Programming Language Concepts

Principles of Programming Languages
Colorado School of Mines

https://lambda.mines.edu
Learning Group Activity

With your learning group:

1. Share your code snippets from the assignment. Explain why one language is inherently less maintainable, readable, or abstractable in one language than the other for that particular example.

2. Collectively, as a group, either:
   1. create a great definition for expressivity
   2. or, create a great explanation for how expressiveness differs from (and is similar to)

Prove Them Wrong?

Think that there’s a better way to express the problem for a piece of code your group member is showing? Show an example. Remember to be nice.
Language Implementation Techniques
Compiled Languages

Advantages:
- Runtime is *fast!*

Disadvantages:
- Compile time is slow
- Source code cannot be a part of the input data

Examples
- C, C++, and FORTRAN are generally implemented as compiled languages
Interpreted Languages

**Advantages:**
- No need to compile
- Source code can be a part of input data: you can transmit functions across the network to be run!

**Disadvantages:**
- Runtime is slow

**Examples**
BASIC, PHP, and Perl are generally implemented as interpreted languages.
Hybrid Interpreters

To speed up the execution of interpreted languages, implementers started getting clever:

- **Interpreted VM Bytecode:** Input is lexed, parsed, then translated to bytecode. The bytecode gets optimized, then the low level bytecode is interpreted. Examples: Python, Java, Ruby

- **Just In Time Compiler:** Source code is compiled as it’s executed, putting machine code on the processor "just in time". Examples: PyPy, LuaJIT, Chrome V8
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Advantages include all the benefits of interpreted languages, with run times occasionally approaching compiled languages.
Evaluating a Programming Language
Evaluating programming languages based on:

- **Writability:** How easy is it to write good code?
- **Readability:** How easy is it to read well written code?
  - Is the language easy enough to learn?
- **Reliability:** What features does the language provide to make sure our code works as it is supposed to?
- **Feasibility:** Does an interpreter or compiler actually exist for the platform we need to use? Is it fast enough for our application?
Evaluation Metrics

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A System of Trade-Offs

Often times, adding features which improve one metric can harm another metric. Examples to come...
The overall simplicity of a language plays a large role in both writability and readability:

- **Feature Multiplicity:** 🌈 Writability, 🔴 Readability
- **Operator Overloading:** 🌈 Writability, 🔴 Readability
- **Large Grammars:** 🌈 Writability, 🔴 Readability
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Simplicity can be carried too far

Assembly languages and esoteric languages generally aren’t considered very writable or readable.
Orthogonality: how consistent is the language with itself?

Example of a lack of orthogonality (C++):
Parameters are passed by value, unless they were specified with an `&`.
Or unless they were an array.

Example of a lack of orthogonality (C/C+):
Arrays can contain data of any type, including pointers.
Unless it's a function pointer.
But you can wrap that function pointer in a struct and you should be fine.

Impacts of poor orthogonality:
poor readability, poor writability, and potentially reduced reliability.
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*Or unless they were an array.*
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Abstraction: The ability to define and use complicated structures and operations in a way that allows implementation to be ignored.

Examples:

- **Functions**: Simplest form of abstraction. Often taken for granted, but gives us easy recursion.
- **Heap Memory**: Imagine trying to create a large unbalanced binary tree in a single-dimensional array.
- **Generics**: Allows us to define operations that apply to multiple data types without reimplementing for each type.
- **Garbage Collection**: A form of automatic memory management.
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With your learning group...

What other kinds of PL-level abstractions can you name?
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Good Abstractions: 👍 Writability, 👍 Readability, 👍
Reliability Features

Some languages come with features designed for reliability:

- **Type Checking**: Making sure the type of data can be used with the function or operation you are calling. Independent of static/dynamic: more on this later.

- **Exception Handling**: The ability of a running program to intercept run-time errors and take corrective measures.

- **Taint Protection**: Protects the security of an application by not allowing privileged operations to be performed on tainted data (e.g., user input from a web application).
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Some features can *harm* a language’s reliability:

- **Goto**: the ability to jump to different locations in the code without restriction.
- **Aliasing**: allows two different symbolic names (variables, function names, etc.) to refer to the same data. Think pointers in C/C++.
Expressivity

With your learning group:

1. If one language is less expressive than another, how might it be less writable?
2. If one language is less expressive than another, how might it be less readable?
3. If one language is less expressive than another, how might it be less reliable?

Be prepared to share your answers with the class.
Typing Systems
A **binding** refers to the association between:

- a variable and its type,
- a function and its definition,
- a type and its representation (e.g., `int` is 32-bits),
- or an operation and its symbol (e.g., multiplication is usually `*`)

**Binding time** refers to the time at which a binding takes place.

**Common Binding Times**
- Design time
- Implementation time
- Compile time
- Link time
- Run time
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**Common Binding Times**

| Design time, implementation time, compile time, link time, run time |
In a **static typing** system, the binding of a variable to its type occurs *before* run time.

In other words, the type of data is associated with the variable.

```c
int x = 12;
```
In a static typing system, the binding of a variable to its type occurs before run time.

In other words, the type of data is associated with the variable.

```c
int x = 12;
```

**Advantages:**
- No need to do type checking at run time, this can be done at compile time.
- 👍 Reliability

**Disadvantages:**
- Generics are needed to create operations and functions that apply to multiple types
- 👎 Writability
Dynamic Typing

In a dynamic typing system, the binding of a variable to a type occurs during run time.

In other words, the type of data is associated with the data itself.

\[ x = \text{int}(12) \]
Dynamic Typing

In a **dynamic typing** system, the binding of a variable to a type occurs *during* run time.

In other words, the type of data is associated with the data itself.

```python
x = int(12)
```

**Advantages:**
- Collections can be of mixed type without generics,
  functions can take multiple types without generics
- Types can be dynamically created at run time
- 🙌 Writability

**Disadvantages:**
- Type checking must be done at run time; makes things slow
- 👎 Reliability
Untyped Systems

In an **untyped** system, variables are never bound to a type. In other words, the functions and operations called on the variables determine the type:

\[ 12 \ x \ \text{define} \]
\[ x \ \text{int->string} \ \text{print-string} \]

**Note**

Don’t confuse untyped for type inference. Type inference is generally used with static typing systems.
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In an **untyped** system, variables are never bound to a type. In other words, the functions and operations called on the variables determine the type:

```
12 x define
x int->string print-string
```

**Note**

Don’t confuse untyped for type inference. Type inference is generally used with static typing systems.

**Advantages:**

- No need to do type checking, ever.
- 👍 Feasibility

**Disadvantages:**

- 👎 👎 👎 Reliability
Type safety means a language will not allow bits to be interpreted as the incorrect data type. For example: treating the bits of an integer as a floating point number.

Implicit type conversions are when a language will automatically convert data types to allow an expression to be computed.

Strongly typed programming languages are both type safe and do not allow implicit type conversions.

Weakly typed programming languages are either not type safe or allow implicit type conversions.

Whether a language is strongly or weakly typed has nothing to do with whether it is statically/dynamically typed, or compiled/interpreted.
## Type Systems: Language Examples

<table>
<thead>
<tr>
<th></th>
<th>Strong</th>
<th>Weak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static</td>
<td>Java, Haskell, Rust, Go</td>
<td>C, C++</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Python, Ruby</td>
<td>PHP, JavaScript</td>
</tr>
</tbody>
</table>

**CSCI-400**
End of Lecture: Roadmap
Before you leave class, divide up LGA-02 with your group members.

I’m going to be in Germany 1/17 thru 1/23. R. Blake Jackson will lecture during this time.

No office hours on Monday 1/22, as I won’t be in the country.

Your first quiz will be Thursday, 1/25. Don’t expect it to be too hard.

Your first programming assignment will be due Friday, 1/26 at midnight. I will post the assignment later today.