Programming Language Economics 101

- Languages are adopted to fill a void
  - Enable a previously difficult/impossible application
  - Orthogonal to language design quality (almost)

- Programmer training is the dominant cost
  - Languages with many users are replaced rarely
  - Popular languages become ossified
  - But easy to start in a new niche . . .

Why So Many Languages?

- Application domains have distinctive and conflicting needs

- Examples:

Topic: Language Design

- No universally accepted metrics for design

- Claim: “A good language is one people use”
Language Evaluation Criteria

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Criteria</th>
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<tbody>
<tr>
<td>Readability</td>
<td>Writeability</td>
</tr>
<tr>
<td>Simplicity</td>
<td>*</td>
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<tr>
<td>Data types</td>
<td>*</td>
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<tr>
<td>Syntax design</td>
<td>*</td>
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<tr>
<td>Abstraction</td>
<td>*</td>
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<tr>
<td>Expressivity</td>
<td>*</td>
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<tr>
<td>Type checking</td>
<td>*</td>
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<tr>
<td>Exception handling</td>
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History of Ideas: Abstraction

- Abstraction = detached from concrete details
- Abstraction necessary to build software systems
- Modes of abstraction
  - Via languages/compilers:
    - Higher-level code, few machine dependencies
  - Via subroutines
    - Abstract interface to behavior
  - Via modules
    - Export interfaces; hide implementation
  - Via abstract data types
    - Bundle data with its operations

History of Ideas: Types

- Originally, few types
  - FORTRAN: scalars, arrays
  - LISP: no static type distinctions
- Realization: Types help
  - Allow the programmer to express abstraction
  - Allow the compiler to check against many frequent errors
  - Sometimes to the point that programs are guaranteed “safe”
- More recently
  - Lots of interest in types
  - Experiments with various forms of parameterization
  - Best developed in functional programming

History of Ideas: Reuse

- Reuse = exploit common patterns in software systems
  - Goal: mass-produced software components
  - Reuse is difficult
- Two popular approaches
  - Type parameterization (List<int>, List<double>)
  - Classes and inheritance: C++ derived classes
  - Combined in C++, Java
- Inheritance allows
  - Specialization of existing abstraction
  - Extension, modification, hiding behavior

Trends

- Language design
  - Many new special-purpose languages
  - Popular languages to stay
- Compilers
  - More needed and more complex
  - Driven by increasing gap between
    - new languages
    - new architectures
  - Venerable and healthy area

Why Study Languages and Compilers?

1. See many basic CS concepts at work
2. Learn to build a large and reliable system
3. Increase ability to learn new languages
4. Improve understanding of program behavior
5. Increase capacity of expression
Cool Overview

- Classroom Object Oriented Language
- Designed to
  - Be implementable in a short time
  - Give a taste of implementation of modern
    - Abstraction
    - Static typing
    - Reuse (inheritance)
    - Memory management
    - And more ...
- But many things are left out

A Simple Example

class Point {
  x : Int ← 0;
  y : Int ← 0;
};

- Cool programs are sets of class definitions
  - A special class Main with a special method main
  - No separate notion of subroutine
- class = a collection of attributes and methods
- Instances of a class are objects

Cool Objects

```haskell
class Point {
  x : Int ← 0;
  y : Int; (* use default value *)
};
```

- The expression "new Point" creates a new object of class Point
- An object can be thought of as a record with a slot for each attribute

<table>
<thead>
<tr>
<th>x</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Information Hiding in Cool

- Methods are global
- Attributes are local to a class
  - They can only be accessed by the class’ methods
- Example:
  ```haskell
class Point {
  . . .
  x () : Int { x };
  setx (newx : Int) : Int { x ← newx };
};
```

Methods

- A class can also define methods for manipulating the attributes
  ```haskell
class Point {
  x : Int ← 0;
  y : Int ← 0;
  movePoint(newx : Int, newy : Int) : Point {
    x ← newx;
    y ← newy;
    self;
  }; -- close block expression
}; -- close method
```

- Methods can refer to the current object using `self`

Methods

- Each object knows how to access the code of a method
- As if the object contains a slot pointing to the code

```haskell
x y
```

- In reality implementations save space by sharing these pointers among instances of the same class

```haskell
x y
```

methods

```
movePoint
```
Inheritance

- We can extend points to colored points using subclassing => class hierarchy

```java
class ColorPoint inherits Point {
    color : Int ← 0;
    movePoint(newx : Int, newy : Int): Point {
        color ← 0;
        x ← newx; y ← newy;
        self;
    }
}
```

Cool Types

- Every class is a type
- Base classes:
  - Int for integers
  - Bool for boolean values: true, false
  - String for strings
  - Object root of the class hierarchy
- All variables must be declared
  - compiler infers types for expressions

Cool Type Checking

- Is well typed if A is an ancestor of B in the class hierarchy
  - Anywhere an A is expected a B can be used
- Type safety:
  - A well-typed program cannot result in runtime type errors

Method Invocation and Inheritance

- Methods are invoked by dispatch
- Understanding dispatch in the presence of inheritance is a subtle aspect of OO languages

```
p : Point;
p ← new ColorPoint;
p.movePoint(1, 2);
```

- p has static type Point
- p has dynamic type ColorPoint
- p.movePoint must invoke the ColorPoint version

Method Invocation

- Example: invoke one-argument method m

```
1. Eval. e
2. Find class of e
3. Find code of m
4. Eval. argm.
5. Bind self and x
6. Run method
```

Other Expressions

- Expression language
  - every expression has a type and a value
  - Loops: while E loop E pool
  - Conditionals if E then E else E fi
  - Case statement case E of x : Type ⇒ E; ... esac
  - Arithmetic, logical operations
  - Assignment x ← E
  - Primitive I/O out_string(s), in_string()

- Missing features:
  - arrays, floating point operations, exceptions, ...
Cool Memory Management

- Memory is allocated every time `new` is invoked
- Memory is deallocated automatically when an object is no longer reachable
- Done by the garbage collector (GC)
  - There is a Cool GC

Course Project

- A complete compiler
  - Cool $\Rightarrow$ MIPS assembly language
  - No optimizations
- Split in 4 programming assignments (PAs)
- There is adequate time to complete assignments
  - But start early and please follow directions
- Individual or team
  - max. 2 students