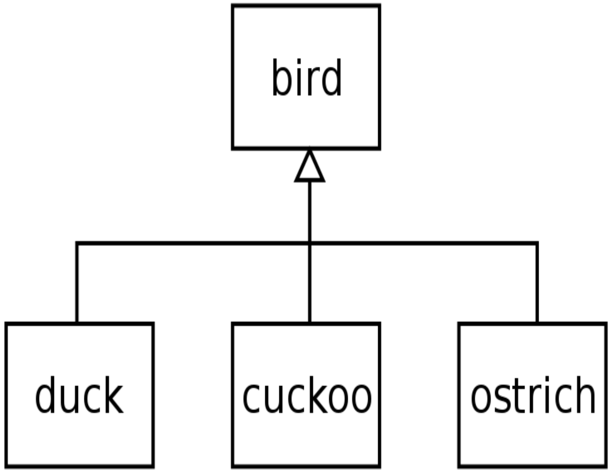
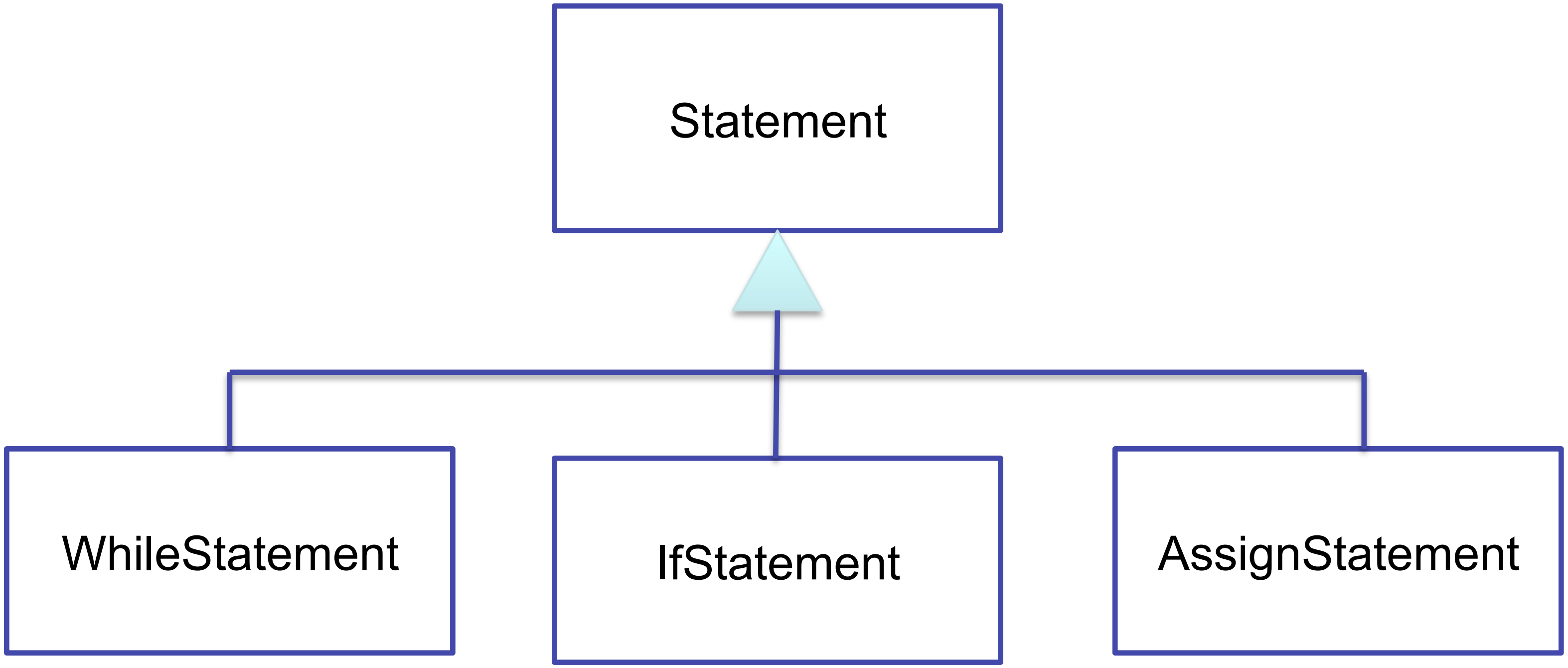


Image from Wikipedia

Language grammars can naturally be expressed through the help of subtyping

Statement ::= WhileStatement | IfStatement | AssignStatement




```
abstract class Statement { … }
class WhileStatement extends Statement { … }
class IfStatement extends Statement { … }
class AssignStatment extends Statement { … }
```

So, what is the proper object oriented way to get rich?

Inherit!

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); ...
```

An abstract datatype is a user defined datatype that:

- Defines representation and operations in one syntactical unit
- Hides the underlying representation from the programmer

Signature of ADT:

- 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); ...
```

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

With abstract data types:
operation (operands)

- meaning of operation is always the same

With classes:
object.operation (arguments)

- meaning depends on object and operation (dynamic lookup, method dispatch)

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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 classes are

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 // priority queue
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

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)
  - In practice this depends on language implementation and type system

- Subclassing <> subtyping

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 interface
  - ColorPoint is a *subtype* of Point

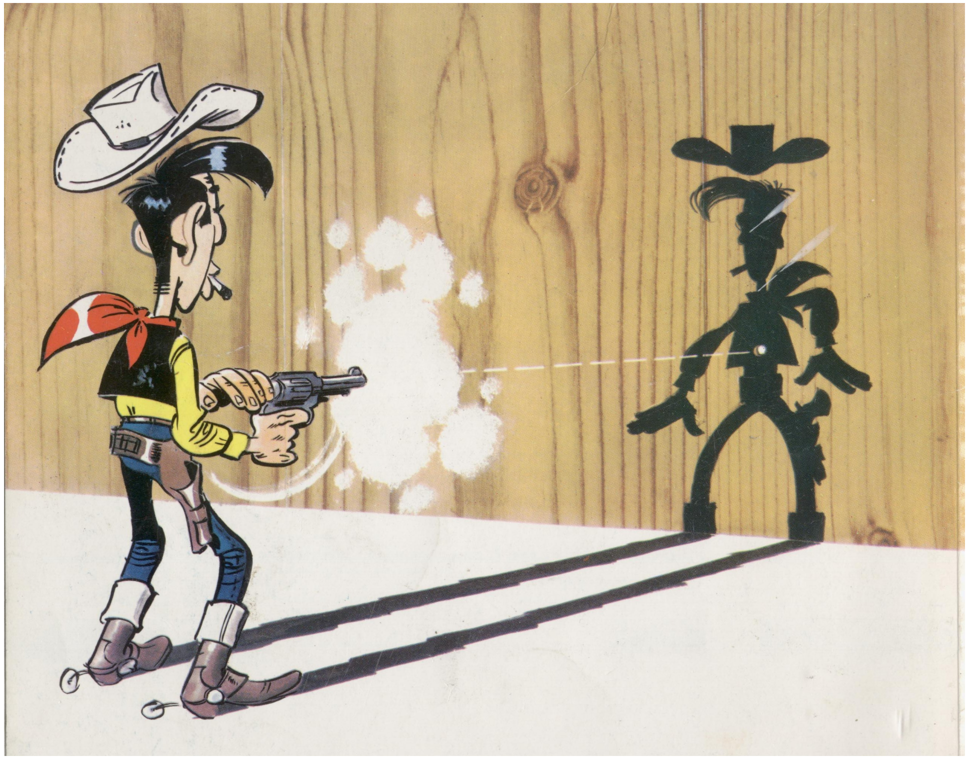
Could not form list of points and colored points if done by abstract data types

Example - Structural (sub) typing

- Two classes with the same structural type

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

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



```
class Luke { ... ? } ...; luke.draw();...; luke.draw();
```

Subclassing

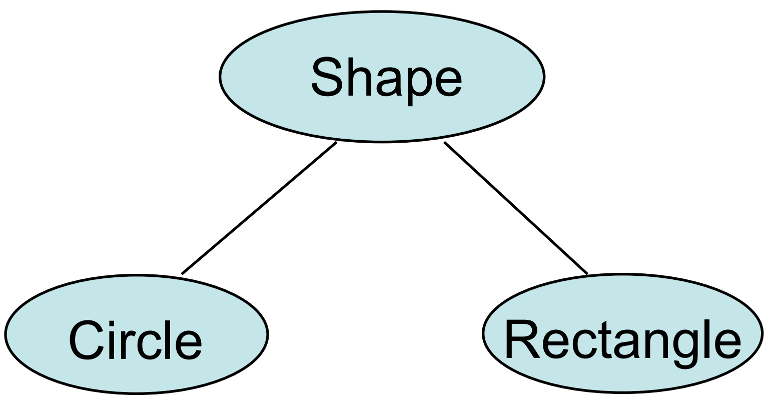
- Two approaches
  - So-called ’Scandinavian’/Modeling Approach
    - Classes represent concepts from the domain
    - Subclasses represent specialized concepts
      - Overriding is specialization/extension
      - Subclass is subtype
    - Reluctant to multiple inheritance (unless it can be understood 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

Kristen Nygård and Ole-Johan Dahl

Example: Shapes

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

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



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

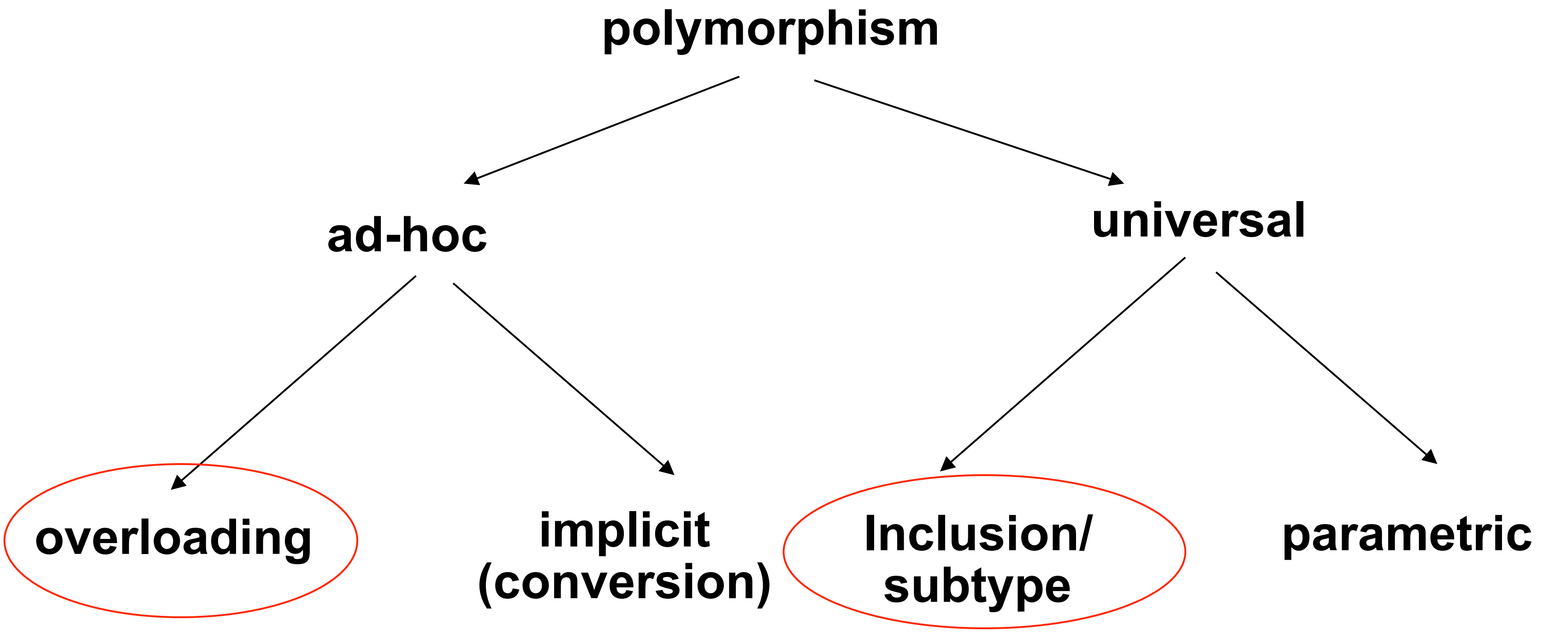
In Simula, C++, C#, a method specified as **virtual** may be overridden.

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

Classification of polymorphism

"Polymorphism: providing a single interface to entities of different types"

- "Bjarne Stroustrup's C++ Glossary".



Inclusion/subtype polymorphism

```
Point  p;
ColorPoint cp;

...; p.equals(cp); ...
```

'equals' works for cp because ColorPoint is a subtype of type Point

```
class Shape {
  void draw() {...}
  ...
};
class Circle extends Shape {
  void draw() {...}
  ...
};
...; aShape.draw(); ...
```

Override

Will draw a Circle if aShape is a Circle

Overloading – two methods with the same name

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


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

- only within the same scope {...}, or
- across superclass boundaries

Overloading vs Overriding (Java and similar languages)

```
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_1
c.equals(c')   //2   C_equals_1
c.equals(sc)   //3   C_equals_1

c'.equals(c)   //4   SC_equals_1
c'.equals(c') //5   SC_equals_1
c'.equals(sc) //6   SC_equals_1

sc.equals(c)   //7   SC_equals_1
sc.equals(c') //8   SC_equals_1
sc.equals(sc) //9   equals_2
```

Covariance/contravariance/novariance

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

   }
}

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

- Covariance:
  - `T1'` must be a subtype of `T1`
  - `T2'` must be a subtype of `T2`
  - `T3'` must be a subtype of `T3`
- Contravariance:
  - The opposite
- Nonvariance: must be the 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

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Example: Point and ColorPoint – I: no variance

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

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

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

Problem??

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

p1.equals(p2)
c1.equals(c2)
p1.equals(c1)
c1.equals(p1)
```

```
return
super.equals(p) and
c=p.c
```

Example: Point and ColorPoint – II: covariance

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

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

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

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

Which of these <u>may</u> be OK, and when to check?

`p1.equals(p2)`	OK	run-time
`c1.equals(c2)`	OK	compile-time
`p1.equals(c1)`	OK	compile-time
`c1.equals(p1)`	OK	run-time

Example: Point and ColorPoint – III: casting

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

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

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

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

```
p1.equals(p2)
c1.equals(c2)
p1.equals(c1)
c1.equals(p1)
```

Example: Point and ColorPoint –

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

  bool equals(Type p) {
    return x=p.x and y=p.y
  }
}

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

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

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Example: Contravariant parameter type

```
class A {

  void m(A a) {
    …
  }
}

class B extends A {

  void m(Object a) {
    …
  }
}
```

- Statically type safe
- Not allowed in Java

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Example: Covariant return type

```
class A {

  A m() {
   return new A();
  }
}

class B extends A {

  B m() {
    return new B();
  }
}
```

- Statically type safe
- Allowed in Java

Practical info

- Mandatory 1 out today
  - Deadline September 30th.
- Next lecture: ML with Volker Stolz
- Have a nice weekend!