

IA010: Principles of Programming Languages

Objects

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Object-Oriented Programming

Original Definition

divide the program state into small parts that communicate via messages

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divide the program state into small parts that communicate via messages

Modern Definition

no consensus, but usually includes features like

- dynamic dispatch
- subtyping
- encapsulated state
- inheritance
- open recursion

Dynamic dispatch

Methods

```
next   : unit -> object  
get    : unit -> int  
iter   : (int -> unit) -> unit  
length : unit -> int
```

Dynamic dispatch

Methods

```
next   : unit -> object  
get    : unit -> int  
iter   : (int -> unit) -> unit  
length : unit -> int
```

Record

```
[ next   : unit -> object,  
  get    : unit -> int,  
  iter   : (int -> unit) -> unit,  
  length : unit -> int ];
```

```
let new_empty() {
  let n =
    [ next    = fun () { n },
      get     = fun () { error },
      iter    = fun (f) { () },
      length  = fun()   { 0 } ];
  n
};
let new_node(val, next) {
  [ next    = fun () { next },
    get     = fun () { val },
    iter    = fun (f) { f(val); next.iter(f) },
    length  = fun () { 1 + next.length() } ]
};

let n1 = new_empty();
let n2 = new_node(1,n1);
let n3 = new_node(2,n2);
n3.iter(fun (x) { print "value is " x });
```

Syntactic sugar

object { $m_1 : t_1$; ... ; $m_k : t_k$; }
 \implies [$m_1 : t_1$, ... , $m_k : t_k$]

object {
 m_1 (a_1) { b_1 } ;
 ...
 m_k (a_k) { b_k } ;
}
 \implies
[$m_1 = \mathbf{fun}$ (a_1) { b_1 } ,
 ...
 $m_k = \mathbf{fun}$ (a_k) { b_k }]

```

type olist =
  object {
    next    : unit -> olist;
    get     : unit -> int;
    iter    : (int -> unit) -> unit;
    length  : unit -> int
  };

let new_empty() {
  let n =
    object {
      next()  { n };
      get()   { error };
      iter(f) { () };
      length() { 0 };
    };
  n
};

let new_node(val, next) {
  object {
    next()  { next };
    get()   { val };
    iter(f) { f(val); next.iter(f) };
    length() { 1 + next.length() };
  }
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let n1 = new_empty();
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```


Multi-methods

How to implement

`intersect : shape * shape -> shape ?`

Multi-methods

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```
intersect : shape * shape -> shape ?
```

First try

```
object {  
  ...  
  intersect(other: shape) : shape { ... } // ???  
  ...  
}
```

Multi-methods

How to implement

```
intersect : shape * shape -> shape ?
```

First try

```
object {  
  ...  
  intersect(other: shape) : shape { ... } // ???  
  ...  
}
```

Multi-methods

```
let intersect(x : circle, y : circle) : shape { ... }  
let intersect(x : circle, y : rectangle) : shape { ... }  
let intersect(x : rectangle, y : circle) : shape { ... }  
let intersect(x : rectangle, y : rectangle) : shape { ... }
```


Comparison with variant types

```
type shape =  
  | Point(int,int)  
  | Circle(int,int,int)  
  | Rectangle(int,int,int,int)  
  | Group(list(shape));  
  
let draw(sh) {  
  case sh  
  | Point(x,y)           => draw_point(x,y)  
  | Circle(x,y,r)       => draw_circle(x,y,r)  
  | Rectangle(x,y,w,h) => draw_rectangle(x,y,w,h)  
  | Group(shapes)       => iter(draw, shapes)  
};  
let move(sh, dx, dy) {  
  case sh  
  | Point(x,y)           => Point(x + dx, y + dy)  
  | Circle(x,y,r)       => Circle(x + dx, y + dy, r)  
  | Rectangle(x,y,w,h) => Rectangle(x + dx, y + dy, w, h)  
  | Group(shapes)       => Group(map(fun (s) { move(s, dx, dy) },  
                                   shapes))  
};
```

Subtyping

s is a **subtype** of t ($s \leq t$) if values of type s can be used everywhere a value of type t is expected.

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Basic types

`int16` \leq `int32` \leq `int64` or `uint16` \leq `int32`

`uint32` \leq `int32` or `int32` \leq `float32` ?

Subtyping

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- **structural** (OCaml) or **by name** (Java, C++)

Basic types

`int16 ≤ int32 ≤ int64` or `uint16 ≤ int32`

`uint32 ≤ int32` or `int32 ≤ float32 ?`

Records

`type shape = [x : int, y : int];`

`type circle = [x : int, y : int, r : int];`

`type rectangle = [x : int, y : int, w : int, h : int];`

`circle <: shape` and `rectangle <: shape`

Functions

$f : a \rightarrow b$ and $g : (c \rightarrow d) \rightarrow e$

$g(f)$ defined?

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- **contravariant** in a and **covariant** in b

Functions

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$g(f)$ defined?

$$a \rightarrow b \leq c \rightarrow d \iff a \geq c \text{ and } b \leq d$$

- **contravariant** in a and **covariant** in b

Example

```
type shape      = [ x : int, y : int ];  
type circle    = [ x : int, y : int, r : int ];  
type rectangle = [ x : int, y : int, w : int, h : int ];
```

```
shape -> circle <: rectangle -> circle <: rectangle -> shape
```

Invariance

```
type box(a) = [ data : a ];
```

```
let get(box : box(a)) : a {  
  box.data  
};
```

```
let set(box : box(a), x : a) : unit {  
  box.data := x  
};
```

When is `box(a) <: box(b)`?

Invariance

```
type box(a) = [ data : a ];  
  
let get(box : box(a)) : a {  
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  box.data := x  
};
```

When is `box(a) <: box(b)`?

Suppose that `box(a) <: box(b)`.

```
x : a  
u : box(a)  
set(u,x); // set : box(a) -> a -> unit  
let y = get(u); // get : box(b) -> b  
y : b
```

Invariance

```
type box(a) = [ data : a ];
```

```
let get(box : box(a)) : a {  
  box.data  
};
```

```
let set(box : box(a), x : a) : unit {  
  box.data := x  
};
```

When is `box(a) <: box(b)`?

Suppose that `box(a) <: box(b)`.

```
y : b  
u : box(a)  
set(u,y); // set : box(b) -> b -> unit  
let x = get(u); // get : box(a) -> a  
x : a
```


Encapsulated state

```
type account = object {  
  deposit : int -> unit;  
  withdraw : int -> unit;  
};  
  
let new_account(balance) {  
  object {  
    deposit(amount) { balance := balance + amount };  
    withdraw(amount) { balance := balance - amount };  
  }  
};
```

```
type shape = object {
  draw      : unit -> unit;
  move      : int -> int -> unit;
  dimensions : unit -> [ min_x : int, min_y : int,
                       max_x : int, max_y : int ];
};

let new_point(x : int, y : int) : shape {
  object {
    draw()      { draw_point(x,y)      };
    move(dx, dy) { x := x + dx; y := y + dy; };
    dimensions() { [ min_x = x, min_y = y, max_x = x, max_y = y ] };
  }
};

let new_circle(x : int, y : int, r : int) : shape {
  object {
    draw()      { draw_circle(x,y,r)      };
    move(dx, dy) { x := x + dx; y := y + dy; };
    dimensions() { [ min_x = x - r, min_y = y - r,
                     max_x = x + r, max_y = y + r ] };
  }
};
```

Inheritance

- mechanism for code reuse
- less typing
- increases maintainability (no duplicated changes)
- reduces code locality

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- mechanism for code reuse
- less typing
- increases maintainability (no duplicated changes)
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Variants

- delegates
- adding methods
- replacing methods
- modifying methods

Delegates

```
type coloured_shape = object {  
  draw      : unit -> unit;  
  move      : int -> int -> shape;  
  dimensions : unit -> [ min_x : int, min_y : int,  
                        max_x : int, max_y : int ];  
  colour    : colour;  
  set_colour : colour -> unit;  
};  
  
let new_coloured_point(x : int, y : int, c : colour) : coloured_shape =  
  let p = new_point(x,y);  
  object {  
    draw()      { set_colour(col); p.draw() };  
    move()      { p.move() };  
    dimensions() { p.dimensions() };  
    colour()    { c };  
    set_colour(col) { c := col };  
  };
```

Adding methods

```
let new_coloured_point(x : int, y : int, c : colour) : coloured_shape =  
  let p = new_point(x,y);  
  [ draw      = p.draw,  
    move      = p.move,  
    dimensions = p.dimensions,  
    colour    = fun () { c },  
    set_colour = fun (col) { c := col } ];
```

```
let new_coloured_point(x : int, y : int, c : colour) : coloured_shape =  
  let p = new_point(x,y);  
  object {  
    include p;  
    colour()      { c },  
    set_colour(col) { c := col };  
  }
```

Replacing methods

```
let new_coloured_point(x : int, y : int, c : colour) : coloured_shape =  
  let p = new_point(x,y);  
  [ draw      = fun () { set_colour(c); draw_point(x,y); },  
    move      = p.move,  
    dimensions = p.dimensions,  
    colour    = fun () { c },  
    set_colour = fun (col) { c := col } ];
```

Replacing methods

```
let new_coloured_point(x : int, y : int, c : colour) : coloured_shape =  
  let p = new_point(x,y);  
  [ draw      = fun () { set_colour(c); draw_point(x,y); },  
    move      = p.move,  
    dimensions = p.dimensions,  
    colour    = fun () { c },  
    set_colour = fun (col) { c := col } ];
```

- If another method calls `draw`, which version does it use?

Open recursion

```
type widget = object {
  draw    : unit -> unit;
  resize  : int -> int -> unit;
  ...
};
let new_widget(width,height) {
  object {
    draw() { () }
    resize(w,h) { width := w; height := h; draw(); }
  }
};

type text_field = object { ... };
let new_text_field() {
  object {
    draw() { ... };
    ...
  };
};
```

Open recursion

```
type widget = object {
  draw    : unit -> unit;
  resize  : int -> int -> unit;
  ...
};
let new_widget(width,height) {
  object {
    draw(obj) { () }
    resize(obj,w,h) { width := w; height := h; obj.draw(obj); }
  }
};

type text_field = object { ... };
let new_text_field() {
  object {
    draw(obj) { ... };
    ...
  };
};
```

Modifying methods

```
let new_coloured_point(x : int, y : int, c : colour) : coloured_shape =  
  let super = new_point(x,y);  
  [ draw      = fun () { set_colour(c); super.draw(); },  
    move      = super.move,  
    dimensions = super.dimensions,  
    colour    = fun () { c },  
    set_colour = fun (col) { c := col } ];
```

Type classes

Adding methods

```
typeclass Eq(a) {  
  equal      : a -> a -> bool;  
  not_equal  : a -> a -> bool;  
};
```

```
typeclass Eq(a) => Ord(a) {  
  type cmp = | LT | EQ | GT;  
  compare : a -> a -> cmp;  
};
```

```
instance Eq(int) {  
  equal(x,y)    { prim_equal_int(x,y) };  
  not_equal(x,y) { not(equal(x,y)) };  
};
```

```
instance Ord(int) {  
  compare(x,y) { if x < y then LT else if x > y then GT else EQ };  
};
```

Type classes

Default implementation

```
typeclass Eq(a) {  
  equal      : a -> a -> bool;  
  not_equal  : a -> a -> bool;  
  not_equal(x,y) { not(equal(x,y)) };  
};  
  
instance Eq(int) {  
  equal(x,y) { prim_equal_int(x,y) };  
};
```

Multiple inheritance

- allows code reuse from several classes
- makes objects more complicated:
 - are common base classes shared or distinct?
 - which super class is used for a method call?

Object types

```
type shape = object type {
  draw : unit -> unit;
  move : int * int -> unit;
  dimensions : unit -> rectangle;
};

let new_point(x : int, y : int) : shape {
  object {
    draw()      { ... };
    move(dx, dy) { ... };
    dimensions() { ... };
  }
};
```

Mixins

function $F : I \rightarrow J$ mapping classes $A : I$ to $F(A) : J$

```
type coloured_shape = object {
  draw      : unit -> unit,
  move      : int -> int -> shape,
  dimensions : unit -> [ min_x : int, min_y : int,
                        max_x : int, max_y : int ],
  colour    : colour,
  set_colour : colour -> unit
};

let make_coloured(s : shape, c : colour) : coloured_shape =
  [ draw      = fun () { set_colour(c); s.draw() },
    move      = s.move,
    dimensions = s.dimensions,
    colour    = fun () { c },
    set_colour = fun (col) { c := col } ];
```

- can replace (multiple) inheritance

Discussion

- common problem: single mechanism combining all features
 - makes system complicated
 - causes conceptual confusion (e.g., 'is-a' vs. 'has-a')
- better: separate mechanisms
 - cleaner code
 - only use needed features
- object-oriented programming is powerful but complex
- simpler solutions (e.g., higher-order functions) are often better
- boiler-plate code gives false sense of productivity
- object-oriented design leads to low performance (poor cache locality)