

# Programming Languages

## CS 214

# Introduction

Let's play the children's game: \_\_\_\_\_

→ You have 20 questions to guess what I'm thinking about...

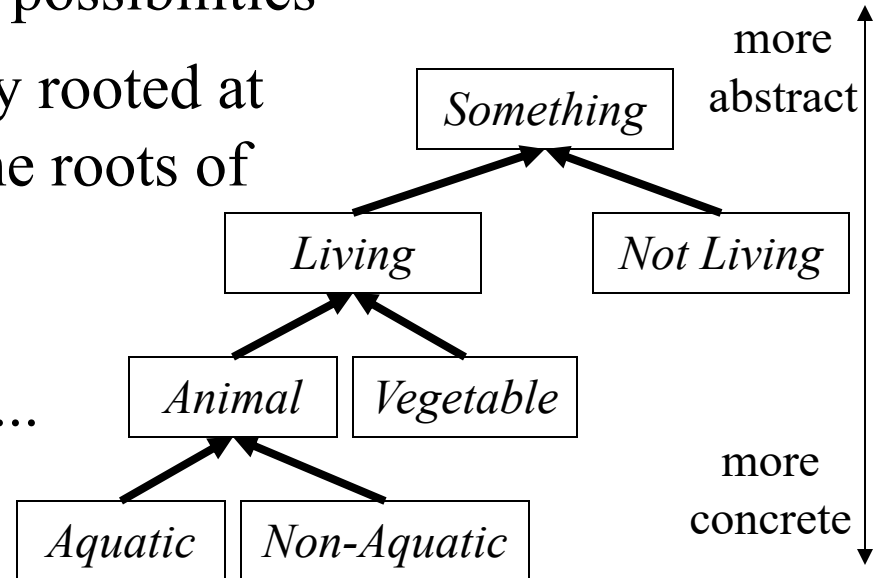
What are you trying to do with your questions?

→ \_\_\_\_\_  
to narrow the number of remaining possibilities

→ The game presupposes a hierarchy rooted at *Something*, whose subclasses are the roots of less general class hierarchies:

→ A good question lets you \_\_\_\_\_ in the hierarchy...

We seem to pick this hierarchy up quite early (as children)...

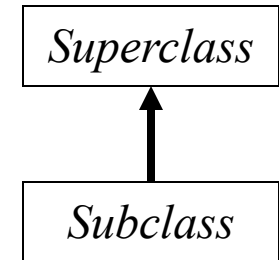


# Object-Oriented Programming (OOP)

One of the basic aims of the \_\_\_\_\_ is to allow programmers to model objects (abstract or concrete) from the real world.

→ OOP supports \_\_\_\_\_:

→ Each ↑ represents the \_\_\_\_\_ relationship, indicating that the *subclass* \_\_\_\_\_ the attributes of its *superclass*.



→ \_\_\_\_\_ (OOD) uses superclasses and inheritance to *consolidate attributes that different objects have in common*, so that those attributes need not be defined more than once.

Different OO languages have different conventions for representing inheritance, but the concept is the same.



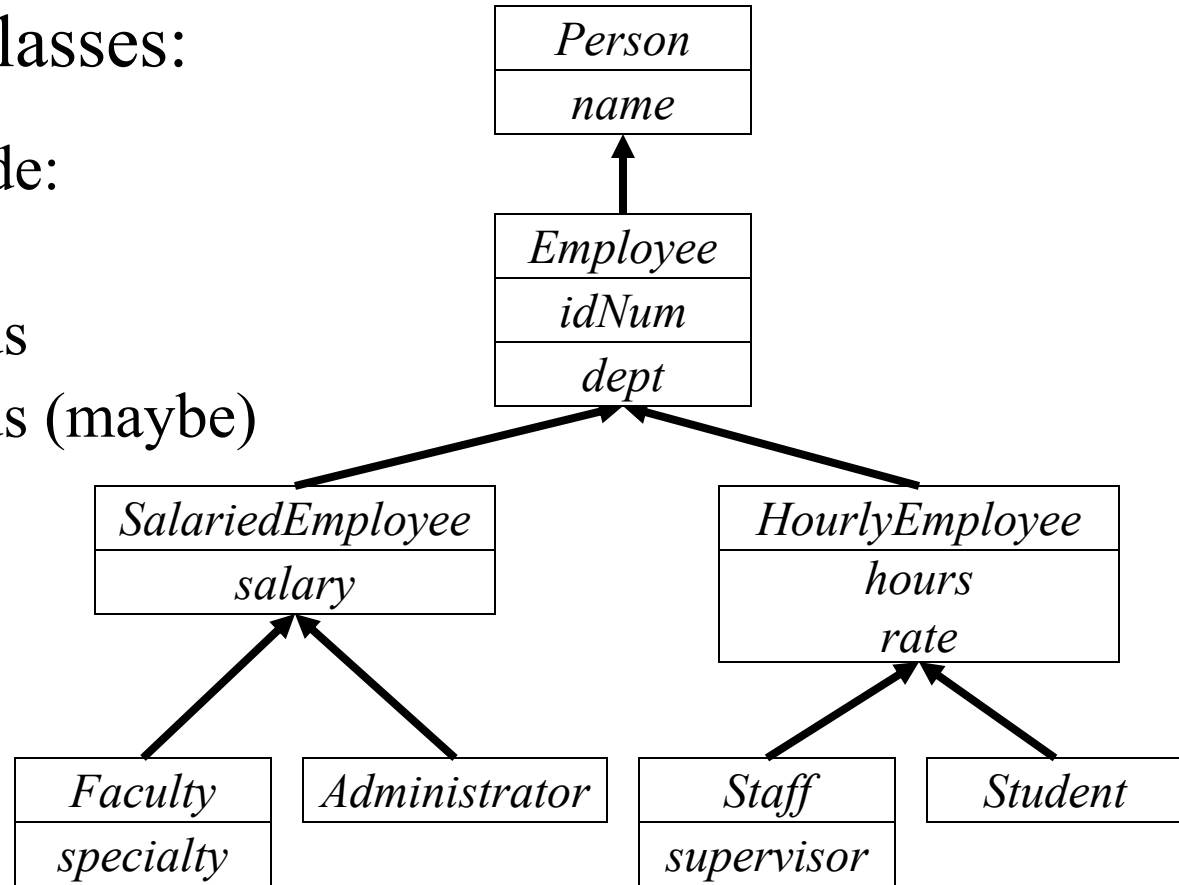
# Design

We can start with the ‘leaf’ classes and consolidate common attributes into superclasses:

Each class should provide:

- \_\_\_\_\_
  - \_\_\_\_\_ methods
  - \_\_\_\_\_ methods (maybe)
  - \_\_\_\_\_ methods
  - \_\_\_\_\_ method
- (*Employee* and below)

Note that our design process is \_\_\_\_\_, not top-down...



# Implementation: C++

Given a design, our *implementation* proceeds \_\_\_\_\_:

```
class Person {
public:
    Person();
    Person(string name);
    string getName() const;
    virtual void write(ostream& out) const;
    virtual void read(istream& in);
    friend ostream& operator<<(ostream & out, const Person & p);
    friend istream& operator>>(istream & in, Person & p);

private:
    string myName;
};
```

In order for subclasses to override `read()` and `write()` with their own definitions, these must be declared as *virtual* methods in C++.

# Implementation: C++ (ii)

```
inline Person::Person() { myName = ""; }

inline Person::Person(string name) { myName = name; }

inline string Person::getName() const { return myName; }

inline void Person::write(ostream& out) const
{ out << myName << endl; }

inline void Person::read(istream& in) { getline(in, myName); }

inline ostream& operator<<(ostream & out, const Person& p)
{ p.write(out); return out; }

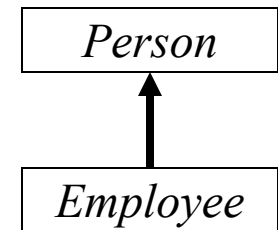
inline istream& operator>>(istream& in, Person& p)
{ p.read(in); return in; }
```

Each of these is simple enough to define \_\_\_\_\_ in C++...

# Implementation: C++ (iii)

We continue with the *Employee* subclass of *Person*:

```
class Employee : public Person {
public:
    Employee();
    Employee(string name, int id, string dept);
    int getID() const;
    string getDept() const;
    virtual void write(ostream& out) const;
    virtual void read(istream& in);
    virtual double pay() const = 0;
private:
    int    myID;
    string myDept;
};
```



*pay()* is a \_\_\_\_\_ function because every *Employee* should respond to that message, but its subclasses must supply its definition.

# Implementation: C++ (iv)

```
inline Employee::Employee()
    : Person()
{ myID = 0; myDept = ""; }

inline Employee::Employee(string name, int id, string dept)
    : Person(name)
{ myID = id; myDept = dept; assert(id > 0); }

inline int Employee::getID() const { return myID; }

inline string Employee::getDept() const { return myDept; }

inline void Employee::write(ostream& out) const {
    Person::write(out);
    out << myID << endl << myDept << endl;
}

inline void Employee::read(istream& in) {
    Person::read(in);
    in >> myID >> myDept; assert(myID > 0);
}
```

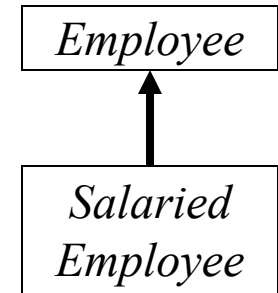
*Employee* inherits  
<< and >>, and since  
they call *write()* and  
*read()*, we need not  
redefine them...

# Implementation: C++ (v)

We continue with *Employee*'s \_\_\_\_\_ subclass:

```
class SalariedEmployee : public Employee {
public:
    SalariedEmployee();
    SalariedEmployee(string name, int id,
                    string dept, double salary);
    double getSalary() const;
    virtual void write(ostream& out) const;
    virtual void read(istream& in);
    virtual double pay() const;

private:
    double    mySalary;
};
```



A *SalariedEmployee* has the information needed to compute its pay, so it supplies the definition for *pay()*.

# Implementation: C++ (vi)

```
inline SalariedEmployee::SalariedEmployee()
    : Employee()
{ mySalary = 0.0; }

inline SalariedEmployee::SalariedEmployee(string name, int id,
                                           string dept, double salary)
    : Employee(name, id, dept)
{ mySalary = salary; assert(mySalary > 0.0); }

inline double SalariedEmployee::getSalary() const
{ return mySalary; }

inline void SalariedEmployee::write(ostream& out) const
{ Employee::write(out);
  out << mySalary << endl; }

inline void SalariedEmployee::read(istream& in)
{ Employee::read(in);
  in >> mySalary; assert(mySalary > 0.0); }

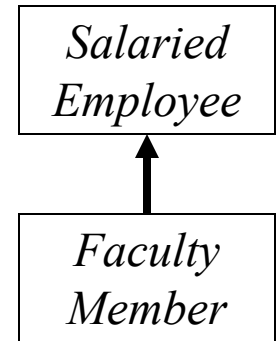
inline double SalariedEmployee::pay() const
{ return mySalary; }
```

# Implementation: C++ (vii)

We continue with the *FacultyMember* subclass:

```
class FacultyMember : public SalariedEmployee {
public:
    FacultyMember();
    FacultyMember(string name, int id, string dept,
                  double salary, string specialty);
    string getSpecialty() const;
    virtual void write(ostream& out) const;
    virtual void read(istream& in);

private:
    string    mySpecialty;
};
```



A *FacultyMember* inherits the \_\_\_\_\_, \_\_\_\_\_, \_\_\_\_\_, and *salary*-related attributes/methods from its superclass.

# Implementation: C++ (viii)

```
inline FacultyMember::FacultyMember()
    : SalariedEmployee()
    { mySpecialty = ""; }

inline FacultyMember::FacultyMember(string name, int id,
                                     string dept, double salary,
                                     string specialty)
    : SalariedEmployee(name, id, dept, salary)
    { mySpecialty = specialty; }

inline string FacultyMember::getSpecialty() const
    { return mySpecialty; }

inline void FacultyMember::write(ostream& out) const
    { SalariedEmployee::write(out);
      out << mySpecialty << endl; }

inline void FacultyMember::read(istream& in)
    { SalariedEmployee::read(in);
      in >> mySpecialty; }
```

We then do the same for the other classes in our design.

# Implementation: C++ (ix)

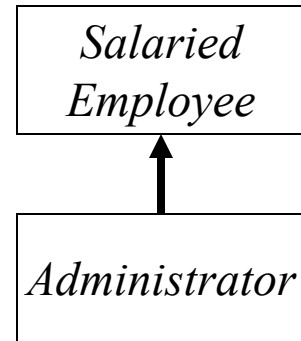
The *Administrator* class is especially easy:

```
class Administrator : public SalariedEmployee {
public:
    Administrator();
    Administrator(string name, int id, string dept,
                 double salary);
};

inline Administrator::Administrator() : SalariedEmployee()
{}

inline Administrator::Administrator(string name, int id,
                                     string dept, double salary)
    : SalariedEmployee(name, id, dept, salary)
{}

```



Our *Administrator* class is this simple because it has no attributes/methods beyond those it inherits from its superclass...

# Use: C++

Given our hierarchy, we can write something like this:

```
// ...
ifstream fin("payroll.data");
Employee* empPtr; char empType;
for (;;) {
    fin >> empType;
    if ( fin.eof() ) break;
    switch (empType) {
        case 'A': empPtr = new Administrator(); break;
        case 'F': empPtr = new FacultyMember(); break;
        case 'S': empPtr = new StaffMember(); break;
        case 'W': empPtr = new StudentWorker(); break;
    }
    fin >> (*empPtr); // equivalent to empPtr->read(fin);
    cout << empPtr->getName() << endl
         << empPtr->pay() << endl;
}
fin.close();
// ...
```

Our variable *empPtr* is called a \_\_\_\_\_, because it can ‘grab’ different objects...

# Compile-Time vs Run-Time Binding

In C++, the \_\_\_\_\_ keyword tells the compiler to \_\_\_\_\_ to bind messages to their definition (by default, binding occurs at compile-time in C++).

If we don't declare prototypes of *write()* as *virtual*:

```
class Employee {  
    public:  
        // ...  
        void write(ostream& out) const;  
        // ...  
};
```

then subsequent calls to *write()*:

```
Employee* empPtr;  
// ...  
empPtr->write(cout);
```

are statically bound to *Employee::write()* at \_\_\_\_\_ (because the handle is an *Employee\**) instead of being dynamically bound to the receiver's *write()* at \_\_\_\_\_.

# Polymorphism

By declaring  
*read()* and  
*write()* as  
\_\_\_\_\_:

```
class Person {  
    // ...  
    _____ void write(ostream& out) const;  
    _____ void read(istream& in);  
    // ...  
};
```

subsequent calls to  
these methods:

```
Employee* empPtr;  
// ...  
empPtr->write(cout);
```

are bound to the \_\_\_\_\_ definitions of those methods at \_\_\_\_\_.

- The same call to *write()* may thus invoke *FacultyMember::write()*, *Administrator::write()*, *StaffMember::write()* or *StudentWorker::write()* depending on the object to which the handle *empPtr* points.
- This behavior is called \_\_\_\_\_, or \_\_\_\_\_.
- \_\_\_\_\_ (aka \_\_\_\_\_) is the mechanism by which a message is bound according to *the receiver's type*, not the handle's type.

# Implementation: Java

Let's compare our C++ implementation to Java:

```
public class Person {
    public Person() { myName = ""; }
    public Person(String name) { myName = name; }
    public final String getName() { return myName; }
    public void write(PrintWriter out) { out.println(myName); }
    public void read(BufferedReader in) { myName = in.readLine(); }

    private String myName;
}
```

Java has no operator overloading, no const methods and no friends\*.

In C++, compile-time binding is the default; run-time binding (polymorphism) must be enabled using the *virtual* keyword.

In Java, run-time binding (polymorphism) is the default; compile-time binding must be enabled using the *final* keyword.

# Implementation: Java (ii)

Continuing with the *Employee* subclass of *Person*:

```
abstract class Employee extends Person {
    public Employee() { super(); myID = 0; myDept = ""; }
    public Employee(String name, int id, String dept)
    { super(name); myID = id; myDept = dept; }

    public final int getID() { return myID; }
    public final String getDept() { return myDept; }

    public void write(PrintWriter out)
    { super.write(out); out.println(myID); out.println(myDept); }

    public void read(BufferedReader in)
    { super.read(in); String idString = in.readLine();
      myID = Integer.parseInt(idString); myDept = in.readLine(); }

    abstract public double pay(); // "pure virtual" in Java
    private int myID;
    private String myDept;
}
```

# Implementation: Java (iii)

```
class SalariedEmployee _____ Employee {
    public SalariedEmployee() { _____; mySalary = 0.0; }

    public SalariedEmployee(String name, int id,
                             String dept, double salary)
    { super(name, id, dept); mySalary = salary; }

    public final double getSalary() { return mySalary; }

    public void write(PrintWriter out)
    { super.write(out); out.println(mySalary); }

    public void read(BufferedReader in)
    { super.read(in); String salaryString = in.readLine();
      mySalary = Double.parseDouble(salaryString); }

    public double pay() { return mySalary; }

    private double mySalary;
}
```

Java lets us do most of the same things, but (usually) more easily...

# Implementation: Java (iv)

```
class FacultyMember extends SalariedEmployee {
    public FacultyMember() { super(); mySpecialty = ""; }
    public FacultyMember(String name, int id, String dept,
                          double salary, String specialty)
    { super(name, id, dept, salary); mySpecialty = specialty; }
    public final String getSpecialty() { return mySpecialty; }
    public void write(PrintWriter out)
    { super.write(out); out.println(mySpecialty); }
    public void read(BufferedReader in)
    { super.read(in); mySpecialty = in.readLine(); }
    private String mySpecialty;
}
```

We then implement the other classes the same way...

# Implementation: Java (v)

As before, *Administrator* indicates how easy this is:

```
class Administrator extends SalariedEmployee {  
    public Administrator() { super(); }  
  
    public Administrator(String name, int id, String dept,  
                          double salary)  
    { super(name, id, dept, salary); }  
}
```

Our *Administrator* class is this simple because it has no attributes/methods beyond those it inherits from its superclass...

# Use: Java

To use these classes, we can write something like this:

```
// ...
BufferedReader fin = new BufferedReader(
    new InputStreamReader(
        new FileReader("payroll.data")));
Employee emp = null; String eType = null;
for (;;) {
    eType = fin.readLine();           // name of class
    if ( eType == null ) break;
    Employee emp = (Employee) Class.forName(eType).newInstance();
    emp.read(fin);
    System.out.println( emp.getName() + "\n" + emp.pay() );
}
fin.close();
// ...
```

All non-fundamental type variables are \_\_\_\_\_ (pointers) in Java.

Java's *Class* class provides a very convenient way to build an instance of a class from a string whose value is the name of the class.

# Implementation: Ada

Let's compare Ada to our other implementations:

```
package PersonPackage is
  type Person is tagged private;
  type PersonRef is access all Person'Class;
  procedure Init(P: in out Person; AName: Unbounded_String);
  function GetName(P: in Person) return Unbounded_String;
  procedure Read(F: in out File_Type; P: in out Person);
  procedure Write(F: in out File_Type; P: in Person);
  procedure Put(F: in out File_Type; P: in Person'Class);
  procedure Get(F: in out File_Type; P: in out Person'Class);
private
  type Person is tagged record
    itsName : Unbounded_String;
  end record;
end PersonPackage;
```

In Ada, a *subtype* can inherit from a *tagged* type (for polymorphism);  
and a *handle* is declared as a pointer to a \_\_\_\_\_ type.

# Implementation: Ada (ii)

Our package body is as follows:

```
package body PersonPackage is
  procedure Init(P: in out Person; AName: Unbounded_String) is
  begin
    P.ItsName := AName;
  end Init;
  function GetName(P: in Person) return Unbounded_String is
  begin
    return P.ItsName;
  end GetName;
  procedure Write(F: in out File_Type; P: in Person) is begin
    Put(F, P.ItsName); New_Line(F);
  end Write;
  procedure Put(F: in out File_Type; P: in Person'Class) is
  begin
    Write(F, P);    -- P is class-wide -> dynamic dispatch
  end Put;
  -- ... Read, Get are similar ...
end PersonPackage;
```

# Implementation: Ada (iii)

We then build *Employee* as an extension of *Person*:

```
package EmployeePackage is
  type Employee is abstract new Person with private;
  type EmployeeRef is access all Employee'Class;
  procedure Init(E: in out Employee; name: Unbounded_String;
                id: Integer; dept: Unbounded_String);
  function GetID(E: in Employee) return Integer;
  function GetDept(E: in Employee) return Unbounded_String;
  procedure Write(F: in out File_Type; E: in Employee);
  procedure Read(F: in out File_Type; E: in out Employee);
  function GetPay(E: in Employee'Class) return float;
  function Pay(E: in Employee) return float is abstract;

private
  type Employee is abstract new Person with record
    itsID : Integer;
    itsDept : Unbounded_String;
  end record;
end EmployeePackage;
```

# Implementation: Ada (iv)

```
package body EmployeePackage is
  procedure Init(E: in out Employee; Name: in Unbounded_String;
                Id: in Integer; Dept: in Unbounded_String)
    is begin
      Init(Person(E), Name); E.ItsID := Id; E.ItsDept := Dept;
    end Init;

  function GetId(E: in Employee) return Integer is begin
    return Emp.ItsId;
  end GetId;

  -- ... GetDept() is similar ...

  procedure Write(F: in out File_Type; E: in Employee) is begin
    Write(F, Person(E));
    Put(F, E.ItsId); New_line(F);
    Put(F, E.ItsDept); New_Line(F);
  end Write;

  -- ... read(F, E) is similar; Get(F,E), Put(F,E) are not needed!

  function GetPay(E: in Employee'Class) return float is begin
    return Pay(E);    // E is class-wide -> dynamic dispatch
  end GetPay;
end EmployeePackage;
```

# Implementation: Ada (v)

We then build *SalariedEmployee* as an extension of *Employee*:

```
package SalariedEmployeePackage is
  type SalariedEmployee is new Employee with private;
  type SalariedEmployeeRef is access all SalariedEmployee'Class;

  procedure Init(sE: in out SalariedEmployee;
                Name: in Unbounded_String; Id: in Integer;
                Dept: in Unbounded_String; Salary: in Float);
  function GetSalary(sE: in SalariedEmployee) return Float;
  procedure Write(F: in out File_Type; sE: in SalariedEmployee);
  procedure Read(F: in out File_Type;
                sE: in out SalariedEmployee);
  function Pay(sE: in SalariedEmployee) return Float;

private
  type SalariedEmployee is new Employee with record
    itsSalary : Float;
  end record;
end SalariedEmployeePackage;
```

# Implementation: Ada (vi)

```
package body SalariedEmployeePackage is
  procedure Init(sE: in out SalariedEmployee;
                Name: in Unbounded_String; Id: in Integer;
                Dept: in Unbounded_String; Salary: in Float)
    is begin
      Init(Employee(sE), Name, Id, Dept); sE.ItsSalary := Salary;
    end Init;

  function GetSalary(sE: in SalariedEmployee) return Float is
    begin
      return sE.ItsSalary;
    end GetSalary;

  procedure Write(F: in out File_Type; sE: out SalariedEmployee)
    is begin
      Write(F, Employee(sE));
      Put(F, sE.ItsSalary); New_line(F);
    end Write;

  -- ... Read(F, sE) is similar...

  function Pay(sE: in SalariedEmployee) return Float is begin
    return mySalary;
  end Pay;
end SalariedEmployeePackage ;
```

# Implementation: Ada (vii)

We then build *Faculty* as an extension of *SalariedEmployee*:

```
package FacultyPackage is
  type Faculty is new SalariedEmployee with private;
  type FacultyRef is access all Faculty'Class;

  procedure Init(F: in out Faculty; Name: in Unbounded_String;
                Id: in Integer; Dept: in Unbounded_String;
                Salary: in Float; Specialty: in Unbounded_String);
  function GetSpecialty(F: in Faculty) return Unbounded_String;
  procedure Write(outf: in out File_Type; F: in Faculty);
  procedure Read(inF: in out File_Type; F: in out Faculty);

private
  type Faculty is new SalariedEmployee with record
    itsSpecialty : Unbounded_String;
  end record;
end FacultyPackage;
```

# Implementation: Ada (viii)

```
package body FacultyPackage is
  procedure Init(F: in out Faculty; Name: in Unbounded_String;
                Id: in Integer; Dept: in Unbounded_String;
                Salary: in Float; Specialty: in Unbounded_String)
  is begin
    Init(SalariedEmployee(F), Name, Id, Dept, Salary);
    F.ItsSpecialty := Specialty;
  end Init;

  function GetSpecialty(F: in Faculty) return Unbounded_String
  is begin
    return F.ItsSpecialty;
  end GetSpecialty;

  procedure Write(outf: in out File_Type; F: in Faculty) is
  begin
    Write(outf, SalariedEmployee(F));
    Put(outf, F.ItsSpecialty); New_Line(F);
  end Write;

  -- ... Read(outf, F) is similar...
end FacultyPackage ;
```

# Implementation: Ada (ix)

We then build *Administrator* as an extension of *SalariedEmployee*:

```
package AdministratorPackage is
  type Administrator is new SalariedEmployee with private;
  type AdministratorRef is access all Administrator'Class;

private
  type Administrator is new SalariedEmployee with record
    null;
  end record;
end AdministratorPackage;
```

Class *Administrator* inherits everything it needs from its superclass *SalariedEmployee*, so its package body is empty:

```
package body AdministratorPackage is
  -- empty body; Administrator defines no new attributes
end AdministratorPackage ;
```

# Use: Ada

Procedure payroll is

```
  EmpRef : EmployeeRef; fin: File_Type;
  eType: Character; Discard: Unbounded_String;
begin
  Open(fin, In_File, "payroll.dat");
  loop
    Get(fin, eType); Discard := Get_Line(fin); // 'F', 'A', ...
    exit when End_Of_File(fin);
    if empType = 'F' then EmpRef := new Faculty;
    elsif empType = 'A' then EmpRef := new Administrator;
    elsif empType = 'S' then EmpRef := new StaffMember;
    elsif empType = 'W' then EmpRef := new StudentWorker;
    end if;
    Get(EmpRef.all, fin);
    Put( GetName(EmpRef.all) ); New_Line;
    Put( GetPay(EmpRef.all) ); New_Line;
  end loop;
  close(fin);
// ...
```

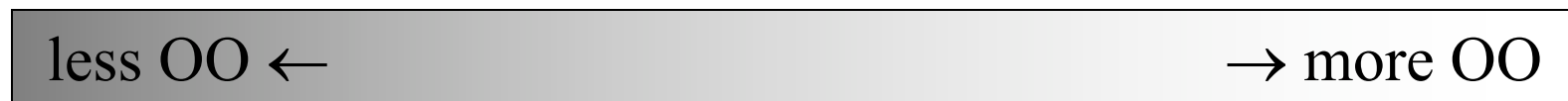
OO capabilities are an add-on in Ada, and they feel like it...

# Summary (ii)

“OO” languages differ in how easy/simple they make OOP:

language/ binding	Ada	C++	Java	Clojure
compile time (static)	<i>default</i>	<i>default</i>	<b>final</b> (method)	<i>not supported</i>
run time (dynamic)	<b>tagged T</b> (type), and <b>T'Class</b> (handle)	<b>virtual</b> (method)	<i>default</i>	<i>all methods</i>

“OO” languages thus lie on an OO continuum:



Ada

Clojure

C++

Java