

Programming Paradigms

Unit 18 — Summary of Basic Concepts

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Basic Concepts of Programming Languages

- Programming languages are **artificial languages** designed to communicate with computers
 - Provide **most powerful** human-computer interface
- There are **thousands** of different languages, which are more or less appropriate for different problems
- Can be classified according to **programming paradigms** and **abstraction level**
- There are many similarities to natural languages, e.g., syntax, semantics
 - **Syntax** determines whether a program is well-formed
 - **Semantic** determines the meaning of language concepts/programs, and can be defined in different ways (operational, axiomatic, denotational semantics)
- **Type system** in a programming language is needed to **organize data** and helps to **check the correctness** of programs
- Different forms of **type checking**, all having pros and cons
 - Weak typing vs. strong typing
 - Static vs. dynamic type checking
 - Type casting

Imperative and Object-oriented Paradigm

- **Imperative paradigm** is the **oldest** programming paradigm, based on von Neumann architecture
 - **Assignment statement** is a central element, assigning values to memory locations
 - Program consists of **sequence of statements** that change the **program state**
- **Procedural programming** is a refinement that makes it easier to write complex programs
- **Machine languages** were the earliest imperative languages, followed by FORTRAN and ALGOL
- **Abstract Data Types** is a further extension of imperative programming
 - **Data** and **operations** are **encapsulated** into a bundle (**information hiding**)
 - This hides the underlying representation and implementation
- **Object-oriented paradigm** extends ADTs
 - **Classes** are **blueprints** for objects that encapsulate both data and operations
 - Objects exchange **messages**
 - Provides **encapsulation**, **information hiding**, **inheritance**, and **dynamic dispatching**

Object-oriented Programming with Ruby/1

- Design goal of Ruby: **simplicity** and **productivity** of the programmer
- Ruby is a **pure object-oriented language**, treating objects in a consistent way
- Ruby is a **strongly typed** language, but applies **dynamic type checking**
- Supports **duck typing**, and is therefore very flexible when it comes to substitutability
 - Exact class of object is less relevant, but what **methods/operations** can be performed counts
 - Comparable to interfaces, e.g., in Java
- Some nice features not present in other languages: **rich set of methods on arrays**, **code blocks** that can be passed as parameters to methods, **modules**, **mixins** (i.e., modules included in class definitions), **accessor methods** that can have the same name as variables
- Programmers can be **very productive** using Ruby, can be used like a scripting language
- Comes with a very successful **web development framework**: Ruby on Rails
 - The original Twitter implementation was done in Ruby

Object-oriented Programming with Ruby/2

- **Performance:** Ruby is not the most efficient language
 - All the flexibility makes it difficult to compile programs
- Concurrent programming is difficult to do (with a state-based language)
- Type Safety: duck typing makes it **harder to debug code** that has type errors in it

Recursion

- **Recursion** is just a different kind of loop, but as **expressive** as loops
- Some programming languages are heavily based on recursion, others do not offer recursion at all
- Two important steps in writing recursive programs
 - **Base** cases
 - **Termination**
- Often recursion allows you to write elegant code
- With the right language, it is even efficient
- **Tail recursion** is important to make recursive programs efficient
 - In tail recursion, the **recursive call is the last statement** before the function terminates, i.e., after returning from the recursive call no other statements need to be executed
 - Therefore, no information need to be stored on the stack

Logic Programming in Prolog/1

- Prolog is a **declarative** programming language based on **first-order logic**
 - Specifies **what** to compute and not **how** to do it
- A Prolog program/knowledge base consists of **facts** and **rules**
- Evaluating a Prolog program means to prove a **goal**
 - Thereby, key concepts are **instantiation**, **(pattern) matching**, and **backtracking**
- Prolog uses **recursion** instead of loops
- **Lists** and **structures** are two very important data structures
- The **cut** operator allows to stop backtracking
 - Should be used with care
 - A better programming style is to replace it by negation
- **“Generate and test”** is a very common programming pattern

Logic Programming in Prolog/2

- The **box model** shows the execution of a Prolog program
 - Has four ports: CALL, EXIT, REDO, FAIL
- **Debugger** shows the program execution according to the box model
 - **trace** provides an exhaustive tracing mode
 - **debug** allows to jump to spy points set by the **spy** predicate
- **Accumulators** are frequently needed to collect intermediate results when traversing structures or lists
 - Helpful to make programs tail-recursive
- **Sorting** is an important operation
 - Generalized insertion sort, which allows to pass a sorting predicate
 - Constructing structures with the **=..** (univ) operator needed
- Another frequent and powerful operation is **mapping** structures and lists
 - General map-functions can be used (**second-order functions**)
- **read** and **write** predicates for simple interactive programs

Logic Programming in Prolog/3

- Prolog has a **steeper learning curve** compared to other languages
- Fairly focused niche applications, not really a **practical general-purpose** language
- Mainly used in application areas, such as **artificial intelligence**, **natural language processing**, and **databases**
- There are **scalability issues**, the basic matching strategy used by Prolog is **computationally expensive**
 - Has problems to process large data sets
- It is not as declarative as it seems at first glance
 - If you want to write efficient Prolog programs, you have to know what is going on behind the scenes

Functional Programming in Haskell/1

- Haskell is a **pure** functional language, providing **referential transparency**
 - function give the same output for the same input
 - functions have no side effects
 - a variable can only be assigned a value once
- The **type system (strong/static)** prevents you from making a lot of mistakes
 - Nevertheless, it is quite **flexible** when it comes to extending it with **user-defined types**
- Haskell offers a lot in terms of **expressiveness**, yielding very **concise code**
- Haskell uses **curried functions** in combination with **partial evaluation** of functions,
 - i.e., internally, functions have only one input parameter;
 - functions with multiple input parameters are decomposed into a sequence of partial functions, each having one parameter
- It is easier to show the **correctness** of your programs, due to the **pure functional** style

Functional Programming in Haskell/2

- Haskell does **lazy evaluation**, which gives you an additional tool for writing programs efficiently
- Lazy evaluation supports to work with **infinite lists**: only those (finite) parts are evaluated that are actually needed and only when they are needed
- Haskell supports **list comprehension**, a powerful way to specify lists
- The pure functional paradigm also has a price: dealing with **messy real-world situations** such as IO and state is not easy
- Haskell has a **steep learning curve**, i.e., it takes a while to learn how to wield the power of Haskell
- This may also explain the fact that the Haskell community is relatively small

Concurrent Programming in Erlang/1

- The **shared-nothing, message-passing** process model is very powerful when it comes to implementing concurrency
 - Concurrency means any execution order (e.g., parallel or serial) without compromising the correctness of the program
- Erlang offers a lot in terms of **reliability** and **fault tolerance**
 - **Controlled crash**
- Erlang was developed with the aim to achieve **industrial-strength high performance**
- Erlang processes run on a virtual machine that **automatically adapts** to the underlying hardware
 - Runs on as many cores/machines as available
- Language supports some powerful **features of functional and logic-oriented languages**
 - e.g., pattern matching, optimized for tail-recursion
- OTP provides a lot of functionality to make it easier to implement concurrent applications

Concurrent Programming in Erlang/2

- The syntax of the language is a weird mix of Prolog with functional language constructs thrown in
- While Erlang shines when it comes to concurrency, programming simpler (serial) things tend to be harder than in other languages