Programming Paradigms
Unit 18 — Summary of Basic Concepts

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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
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
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
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.
Haskell is a **pure** functional language, providing **referential transparency**
- functions 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
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 machining 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.