Advanced Programming - Appunti

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Contents

Chapter 1

Introduction

19 - Settembre

Info and Contact

Pagina del corso

1.1 Introduction

1.1.1 Framework

A software **framework** is a collection of common code providing generic functionality that can selectively overryidden or specialized by user code prvoiding specific functionality.

When using *framworks* htere is an **inversion of control**. Differently from what happens when using libraries, the program-flow is dictated by the framework, not the caller.

1.1.2 Design Patterns

A **design pattern** is a general reusable solution to a commonly occurring problem within a given context in software design. A design pattern is characterized by:

- **Name**
- **Problem Addressed**
- **Context** - Used to determine applicability
- **Forces** - Constraints or issues that the solution must address
- **Solution** - It must resolve all *forces*

20 - Settembre

Useful tool, to see preprocessor output, compiling, ecc.

1.1.3 Programming Languages

A **PL** is defined via **syntax**, **semantics** and **pragmatics**[1].

1.1.3.1 Syntax

Used by the compiler for *scanning* and *parsing*. The *lexical* grammar defines the syntax of token (e.g. "for" blocks, constants)

1.1.3.2 Semantics

Semantics might be described using natural language, which even if precise, allows amibguousity. Formal approches to semantics definition are:

1. Denotational - Mapping every syntactic entity with a mathematical entity
2. Operational - Defining a computation relation in a form $e \Rightarrow v$, where e is a program

[1] the way in which the PL is intended to be used in practice

3. Axiomatic - Based on Hoare-triples $Precondition \wedge Program \Rightarrow Postcondition$

However, they rarely scale to fully-fledged programming languages.

1.1.3.3 Pragmatics

Pragmatics include coding conventions, guidelines for elegant code, etc.

1.1.4 Programming Paradigms

Paradigms belong to languages *pragmatics*, not to the way the language is defined, i.e. not syntax nor semantics.

1. **Imperative**
2. **Object-oriented**
3. **Concurrent** - Processes, communication, ...
4. **Functional** - values, expressions, functions, higher-order functions, ...
5. **Logic** - Assertions, relations, *strange sorceries*...

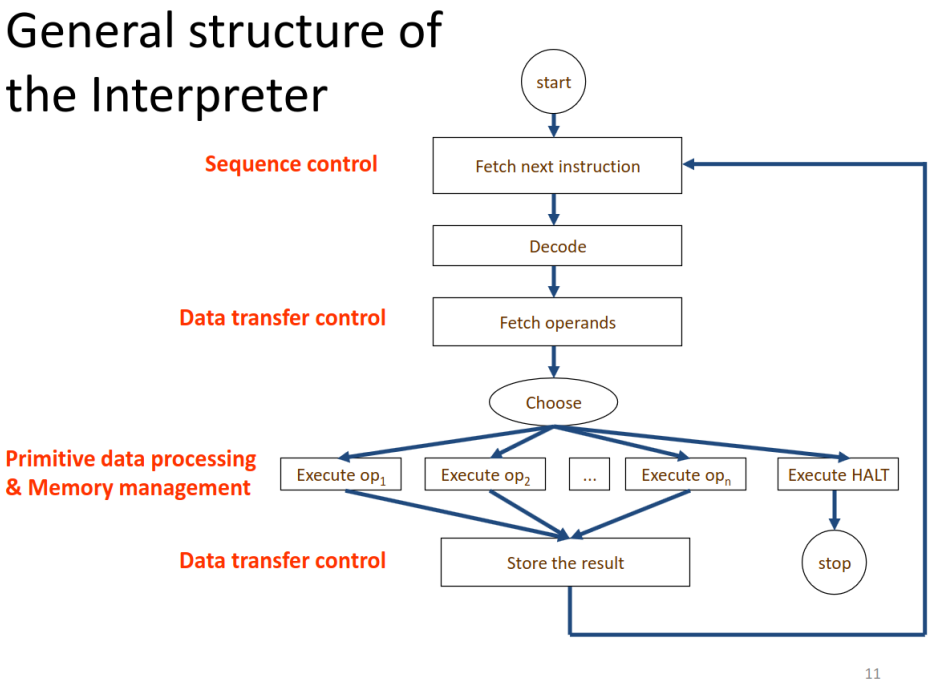
Modern PLs, provide constructs and solutions to program in all these paradigms

1.1.5 Implementing PLs

- Programs written in **L** must be *executable*
- Every language **L** implicitly defines and *Abstract Machine* M_L having **L** as a Machine Language
- Implementing M_L on an existing host machine M_O via compilation or interpretation (or both) makes programs written in **L** executables

An **Abstract Machine** M_L for L is a collection of data structures and algorithms which can perform the storage and execution of programs written in L.
Viceversa, M defines a language L_M including all programs which can be executed by the interpreter M.
There is a bidirectional correspondance between machines and languages components.

Primitive data processing	$\longleftrightarrow$	*Primitive data types*
Sequence control	$\longleftrightarrow$	*Control structures*
Data transfer control	$\longleftrightarrow$	*Parameter passing and value return*
Memory management	$\longleftrightarrow$	*Memory management*



In computer science one of the main focuses is **abstraction**, and this applies also to the implementation of AMs, leading to an onion-like structure, or **hierarchical** structure, as can be seen in the scheme in 1.1.

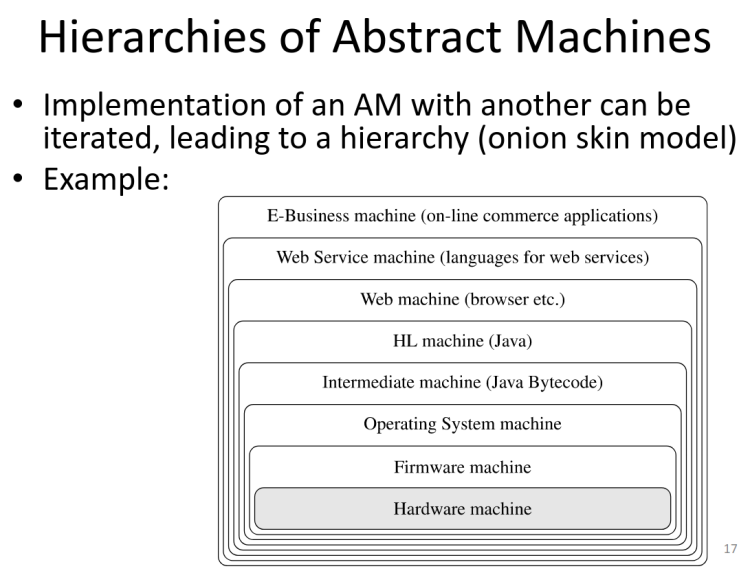


Figure 1.1: AM Hierarchical Structure

Implementing PLs - Wrap Up

- ◇ L High-level programming language
- ◇ M_L Abstract machine for L
- ◇ M_O host machine

1.1.5.1 Pure Interpretation

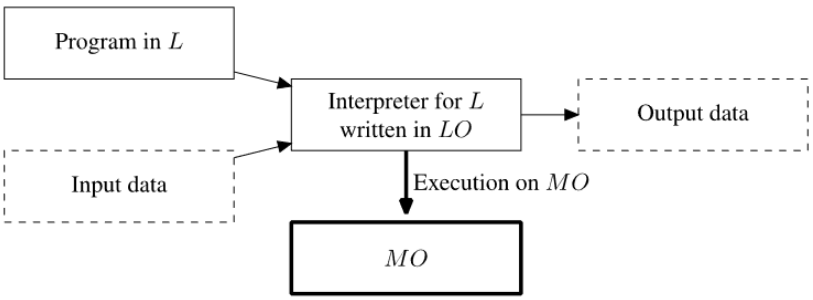


Figure 1.2: Pure Interpretation

M_L is interpreted over M_O. It isn't very efficient, mainly because of fetch-decode phases

1.1.5.2 Pure Compilation

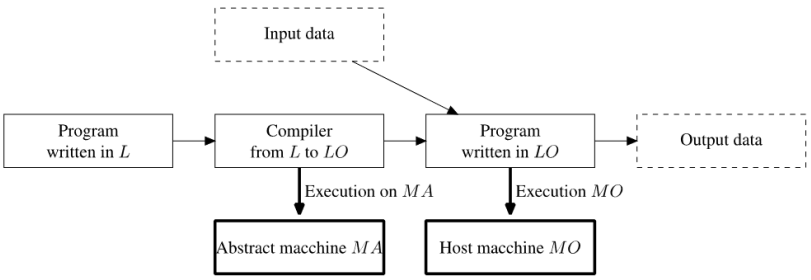


Figure 1.3: Pure Compilation

L programs are translated into L_O, the machine laguange of M_O, hence, M_L is not realized at all and the programs are directly executed on M_O.
Compilation is more efficient than *Interpretation*, but produced code is larger

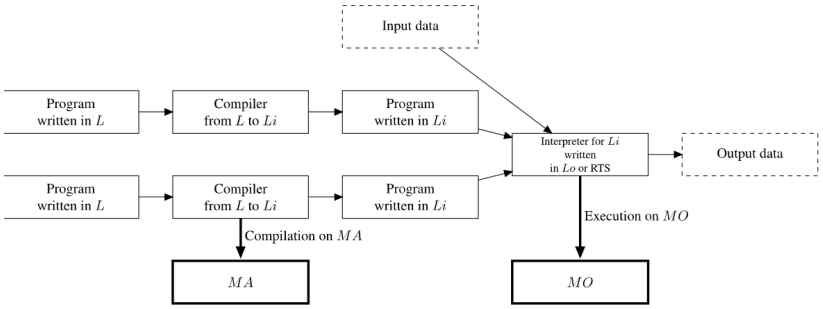


Figure 1.4: Both

1.1.5.3 Both

All real languages use both *interpretation* and *compilation*, the *"pure"* cases are only limit cases.

Some languages, e.g. Java, use an intermediate Abstract Machine, called a *Virtual Machine*, which increases *Portability* and *Interoperability*.

- ◇ Compilation leads to better performance in general
  - – Allocation of variables without variable lookup at run time
  - – Aggressive code optimization to exploit hardware features
- ◇ Interpretation facilitates interactive debugging and testing
  - – Interpretation leads to better diagnostics of a programming
  - – roblem
  - – Procedures can be invoked from command line by a user
  - – Variable values can be inspected and modified by a user

Chapter 2

JVM

25 - Settembre

2.1 Runtime System

Every language defines and **execution model**, which is (partially) implemented by a **runtime system**, providing runtime **support** needed by both *compiled* and *interpreted* programs.

A **Runtime system** includes (eventually):

- Code:
  - in the executing program generated by the compiler
  - running in other threads/processes]
- Language libraries
- Operating system functionalities
- The interpreter/virtual machine itself

Runtime support can be needed for various reasons:

- Memory Management → Stack Management, Heap Management
- I/O operations → File System, Sockets, I/O devices
- Intercation with runtime environment
- Parallel execution (threads/processes)
- Dynamic binding type checking
- Dynamic loading and linking of modules
- Debugging
- Code Generation for JIT compilation and optimization
- Verification and Monitoring

2.1.1 JRE

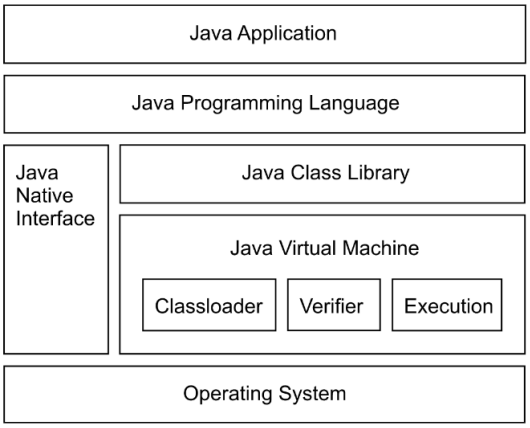
The **Java Runtime Environmnet** includes **JVM** and **JCL** (*Java Class Library*).

2.2 JVM

JVM is an *abstract* machine, defined by the documentation, which `omits implementation details` on stuff like memory layout of runtime data area, garbage-collection, internal optimization, and even the representation of the `null` constant. The JVM specification, instead, defines precisely a machine indipendent *"class file format"* that all JVM implementations must support; it also imposes strong **synctatic** and **structural constraints** on the code in a class file.

The **JVM** is not *register-based*, instead it is a *multi-threaded* ***stack***[1] *based machine*. Id est the JVM pops intructions from the top of **operand stack** of the current frame, and pushes their result on the top of the **operand stack**. The **operand stack** is used to:

- ◇ Pass arguments to functions
- ◇ Return results from a function
- ◇ Store intermediate values while evaluating expressions
- ◇ Store local variables



2.2.1 Data types

`.class` file are platform independent external represantions, which are represented internally by the JVM using simpler data types, which are implementation dependent.

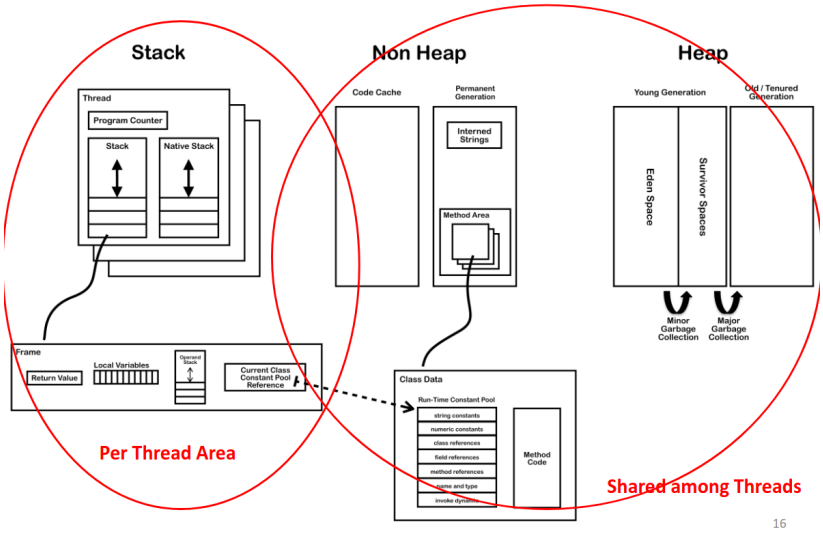
- ◇ **Primitive types**
  - – Numerica integral
  - – Numeric floating point
  - – boolean (support only for arrays)
  - – internal (for exception handling)
- ◇ **Reference types**
  - – Class types
  - – Array types
  - – Interface types

  No type information on local variables at runtime, there are only operand types specified by **opcodes** e.g. `iadd, fadd` , . . .

2.2.2 Threads

There are some runtime areas of the JVM related to a single thread, while others are shared among threads

[1] Not to be confused with the stack of activation records!



All Java Programs are multithreaded, since there is at least a `main` thread running the user's program, and many **daemons**:

- Garbage collector
- Signal Dispatching
- Compilation
- etc ...

JVM doesn't pose strong implementation constraints by defining a precise abstract consistency model, including volatiles, allowing non-atomic longs and doubles, distinguishing working-memory and general store.

2.2.3 per-thread Data Areas

- **pc** pointer to next instruction in *method area*
  undefined if current method is *native*. When a native function is invoked, execution continues using the native stack. However, a native function, can invoke a Java method, in which case the pc is set to the first instruction of the invoked method, in Java stack.
- **Java stack**: stack of *frames* (or *activation records)*
- **Native stack**: used for invocation of natve functions through the *Java Native Interface* (*JNI*)

2.2.3.1 Frames

Considering the **structure** of **frames**, each one is composed by:

- **Local Variable Array** (32 bits) containing:
  1. Reference to `this`
  2. Method parameters
  3. Local variables
- **Operand stack**
- Reference to **Constant Pool** of current class

Differently from C/C++, where the **linking** phase is done before running an executable, java computes linking **dynamically** at **runtime**; this is achieved using **symbolic** references, which can be resolved using *static* (eager) or *late* (lazy) resolution.
Since the execution of a Java program must **not** depend on the JVM implementation, the JVM always behaves as if the implementation implies *lazy* resolution, even if the actual implementation provides static resolution instead.

2.2.4 Shared data areas

2.2.4.1 Heap

- Memory for objects and arrays
- No explicit deallocation, it is demanded to the garbage collection.

2.2.4.2 Non-Heap

Memory for objects never deallocated

- Method area
- Interned strings
- Code cache for JIT

Just In Time (JIT) compilation refers to profiling as "hot" code areas of bytecode which may be executed many times, and storing the compiled native code in a cache in the *Non-heap* memory.

2.2.4.3 Method-area

Here `class` files are loaded. For each class a classloader reference and the following info from the `class` file are stored:

- Runtime Constant Pool
- Field data
- Method data
- Method code

`Method area is` *`shared`* `among threads`! Access to it must be ***thread safe***.

This should a **permanent** area of the memory, but it may be **edited** when a new class is loaded or when a symbolic link is resolved by dynamic linking.

26 - Settembre

2.2.4.4 Constant Pool

Contains constants and symbolic references for dynamic binding. It is possible to see the constant pool of a compiled `.class` file using the command:

```
javap -v name.class
```

Displaying something resembling to:

```
   #1 = Methodref          #6.#14         // java/lang/Object."<init>":()V
   #2 = Fieldref           #15.#16        // java/lang/System.out:Ljava/io/PrintStream;
   #3 = String             #17            // Hello World
   #4 = Methodref          #18.#19        // java/io/PrintStream.println:(Ljava/lang/
       String;)V
   #5 = Class              #20            // com/baeldung/jvm/ConstantPool
   #6 = Class              #21            // java/lang/Object
   #7 = Utf8               <init>
   #8 = Utf8               ()V
   #9 = Utf8               Code
  #10 = Utf8               LineNumberTable
  #11 = Utf8               sayHello
  #12 = Utf8               SourceFile
```

Similar to symbol table, but with more info: it contains constants and symbolic references used for dynamic binding, suitably tagged

- numeric literals (Integer, Float, Long, Double)
- string literals (Utf8)
- class references (Class)
- field references (Fieldref)
- method references (Mehodref, InterfaceMethodref, MethodHandle)
- signatures (NameAndType)

Operands in bytecodes often are indexes in the constant pool

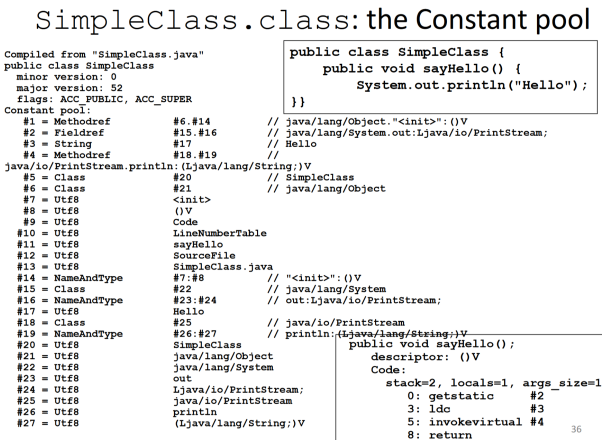


Figure 2.1: Constant Pool example

2.2.5 Loading

Loading is finding the binary representation of a class or interface type with a given name and creating a class or interface from it.
Class (or Interface) C creation is *triggered* by other classes **referencing** C or by methods (e.g. reflection). If not previously loaded, `loader.loadClass` is invoked.

There are 4 **Classloaders**:

1. **Bootstrap CL**: loads basic Java APIs
2. **Extension CL**: loads classes from standard Java extension APIs
3. **System CL**: loads application classes from *classpath*
   (default application CL)
4. **User Defined CLs**: can be used for:
   - ◇ runtime classes reloading
   - ◇ loading network, encrypted files or on-the-fly generated classes
   - ◇ supporting separation between different groups of loaded classes as required by web servers

2.2.5.1 Runtime Constant Pool

- ◇ The `constant_pool` table in the `.class` file is used to construct the run-time constant pool upon class or interface creation.
- ◇ All references in the run-time constant pool are initially symbolic.
- ◇ Symbolic references are derived from the `.class` file in the expected way
- ◇ Class names are those returned by `Class.getName()`
- ◇ Field and method references are made of name, descriptor and class name

2.2.6 Linking

Linking includes *verification, preparation, resolution.*

1. **Verification** multiple checks at runtime, e.g. operand stack under/overflows, validity of variable uses and stores, validity arguments type. Details later on
2. **Preparation** Allocation of storage
3. **Resolution**[2] resolve symbol references by loading referred classes/interfaces

Verification is a relevant part of JVM Specification, it is described in 170pp over a total of 600pp. When a class file is loaded there is a *first* verification pass to check formatting, there is a *second* one when a class file is linked regarding only not instruction-dependant checks. During the linking phase there is a data-flow analysis on each method (*third check*), and lastly (*fourth check*) when a method is invoked for the first time.

2.2.7 Initialization

`<clinit>` initialization method is invoked on classes and interfaces to initialize class variables; it also executes static initializers. `<init>` initialization method instead is used for instances.

[2] Optional, it may be postponed till first use by an instruction

Chapter 3

JVM Instr Set & JIT

3.1 Instruction Set

26 - Settembre

Let's consider the instructions **format**. Each instr may have different *"forms"* supporting different kinds of operands. For example there are different forms of `iload` (i.e. push).

- `iload_0` pushes the first local variable
- `iload_1` pushes the second local variable
- `iload_2` pushes the third local variable
- ...

Runtime memory contains

- Local variable array (frame)
- Operand stack (frame)
- Object fields (heap)
- Static fields (method area)

Note that Java instructions are explicitly typed through **opCodes**, e.g. `dload`,`iload`,`fload`.
opCodes are bytes, allowing only for 256 distinct ones; hence it is impossible to have for each instruction one opCode per type. The JVM specification indicates a selection of which types to support for each op instruction, and not supported types have to be converted; resulting in the Instruction Set Architecture to present non-orthogonality.
Types like `byte`, `char` and `short` are usually converted to `int` when performing computations.

27 - Settembre

3.1.1 Invoking methods

`invokevirtual` causes the allocation of a new frame, pops the arguments from the stack into the local variables of the caller (putting this in 0), and passes the control to it by changing the `pc`.

- A resolution of the symbolic link is performed
- `ireturn` pushes the top of the current stack to the stack of the caller, and passes the control to it. Similarly for `dreturn`, `freturn` ...
- `return` just passes the control to the caller

There are 4 others kinds of method invocation:

- `invokestatic`: call methods with `static` modifier; *this* is not passed
- `invokespecial`: call constructors, `private` methods or *superclass* methods; *this* is always passed
- `invokeinterface`: identical to `invokevirtual`, but used when the method is declared in an interface, thus a different lookup is required

- ◇ `invokedynamic`: introduced in Java 7 to support dynamic typing[1]

In the slides ("JVM Instruction Set") there are many examples on how code snippets are translated into bytecode.

3.2 JIT

AOT **Ahead of Time** *Compilation* leads to better performance in general, exploiting hardware features and variables allocation without runtime lookup; While **Interpretation** facilitates interactive debugging and testing: it allows command-line invocation.

JIT aims to get the advantages of both.

JIT differs from *AOT* since it runs in the same process of the application and competes with the app for resources, thus compilation time for JIT is more relevant than for an AOT Compiler. Besides, a JIT compiler doesn't verify classes at compile time, it is a task performed by the JVM at load time. JIT can exploit new optimization possibilities, e.g. *deoptimization* and *speculation*. A JIT takes bytecode as input and outputs machine code that the CPU executes directly.
Wrapping up:

- ◇ Code starts executing interpreted with no delay
- ◇ Methods that are found commonly executed (*hot*) are JIT compiled
- ◇ Once compiled code is available, the execution switches to it.

To identify *hot* methods, there is a **threshold** on two *per-method* counters:

1. Times the method is invoked
2. Times a brach back to the start of a loop is taken in the method

JIT aims for a tradeoff between "fast-to-start-but-slow-to-execute" interpreter vs "slow-to- start-but-fast-to-execute" compiled code, which may be efficiently implemented by a **multi tier system**, consisting of *interpreter*, *quick compiler*, and *optimizing compiler*.

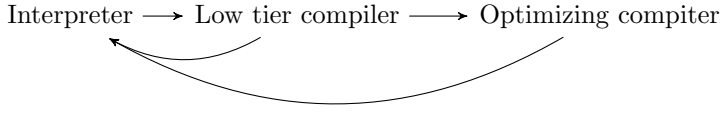
- ◇ Java code starts execution in the interpreter.
- ◇ When a method becomes warm ($threshold :\approx 1.500$), it's enqueued for compilation by the quick compiler.
- ◇ Execution switches to that compiled code when it's ready.
- ◇ Method executing in the second tier is still instrumented: when it becomes hot ($threshold :\approx 10.000$), then it's enqueued for compilation by the optimizing compiler.
- ◇ Execution continues in the second-tier compiled code until the faster code is available.

3.2.1 Deoptimization and Speculation

Usually method executions pass in three phases:

Interpreter $\longrightarrow$ Low tier compiler $\longrightarrow$ Optimizing compiter

But sometimes **deoptimization** can happen, i.e. :



There are Two main possible causes for deoptimization:
- ◇ Corner cases in code
- ◇ *Speculation*: the compiler makes some assumption to generate better (faster) code, but if an assumption is invalidated, then the thread that executes a method that makes such assumption, deoptimizes in order to not execute code that's erroneous (being based on wrong assumptions).

Note that deoptimization is only possible at locations known as **safepoints**; the JVM has to be able to reconstruct the state of execution so the interpreter can resume the thread where the compiled execution stopped.

[1] lambda functions related?

Chapter 4

Component-Based software

2 - Ottobre

Component software indicates **composite systems** made of **software components**. In short, component software allows reuse, improving reliability[1] and reducing costs.
Bertrand Meyer suggests some guidelines regarding Object-Oriented software construction (1997):

1. modular
2. reliable
3. efficient
4. portable
5. timely

4.1 Definitions

Definition 4.1 (Software Component) *A **software component** is a unit of composition with contractually specified **interfaces** and explicit context dependencies only. A software component can be deployed independently and is subject to composition by third parties.*

Let's break down this definition, and explain the key concepts it mentions.

A **contract** is a specification attached to an **interface** (component specification) that mutually binds the clients and providers of the components.
However, contracts in general specify more than dependencies and interfaces, they also specify how the component can be deployed, instatiated, and how its instances behave, ultimately summing up to more than a simple set of per-interface interfaces.

Context dependencies are specification of the deployment environment and run-time environment. This goes beyond the simple interfaces required and provided which are specified in the contract. Context dependencies include required tools, platform and resources.

Deployed independently means that a component can be plugged or unplugged from an architecture, even at runtime in some cases. It is common-practice to deploy "small components" called connectors, to resolve situations where two components supposed to interact do not provide identical interfaces, creating the need for a intermediary.

composition by third party means that a component may interact with third parties components without knowing the internals of such components.

4.2 Concepts of Component Model

- ◇ **Component interface** describes the operations implemented and exposed by the component
- ◇ **Composition mechanism** How components can be composed to work together to accomplish a task
- ◇ **Component platform** A platfom for the development of the compnents

[1] Industries may even require to use *certified* components

Concepts should be laguage/paradigm agnostic, laying the ground for language interoperability.

The ancestors of Components are **Modules**, whose support has been introduced in Java 9, but aren't very common. Some concepts related to modules can be found in more modern notions such as classes, components and packages. For example, objects inside a module are visible to each other, but not visible from outside unless exported. Modules worked —pretty much like classes— as abstraction mechanism → *collection of data with operations defined on them.* In OOP the concept of **inheritance**, unknown in modules, is introduced.

4.3 Components and Programming Concepts

Components can be anything and can contain anything, they can be *collections of* classes, objects, functions/algorithms, data structures.
They support:

- ◇ **Unification** of data and function
- ◇ **Encapsulation**: no visible state
- ◇ **Identity**: each software entity has a unique identity
- ◇ Use of interfaces to represent specification dependencies

4.3.1 OOP vs COP Comparison

¡Note that ***OOP*** $\neq$ ***COP!***

OOP *isn't* focused on **reuse**, instead its focus in onto appropriate domain and problem representation. Objects, classes, inheritance and polymorphism are concepts/tools typically exploited in OOP.
COP (more precisely CBSE[2]), on the other hand, is focused on **reuse** and **composition** of software components. It is a way to build software systems by assembling prefabricated components. In general it provides methods and tool for:

- ◇ Building systems from components
- ◇ Building components as reusable units
- ◇ Performing maintenance by replacement of components and introducing new components into the system
- ◇ System architecture detailed in terms of components

4.3.2 Component forms

- ◇ **Component Specification** describes the behavior (as a set of *Interfaces*) of a set of Component Objects and defines a unit of implementation.
- ◇ **Component Implementation** is a realization of *Component Specification* which can be independently deployed[3].
- ◇ **Installed Component** is an installed (i.e. *deployed*) copy of a *Component Implementation.*
  A Component Implementation is deployed by registering it with the runtime environment
- ◇ **Component Object** is an instance of a *Installed Component.* It is a runtime concept, an object with its own data and unique identity. Ideally, it is the "thing that performs the implemented behaviour". An *Installed Component* may have multiple *Component Objects.*

Some examples of successful components are Plugin architectures, Microsoft's Visual Basic, Operating Systems, Java Beans, and others. It is clear that components can be purchased by independent providers and deployed by the clients, and that multiple components can coexist in the same installation. Besides, components exist on a level on abstraction where they directly mean something to the deploying client.

Recalling the comparison with modules, while modules are usually seen as part of a program, *components are parts of a system.*

[2]Component-based software engineering
[3]It does **not** mean that it cannot have *dependencies* nor that it must be a *single file*

Chapter 5

Java Beans

3 - Ottobre

5.1 Components applied to Java

"A **Java Bean** is a *reusable* software component that can be manipulated visually in a builder tool."

Typically a Bean has a GUI representation but is not necessary; there exist *invisible beans* as well. What is necessary instead for a class to be recognized as a bean is that it:

- ◇ has a public constructor with no arguments
- ◇ implements `java.io.Serializable`
- ◇ is in a `jar` file with a *manifest* file that contains: `Java-Bean: True`
  Actually this ain't true. The JVM itself does not require this manifest entry to recognize a class as a JavaBean. The JVM relies on the class's structure and interfaces (like having a no-argument constructor and implementing Serializable). Tools like IDEs and builders might require the manifest entry to recognize a class as a JavaBean.
  In my assignments, i didn't need to add this entry to the manifest file. ☺

Beans can be **assembled** to build a new bean or application, writing clue code to wire beans together. *Connection-oriented* programming is based on the **Observer** or (*Publish-Subscribe*) paradigm. *Observers* come into play when there is a $1 : N$ dependency between objects and one of them changes state, creating the need for the others to be notified and updated. Beans must be able to run in a *design environment* allowing the user to customize aspect and behaviour. Beans provide support for some standard features:

1. **Properties** e.g. color. **Bounded** properties generate an *event* of type `PropertyChangeEvent`, while **constrained** can only change value if none of the registered *observers* "poses a veto", by raising an *exception* when they receive the `PropertyChangeEvent` object.
   A subject should register an observer implementing `PropertyChangeListener` and use— `firePropertyChange` to notify the observer, allowing him to **veto** the change, in case constrained.
2. **Events**: The **Observer** pattern is based on *Events* and *Events listeners*. An *event* is an object created by an *event source* and propagated to the registered *event listeners*.
   Sometimes event **adaptors** can be placed between source and listener, which might implement queuing mechanism, filter events, demuxing from many sources to a single listener.
   In general the *Observer* pattern aims at defining a one-to-many dependency among objects so that when one object changes state, all of its dependents are notified and updated automatically.
   - ◇ **Design Patterns for Events**

   ```
   public void add<EventListType>(<EventListType> a)
   public void remove<EventListType>(<EventListType> a)
   ```

3. **Customization**: in the builder the user can customize the appearance and behaviour of the bean.
4. **Persistence**: a bean can be customized in an application builder and then have its customized state saved away and reloaded later.
5. **Introspection**: process of analyzing a bean to determine capabilities. There are implicit methods based on *reflection*, *naming conventions* and *design patterns*, but can be simplified by explicitly defining info for the builder tool in the `<BeanName>BeanInfo` class. Such class allows exposition of features, specifying customizer class, segregate feats in normal/expert mode, and some other stuff.
   - ◇ **Design Patterns for Simple Methods**

```
public <PropertyType> get<PropertyName>();
public void set<PropertyName>(<PropertyType> a);
```

◇ **Design Patterns for Simple Methods**

```
public java.awt.Color getSpectrum (int index);
public java.awt.Color[] getSpectrum ();
public void setSpectrum (int index, java.awt.Color color);
public void setSpectrum (java.awt.Color[] colors);
```

Chapter 6

Reflection

9 - Ottobre

6.1 Introduction and Definitions

Reflection is the ability of a program to manipulate as data something representing the state of the program during its own execution. Another dimension of reflection is if a program is allowed to **read only**, or also to **change** itself.

- ◇ **Introspection** is the ability of a program to observe and therefore reason about its own state
- ◇ **Intercession** is the ability for a program to modify its own execution state or alter its own interpretation or meaning
- ◇ **Reification** is the mechanism of encoding execution state into data, which is needed by both *introspection* and *intercession*

Structural reflection is concerned with the ability of the **language** to provide a complete *reification* of both the *program* executed and its *abstract data types*.
Behavioral reflection is concerned instead with the reification of its[1] *semantics* & *implementation* (processor) and the data and implementation of the *run-time system*.

6.2 Uses and drawbacks

6.2.1 Uses

- ◇ *Class Browsers* need to be able to enumerate the number of classes
- ◇ *Visual Development Environments* can exploit type info available in reflection to aid the developer in writing correct code
- ◇ *Debuggers* need to be able to examine private members on classes
- ◇ *Test Tools* exploit reflection to ensure a high level of code coverage in a test suite
- ◇ *Extensibility Features* an app may make use of external, user-defined classes by creating instances of extensibility objects.

6.2.2 Drawbacks

If it is possible to perform an operation without using reflection, then it is preferable to avoid using it. Reflection is powerful, but it has some drawbacks:

- ◇ **Performance Overhead** - Reflection involves types that are dynamically resolved, thus optimizations can not be performed, and reflective operations have slower performance than their non-reflective counterparts
- ◇ **Security Restrictions** - Reflection requires a runtime permission which may not be present when running under a security manager. This affects code which has to run in a restricted security context, such as in an Applet.
- ◇ **Exposure of internals** - Reflective code may access internals (like private fields), thus it breaks abstractions and may change behavior with upgrades of the platform, destroying portability.

[1] referred to a **language**

6.3 Reflection in Java

Java supports **introspection** and **reflexive invocation**, but not *code modification*.

6.3.1 Introspection

The JVM mantains for every type an associated object of type `java.lang.Class` which "*reflects*" the type it represents, acting as entry point for reflection, since it provides all info needed:

- ◇ Class name and modifiers
- ◇ Extended superclasses and implemented inferfaces
- ◇ Methods, fields, constructors, etc.

- After we obtain a Class object `myClass`, we can:
- Get the class name
  ```
  String s = myClass.getName() ;
  ```
- Get the class modifiers
  ```
  int m = myClass.getModifiers() ;
  bool isPublic = Modifier.isPublic(m) ;
  bool isAbstract = Modifier.isAbstract(m) ;
  bool isFinal = Modifier.isFinal(m) ;
  ```
- Test if it is an interface
  ```
  bool isInterface = myClass.isInterface() ;
  ```
- Get the interfaces implemented by a class
  ```
  Class [] itfs = myClass.getInterfaces() ;
  ```
- Get the superclass
  ```
  Class super = myClass.getSuperClass() ;
  ```

Figure 6.2: Inspecting a Class

To retrieve such `java.lang.Class` object it is sufficient to do `Object.getClass()`. `Class` objects are constructed automatically by the JVM as classes are loaded.

Using `java.util.reflect.*` it is possible also to retrieve class **Members** i.e. *fields, constructors* and *methods*. The extensive `java.util.reflect.*` API provides many *methods* to achieve this which will not be reported here.
There is a class for each Member

- ◇ `java.util.reflect.Field`: access type info and set/get values.
- ◇ `java.util.reflect.Method`: type info for parameters and return type; invoking method on a given object.
- ◇ `java.util.reflect.Constructor`: note that constructors have no return values and invocation creates a new instance of the given class.

Member	Class API	List of members?	Inherited members?	Private members?
Field	`getDeclaredField(String)`	no	no	yes
	`getField(String)`	no	yes	no
	`getDeclaredFields()`	yes	no	yes
	`getFields()`	yes	yes	no
Method	`getDeclaredMethod(...)`	no	no	yes
	`getMethod(...)`	no	yes	no
	`getDeclaredMethods()`	yes	no	yes
	`getMethods()`	yes	yes	no
Constructor	`getDeclaredConstructor(...)`	no	N/A	yes
	`getConstructor(...)`	no	N/A	no
	`getDeclaredConstructors()`	yes	N/A	yes
	`getConstructors()`	yes	N/A	no

Table 6.1: Class API Members

6.3.2 Program Manipulation

By now we have talked only about **introspection** in java, but reflection can be used also to create objects of a type not known at compile time, or to access members (access fields or invoke methods) unknown at compile time.

Certain operations are forbidden by privacy rules and fail if invoked through reflection:

- ◇ Changing a final field
- ◇ Reading or writing a private field
- ◇ Invoking a private method...

However The programmer can request that Field, Method, and Constructor objects to be "accessible". In this case you can invoke method or access field, even if inaccessible via privacy rules! `AccessibleObject` Class is the superclass of `Field`, `Method`, and `Constructor`

Request granted if no security manager, or if the existing security manager allows it

`AccessibleObject` provides the methods:

- ◇ `boolean isAccessible( )` - Gets the value of the accessible flag for this object

- ◇ `void setAccessible(boolean flag)` - Sets the accessible flag for this object to the indicated boolean value. This makes a private field accessible, preventing from throwing an `IllegalAccessException`.
- ◇ `static void setAccessible(AccessibleObject[] array, boolean flag)` - Sets the accessible flag for an array of objects with a single security check

6.4 Case of use

Reflection may be used for **Unit Testing** to test methods and their result. JUnit is a framework that makes use of reflection to test methods, exploiting constructs similar to the generic driver below:

```
public static void testDriver( String testClass ) {
    Class c = Class.forName( testClass );
    Object tc = c.newInstance( );
    Method[ ] methods = c.getDeclaredMethods( );

    for( int i = 0; i < methods.length; i++ ) {
    if( methods[ i ].getName( ).startsWith( "test" ) &&
        methods[ i ].getParameterTypes( ).length == 0 )
        methods[ i ].invoke( tc );
    }
}
```

Chapter 7

Annotations

9 - Ottobre

In java, `static`,`private`,... modifiers are *meta-data* describing properties of program elements. **Annotations** can be understood as (user-) definable modifiers. They are composed by one or two parts:

1. **name**
2. finite number of **attributes** i.e. `name=value`. There may be no attributes.

The syntax is the following:

```
    @annName             // e.g. Override
    @annName{constExp}   // shorthand for @annName{value=constExp}
    @annName{name_1 = constExp_1, ..., name_k = constExp_k}
```

`constExp` are expression which can be evaluated at *compile time*. Besides, attributes have a *type*, thus the supplied values have to convertible to that type.
Annotations can be applied to almost any syntactic element, from packages to parameters and any type use.

7.1 Defining annotations

```
@interface InfoCode {
    String author ();
    String date ();
    int ver () default 1;
    int rev () default 0;
    String [] changes () default {};
}
```

This defines the custom annotation InfoCode, imposing some fields possibly with default values. It can be used as follows:

```
@InfoCode(author="Beppe", date="10/12/07")
    public class C {
    public static void m1() { /* ... */ }
    @InfoCode(author="Gianni",
        date="4/8/08", ver=1, rev=2)
    public static void m2() { /* ... */ }
}
```

Clearly, reflection can be used to access annotations at runtime using `getAnnotations()`, if they have been **retained** by the compiler; in fact, annotations are not retained by default, but they can be forced to be retained by using the `@Retention` annotation, which takes a `RetentionPolicy` as argument, either `SOURCE`, `CLASS` or `RUNTIME`.

Chapter 8

Polymorphism

Polymorphism basically means *"many forms"*, where *forms* are **types**. Thus there may be *polymorphic* function names, or *polymorphic* types.

There are many "flavors" of polymorphism, many variations. Two main kinds opposed to each other are *ad hoc* and *universal* polymorphism, which however, may coexist:

- ◇ **ad hoc** PM indicates that a single function name denotes different algorithms, determined by the actual types.
- ◇ **universal** PM indicates a single algorithm (solution) applicable to objects of different types.

When PM is taken into account, it is crucial to consider when happens the **binding** between a function name and the actual code to be executed:

- ◇ compile time; *static/early binding*
- ◇ linking time
- ◇ execution time; *late/dynamic binding*

In general the earlier the binding happens, the better (for debugging reasons). If the binding spans over more phases (e.g. *overriding* in Java), as a convention we consider the **binding time** the last phase.

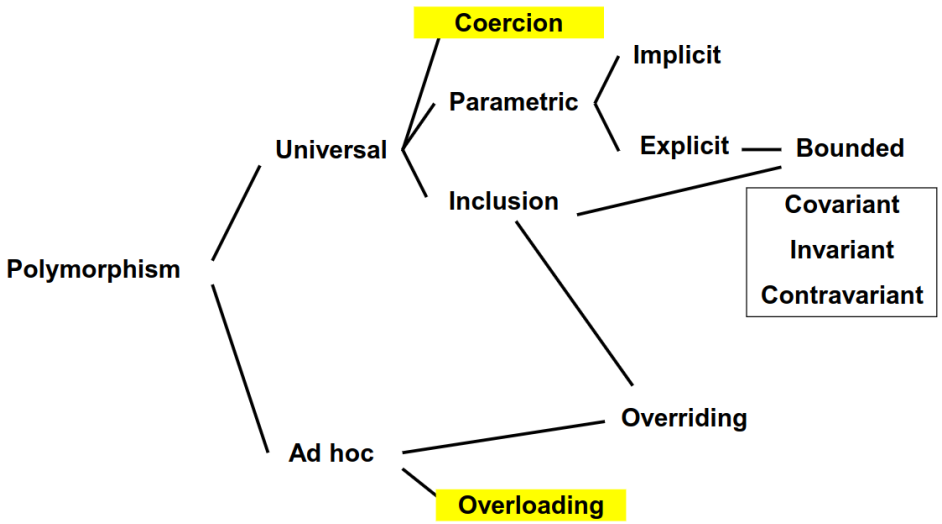


Figure 8.1: Polymorphism classification

8.1 Overloading

Overloading is present in every language for basic operators $+ - *$..., and sometimes is supported for user-defined functions, and in some languages it is even allowed the overloading of primitive operator by user-defined functions. Since this falls under the **ad hoc** polymorphism family, the code to be executed is determined by the type of the arguments; the binding can either happen at *compile* or at *runtime*, depending on the typing of the language, whether

it is static or dynamic.

```
// C language doesn't allow overloading for user-defined functions
int sqrInt(int x) { return x * x; }
double sqrDouble(double x) { return x * x; }

// Overloading in Java & C++
int sqr(int x) { return x * x; }
double sqr(double x) { return x * x; }
```

8.1.1 Haskell and Rust

Haskell introduces **type classes** for handling overloading in presence of type inference.
A type class defines a set of functions that can be implemented by different types. For example, the `Eq` type class defines the equality operator (`==`) which can be used to compare integers, characters, and other types.

Haskell's compiler can automatically determine the types of expressions without explicit type annotations. Type classes work seamlessly with **type inference** to ensure that the correct function implementation is chosen based on the inferred types.

```
-- Define a custom data type
data Color = Red | Green | Blue

-- Make Color an instance of Eq
instance Eq Color where
Red == Red = True
Green == Green = True
Blue == Blue = True
_ == _ = False

-- Example usage
main :: IO ()
main = do
print (Red == Red)   -- Output: True
print (Red == Green) -- Output: False
```

In Rust instead has **Traits** which are similar to type classes in Haskell: they define a set of methods that a type must implement.

```
use std::ops::Add;
// Define a custom struct
#[derive(Debug)]
struct Point {
    x: i32,
    y: i32,
}

// Implement the Add trait for Point
impl Add for Point {
    type Output = Point;

    fn add(self, other: Point) -> Point {
        Point {
            x: self.x + other.x,
            y: self.y + other.y,
        }
    }
}
```

8.2 Coercion

Coercion is the automatic (implicit) conversion of an object to a different type, opposed to casting which is explicit instead. Coercion allows a code snippet to be applied of arguments of different (convertible) types. Sometimes coercion is allowed only if there is no **information loss**.

```
double sqrt(double x){...}
double d = sqrt(5) // applied to int
```

8.3 Inclusion Polymorphism

Inclusion polymorphism is also known as *subtyping polymorphism* or ***inheritance***. It is ensured by *Barbara Liskov*'s **substitution principle**:

A subtype object can be used in any context where a supertype object is expected

Methods and fields defined in a superclass may be invoked and accessed by subclasses if not redefined (see *Overriding*). Note, again, that this refers to using superclass methods, not overriding them.

8.4 Overriding

In Java a method m of a class A can be redefined in a subclass B of A.

Overriding introduces ad hoc polymorphism in the universal polymorphism of inheritance. Notice that even though written in the subclass definition, overriding requires the final binding to happen at runtime: it happens through the lookup done by `invokevirtual` in the JVM.

8.5 C++ v Java

```
class A {
 public:
  virtual void onFoo() {}
  virtual void onFoo(int i) {}
};
class B : public A {
 public:
  virtual void onFoo(int i) {}
};
class C : public B {};
int main() {
  C* c = new C();
  c->onFoo();
  // Compile error - doesn't exist
}
```

The equivalent code in Java compiles, because in java invokes the function `onFoo()` with no arguments defined in the superclass A. In C++ instead, the function `onFoo(int i)` defined in B is found and stops the search, but there is arguments type mismatch, thus it doesn't compile. This happens because in C++ the method lookup is based on the method *name*, not on its *signature*.

The solution is to add using `A::onFoo;` to class B.

8.6 Parametric Polymorphism

8.6.1 Templates vs Generics

They are similar to *Generics* in Java, they are used as function and class templates each concrete instantiation produces a copy of the generic code, specialized for that type: **monomorphization**. In java Generics, instead, **type erasure** happens at runtime, i.e. type variables `T` are replaced by `Object` variables.
Templates support parametric polymorphism and type parameters can also be primitive types (unlike Java generics)

```
    template <class T> // or <typename T>
    T sqr(T x) { return x * x; }
```

Assuming to invoke `sqr(T x)` on variables of different types, the compiler will generated a specific code for each type used. This works even on user-defined types; check the following code for an example:

```
class Complex {
 public:
  double real;
  double imag;
  Complex(double r, double im) : real(r), imag(im){};
  Complex operator*(Complex y) {  // overloading of *
    return Complex(real * y.real - imag * y.imag,
                   real * y.imag + imag * y.real);
  }
};

Complex cc = sqr(c); // legal and produces a function "Complex sqr(Complex x) {...}"
```

It is important to check for type ambiguosity; in the following example, it is highlighted a case where it's not clear whether it is `i` to be converted to `long` or `m` to `i`.

```
template <class T>
T GetMax(T a, T b) {  return (a > b) ? a : b; }
```

```
...
n = GetMax(l, m);        // ok: GetMax<long>
// v = GetMax(i, m);     // no: ambiguous
v = GetMax<int>(i, m);   // ok
```

8.6.2 Macros

Macros can be exploited to achieve *polymorphism* and can have the same effect of the templates, but notice that macros are executed by the preprocessor[1] and are only **textual substition**, there is no parsing, no static analysis checks or whatsoever.

```
#define sqr(x) ((x) * (x))
int a = 2;
int aa = sqr(a++); // int aa = ((a++) * (a++));
// value of aa? aa contains 6  :(

#define fact(n) (n == 0) ? 1 : fact(n-1) * n
// compilation fails because fact is not defined
```

16 - Ottobre

8.6.3 Specialization

A template can be **specialized** by defining a template with the same name but with more specific parameters (*partial specialization*) or with no parameters (*full specialization*). This is kinda similar to *Overriding*, leaving to the compiler the choice of the most appropriate template.

```
/* Primary template */
template <typename T> class Set {
        // Use a binary tree
    };
/* Full specialization */
template <> class Set<char> {
        // Use a bit vector
    };
/* Partial specialization */
template <typename T> class Set<T*> {
        // Use a hash table
    };
```

Templates can be used by a compiler to generate temporary source code, which is merged by the compiler with the rest of the source code and then compiled.

Template compilation happens *on demand*: the code of a template is not compiled until an instantiation is required, however in case of *fully-specialized* template, the compiler treats the template as a function, thus it generates its code **regardless** whether it is ever used or not.

Note that in C/C++ while method *prototypes* usually are in a separate `.h` file, the compiler needs the template *declaration* and *definition* in the same place to instatiate it.

[1] Macro expansion can be seen using the option *-E* when compiling

Chapter 9

Generics

Generics are instance of *Universal Polymorphism* with *explicit parameters* (see Fig 8.1).

9.1 Methods

Methods can use the type parameters of the class where they are defined, if any, but they can also introduce their own type parameters

```
class MyList<T> {
   List <T> list = new ArrayList<T>();
   public T getFirst() {}
   public static <V> V getFirst(List<V> list) {}
```

Invocations of generic methods must instantiate all type parameters, either explicitly or implicitly. Some sort of *type inference* is applied in case of implicit instantiation.

9.1.1 Bounded Type Parameters

```
class NumList<E extends Number> {
      void m(E arg) {
            arg.intValue();   // OK, since...
            // Number and its subtypes support intValue()
         }
   }
```

Type parameters can also be **bounded** as in the above example, allowing methods (and fields) defined in the **bound** to be invoked on objects of the type parameter `T`.
There may be various kinds of type bounds:

```
<TypeVar extends SuperType>
   // UPPER bound; SuperType and any of its subtype are ok.
<TypeVar extends ClassA & InterfaceB & InterfaceC & ...>
   // MULTIPLE UPPER bounds
<TypeVar super SubType>
   // LOWER bound; SubType and any of its supertype are ok
```

Unlike C++ where *overloading* is resolved and can **fail** after instantiating a template, in Java **type checking** ensures that overloading will succeed.

9.2 Inheritance and Arrays

9.2.1 SubTyping (Inheritance)

There are two major issues which came up along with generics. The first one regards **inheritance**; consider the following example:

Since `Integer` is a *subtype* of `Number`,
is `List<Integer>` *subtype* of `List<Number>`?

NO!

In a formal way, *subtyping is invariant* for Generic classes. Informally, given `A,B` concrete types, `MyClass<A>` has no relationship to `MyClass<B>`, even if `A,B` have one.
On the other hand if `A extends B` and are *generic* classes, then `A<C> extends B<C>` for any type `C`. For example, `ArrayList<Integer> extends List<Integer>`.

Note that the common parent of `MyClass<B>` and `MyClass<A>` is `MyClass<?>`. This misty wildcard `?` will be discussed later.

9.2.2 Covariance

Let's now discuss **covariance** and **contravariance**, with the aid of a few examples.

```
List<Integer> lisInt = new ...;
List<Number> lisNum = new ...;
//lisNum = lisInt; // COMPILER ERROR - Reassign pointer
lisNum.add(new Number(...)); // NOT ALLOWED
//listInt = lisNum; // COMPILER ERROR - Reassign pointer
Integer n = lisInt.get(0); // NOT ALLOWED
```

`List<Integer>` is neither a subtype or a supertype of `List<Number>`, thus the above operations aren't allowed. However there are *read-only* and *write-only* situations where they may be allowed.

```
RO_List<Integer> lisInt = new ...;
RO_List<Number> lisNum = new ...;
//lisNum = lisInt; // COMPILER ERROR
Number n = lisNum.get(0); // OK
```

Covariance refers to the ability to substitute a subtype where a supertype is expected. In simpler terms, it means that if you have a class `RoList<Number>`, you should be able to use `RoList<Integer>` wherever `RoList<Number>` is expected, because `Integer` is a subtype of `Number`.
This is in Java allowed only for *read-only* operations. It is ok to *read* a **supertype** starting from a **subtype**.

covariance** is safe if the type is **read-only

In Java everything is invariant by default -except for `arrays[]`, which are covariant-, but it is possible to use *wildcards* to allow covariance and contravariance.

Let's provide a different example to understand the concept of covariance: you can assign to a *covariant* ***`Fruit`** list* a list of `Apples`, because `Apples` are a subtype of `Fruit` and you can legally read from a `Fruit` list an `Apple`, since it is a `Fruit`. However, you cannot write any subtype of `Fruit` in a covariant `Fruit` list, because such thing would allow you to add a `Banana` in a list of `Apples`, which we don't want. So... **read-only**.

This implicitly happens with *wildcards* in Java, while in other languages such as C# and Scala, when a class is declared as *covariant*, limitations are applied to the class itself.

9.2.3 Contravariance

```
WO_List<Integer> lisInt = new ...;
WO_List<Number> lisNum = new ...;
//lisInt = lisNum; // COMPILER ERROR
lisInt.add(new Integer(...)); // OK
```

Contravariance allows a supertype to be substituted where a subtype is expected. In simpler terms, it means that if you have a class `WoList<Integer>`, you should be able to use `WoList<Number>` wherever `WoList<Integer>` is expected,

because `Number` is a supertype of `Integer`.
This is in Java allowed only for *write-only* operations. It is ok to *write* a **subtype** in the place of from a **supertype**.

contravariance** is safe if the type is **write-only

Copilot example

So, let's go back to fruit. Imagine you have a contravariant function that accepts a list of `Fruit` and processes it. This function can also accept a list of `Apples`, because `Apples` are a subtype of `Fruit`. However, you cannot pass a list of `Fruit` to a function that expects a list of `Apples`, because the function might expect specific behaviors or properties of `Apples` that `Fruit` might not have. However, you cannot assign a `Fruit` processor to a *contravariant* ***`Apple` processor***, because the `Apple` processor might expect specific behaviors or properties of `Apples` that not all `Fruit` possess. So, the assignment is restricted to ensure type safety.

In summary, contravariance allows you to use a more specific type (like `Apple`) where a more general type (like `Fruit`) is expected, but not the other way around. This ensures that the specific requirements of the subtype are always met.

9.2.4 Wildcards

Wildcards are strongly related to the topic of *covariance* and *contravariance*.
As briefly mentioned before, wildcards are the only relationship between generic classes.

To use *wildcards*, the **PECS** principle is applied: ***P**roducer **E**xtends, **C**onsumer **S**uper*.

- ◇ `? extends T` to **get** values from a *Producer*: **covariance** allowed
- ◇ `? super T` to **insert** values into a *Consumer*: **contravariance** allowed
- ◇ Never use `?` when both insertion and retrieving is needed, `T` is sufficient and way more appropriate.

Wildcards improve type-safety, allowing a program to fail at *compile-time* instead of *runtime*.

```
List<Apple> apples = new ArrayList<Apple>();
List<? extends Fruit> fruits = apples;
fruits.add(new Strawberry()); // COMPILING FAILS
```

17 - Ottobre

Other languages

In the case of **C#**, generic classes can be marked with the keyword `out` (*covariant*) or `in` (*contravariant*), otherwise the class is invariant. In **Scala** the same happens, but with the `+` or `-` operators.

9.2.5 Arrays

Let's now discuss **arrays**.
Let `A extends B`, then `A[] extends B[]` even if instead `Array<A>` is not related to `Array<B>`.

Thus, *arrays in Java are **covariant**.*

However there is a counterpart, since this allows rule-breaking assignments which are allowed by the compiler but which lead to a runtime `ArrayStoreException`. This happens because the dynamic type of an array is checked at runtime. Knowing this, for each array update, a runtime check is performed by the JVM which throws the exception if needed.

```
Apple[] apples = new Apple[1];
Fruit[] fruits = apples;       // Ok, covariance
fruits[0] = new Strawberry(); // Compiles!
// Throws ArrayStoreException at runtime
```

After compilation Generic are all **type-erasured** to `Object` or to their first *bound*, if present. This choice has been made mainly for compatibility with legacy code, leading all instances of the same generic type to have the same type at runtime; i.e.

```
List<String> lst1 = new ArrayList<String>();
List<Integer> lst2 = new ArrayList<Integer>();
assert(lst1.getClass() == lst2.getClass())   // true!
```

9.2.5.1 Generic Arrays

What about *arrays of generics*? Such arrays in Java are **not allowed**, because every array update needs a runtime check which is impossible to perform on generics, since at runtime generics are all of the same type due to *type-erasure*.

9.3 Generics Limitations

- ◇ Cannot instantiate Generics with primitive types:

```
ArrayList<int> a = ...                    // compile error
```

- ◇ Cannot create instances of type parameters
- ◇ Cannot declare static fields whose types are type parameters

```
public class C<T>{ public static T local; ...}
```

Because static fields are represented in the **unique** representation of the class in the dedicated static memory area of the JVM for classes

- ◇ Cannot use casts or instanceof with parameterized types

```
mylist instanceof ArrayList<Integer>      // fails
mylist instanceof ArrayList<?>            // OK
```

- ◇ Cannot Create arrays of parameterized types
- ◇ Cannot create, catch, or throw objects of parameterized types
- ◇ Cannot overload a method where the formal parameter types of each overload erase to the same raw type.

```
public class Example {                    // does not compile
   public void print(Set<String> strSet) { }
   public void print(Set<Integer> intSet) { } }
```

Chapter 10

Standard Templates Library

17 - Ottobre

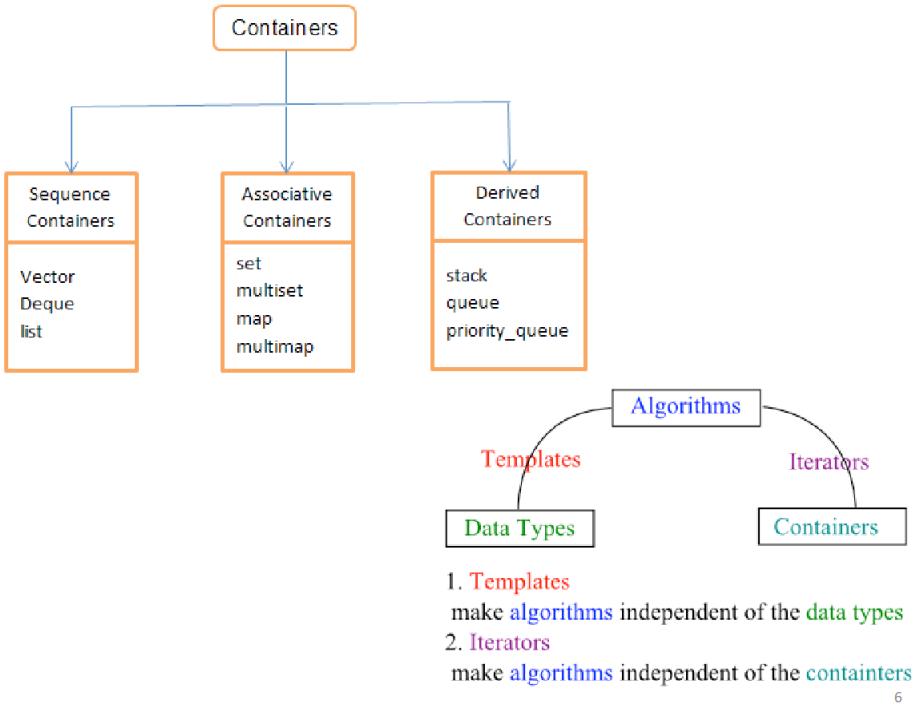
The goal of STL is to represent algorithms in as general form as possible without compromising efficiency. There is an extensive use of **templates**, **overloading**

Same function name, the algorithm to be executed is determined by the type of the arguments

and **iterators**, which are used for decoupling algorithms from containers, and can be seen as an abstraction of pointers.
STL is very different from the *Java Collection Library* since it does **not** use *dynamic binding* and is **not** *object oriented*; instead the STL uses only *static binding* and *inlining*.

10.1 Main Entities

- **Container** collection of *typed* objects
- **Iterator** Generalization of pointer or address; used to step through the elements of collections
- **Algorithm** initializing, sorting, searching, and transforming contents of containers
- **Adaptor** Convert from one form to another e.g. iterator from updatable container; or stack from list
- **Function Object** Form of closure (class with "operator()" defined)
- **Allocator** encapsulation of a memory pool



10.2 Iterators

Since algorithms cannot be used *directly* on different kinds of collections, Iterators come in handy by providing a **uniform**, **linear** access to elements of different collections.

In **Java** iterators are supported by the *JCF*[1] through the interface `Interface<T>`. They are related to an **instance** of a class and are usually defined as *nested classes*, more precisely *non-static private member classes*.
Collections equipped with iterators must `implements Iterable<T>` interface.

18 - Ottobre

In **C++** there is no `next/hasNext()` function, standard `++ --` operators are used instead.
In case of *arrays* pointers can be trivially used, since `int v[]` is no different `int *v`[2]. In the case of `vector` instead, an actual *iterator* may be instantiated, but the operator `++` stays the same.

```
vector<int> vec;
vector<int>::iterator v = vec.begin();
while( v != vec.end()) {
   cout << "value of v = " << *v << endl;
   v++;
}
```

Every class in C++ has its own iterator; more specifically, containers define and expose a type named iterator in the container's **namespace**, allowing the semantic value of `iterator` to change according to the context.

10.2.1 C++ iterators implementation

Typically iterators are implemented as `struct` and provide a visit of the container, retaining information about the **state** of the visit, e.g. pointer to next element, remaining elements, and so on. Note that in case of *trees* or *graphs* the visit's state may not be trivial to be represented.

```
template <class T>
struct v_iterator {
  T* v;
  int sz;
  v_iterator(T* v, int sz) : v(v), sz(sz) {}
  // != implicitly defined
  bool operator==(v_iterator& p) { return v == p->v; }
  T operator*() { return *v; }
  v_iterator& operator++() {  // Pre-increment
    if (sz)
      ++v, --sz;
    else
      v = NULL;
    return *this;
  }
  v_iterator operator++(int) {  // Post-increment!
    v_iterator ret = *this;
    ++(*this);  // call pre-increment
    return ret;
  }
};
```

Container	*insert/erase* beginning	middle	end
vector	linear	linear	amortized constant
list	constant	constant	constant
deque	amortized constant	linear	amortized constant

Table 10.1: **Guaranteed** time complexity for iterators

To achieve transparency to third-party algorithms STL assumes *constant* time for every operation, and allows 5 types of operators:

[1] *Java Collection Framework*
[2] At least from an "accessing values" point of view, there are some differences in terms of static/dynamic allocation of memory.

- ◇ *Formard iterators* only dereference and pre/post increment
- ◇ *Input (and Output) iterators* same as *formard iterators* but with possible issues when dereferencing
- ◇ *Bidirectional iterators* dereference, pre/post increment and decrement
- ◇ *Random access iterators* same as Bidirectional but allow also integer sum $(p + n)$ and difference $(p - q)$

Each category defines only the functions which take constant time. Not all iterators are defined for all containers, e.g. since *random access* takes *linear* time on lists, there is no *random access* iterator on *lists*.

Any C++ pointer type, T*, obeys all the laws of the random access iterator category

10.2.2 Invalidation

When a container is *modified*, iterators *may* become **invalid**: no "exception" is thrown, iterators can still be used, but their behaviour is **undefined**. ***Not*** *every operation* invalidates iterators, it depends on the operation and on the container. For example, inserting an element in a `list` allows all iterators to remain valid, while inserting an element in a `vector` invalidates all of them, since reallocation is necessary.

The main limiting aspect of STL's iterators is that they provide a **linear view** of the container, allowing the definition of operations only on one-dimensional containers; thus, if it is needed to access the organization of the container (e.g. tree custom visist), the only way-to-go is to define a custom iterator which behaves as desired.

10.3 C++ specific features

10.3.1 Inheritance

STL relies on typedefs combined with namespaces to implement genericity, the programmer always refers to `container ::iterator` to know the type of the iterator. Note that there is no relation among iterators for different containers (!), if not a semantically abstract one. The reason for this is **performance**: without *inheritance*, types are resolved at compile time and the compiler may produce better and optimized code. On the other hand sacrificing inheritance may lead to lower expressivity and lack of type-checking; in fact, STL relies only on coding conventions: when the programmer uses a wrong iterator the compiler complains of a bug in the library.

10.3.2 Inlining

C++ standard has the notion of **inlining** which is a form of semantic macros. Inline methods should be available in header files and can be labelled *inline* or defined within class definition, invocation on such methods is type-checked and then it is replaced by the method body. The compiler tends to (automatically?) inline methods with small bodies and without iteration; it is able to determine types at compile time and usually does inlining of function objects.

```
template <class T>
inline T sqr(T x) { return x * x; }
```

10.3.3 Memory management

STL abstract from the specific memory model using a concept named **allocators**. All the information about the memory model is encapsulated in the **Allocator** class. Each container is parametrized by such an allocator to let the implementation be unchanged when switching memory models.

10.3.4 Potential Problems

The problem may be error checking: almost all facilities of the compiler fail with STL resulting in lengthy error messages that ends with error within the library

Chapter 11

Functional Programming

Functional Programming languages radicate their roots in the Church's model of computing known as ***lambda calculus***. Such model is based on the notion $\lambda -$ *parametrized expressions*, with the focus on defining mathematical functions in a constructive and effective way. The computation proceeds by substituting parameters into expressions.

Functional programming languages such as *Lisp, Scheme, FP, ML, Miranda* and *Haskell* aim to implement Church's lambda calculus in the form of a programming language which does everything needed by **composing functions**, thus no *mutable* ***state*** and no *side effects*.

FPL[1] needs some key features which are often absent in *imperative* languages:

- 1^{st}-class order and **high-order** functions: Functions can be *denoted*, passed as *arguments* to other functions, *returned* as result of function invocation
- **Recursion** opposed to *"control variables"*
- **Powerful list facilities**: Recursive functions exploit recursive definition of lists
- **Polymorphism** typically universal parametric implicit, which plays a key role when handling containers/collections.
- **Fully general aggregates**: there is a wide use of tuples and records, besides, data structures cannot be modified (*no state!*), they have to be re-created.
- **Structured function returns** allow to pass more meaningful information to the caller, avoiding the need for "side-effects".
- **Gargabe collection**

23 - Ottobre

11.1 FP language families

1. **LISP**: currently most used for *AI* after Python. Original LISP is no longer used, the current standard is *Common LISP* which introduced statical scope opposed to the dynamic one of *Original LISP* ; another version is called *Scheme*
2. **ML**: Common languages of this family are *Standard ML, Caml,OCaml, F#*. These are compiled languages, but intended for interactive use. ML results from the combination of Lisp and Algol-like features, including Garbage collection, Abstract data types, Module system and Exceptions
3. **Haskell**: Many features are shared with *ML* languages, but with some differences.
   - Type inference, Implicit parametric polymorphism, Ad hoc polymorphism (**overloading**) with type classes
   - **Lazy** evaluation, Tail recursion and continuations
   - **Purely functional** $\rightarrow$ precise management of side effects

[1] Short for ***F**unctional **P**rogramming **L**anguages*

11.2 Haskell basics

Basic types

- ◇ `Unit`
- ◇ `Booleans`
- ◇ `Integers`
- ◇ `Strings`
- ◇ `Reals`
- ◇ `Tuples`
- ◇ `Lists`
- ◇ `Records`

Other types

- ○ Patterns
- ○ Declarations
- ○ Functions
- ○ Polymorphism
- ○ Type declarations
- ○ Type Classes
- ○ Monads
- ○ Exceptions

Note that basic types are written with the first letter Uppercased.

Haskell provides an interactive read-eval-print interpreter (`ghci`): many examples are available in the lecture's slides, here we will discuss only some more interesting ones.

Variables (**names**) are bound to expressions, *without* evaluating them (because of *lazy evaluation*); the scope of the binding is the rest of the session.

```
ghci> let a = 3    -- 'let' can be omitted
ghci> b = a + 2
ghci> b
5
ghci> a = a + 1    -- okay, until here
ghci> a            -- infinite recursion
-- CTRL+C Manual Interrupt
ghci> x = 1:x
ghci> x            -- infinite ',1' print
```

Moving onto **anonymous functions** i.e. `\x -> ...` lambda notation

```
ghci> (\x -> x+1)5       -- apply 5 to anon function
6
ghci> f = (\x -> x+1)
ghci> f 5                -- brackets () can be omitted
6
ghci> h = \(x,y) -> x+y -- tuple Pattern instead of single variable
ghci> h (3,4)            -- brackets are needed here
7
ghci> h 3 4              -- brackets are needed here
-- ERROR
ghci> :t f
f :: Num a => a -> a
ghci> :t h
h :: Num a => (a, a) -> a
```

To declare explicit functions instead, the syntax is quite simple

```
f (x,y) = x+y --argument must match pattern (x,y)
```

```
   reverse xs =      -- linear, tail recursive
      let rev ( [], accum ) = accum
          rev ( y:ys, accum ) = rev ( ys, y:accum )
      in rev ( xs, [] )
```

24 - Ottobre

11.3 More on Haskell features

Let's recall that Haskell is a **lazy** language, thus functions and data constructor don't evaluate arguments until they actually need them.

11.3.1 List comprehension

```
   myData = [1,2,3,4,5,6,7]
   twiceData = [2 * x | x <- myData]
   -- [2,4,6,8,10,12,14]
   twiceEvenData = [2 * x| x <- myData, x `mod` 2 == 0]
   -- [4,8,12]
```

```
ghci> [ x | x <- [10..20], x /= 13, x /= 15, x /= 19]
      [10,11,12,14,16,17,18,20] -- more predicates
ghci> [ x*y | x <- [2,5,10], y <- [8,10,11]]
      [16,20,22,40,50,55,80,100,110] -- more lists
length xs = sum [1 | _ <- xs] -- anonymous (dont care) var
      -- strings are lists...
removeNonUppercase st = [ c | c <- st, c `elem` ['A'..'Z']]
```

11.3.2 Datatype declarations

```
   data Color = Red | Yellow | Blue
   data Atom = Atom String | Number
   data List = Nil | Cons (Atom, List)

   -- General form:
   data <name> = <clause> | ... | <clause>
   <clause> ::= <constructor> | <contructor> <type>
```

```
   -- also possible to define Recursive data types
   data Tree = Leaf Int | Node (Int, Tree, Tree)

   Node(4, Node(3, Leaf 1, Leaf 2), Node(5, Leaf 6, Leaf 7))

   -- it is possible to use constructors in pattern matching
   sum (Leaf n) = n
   sum (Node(n,t1,t2)) = n + sum(t1) + sum(t2)
```

Besides it is possible to match different cases with a specific `case` statement; note that **Indendation** in case statement *MATTERS*

```
   data Exp = Var Int | Const Int | Plus (Exp, Exp)

   case e of
      Var n -> ...
      Const n -> ...
      Plus(e1,e2) -> ...

   -- Indendation in case statement MATTERS
```

11.3.3 Function Types

`f :: A -> B` means that:

$$\forall x \in A f(x) = \begin{cases} \exists y = f(x) \in B \\ run\ forever \end{cases}$$

In other words, if $f(x)$ terminates, then $f(x) \in B$. In ML, functions with type A $\rightarrow$ B can throw an exception or have other effects, but **not** in Haskell.

11.3.4 Loops and Recursion

In FP `for` and `while` iterative loops are replaced by **recusive** subroutines calling themselves directly or indirectly (*mutual recursion*).

```
length' [] = 0
length' (x:s) = 1 + length'(s)
   -- definition using guards and pattern matching
   -- take' n lst returns first n elements of a list
take' :: (Num i, Ord i) => i -> [a] -> [a]
take' n _
| n <= 0 = []
take' _ [] = []
take' n (x:xs) = x : take' (n-1) xs
```

11.3.5 Higher-Order functions

Functions that take other functions as arguments or return a function as a result are **higher-order** functions.

Note also that any curried function with more than one argument is higher-order: applied to one argument it returns a function.

```
applyTwice :: (a -> a) -> a -> a     -- function as arg and res
applyTwice f x = f (f x)

> applyTwice (+3) 10 => 16
> applyTwice (++ " HAHA") "HEY" => "HEY HAHA HAHA"
> applyTwice (3:) [1] => [3,3,1]

applyTwice' f = f.f                  -- equivalent definition
:t (.)
> (.) :: (b -> c) -> (a -> b) -> a -> c
```

```
   -- define the operator |> which inverts the order between function and argument
   (|>) a f = f a
   (|>) :: t1 -> (t1 -> t2) -> t2
   -- Seems dull right?
   -- Look at the following example

   -- Here, the order of invocation is the same,
   -- but the second "infix" form is (might be) more readable
   > length ( tail ( reverse [1,2,3]))
      2
   > [1,2,3] |> reverse |> tail |> length
      2
```

```
-- Even these are higher order functions, since they return a function when applied to one
     argument
(+) :: Num a => a -> a -> a
> let f = (+) 5 // partial application
>:t f ==> f :: Num a => a -> a
> f 4 ==> 9
elem :: (Eq a, Foldable t) => a -> t a -> Bool
> let isUpper = (`elem` ['A'..'Z'])
>:t isUpper ==> isUpper :: Char -> Bool
> isUpper 'A' ==> True
> isUpper '0' ==> False
```

11.3.6 Combinators

`map` *combinator* applies argument function to each element in a collection.

```
   map :: (a -> b) -> [a] -> [b]
   map _ [] = []
   map f (x:xs) = f x : map f xs
```

`filter` takes a collection and a boolean predicate, and returns the collection of the elements satisfying the predicate. It is defined as follows:

```
   filter :: (a -> Bool) -> [a] -> [a]
   filter _ [] = []
   filter p (x:xs)
      | p x = x : filter p xs
      | otherwise = filter p xs
```

And can be applied in the following way

```
   > filter (>3) [1,5,3,2,1,6,4,3,2,1]
   [5,6,4]
   > filter (==3) [1,2,3,4,5]
   [3]
   > filter even [1..10]
   [2,4,6,8,10]
```

```
> let notNull x = not (null x)
in filter notNull [[1,2,3],[],[3,4,5],[2,2],[],[],[]]
[[1,2,3],[3,4,5],[2,2]]
```

reduce (`foldl`,`foldr`): takes a collection, an initial value, and a function, and combines the elements in the collection according to the function.

```
-- folds values from end to beginning of list
foldr :: Foldable t => (a -> b -> b) -> b -> t a -> b
foldr f z [] = z
foldr f z (x:xs) = f x (foldr f z xs)
-- folds values from beginning to end of list
foldl :: Foldable t => (b -> a -> b) -> b -> t a -> b
foldl f z [] = z
foldl f z (x:xs) = foldl f (f z x) xs
-- variants for non-empty lists
foldr1 :: Foldable t => (a -> a -> a) -> t a -> a
foldl1 :: Foldable t => (a -> a -> a) -> t a -> a
```

Let's provide some examples:

```
sum' :: (Num a) => [a] -> a
sum' xs = foldl (\acc x -> acc + x) 0 xs

maximum' :: (Ord a) => [a] -> a
maximum' = foldr1 (\x acc -> if x > acc then x else acc)

reverse' :: [a] -> [a]
reverse' = foldl (\acc x -> x : acc) []

product' :: (Num a) => [a] -> a
product' = foldr1 (*)
product' = foldr (*) 1
-- Notice that product' [] returns 1 !

filter' :: (a -> Bool) -> [a] -> [a]
filter' p = foldr (\x acc -> if p x then x : acc else acc)[]

head' :: [a] -> a
head' = foldr1 (\x _ -> x)
last' :: [a] -> a
last' = foldl1 (\_ x -> x)
```

11.3.7 Recursion and Optimization

From a theoretical point of view recursion and iteration are equivalently expressive, and typically one is preferred over the other depending on the problem being faced to make the code more intuitive. In general a procedure call is *much more expensive* than a conditinoal branch, however FP compilers can perform many optimizations and produce better code, especially for known blocks; for this reason the use of combinators such as `map`,`reduce`,`filter`, `foreach`,... is strongly encouraged.

Tail-recursive functions are functions in which no operations follow the recursive call(s) in the function, thus the function returns immediately after the recursive call, allowing the compiler to reuse the subroutine's frame on the run-time stack, since the current subroutine state is no longer needed. Besides many compilers instead of re-invoking the function, simply jump to the beginning of the function.

Let's provide the classic example of Fibonacci to illustrate how to convert a normal recursive function to its tail-recursive correspondant one:

```
-- typical Fibonacci
fib = \n -> if n == 0 then 1
   else if n == 1 then 1
      else fib (n - 1) + fib (n - 2)

fibTR = \n -> let fibhelper (f1, f2, i) =
   if (n == i) then f2
      else fibhelper (f2, f1 + f2, i + 1)
```

```
    in fibhelper(0,1,0)
```

Notice that fibTR takes only $\mathcal{O}(n)$ since it builds the Fibonacci sequence starting from 1 to n, while the more canonical approach calculates multiple times the same values, and starts from n until 1 is reached.

`foldl` is tail-recursive, `foldr` is not. But because of laziness Haskell has **no** tail-recursion optimization. Despite this, it provides a more efficient variant of foldl called `foldl'` where f is evaluated **strictly**.
Strictly means that the compiler evaluates the accumulator at *each step* of the folding process, ensuring that intermediate values are not built up as *unevaluated thunks* i.e. Haskell's term for delayed computations. Due to its *strictness* `fold'` is less likely to cause **space leaks** (see note below), and it generally has better performance for many common folding operations.

"Space leaks" may happen when a program retains references to data that should no longer be needed, preventing the garbage collector from reclaiming memory. This can lead to inefficient memory usage and, in some cases, cause the program to run out of memory. This (generally) occurs only when handling large data sources or *infinite data structures* (which are allowed in Haskell); space leaks may be very hard to debug, tools like memory profilers and heap profiling can be helpful in identifying them

Chapter 12

λ Lambda calculus

Due to Haskell's **laziness**, functions and data constructors don't evaluate their arguments until they need them. In several languages there are forms of lazy evaluations (`if-then-else`, shortcutting `&&` and `||`).

12.1 Syntax

```
t ::= x | λ x.t | t t' | (t)
```

- ◇ `x` variable, name, symbol,...
- ◇ λ `x.t` abstraction, defines an anonymous function
- ◇ `t t'` application of function `t` to argument `t'`

We say that an occurrence of x is **free** in a term t if it is **not** in the body of an abstraction $\lambda x.t$, otherwise it is **bound**; λx instead is a **binder**.
Examples

- ◇ $\lambda z.\lambda x.\lambda y.x(yz)$
- ◇ $(\lambda x.x)x$

Terms without free variables are **combinators**. Identity function: $id = \lambda x.x$
First projection: $fst = \lambda x.\lambda y.x$.

β-Reduction

β-reduction, i.e. *function application*, also called **redex**:

$$(\lambda x.t)t' = t[t'/x]$$

Examples

$$(\lambda x.x)y \longrightarrow y \tag{12.1}$$
$$(\lambda x.x(\lambda x.x))(ur) \longrightarrow ur(\lambda x.x) \tag{12.2}$$
$$(\lambda x.(\lambda w.xw))(yz) \longrightarrow \lambda w.yzw \tag{12.3}$$
$$\Omega - combinator \quad (\lambda x.xx)(\lambda x.xx) \longrightarrow (\lambda x.xx)(\lambda x.xx) \tag{12.4}$$

Note that in the example 12.3, the variable x is bound in the outer λ-abstraction, is the same x of the inner one. Besides, note that the parameters are substituted first in the outer λ-abstraction, then in the inner one.

12.2 Functions and lambdas

We can express most aspects of functional languages using λ-calculus.

A definition of a function with a single argument associates a name with a λ-abstraction, while a function with several arguments is equivalent to a sequence of λ-abstractions

```
f x = <exp> -- is equivalent to
f = λ x.<exp>

f(x,y) = <exp> -- is equivalent to
f = λ x. λ y.<exp>

-- Curriend and uncurried functions
curry :: ((a, b) → c) → a → b → c
curry f x y = f(x,y)
uncurry :: (a → b → c) → (a, b) → c
uncurry f (x,y) = f x y
```

12.3 Well-known functions

- T = λt.λf.t -- first
- F = λt.λf.f -- second
- and = λb.λc.bcF
- or = λb.λc.bTc
- not = λx.xFT
- test =λl.λm.λn.lmn

```
and T F
→ (λb.λc.bcF) T F
→ (λc.TcF) F
→ TFF
→ F
```

```
not F
→ (λx.xFT) F
→ FFT
→ T
```

```
test F u w
→ (λl.λm.λn.lmn) F u w
→ (λm.λn.Fmn) u w
→ (λn.Fun) w
→ Fuw
→ w
```

Figure 12.1: Church Booleans using λ-calculus

***Pair** function*

$$pair = \lambda f.\lambda s.\lambda b.b\ f\ s$$
$$fst = \lambda p.p\ T$$
$$snd = \lambda p.p\ F$$

$$\begin{aligned} fst(pair u w) & \\ &\longrightarrow (\lambda p.p\ T)(pair\ u\ w) \\ &\longrightarrow (pair\ u\ w)\ T \\ &\longrightarrow (\lambda f.\lambda s.\lambda b.b\ f\ s)\ u\ wT \\ &\longrightarrow (\lambda s.\lambda b.b\ u\ s)\ w\ T \\ &\longrightarrow (\lambda b.b\ u\ w)\ T \\ &\longrightarrow T\ u\ w \\ &\longrightarrow u \end{aligned}$$

Church ***Numerals***

$$0 = \lambda s.\lambda z.z \tag{12.5}$$
$$1 = \lambda s.\lambda z.s\ z \tag{12.6}$$
$$2 = \lambda s.\lambda z.s\ (s\ z) \tag{12.7}$$
$$3 = \lambda s.\lambda z.s\ (s(s\ z)) \tag{12.8}$$

Numerals n takes a function s as argument and returns the *n-th* composition of s with itself, s^n.
$succ = \lambda n.\lambda s.\lambda z.s(nsz)$ hence allows to compute the successor of 2, by substituing the -identifier- "2" with its numeral and viceversa.

Given:	$\text{succ} = \lambda n.\lambda s.\lambda z.s(n\,s\,z)$
Compute:	$\text{succ}\,2 = (\lambda n.\lambda s.\lambda z.s(n\,s\,z))\,2$
Substitute n with 2 :	$= \lambda s.\lambda z.s(2\,s\,z)$
Substitute 2 with its Church numeral:	$2 = \lambda s.\lambda z.s(sz)$
Evaluate $2\,s\,z$:	$2\,s\,z = (\lambda s.\lambda z.s(sz))\,s\,z$
	$= s(sz)$
Substitute back into the expression for succ:	$= \lambda s.\lambda z.s(s(sz))$
Which is the Church numeral for 3:	$= 3$

12.4 Fix-point *Y* combinator

The following *fix-point combinator* ***Y***, when applied to a function R, returns a **fix-point** of R, i.e. $R(YR) = YR$

$$Y = (\lambda y.(\lambda x.y(x\ x))(\lambda x.y(x\ x))) \tag{12.9}$$
$$\begin{aligned} YR &= (\lambda x.R(x\ x))(\lambda x.R(x\ x)) \\ &= R((\lambda x.R(x\ x))(\lambda x.R(x\ x))) \\ &= R(YR) \end{aligned} \tag{12.10}$$

12.5 Evaluation ordering

Consider the two following ways of evaluating a redex, but remember that *regardless* of the evaluation order, the evaluation result is only one, and it is **unique**[1]

Applicative order evaluation implies eager evaluation of arguments before applying them to the function

```
(λ x.(+ x x)) (+ 3 2)
→ (λ x.(+ x x)) 5
→ (+ 5 5)
→ 10
```

Normal order evaluation implies functions to be evaluated first, and delay argument evaluation only when needed. Note that this may lead to multiple re-evaluations of the same argument.

```
(λ x.(+ x x)) (+ 3 2)
→ (+ (+ 3 2) (+ 3 2))
→ (+ 5 (+ 3 2))
→ (+ 5 5)
→ 10
```

Haskell realizes **lazy evaluation** by using **call by need** parameter passing: an expression passed as argument is bound to the formal parameter, but it is evaluated *only if* its value is **needed**. Besides, the argument is evaluated *only* the **first time**, using the **memoization** technique: the result is saved and further uses of the argument do not need to re-evaluate it.

Combined with **lazy data constructors**, this allows to construct *potentially* ***infinite*** *data structures* and to call *infinitely recursive* functions without necessarily causing non-termination.

Note: lazy evaluation works fine with purely **functional languages**. Side effects such as IO operations force the programmer

[1] Proved by Church and Rosser

to reason about the order in which things happen, which not predictable in lazy languages. We will address this fact when introducing Haskell's IO-*Monad*.

12.6 Value vs Reference model

Consider the assignment $a = b$: a is an `l-value` denoting a location, while b is any syntactically correct expression with a type compatible to the type of a. Depending on the model adopted by the language, two things may happen:

- ◇ **Value model**: b value is copied into the location of a.
  Most imperative languages use this model.
- ◇ **Reference model**: a reference -to the location of- b is copied onto a. TThis results in shared data values via multiple references.
  Haskell, LISP, ML, Scheme, and Smalltalk use this model.
- Java uses the value model for built-in types and the reference model for class instances
- C# uses value model for value types, reference model for reference types

Note that there is a subtle difference between *reference* and *pointer*:

- ◇ A reference to `X` is the address of the (base) cell where `X` is stored
- ◇ A pointer to `X` is a location containing the address of `X`

Call by name is a parameter passing mechanism where the actual parameter is passed as it is, and the formal parameter is substituted with the actual parameter in the function body. This was used in Algol 60, it is powerful, but very difficult to read and debug (think of λ-calculus...).
In this mechanism arguments are passed as a closure ("thunk") to the subroutine and re-evaluated every time they are used.

12.7 Very important Post-lecture Takeaway message

While discussing with the professor after the lecture, an important intuition emerged about evaluation and memoization.

```
a = 5
b = a + 3
```

b would evaluate to 8 but it is not evaluated until it is strictly necessarily.

```
a = 5
b = a + 3
a = 2
-- b?
```

Someone may think that due to lazy evaluation, b would now evaluate to 5. However, this is ***NOT*** Haskell's case. Due to **memoization**, even if `b = a + 3` doesn't get evaluated, the current value of `a` is memoized and its re-definition doens't affect b evaluation. Thus this snippet code leads `b` to be evaluated as `8`, regardless of `a` redefinition.

```
a = 5
b = a + 3
a = 2
b
> 8
```

Chapter 13

Type Inference

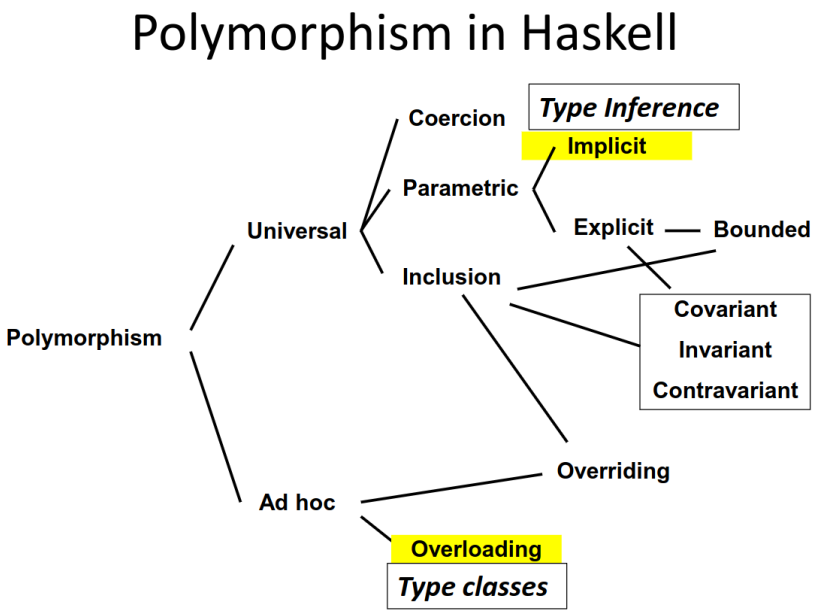


Figure 13.1: Haskell Polymorphism Recap

13.1 Overloading

Haskell allows **overloading** even of **primitive types**: the code to be executed is determined by the type of the arguments, leading to have *early binding* in *statically* typed languages or *late binding* in *dynamically* typed languages.

In Haskell we can write the following, but what is the type? May be float, int, double, etc.

```
sqr x = x * x
```

Actually in Haskell, we have type classes `sqr :: Num a => a -> a`

When considering overloading besides arithmetic, we find that some functions are **fully polymorphic**:

```
length :: [w] → Int
```

While others not so much; for example, *membership* works only for types that support equality, while *sorting* works only for types which support *ordering*.

```
member :: [w] → w → Bool
sort :: [w] → [w]
```

13.2 Type Classes

Type Classes solve many overloading problems concerning arithmetic and equality (and similar properties) support.

The idea is to generalize ML's eqtypes to arbitrary types and provide concise types to describe overloaded functions, so no exponential blow-up (i.e. defining functions for every possible combination of type arguments).
Type classes allow users to define functions using overloaded operations —e.g. square, squares, and member— and to declare new collections of overloaded functions: equality and arithmetic operators are not privileged built-ins. Haskell's solutions fits perfectly within type inference framework.

The intuition is that a sorting function may allow to be passed a comparison `cmp` operator as argument, thus making the function parametric.

```
qsort:: (a → a → Bool) → [a] → [a]
qsort cmp [] = []
qsort cmp (x:xs) = qsort cmp (filter (cmp x) xs) ++ [x] ++
qsort cmp (filter (not.cmp x) xs)
```

Developing this idea, consider rewriting the parabola function to take operators as argument

```
parabola x = (x * x) + x
parabola' (plus, times) x = plus (times x x) x
```

Here the extra parameter is a ***dictionary*** that provides implementations for the overloaded ops. These implies rewriting calls to pass appropriate implementations for plus and times:

```
y = parabola'(intPlus,intTimes) 10
z = parabola'(floatPlus, floatTimes) 3.14
```

1. Type class declarations
   i. Define a set of operations, give it a name
   ii. Example: `Eq a` type class • operations `==` and `\=` with `type a →a → Bool`
2. Type class instance declarations
   i. Specify the implementations for a particular type
   ii. For `Int` instance, `==` is defined to be integer equality
3. Qualified types (or Type Constraints) Concisely express the operations required on otherwise polymorphic type
   `member:: Eq w =>w →[w] →Bool`

So, considering our previous examples, the type of `member` parameters is any type `w` that supports equality, i.e. that belongs to the `Eq` type class. `reverse` instead, works for any list of any type.

```
member :: Eq w => w → [w] → Bool
sort :: Ord w => [w] → [w]
reverse :: [w] → [w]
```

implementation summary

1. Each overloaded symbol has to be introduced in at least one type class
2. The compiler translates each function that uses an overloaded symbol into a function with an extra parameter: the dictionary.
3. References to overloaded symbols are rewritten by the compiler to lookup the symbol in the dictionary.
4. The compiler converts each type class declaration into a dictionary type declaration and a set of selector functions.
5. The compiler converts each instance declaration into a dictionary of the appropriate type.
6. The compiler rewrites calls to overloaded functions to pass a dictionary. It uses the static, qualified type of the function to select the dictionary.

13.2.1 Compositionality

```
class Eq a where
(==) :: a → a → Bool
instance Eq Int where
(==) = intEq -- intEq primitive equality
instance (Eq a, Eq b) => Eq(a,b) where
(u,v) == (x,y) = (u == x) && (v == y)
instance Eq a => Eq [a] where
(==) [] [] = True
(==) (x:xs) (y:ys) = x==y && xs == ys
(==) _ _ = False
```

13.2.2 Compound Translation

13.2.3 Subclasses

```
memsq :: (Eq a, Num a) => a → [a] →
    Bool
memsq x xs = member (square x) xs
```

We could treat the Eq and Num type classes separately as in 13.2.3, but we expect that every instance of Num is also an instance of Eq. A subclass declaration expresses this relationship:

```
class Eq a => Num a where
(+) :: a → a → a
(*) :: a → a → a
```

• With that declaration, we can simplify the type of the function

```
memsq :: (Eq a, Num a) => a → [a] →
    Bool
memsq x xs = member (square x) xs
```

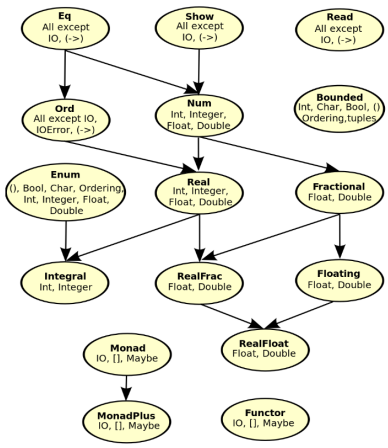


Figure 13.2: Haskell Subclasses relationships

13.2.4 Deriving

For Read, Show, Bounded, Enum, Eq, and Ord, the compiler can generate instance declarations automatically.

```
data Color = Red | Green | Blue
   deriving (Show, Read, Eq, Ord)

Main>:t show
show :: Show a => a → String
Main> show Red
"Red"
Main> Red < Green
True
Main>:t read
read :: Read a => String → a
Main> let c :: Color = read "Red"
Main> c
Red
```

13.2.5 Numeric Literals

```
class Num a where
   (+) :: a → a → a
   (-) :: a → a → a
   fromInteger :: Integer → a
   -- Even literals are overloaded.
   -- 1 :: (Num a) => a
   ...

inc :: Num a => a → a
inc x = x + 1
```

Advantages

Numeric literals can be interpreted as values of any appropriate numeric type, for example: 1 can be an Integer or a Float or a user- defined numeric type.

13.2.6 Missing Notes

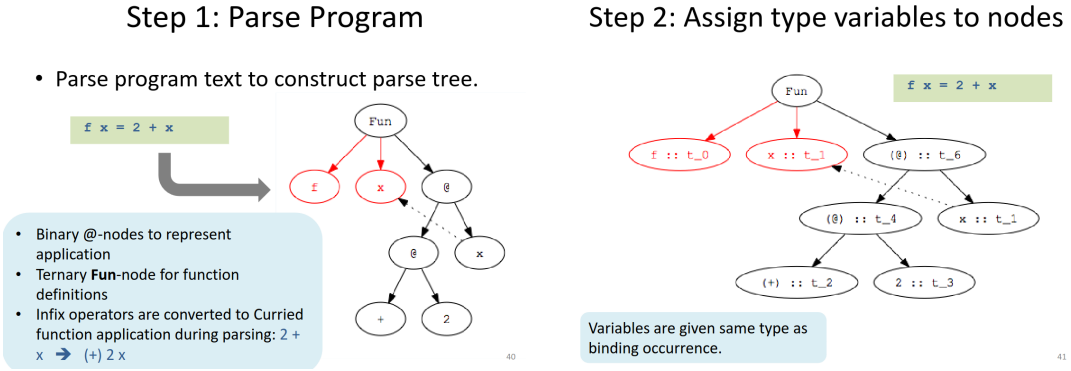
Look at slides 34...64 for more on Type Inference.

13.3 Inferencing types

In standard type checking the compiler examine body of each function and uses declared types to check agreement; type inference instead consists in examining code without type information, and infer the most general types that

could have been declared

13.3.1 Steps schematics



Constraints can be deduced from (function) *Application* nodes `f x` and from *Abstractions* `f x = e`.

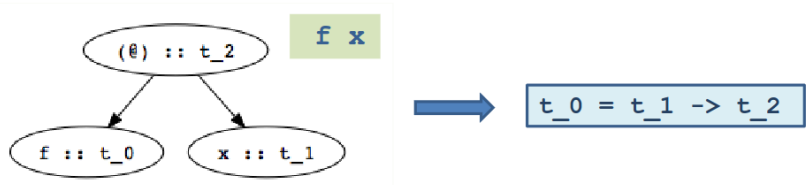


Figure 13.2: Deducing constraints from function application

- ◇ Type of `f` (`t_0` in figure) must be *domain* $\longrightarrow$ *range*.
- ◇ **Domain** of `f` must be type of argument `x` (`t_1`)
- ◇ **Range** of f must be result of application (`t_2`)
- ◇ **Constraint**: `t_0 = t_1 →t_2`

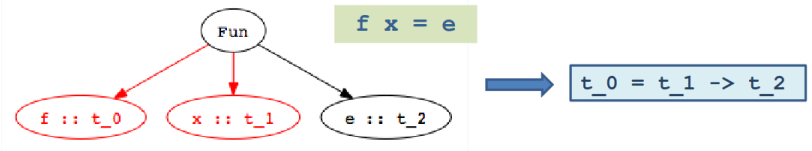
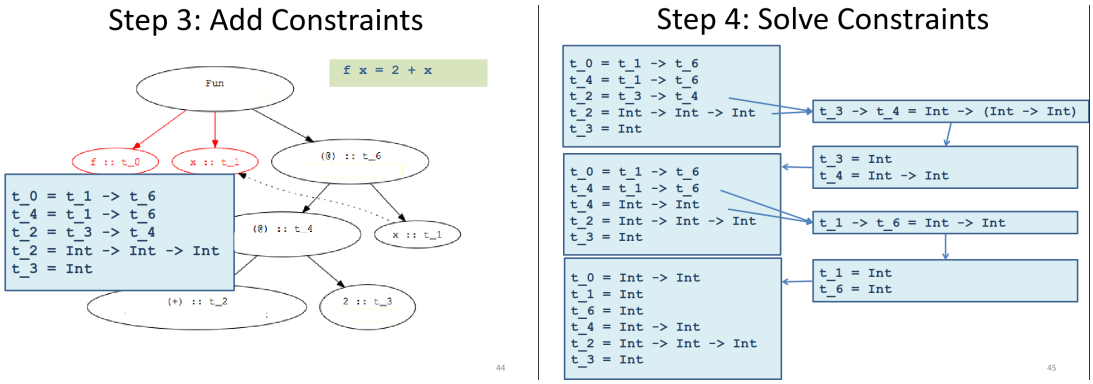
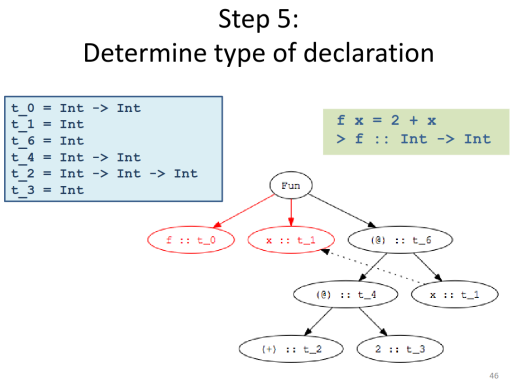


Figure 13.3: Deducing constraints from abstractions





13.3.1.1 Steps summary

1. Parse program to build parse tree
   - ◇ Each node is a function application `@`, variable x, or constant
2. Assign type variables to nodes in tree
3. Generate constraints:
   i. From environment: constants (`2`), built-in operators (`+`), known functions (`tail`).
   ii. From shape of parse tree: e.g., application and abstraction nodes.
4. Solve constraints using unification
5. Determine types of top-level declarations

13.3.2 Polymorphism

In general **unconstrained** type variables become **polymorphic types**; for instance, in the example below `t_4` is unconstrained, hence we get a polymorphic type:

```
f g = g 2
> f :: (Int → t_4) → t_4
```

For functions with multiple clauses, i.e. *polymorphic datatypes*, for each clause a separate type is inferred, and then the resulting types are combined by adding constraints such as that all clauses have the same type. In case of *recursive calls*: the function has same type as its definition.

```
append ([],r) = r
append (x:xs, r) = x : append (xs, r)
```

1. Infer type of each clause
   i. First clause:

   ```
   > append :: ([t_1], t_2) → t_2
   ```

   ii. Second clause:

   ```
   > append :: ([t_3], t_4) → [t_3]
   ```

2. Combine by equating types of two clauses

   ```
   > append :: ([t_1], [t_1]) → [t_1]
   ```

13.3.3 Overloading

In presence of **overloading** (*Type Classes*), type inference infers a **qualified type** `Q => T`

- ◇ T is a Hindley Milner type, inferred as seen before
- ◇ Q is set of type class predicates, called a constraint

```
example :: Ord a => a → [a] → Bool
example z xs =
   case xs of
      [] → False
      (y:ys) → y > z || (y==z && ys == [z])
```

In the example **Type** `T` is `a → [a] → Bool` while the **Constraint** `Q` is `{ Ord a, Eq a, Eq [a]}`. `Q` later simplifies[1] to `Ord a`

- ◇ `Ord a` because `y>z`
- ◇ `Eq a` because `y==z`
- ◇ `Eq [a]` because `ys == [z]`

[1] According to some rules not discussed here

13.4 Type Constructors

Type Classes are *predicates* over *types*, while **[Type] Constructor Classes** are *predicates* over *type constructors*.

For example, consider three versions of the `map` function (implementation is omitted): the basic one for lists, one for trees and one for `Maybe`.

```
map :: (a → b) → [a] → [b]
mapTree :: (a → b) → Tree a → Tree b
mapMaybe :: (a → b) → Maybe a → Maybe b
```

They all share the same structure, thus they can all be written as

```
fmap:: (a → b) → g a → g b
```

where `g` is a function from *types to types*, i.e. a **type constructor**; it is: `[-]` for lists, `Tree` for trees, and `Maybe` for options.

13.4.1 Functor

This pattern can be captured in a constructor class `Functor`. A **constructor class** is simply a type class where the predicate is over a type constructors rather than on a type:

```
class Functor g where
   fmap :: (a → b) → g a → g b
```

Compare with the definition of a *standard type class*:

```
class Eq a where
   (==) :: a → a → Bool
```

So, wrapping up, we can instantiate `Functor` on all three data structures, and then simply use the *overloaded* symbol `fmap`, instead of `map`, `mapTree` and `mapMaybe`.

```
class Functor f where
   fmap :: (a → b) → f a → f b
instance Functor [] where // [] is an instance of Functor
   fmap f [] = []
   fmap f (x:xs) = f x : fmap f xs
instance Functor Tree where // Tree is an instance of Functor
   fmap f (Leaf x) = Leaf (f x)
   fmap f (Node(t1,t2)) = Node(fmap f t1, fmap f t2)
instance Functor Maybe where // Maybe is an instance of Functor
   fmap f (Just s) = Just(f s)
   fmap f Nothing = Nothing
```

Alternatively we could also write `fmap = map`, `fmap = mapTree`, fmap = `mapMaybe`

The following is an example on how to use the obtained fmap:

```
ghci> fmap (\x→x+1) [1,2,3]
[2,3,4]
it :: [Integer]
ghci> fmap (\x→x+1) (Node(Leaf 1, Leaf 2))
Node (Leaf 2,Leaf 3)
it :: Tree Integer
ghci> fmap (\x→x+1) (Just 1)
Just 2
it :: Maybe Integer
```

Chapter 14

Monads

14.1 Type Constructors

14.1.1 Towards Monads

Often type constructors can be thought of as defining *"boxes"* for values, and `Functors` with `fmap` allow to apply functions inside such *"boxes"*.
`Monad` is a constructor class introducing operations for *putting a value* into a "box" (`return`) and *composing* functions that return "boxed" values (`bind`).
"Monads" are type constructors that are instances of `Monad`

A *Type constructor* is a generic type with one or more type variables

14.1.2 Maybe

`data Maybe a = Nothing | Just a` is a type constructor with a single type variable `a`. A value of type `Maybe a` is either `Nothing` or `Just x` for some `x::a`.

A function `f :: a →Maybe b` is a partial function from `a` to `b`.

```
father :: Person → Maybe Person -- partial function
mother :: Person → Maybe Person -- (lookup in a DB)
maternalGrandfather :: Person → Maybe Person
maternalGrandfather p =
case mother p of
Nothing → Nothing
Just mom → father mom -- Nothing or a Person
```

14.1.3 Bind operator

We introduce a higher order operator to compose partial functions in order to "propagate" undefinedness automatically.

The bind operator will be part of the definition of a monad.

```
y >= g = case y of
     Nothing → Nothing
     Just x → g x

(>>=) :: Maybe a → (a → Maybe b) → Maybe b
```

```
bothGrandfathers p =
father p >>=
(\dad → father dad >>=
(\gfl → mother p >>=
(\mom → father mom >>=
(\gf2 → return (gfl, gf2)))))
```

`do{}` is an alternative equivalent syntax,more *imperative-like*.

```
bothGrandfathers p = do
dad <- father p
gfl <- father dad
mom <- mother p
gf2 <- father mom
return (gfl, gf2)
```

14.2 Monads as *

14.2.1 ...containers

```
class Monad m where -- definition of Monad type class
   return :: a → m a
   (>>=) :: m a → (a → m b) → m b -- "bind"
   ... -- + something more + a few axioms
```

The monadic constructor can be seen as a container: let's see this for `lists`

```
map :: (a → b) → [a] → [b] -- seen. "fmap" for Functors
return :: a → [a] -- container with single element
return x = [x]
concat :: [[a]] → [a] -- flattens two-level containers
   Example: concat [[1,2],[],[4]] = [1,2,4]
(>>=) :: [a] → (a → [b]) → [b]
xs >>= f = concat(map f xs)
Exercise: define map and concat using bind and return
```

14.2.2 ... computations

```
class Monad m where -- definition of Monad type class
   return :: a → m a
   (>>=) :: m a → (a → m b) → m b -- "bind"
   (>>) :: m a → m b → m b -- "then"
   ... -- + something more + a few axioms
```

A value of type m a is a "computation returning a value of type a"

For any value, there is a computation which "does nothing" and produces that result. This is given by function `return`.

Given two computations `x` and `y`, one can form the computation `x >> y` which intuitively "runs" `x`, throws away its result, then runs `y` returning its result.

Given computation `x`, we can use its result to decide what to do next. Given `f: a →m b`, computation `x >>= f` runs `x`, then applies `f` to its result, and runs the resulting computation.

Note that we can define `then` using `bind`:

```
x >> y = x >>= (\_ → y)
```

return, bind and then define basic ways to compose computations. They are used in Haskell libraries to define more complex composition operators and control structures (sequence, for-each loops, ...).
If a type constructor defining a library of computations is monadic, one gets automatically benefit of such libraries

Example: MAYBE

- ◇ `f:a →Maybe b` is a partial function
- ◇ `bind` applies a partial function to a possibly undefined value, propagating undefinedness

Example: LISTS

- ◇ `f:a → [b]` is a non-deterministic function
- ◇ `bind` applies a non-deterministic function to a list of values, collecting all possible results

14.3 IO Monad

14.3.1 FP pros & cons

Pros

- ◇ Concise and powerful abstractions
  - higher-order functions, algebraic data types, parametric polymorphism, principled overloading, ...
- ◇ Close correspondence with mathematics
  - Semantics of a code function is the mathematical function
  - Equational reasoning: if x = y, then f x = f y
  - Independence of order-of-evaluation (Confluence, aka Church-Rosser)

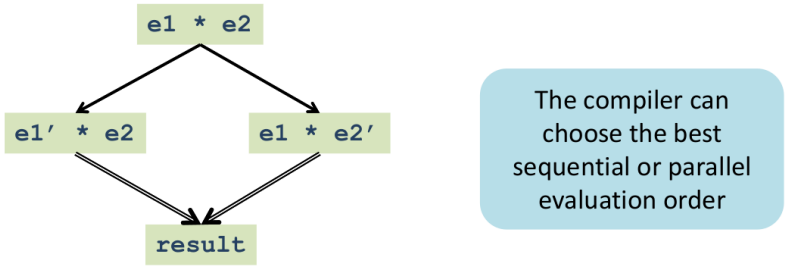


Figure 14.1: Evaluation order freedom

Cons

- ◇ Input/Output
- ◇ Imperative update
- ◇ Error recovery (eg, timeout, divide by zero, etc.)
- ◇ Foreign-language interfaces
- ◇ Concurrency control

Besides, recall that the whole point of a running a program is to **interact** with the external environment and affect it

14.3.2 Towards IO

To overcome the problem of interaction, an approach is to add imperative constructs to the language, for instance:

```
res = putchar 'x' + putchar 'y'
```

Seems easy right? Well, in fact no, because in lazy languages like Haskell, the evaluation order is **undefined**; so, in the previous example, which char will be printed first, `x` or `y`? The answer is not trivial for Haskell. However it is not an impossible problem. Haskell's approach is to exploit the concept of **Monads**.

Recall that the bind operator `>>=` forces a **sequence** between the evaluation of terms; the IO monad exploits this and defines monadic values which are called **actions**, and prescribes how to compose them *sequentially*

Before Monads

Before Monads there were **Streams**, which allowed a program to send stream of requests to OS and receive stream of responses, or the user could supply **continuations** to I/O routines to specify how to process results.
However, both of these approaches revealed to be not so useful.

14.3.3 Key Ideas - Monadic I/O

`IO` is a type constructor, instance of `Monad`, and a value of type `(IO t)` is an *action* (i.e. computation) that, when **performed**, may do some input/output before delivering a result of type `t`

- ◇ `return` returns the value without making I/O
- ◇ `then (>>)` (and also `bind (>>=)`) composes two actions sequentially into a larger action
- ◇ The only way to perform an action is to call it at some point, directly or indirectly, from `Main.main`, which is the standard entry point for Haskell programs.

An **action** is a *first-class* value, and **evaluating** has *no effect*: **performing** the action has the *effect*.

The actual meaning of this statement is unclear even to the professor ☺

```
return :: a → IO a
return a = \w → (a,w)
(>>=) :: IO a → (a → IO b) → IO b
(>>=) m k = \w → case m w of (r,w') → k r w'
```

By writing `case m w ...` we force the evaluation of `m`, resulting in the application of `k` to `r w'` to be performed (evaluated?) *after* the evaluation of `m`.

14.3.4 >>= and >>combinators

Operator is called **bind** because it binds the result of the left-hand action in the action on the right. Performing compound action `a >>= \x→b` :

1. performs action `a`, to yield value `r`
2. applies function `\x→b` to `r`
3. performs the resulting action `b{x <- r}`
4. returns the resulting value `v`

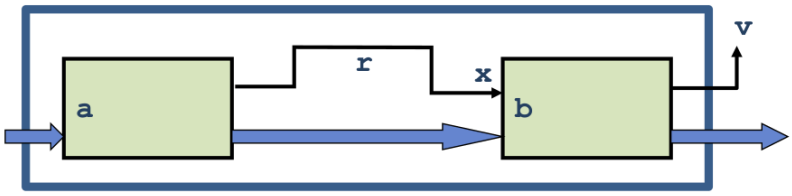


Figure 14.2: Bind Combinator

The **then** combinator `(>>)` instead does sequencing when there is no value to pass (for instance a sequence of `putChar`s):

```
(>>) :: IO a → IO b → IO b
m >> n = m >>= (\_ → n)

echoDup :: IO ()
echoDup = getChar >>= \c →
   putChar c >>
   putChar c
```

14.3.5 do notation

The "do" notation is a syntactic sugar for `>>=` and `>>`, and it is used to write monadic code in a more imperative style, making it easier to read and write.

```
-- Do Notation
getTwoCharsDo :: IO(Char,Char)
getTwoCharsDo = do { c1 <- getChar ;
   c2 <- getChar ;
   return (c1,c2) }
```

```
-- Plain Syntax
getTwoChars :: IO (Char,Char)
getTwoChars = getChar >>= \c1 →
   getChar >>= \c2 →
   return (c1,c2)
```

```
do { x } = x
do { x; stmts } = x >> do { stmts }
do { v<-x; stmts } = x >>= \v → do { stmts }
do {let ds; stmts } = let ds in do { stmts }
```

14.3.6 Restrictions

In pure Haskell, there is no way to transform a value of type `IO a` into a value of type `a`.
Suppose you wanted to read a configuration file at the beginning of your program:

```
configFileContents :: [String]
configFileContents = lines (readFile "config") -- WRONG!
useOptimisation :: Bool
useOptimisation = "optimise" 'elem' configFileContents
```

The problem is that `readFile` returns an `IO String`, not a `String`.

Possible workarounds

1. Write entire program in IO monad. But then we lose the simplicity of **pure** code.
2. Escape from the IO Monad using a function from `IO String` →`String`. But this is **disallowed**!

We know the configuration file will *not change* during the program, so it doesn't matter ***when*** we read it.
This situation arises sufficiently often that Haskell implementations offer one last unsafe I/O primitive: `unsafePerformIO`

```
unsafePerformIO :: IO a → a
configFileContents :: [String]
configFileContents = lines(unsafePerformIO(readFile "config"))
```

The operator has a deliberately long name to *discourage* its use. Besides, its use comes with a proof obligation: a promise to the compiler that the *timing* of this operation relative to all other operations doesn't matter.

It is called *unsafe* because it breaks the soundness of the type system; thus, claims that Haskell is type safe are valid only when `unsafePerformIO` is **not** used.

14.4 Summary

- ◇ A complete Haskell program is a single IO action called main. Inside IO, code is **single-threaded**.
- ◇ Big IO actions are built by gluing together smaller ones with `bind (>>=)` and by converting pure code into actions with return.
- ◇ IO actions are first-class. They can be passed to functions, returned from functions, and stored in data structures; so, it is easy to define new "glue" combinators.
- ◇ The IO Monad allows Haskell to be pure while efficiently supporting side effects.
- ◇ The type system separates the *pure* from the *effectful* code.

Comparison

- ◇ In languages like ML or Java, the fact that the language is in the IO monad is baked in to the language. There is no need to mark anything in the type system because it is everywhere.
- ◇ In Haskell, the programmer can choose when to live in the IO monad and when to live in the realm of pure functional programming.
- ◇ So it is not Haskell that lacks imperative features, but rather the other languages that lack the ability to have a statically distinguishable pure subset.

Chapter 15

Lambdas in KJava

The purpose of lambdas was enabling —without requiring recompilation of existing binaries— functional programming in Java, that is being able to pass behaviors as well as data to functions, and to introduce lazy evaluation with stream processing.

15.1 Java 8

```
List<Integer> intSeq = Arrays.asList(1,2,3);
intSeq.forEach(x → System.out.println(x));
// equivalent syntax
intSeq.forEach((Integer x) → System.out.println(x));
intSeq.forEach(x → {System.out.println(x);});
intSeq.forEach(System.out::println); //method reference
```

Note that class variables used inside the body of a lambda must be `final` or *effectively* `final`, or have to be static. This is fundamental design choice, as it makes **closures**[1] not necessary.

```
int var = 10; // must be [effectively] final
intSeq.forEach(x → System.out.println(x + var));
// var = 3; // uncommenting this line it does not compile
```

```
public class SVCExample { // static variable capture
   private static int var = 10;
   public static void main(String[] args) {
      List<Integer> intSeq = Arrays.asList(1,2,3);
      static int var = 10;

      intSeq.forEach(x → System.out.println(x + var));
      var = 3; // OK! it compiles
}}
```

15.2 Functional Interfaces

15.2.1 Implementation

The Java 8 compiler conceptually first converts a lambda expression into a function, compiling its code; then it generates code to call the compiled function where needed.
For example, `x → System.out.println(x)` could be converted into a generated static function

```
public static void genName(Integer x) {
   System.out.println(x);
}
```

But what **type** should be generated for this function? How should it be called? What class should it go in?

[1] A closure is a function that captures the lexical context in which it was defined.

15.2.2 Functional Interfaces

Java 8 *lambdas* are instances of *functional interfaces*, which are java interfaces with exactly *one* ***abstract*** method.

```
public interface Comparator<T> { //java.util
   int compare(T o1, T o2);
}
public interface Runnable { //java.lang
   void run();
}
public interface Consumer<T>{ //java.util.function
   void accept(T t)
}
public interface Callable<V> {//java.util.concurrent
   V call() throws Exception;
}
```

Functional Interfaces can be used as target type of lambda expressions, i.e.

- ◇ As type of variable to which the lambda is assigned
- ◇ As type of formal parameter to which the lambda is passed

The lambda is invoked by calling the only abstract method of the functional interface; lambdas can be interpreted as instances of anonymous inner classes implementing the functional interface.

For instance, recalling the `forEach` presented earlier, the corresponding interface is the following. Note that it must be checked that the lambda matches the `forEach` signature defined in the interface:

```
intSeq.forEach(x → System.out.println(x));

// List<T> extends Iterable<T>
interface Iterable<T>{ //java.lang
   default void forEach(Consumer<? super T> action)
      for (T t : this)
         action.accept(t);
```

Lambdas could, in principle, be compiled as instances of anonymous inner classes, but there is no default strategy for compiling lambdas indicated in neither JLS8 nor JVMS8. The compiler can choose to compile them as anonymous inner classes, or it can choose to use `invokedynamic` to implement them, as it is usually done nowdays.

15.2.2.1 Default Methods

Adding new abstract methods to interfaces breaks existing implementations of such interface. To avoid this, Java 8 introduced *default methods* in interfaces, which are methods with a body that can be overridden by implementing classes, enforcing backward compatibility with existing solutions.

15.2.2.2 Method References

Method references can be used to pass an existing function in places where a lambda is expected, but their signature needs to match the signature of the functional interface method required.

static	`ClassName::StaticMethodName`	`String::valueOf`
constructor	`ClassName::new`	`ArrayList::new`
specific object instance	`objectReference::MethodName`	`x::toString`
arbitrary object of a given type	`ClassName::InstanceMethodName`	`Object::toString`

Table 15.1: Method references examples

Chapter 16

Streams

Streams were introduced to support functional-style operations on streams of elements, such as map-reduce transformations on collections.
Let's consider the properties of **Streams**, and we'll clearly see how they are different from Collections.

- **No storage**
  A stream is *not* a data structure that stores elements; instead, it conveys elements from a *source* [1] through a pipeline of computational operations.
- **Functional** in nature
  An operation on a stream produces a *result*, but does *not* modify its source.
  In fact —if I recall correctly— modifying a stream while iterating over it with `forEach` would result in messed up behavior; more precisely, a `ConcurrentModificationException`
- **Laziness-seeking** Many stream operations can be implemented lazily, exposing opportunities for optimization. Stream operations are divided into **intermediate** (*stream-producing*) operations —which are *always lazy*— and **terminal** (*value-* or *side-effect-producing*) operations.
- Possibly **unbounded**
  While collections have a *finite size*, streams need *not*. Short-circuiting operations such as `limit(n)` or `findFirst()` can allow computations on *infinite streams* to complete in *finite time*.
- **Consumable**
  The elements of a stream are only *visited once* during the life of a stream. Like an Iterator, a new stream must be generated to *revisit* the same elements of the source.
  The Stream is considered *consumed* when a *terminal* operation is invoked. No other operation can be performed on the Stream elements afterwards.

16.1 Pipelines

A typical pipeline contains
1. A **source**, producing (by need) the elements of the stream
2. Zero or more **intermediate** operations, producing streams
3. A **terminal** operation, producing side-effects or non-stream values

Example of typical pattern: `filter / map / reduce`

```
double average = listing // collection of Person
   .stream() // stream wrapper over a collection
   .filter(p → p.getGender() == Person.Sex.MALE) // filter
   .mapToInt(Person::getAge) // extracts stream of ages
   .average() // computes average (reduce/fold)
   .getAsDouble(); // extracts result from OptionalDouble
```

16.1.1 Sources

Common sources are `Collections` via `stream()` and `parallelStream()` methods, but there are several and various other sources, like `IntStream.range(int, int)`, `Stream.iterate(Object, UnaryOperator)`, `BufferedReader.lines()`, `Random.ints()`, and many others.

[1] e.g. a data structure, an array, a generator function, an I/O channel,...

16.1.2 Intermediate operations

An intermediate operation keeps a stream *open* for further operations. Intermediate operations are lazy, and several of them have arguments of *functional interfaces*, thus **lambdas** can be used.
Exampls are `map()`, `peek()`, `distinct()`, `sorted()`

16.1.3 Terminal operations

A terminal operation must be the *final operation* on a stream. Once a terminal operation is invoked, the stream is consumed and is no longer usable. As said before, the typical approach is to collect values in a data structure, reduce to a value, and lastly print or cause other side effects.
Examples are `reduce()`,`forEach()`,`allMatch()` and others.

`reduce()` is basically our well-known `fold`

16.2 Mutable Reduction

Suppose we want to concatenate a stream of strings:

```
String concatenated = listOfStrings
    .stream()
    .reduce("", String::concat)
```

The above works, but is highly inefficient: it builds one new string for each element, since `Strings` are immutable in Java.
It would be better to "accumulate" the elements in a mutable object (e.g. a `StringBuilder`, a `collection`, ...). In our aid comes the **mutable reduction operation** which is called `collect()`, which requires three functions:

1. a **supplier** function to *construct* new instances of the result container,
2. an **accumulator** function to *incorporate* an input element into a result container,
3. a **combining** function to *merge* the contents of one result container into another.

```
<R> R collect( Supplier<R> supplier,
               BiConsumer<R, ? super T> accumulator,
               BiConsumer<R, R> combiner);
```

```
// NO streams
ArrayList<String> strings = new ArrayList<>();
for (T element : stream) {
    strings.add(element.toString());
}

// with streams and λs
ArrayList<String> strings =
stream.collect(
    () → new ArrayList<>(),          // Supplier
    (c, e) → c.add(e.toString()),    // Accumulator
    (c1, c2) → c1.addAll(c2));       // Combining

// with streams and method references
ArrayList<String> strings = stream.map(Object::toString)
.collect(   ArrayList::new,      // Supplier
            ArrayList::add,      // Accumulator
            ArrayList::addAll);  // Combining
```

However, `collect()` can also be invoked with a `Collector` argument, which encapsulates the functions used as arguments to collect (*Supplier*, *BiConsumer*, *BiConsumer*), allowing for reuse of collection strategies and composition of collect operations.

```
Map<String, List<Person>> peopleByCity =
    personStream.collect(Collectors.groupingBy(Person::getCity));
```

16.3 Parallelism

Streams facilitate parallel execution: stream operations can execute either in serial (default) or in parallel, with the runtime support transparently taking care of using multithreading for parallel execution. If operations *don't* have side-effects, *thread-safety* is **guaranteed** even if *non-thread-safe collections* are used (e.g. `ArrayList`).

Also *concurrent mutable reduction* (collect) is supported for parallel streams, however Order of processing stream elements depends on serial/parallel execution and intermediate operations, and may not be predictable.

```
double average = persons    // average age of all males
   .parallelStream()        // members in PARALLEL
   .filter(p → p.getGender() == Person.Sex.MALE)
   .mapToInt(Person::getAge)
   .average()
   .getAsDouble();

   sorted_listOfIntegers.parallelStream()
   .forEach(e → System.out.print(e + " "));
   // may print: 3 4 1 6 2 5 7 8
```

16.3.1 Summing up

One should use Parallelism

- ◇ When operations are independent, and
- ◇ Either or both:
  - Operations are computationally expensive
  - Operations are applied to many elements of efficiently splittable data structures

"Always measure before and after parallelizing*!"*

16.3.2 Critical Issues

- ◇ **Non-interference**
  - Behavioural parameters (like *lambdas*) of stream operations should *not affect* the source (i.e. *non-interfering behaviour*)
  - Risk of `ConcurrentModificationExceptions`, even in single-threaded execution
- ◇ **Stateless behaviours**
  - *Stateless* behaviour for intermediate operations is *encouraged*, as it facilitates parallelism, and functional style, thus maintenance
- ◇ **Parallelism and thread safety**
  - For parallel streams with *side-effects*, ensuring thread safety is the programmers' responsibility

```
String concatenatedString = listOfStrings
.stream()
.peek(s → listOfStrings.add("three")) // DON'T DO THIS!
   // Interference occurs here.
.reduce((a, b) → a + " " + b)
.get();
```

16.4 Monads in Java

```
public static <T> Optional<T> of(T value)
// Returns an Optional with the specified present non-null value.
<U> Optional<U> flatMap(Function<? super T,Optional<U>> mapper)
```

If a value is present, `flatMap` applies the provided *Optional-bearing* mapping function to it, return that result, otherwise return an empty `Optional`.

```
static <T> Stream<T> of(T t)
// Returns a sequential Stream containing a single element.
<R> Stream<R> flatMap(
Function<? super T,? extends Stream<? extends R>> mapper)
```

Here `flatMap` returns a `Stream` consisting of the results of replacing each element of this stream with the contents of a mapped stream produced by applying the provided mapping function to each element.

Chapter 17

Frameworks and IOC

17.1 Frameworks

A **Software Framework** is a collection of common code providing generic functionality that can be selectively overridden or specialized by user code providing specific functionality.
An **Application Framework** is a software framework used to implement the standard structure of an *application* for a specific development environment.

Examples

1. General Software Frameworks
   i. `.NET`
   ii. `Android SDK`
   iii. `Cocoa`
   iv. `Eclipse`
2. GUI Frameworks
   i. `MFC`
   ii. `Gnome`
   iii. `Qt`
3. Web Frameworks
   i. `ASP.NET`
   ii. `Rails`
   iii. `GWT`
   iv. `Spring`
   v. `Flask`

A framework embodies some *abstract design*, with more behavior built in. In order to use it you need to insert your behavior into various places in the framework either by subclassing or by plugging in your own classes, then the framework's code, which handles the program's **control flow** (the "`main` execution"), then calls your code at these points.
This realizes a very general concept, emphasizing **inversion of control** as opposed to libraries, where the user's code calls the library one, here is the code of the framework that calls the user's one.

17.1.1 Component Frameworks

Componenent Frameworks support development, deployment, composition and execution of components designed according to a given **Component Model**. More specifically, they support **composition/connection** of components according to the mechanisms provided by the *Component Model*, allowing instances to be "plugged" into the component framework itself, and regulating their **interaction**.

17.1.1.1 IDE and Frameworks

NetBeans is both an `IDE` and supports the `JavaBeans` *Component Framework*.
In general a framework can be supported by several `IDE`s

e.g. `Spring` supported by `Spring Tool Suite` (based on `Eclipse`), `NetBeans`, `IntelliJ IDEA`, `Eclipse`, ...

While an `IDE` can support several frameworks

e.g `NetBeans` supports `JavaBeans`, `Spring`, `J2EE`, `Maven`, `Hibernate`, `JavaServer Faces`, `Struts`, `Qt`, ...

17.1.2 Features

Consist of **parts** that are found in many apps of that type

- ◇ **Libraries** with APIs (classes with methods etc.)
- ◇ Ready-made extensible programs ("**engines**")
- ◇ Sometimes also **tools** (e.g. for development, configuration, content)

They also provide reusable abstractions of code wrapped in a well-defined API, however recall that,unlike in libraries, the overall program's **flow of control** is *not* dictated by the caller, but by the *framework*.

Frameworks usually support extensibility, either by extending within the framework language — using, subclassing, overriding, implementing interfaces, registering event handlers, ...— or through plug-ins defined in a specific format.

17.2 Inversion of Control

17.2.1 GUI

In *text-based interaction*, the order of interactions and of invocations is decided by the the code, while in the ***GUI**-based interaction*, the *GUI* loop decides when to invoke the methods (listeners), based on the order of events.

```
#ruby
puts 'What is your name?'
name = gets
process_name(name)
puts 'What is your quest?'
quest = gets
process_quest(quest)
```
TEXT

```
require 'tk'
root = TkRoot.new()
name_label = TkLabel.new() {text "What is Your Name?"}
name_label.pack
name = TkEntry.new(root).pack
name.bind("FocusOut") {process_name(name)}
quest_label = TkLabel.new() {text "What is Your Quest?"}
quest_label.pack
quest = TkEntry.new(root).pack
quest.bind("FocusOut") {process_quest(quest)}
Tk.mainloop()
```
GUI

Figure 17.1: Text vs GUI interaction

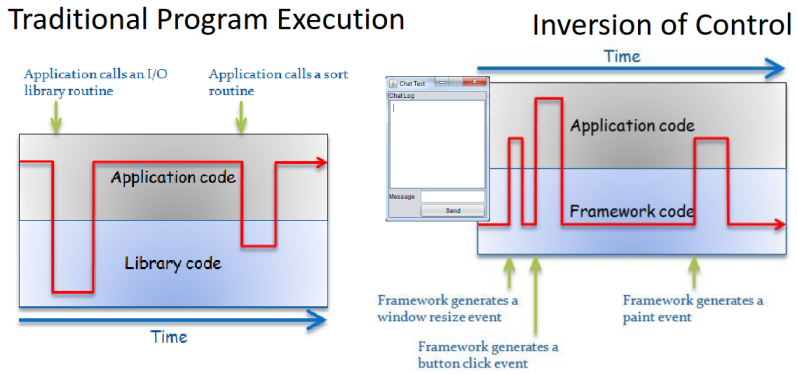


Figure 17.2: IoC: Library vs Framework approach

17.2.2 Containers

Often Frameworks provide **containers** for deploying *components*: a container may provide at *runtime functionalities* needed by the components to execute.

For examples `EJB` containers are responsible of the persistent storage of data and of the availability of `EJB`'s for all authorized clients.

17.3 Loosely Coupled Systems

Good *OO Systems* should be organised as a network of interacting objects, keeping in mind as a goal to have *high **cohesion***, *low **coupling***.
Low coupling has as key advantages

- ◇ Extensibility
- ◇ Testability
- ◇ Reusability

17.3.1 Dependecy Injection

When discussing **IoC** in Frameworks, *"Control"* does not refer only to control flow, but also control over *dependencies*, *coupling*, *configuration*.

We can make a few considerations on IoC with respect to dependencies:

- ◇ something outside a component handles:
  - configuration (properties)
  - wiring / dependencies (components)
- ◇ component-oriented
- ◇ removes coupling
  - coupling of configuration and dependencies to the point of use
  - coupling of component to concrete dependent components
- ◇ somewhat contrary to encapsulation

17.4 Trade Monitor

Let's discuss this example to see how all of this comes into practice.

A trader wants that the system rejects trades when the exposure reaches a certain limit

Thus the component (class) `TradeMonitor` provides a method `TryTrade` (below) which checks the condition, accessing *current exposure* and *exposure limit* from a `DAO` (*Data Access Object*), a persistent storage.

```
public bool TryTrade(string symbol, int amount){
   int limit = limitDao.GetLimit(symbol);
   int exposure = limitDao.GetExposure(symbol);
   return (exposure + amount > limit) ? false : true;
   }
```

How can we limit dependencies among the two components?

17.4.1 Interfaces - Refactoring 1

Let's consider a possible refactoring, introducing **interface** and implementation separation, which still has a static dependency on `DAO` :

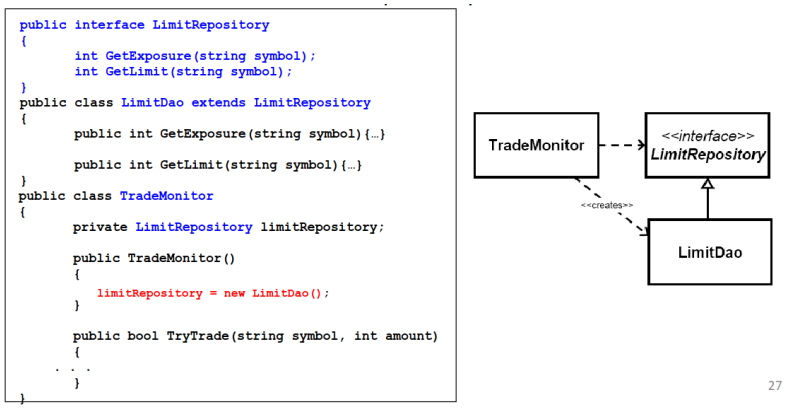


Figure 17.3: Refactoring 1

17.4.2 Factory - Refactoring 2

Here we introduce a **factory** which resolves the previous problem, but `LimitDao` is still tightly coupled, but to `Factory`.

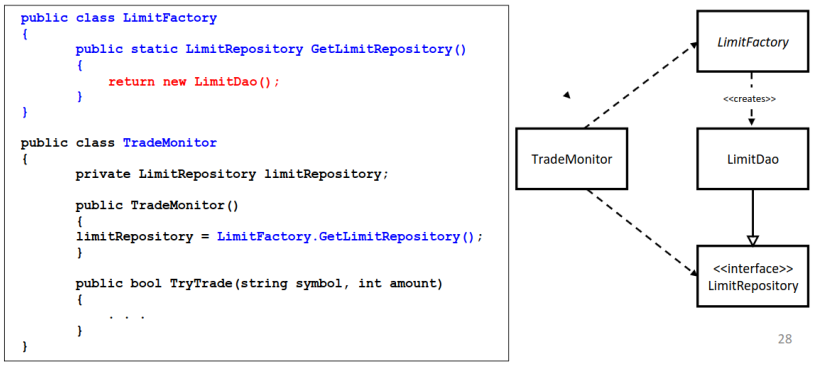


Figure 17.4: Refactoring 2

17.4.3 ServiceLocator - Refactoring 3

Introduce a `ServiceLocator`. This object acts as a (static) registry for the `LimitDao` you need, giving us extensibility, testability, reusability.
However ote that an external `Assembler` sets up the registry.

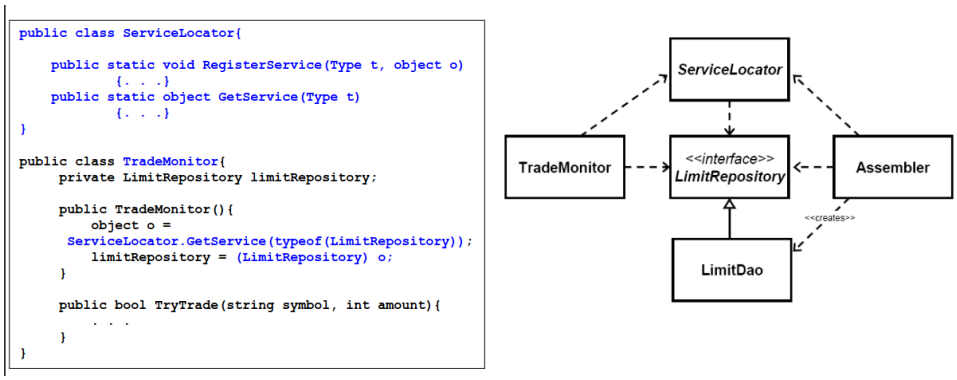


Figure 17.5: Refactoring 3

Pros

- ◇ The Service Locator pattern succeeds in decoupling the TradeMonitor from the LimitDao
- ◇ Allows new components to be dynamically created and used by other components later
- ◇ It can be generalized in several ways, eg. to cover dynamic lookup

Cons

- ◇ Every component that needs a dependency must have a reference to the service locator
- ◇ All components need to be registered with the service locator
- ◇ If bound by name:
  - Services can't be type-checked
  - Component has a dependency to the dependent component names
  - if many components share an instance but later you want to specify different instance for some, this becomes difficult
- ◇ If bound by type can only bind one instance of a type in a container
- ◇ Code needs to handle lookup problems

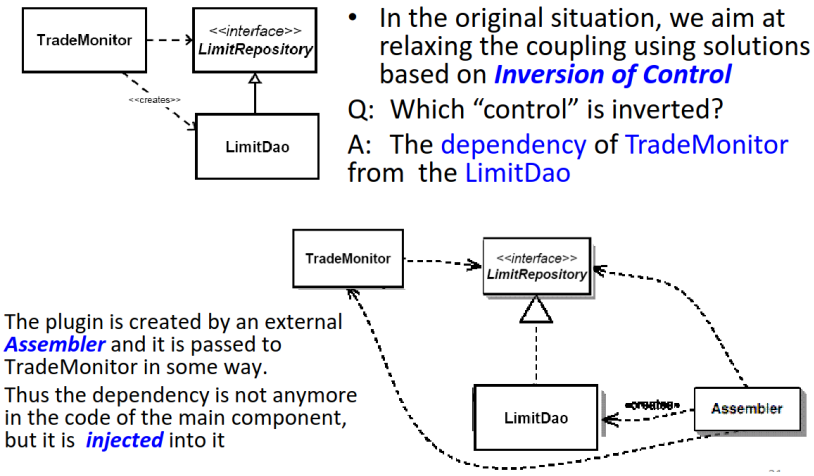
17.5 Dependency Injection

Dependency injection allows avoiding *hard-coded* dependencies (strong coupling) and changing them, and allows selection among multiple implementations of a given dependency interface at run time. It can be achieved through:

1. Setter injection
2. Constructor injection
3. (Interface injection)

Both **Service Locator** and **Dependency Injection** provide the desired decoupling, but let's compare the two solutions:

- ◇ With service locator there is no **IoC**, since the desired component is obtained after request by the `TradeMonitor` to the `Locator`; this makes the application still depending on the locator.



◇ With dependency injection there is *no explicit request*: the component appears in the application class.

Inversion of control is a bit harder to understand. With Service Locator the application still depends on the locator, besides, it is easier to find dependencies of component if *Dependency Injection* is used.

Check *constructors* and *setters*
vs
Check *all invocations* to `Locator` in the source code

17.6 Designing Frameworks

Frameworks are normally implemented in an object- oriented language such as Java. It is important to learn to analyze a potential software family, identifying its possible common and variable aspects, and evaluating alternative framework architectures.

A possible idea is to start from a known divide-and-conquer algorithm such as:

Listing 17.1: Example pseudocode of a Divide-and-Conquer algorithm

```
function solve (Problem p) returns Solution {
   if isSimple(p)
      return simplySolve(p);
   else
      sp[] = decompose(p);
      for (i= 0; i < sp.length; i = i+1)
         sol[i] = solve(sp[i]);
      return combine(sol);
}
```

We can apply known techniques and patterns to **define** a *framework* for a **software family**. Instances of the defined framework, obtained by standard extension mechanism, will be concrete algorithms of the *family*.

17.6.1 Terminology

◇ **Frozen Spot**
common (shared) aspect of the software family
◇ **Hot Spot**
variable aspect of the family
◇ **Template method**
concrete method of base (abstract) class implementing behavior common to all members of the family
◇ A hot spot is represented by a group of abstract ***hook*** *methods.*
◇ A template method calls a *hook method* to invoke a function that is specific to one family member —Inversion of Control—.
◇ A hot spot is realized in a framework as hot spot subsystem:

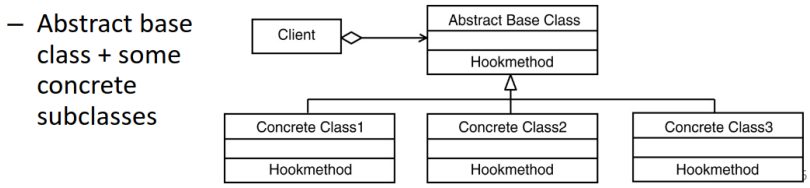


Figure 17.6: *Hotspot* implementation

Principles

1. The **unification** principle [*Template Method* Design Pattern]
   i. Exploits *inheritance* to implement the hot spot subsystem
   ii. Both the template methods and hook methods are defined in the same abstract base class
   iii. Hook methods are implemented in subclasses of the base class
2. The **separation** principle [*Strategy* Design Pattern]
   i. It uses *delegation* to implement the hot spot subsystem
   ii. The template methods are implemented in a **concrete** context class; the hook methods are defined in a separate `abstract class` and implemented in its subclasses
   iii. The template methods delegate work to an instance of the subclass that implements the hook methods

17.6.2 Template Method design pattern

It is one of the behavioural pattern of the *Gang of Four*; Its intent is to define the skeleton of an algorithm in an operation, *deferring* some steps to subclasses: A **template method** belongs to an *abstract* class and it defines an algorithm in terms of *abstract* operations that subclasses **override** to provide *concrete behavior*.

Template methods call, among others, the following operations:

1. **concrete** operations of the abstract class ⟶ fixed parts of the algorithm
2. **primitive** operations, ⟶ abstract operations that subclasses have to implement
3. **hook** operations ⟶ provide default behavior that subclasses may override if necessary. A hook operation often does nothing by default.

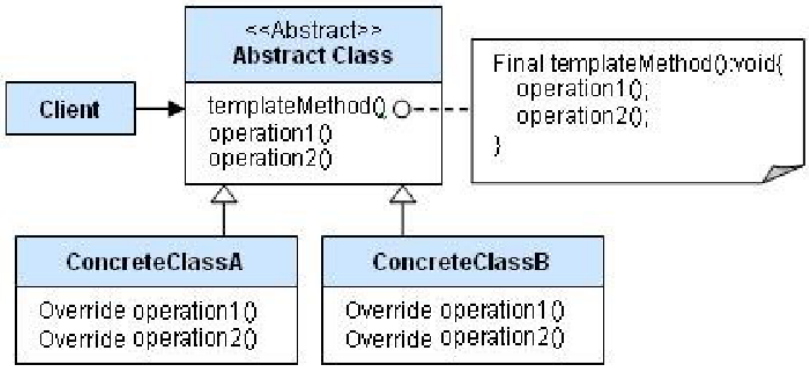


Figure 17.7: Template method

17.6.2.1 Applying *Unification Principle*

Let's consider the result of applying *unification principle* to the example code 17.1 provided before.

```
-- hotspots
-- templatemethod
abstract public class DivConqTemplate
function solve (Problem p) returns Solution {
   if isSimple(p)
      return simplySolve(p);
   else
      sp[] = decompose(p);
      for (i= 0; i < sp.length; i = i+1)
         sol[i] = solve(sp[i]);
      return combine(sol);
}
abstract protected boolean isSimple (Problem p);
abstract protected Solution simplySolve (Problem p);
abstract protected Problem[] decompose (Problem p);
abstract protected Solution combine(Problem p, Solution[] ss) ;
```

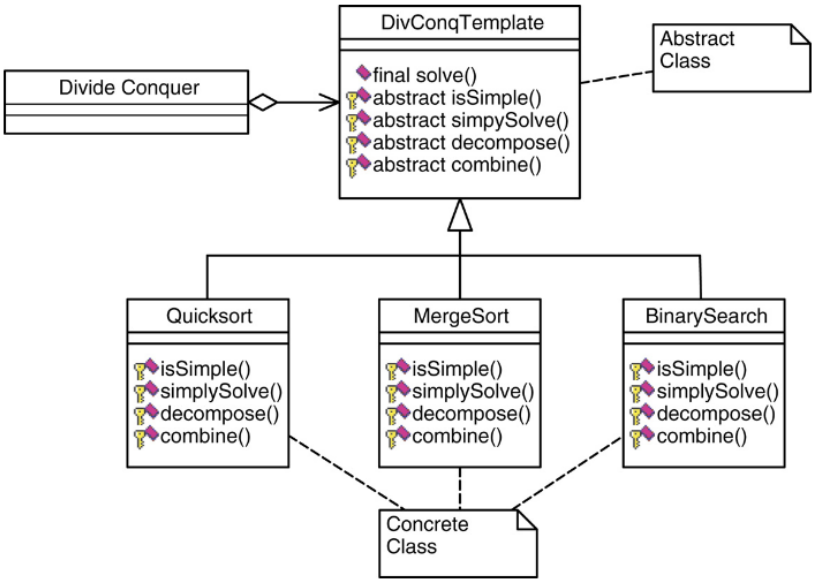


Figure 17.8: The generic schema of a Divide-and-Conquer *Template Method* designed Framework, with the concrete implementations for various sorting algorithms.

17.6.3 Strategy design pattern

Another one of the behavioural pattern of the *Gang of Four*; Its intent is to allow to select (part of) an algorithm at runtime, leading the client to use an object implementing the interface and invoking methods of the interface for the hot spots of the algorithm.

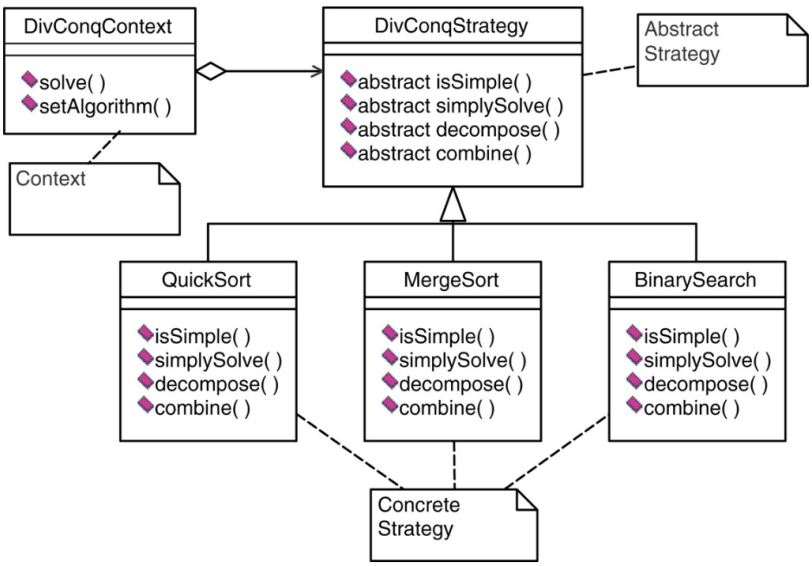


Figure 17.9: Strataegy UML Class Diagram

17.6.3.1 Applying the *Separation Principle*

The client delegates the hot spots to an object implementing the strategy.

The implementations of `DivCongStrategy` are similar to the previous case.

```
public final class DivConqContext {
   public DivConqContext(DivCongStrategy dc) {
this.dc = dc;
}

public Solution solve (Problem p)
{ Problem[] pp;
if (dc.isSimple(p)) { return dc.simplySolve(p); }
else { pp = dc.decompose(p); }
Solution[] ss = new Solution[pp.length];
for (int i = 0; i < pp.length; i++)
{  ss[i] = solve(pp[i]); }
return dc.combine(p, ss);
}

public void setAlgorithm(DivCongStrategy dc) {
   this.dc = dc;
   }

   private DivCongStrategy dc;
   }
```

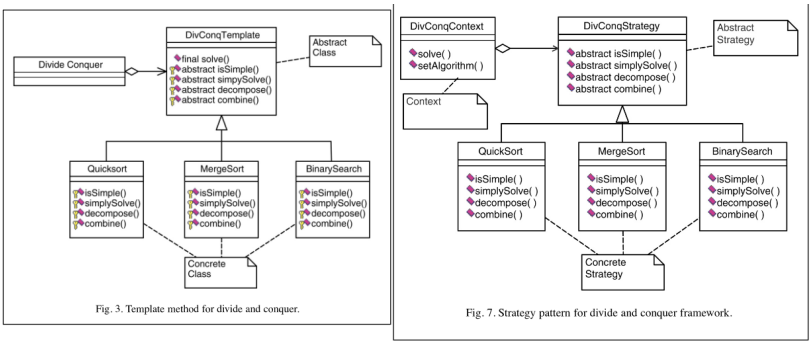


Figure 17.10: Comparison between the two pattern's schemas

17.7 Development by generalization

Recalling what said earlier, we try to address:

*Learning to analyze a potential software **family**, identifying its possible common and variable aspects, and evaluating alternative framework architectures. Framework design involves incrementally **evolving** a design rather than discovering it in one single step*

Where the *evolution* consists of examining **existing designs** for family members, identifying the **frozen** and **hot spots** of the family, and ultimately **generalizing** the program structure to enable *code reusing* for frozen spots and multiple *different implementations* for each hot spot.

In the slides there is an example based on binary tree traversals, with a discussion on each generalization step.

17.7.1 Identifying Frozen and Hot spots

Frozen Spots, which are fixed for the whole family:

1. The structure of the tree, as defined by the BinTree hierarchy

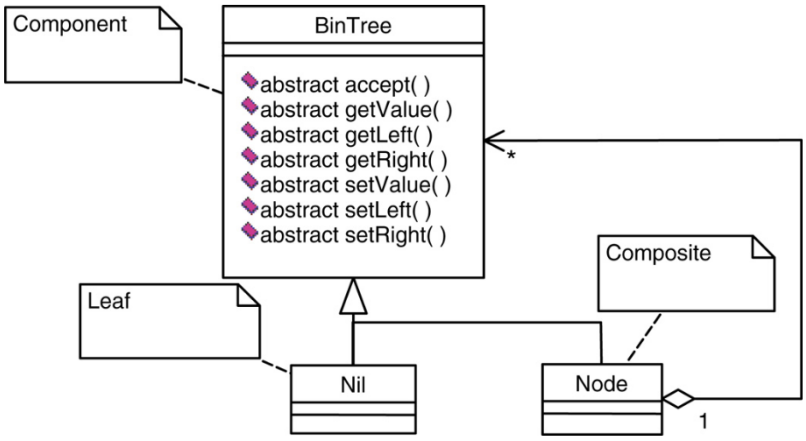


Figure 17.11: Binary tree using the Composite design pattern

2. A traversal accesses every element of the tree once, but it can stop before completing
3. A traversal performs one or more visit actions accessing an element of the tree
   meaning that there may be different and multiple actions after visiting a node, since it may represent the end of a left subtree visit, a right subtree visit or a root.

Let's identify possible **Hot Spots**, which have to be fixed in each element of the family.

1. Variability in the visit operation's **action**: a function of the current node's value and the accumulated result
2. Variability in **ordering** of the visit *action* with respect to subtree traversals; Should support *preorder*, *postorder*, *in-order*, and their combination.
3. Variability in the **tree navigation** technique. Should support any access order.
   not only left-to-right, depth-first, total traversals

17.8 Visitor Pattern

The **Visitor** pattern guarantees *separation* between algorithm and data structure.

The data structure can be made of different types of components (*ConcreteElements*), and each component implements an `accept(Visitor)` method. The `Visitor` defines one visit method for each type, including the navigation logic in itself. At each step, the correct visit method is selected by **overloading**.

```
public interface BinTreeVisitor
{   abstract void visit(Node t);
    abstract void visit(Nil t);
}
```

```
abstract public class BinTree
{   public void setValue(Object v)  { }        // mutators
    public void setLeft(BinTree l)  { }        //  default
    public void setRight(BinTree r) { }
    abstract public void accept(BinTreeVisitor v); // accept Visitor
    public Object  getValue() { return null; } // accessors
    public BinTree getLeft()  { return null; } //   default
    public BinTree getRight() { return null; }
}
```

```
public class Node extends BinTree
{   public Node(Object v, BinTree l, BinTree r)
    {   value = v; left = l; right = r; }
    public void setValue(Object v)  { value = v; }  // mutators
    public void setLeft(BinTree l)  { left = l;  }
    public void setRight(BinTree r) { right = r; }
    // accept a Visitor object
    public void accept(BinTreeVisitor v) { v.visit(this); }
    public Object  getValue() { return value; }    // accessors
    public BinTree getLeft()  { return left;  }
    public BinTree getRight() { return right; }
    private Object  value;    // instance data
    private BinTree left, right;
}
```

```
public class Nil extends BinTree
{   private Nil() { }   // private to require use of getNil()
    // accept a Visitor object
    public void accept(BinTreeVisitor v) { v.visit(this); }
    static public BinTree getNil() { return theNil; } // Singleton
    static public BinTree theNil = new Nil();
```

Figure 17.12: Visitor Pattern applied to the BinTree visit

Even if in the *Visitor* pattern, as in the *Template Method* pattern, an abstract class is defined and later implemented by subclasses which provide concrete behaviour, in the *Visitor* pattern such classes are ***intended*** to be used directly by *clients*, while in the *Template Method* pattern they are ***intended*** to be called by the *Frozen Spots* inside the abstract class itself, not by *clients*.

17.8.1 Wrap Up and Comparison

The **Visitor** Pattern consists of "Visitees" or "Hosts" and "Visitors". Hosts are objects within an object tree, and Visitors contain operations to be performed on these Hosts.

Hosts expose an `Accept()` method, which takes a Visitor object, and Visitors expose a `Visit()` method which has an overload for each Host. When the `Accept()` method is called on the Host, and a Visitor passed, a `Visit()` method is called on the visitor.

Using this pattern, operations become *Double Dispatch*, meaning they are executed based on two classes: the Host and the Visitor.

The **Strategy** Pattern consists of a "Context" and a "Strategy". Contexts are ~~objects within a tree~~ related classes, and a Strategy is a class containing a series of operations to be used by the Contexts.

Strategy provides an interface of which Context objects are aware. When a Context object is created, a Strategy is also created (if not static) and given to the Context. Operations can then be selected from the selected Strategy as desired.

Chapter 18

Java Memory Model

A **memory model** for *multithreaded* systems specifies how mem actions in a program will appear to execute to the programmer, i.e. —more specifically— which value each read of a memory location may return.
Every hardware and software interface of a system that admits multithreaded access to shared memory **requires** a memory model determining the transformations that the system can apply to a program.

In the case of high-level programming languages such as Java the memory model determines
1. the transformations the compiler may apply to a program when **producing bytecode**
2. the transformations a Virtual-Machine may apply to bytecode when **producing native code**
3. The **optimizations** that hardware may perform on the native

Besides, the model also impacts the programmer, since such transformations determine the possible outcomes of a program.
Without a well defined memory model for a programming language, it is impossible to known what the legal results are for a program in such language.

When programming *"correctly"* in Java, using `volatile` keywords and related constructs, we can —in some sense— ignore the memory model

Memory Hierarchy

In modern architectures memory is stratified ranging from mass memory (hard disks) to `CPU` registers, passing through different cache levels (`L1,L2,L3`), obtaining a **memory hierarchy**; depending on `CPU` architectures, cache levels may be shared or not among cores.

18.1 Java Memory Model

The JMM —updated with Java 5— first of all, provides standard guarantees for *correctly synchronized* programs, i.e. sequential consistency of data-race-free programs.
For what concerns *incorretly synchronized* programs instead, the behaviour is *bounded* by a well-defined notion of **causality**, so the semantics are *not* completely undefined as they were in the early (pre `Java 5` - 2004) versions of the memory model.
The causality constraints are *strong enough* to *respect* the **safety** and **security properties** of java, and *weak enough* to *allow* standard compiler and hardware **optimizations**.

18.1.1 Runtime Data Areas

Local -*primitive* type- **variables** of methods are allocated on thread stacks, and *cannot* be accessed by other threads; *Objects* are instead allocated on the Heap, and are the only ones which can be shared among threads.

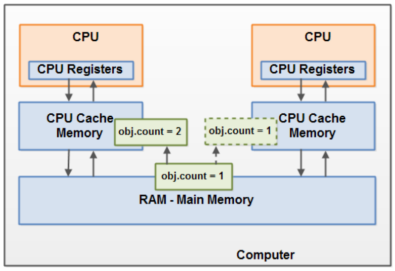


Figure 18.1: Visibility issues across memory areas

For what concerns the distribution of data in Java, it may be spread orthogonally around the memory hierarchy, i.e. anything can go anywhere.
Access to shared variables, possibly in different memory areas, leads to two key issues:

1. **Visibility** of variable updates
2. **Data Races**

To overcome these issues Java provides the `volatile` modifier, and `synchronized` `methods/blocks`, which are explicitly taken into account by the JMM.

18.2 `volatile` modifier

`volatile` is a modifier that can only be applied to fields of a class, and intuitively it declares that a field can be modified by multiple threads[1]. The JMM guarantees that the write of a volatile variable is visible when it is read. An *implementation* should guarantee that the new value is flushed from the cache to the RAM, if a read happens "after" a write.

What does it mean that *"a read happens after a write"*?

This will be discussed later on in Sec 18.3, however, When threads do *not* use any synchronization mechanism, their behavior is described as the sequence of performed read/write **actions**, along with the results of the read operations; such sequence has a **partial ordering** whose *legitimacy* is checked by the JMM which aims to ensure that a read results in the actual last value written in this partial ordering.

18.2.1 Data Races

Notice that `volatile` doesn't solve **Data Races**, which need synchronization mechanism; the typical example is incrementing a shared counter, which actually consists of three operations, `read`, increment the value read, and `write` it; such actions are **not** performed *atomically*[2], thus a second thread may read the "old" before the first one writes the updated one, resulting in only one incrementation instead of two.

18.2.2 Monitors

Monitors are the default Java synchronization mechanisms. Every object has a monitor exposing a lock which can be held only by one thread at a time. methods and ... with the `synchronized` modifier are guarded by the lock.

18.3 Describing thread behaviour

The JMM has no explicit global ordering of all actions by time consistent with each thread's perception of time, and has no global store.
Executions are instead described in terms of memory **actions**, **partial orders** on these actions, and a **visibility function** that assigns a write action to each read action.

[1] Clearly incompatible with `final`
[2] So... which operations are atomic and which are not?

Actions

1. Volatile read
2. Volatile write
3. Lock on monitor $m \in \mathbb{M}$
4. Unlock of monitor $m \in \mathbb{M}$
5. Normal read from $v \in \mathbb{L}$
6. Normal write to $v \in \mathbb{L}$
7. External action

Here "Synchronization" actions are marked in red.

An execution of a *single-threaded* program fixes a total order $\leq_{po}$ on its *actions*, called **program order**; while for a *multi-threaded* the program order consists in the union the program order of its threads, so it does not relate actions of different threads.
An execution of a *multi-threaded* program is **sequentially consistent** if there is a total order of its actions consistent with the program order —and such that each read has the value of the last write—.
For *datarace-free*[3] mt-programs, the JMM guarantees that only **sequential consistent** executions are legal.

JMM has been designed to guarantee three things:

1. Promise for programmers
   Sequential consistency must be sacrificed to allow optimizations, but it still holds for datarace-free program
2. Promise for security
   Values should not appear "out of thin air", allowing for information leakage
   Even for non-datarace-free programs!
3. Promise for compilers
   HW and SW optimizations should be applied without violating (both) the first two requirements

18.3.1 Sequential Consistency is too strong

[3] Also called *corretly* or *well synchronized programs*

Listing 18.1: Thread 1

```
int r1;
r1 = B;
A = 1;
```

Listing 18.1: Thread 2

```
int r2;
r2 = A;
B = 1;
```

Which values can `r1` and `r2` take?
Depends on who writes first, but in a *sequentially consistent* execution, `r1 == r2 == 1` is not possible.
However, it may occur in case of **instruction reordering**. Conceptually, in the absence of synchronization, the compiler/JVM/CPU is allowed to reorder the instructions (typically to improve performance) as long as this reordering is irrelevant from the point of view of the single thread.
Indeed, if the order of the instructions of Thread 1 and/or Thread 2 is reversed, the result `r1 == r2 == 1` becomes possible.

18.3.2 Out-of-thin-air

Listing 18.2: Thread 1

```
r1 = x;
y = r1;
```

Listing 18.2: Thread 2

```
r2 = y;
x = r2;
```

`x = y = 0` initially; can we obtain `r1 == r2 == 42` at the end?
*"Well **no**, but actually **yes**..."*
In some situations the Runtime environment may *guess* that, at some point, `x` evaluates to `42`: we say that `42` comes *"out-of-thin-air"*. Then it checks by looking at the two thread instructions if it may happen that `r1 == r2 == 42`:

"Yes! So x actually really evaluates to 42! I guessed right! ☺"

This was an accepted guess before the JMM introduced with Java 5 (2004), but currently such claims at runtime are forbidden.

18.3.3 Synchronization order

Each execution of a program is associated with a **synchronization order** $\leq_{so}$ which is a total order over all synchronization actions satisfying:

1. Consistency with program order
2. Read to a volatile variable v returns the value of the write to v that is ordered last before the read by the

synchronization order.

$a \leq_{sw} b$ is read "action a synchronizes with action b". This holds if $a \leq_{so} b$ and:
- ◇ a unlocks a monitor and b locks it
- ◇ a writes to a volatile variable and b reads it

Relation *happens-before* $\leq_{hb}$ is the —(smallest relation)— transitive closure of the *program order* $\leq_{po}$ and the *synchronizes-with* relation.

18.3.4 Formally Defining Data Races

Definition 18.1 (Data Race) *Two accesses x and y form a data race in an execution of a program if they are from different threads, they conflict, and they are not ordered by happens-before in a sequential consistent execution.*

A program is said to be **correctly synchronized** —or datarace-free— if and only if all sequentially consistent executions of the program are free of data races.

The first requirement for the JMM is to ensure sequential consistency for correctly synchronized or datarace free programs
Programmers should not worry about code transformations for datarace-free programs. TODO

$E = (P, A, \leq_{po}, \leq_{so}, W, V, \leq_{sw}, \leq_{hb})$, where
- P is a **program**
- A is a **set of actions**
- $\leq_{po}$ **program order**, total on actions of each thread
- $\leq_{so}$ **synchronization order**, total on synchronization actions in A
- W - a **write-seen function**, which for each read r in A, gives $W(r)$, the write action seen by r in E.
- V - a **value-written function**, which for each write w in A, gives $V(w)$, the value written by w in E.
- $\leq_{sw}$, **synchronizes-with** partial order
- $\leq_{hb}$ **happen-before** partial order

Figure 18.2: Dataraces Formally

$E = (P, A, \leq_{po}, \leq_{so}, W, V, \leq_{sw}, \leq_{hb})$ is a **well-formed execution** if:

1. Each read of a var x sees a write to x, and all reads and writes of volatile variables are volatile actions
2. Synchronization order is consistent with program order and mutual exclusion
3. The execution obeys intra-thread consistency
4. The execution obeys intra-thread and happens-before consistency (each read of v sees the last preceding write to v)

Now, which *well-formed executions* are **legal**? **Legal executions** are built iteratively: in each iterations, the JMM commits a set of memory actions; actions can be committed if they occur in some well-behaved...

A well-formed $E = (P, A, \leq_{po}, \leq_{so}, W, V, \leq_{sw}, \leq_{hb})$ is validated by *commiting* actions in A; if all actions of A are committed, then E is legal. There must exists a sequence of subsets of a

$$C_0 \subset C_1 \subset \cdots \subset C_n = A$$

and one $\{E_i\}_{i \leq n}$ of well-formed executions such that each E_i "witnesses" the actions in C_i

I did not understand this witnessing part honestly...

18.4 Rules for Java Programmers

Even disregarding the technicalities of the model, its impact can be translated to a set of useful rules for Java programmers, which may be of three types:
- ◇ **Atomicity** - Which operations are naturally atomic?

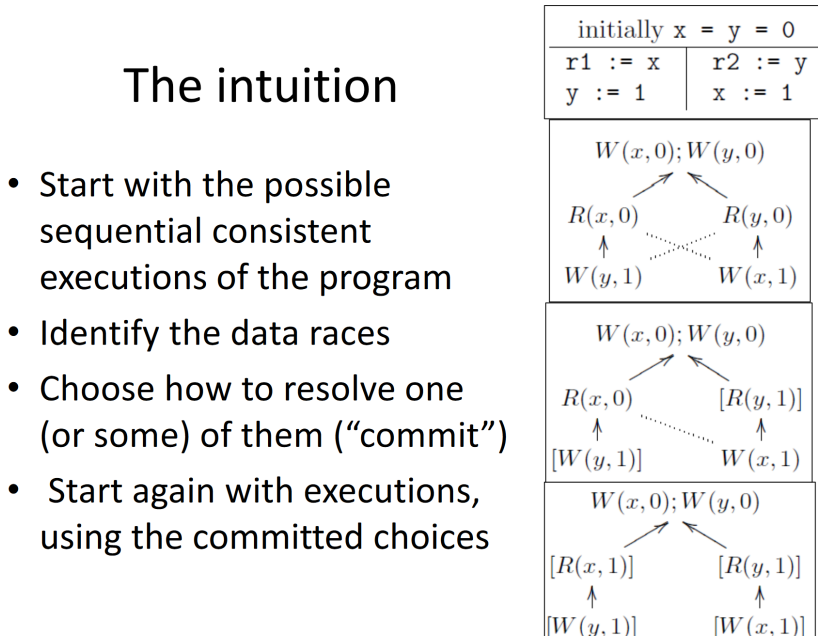


Figure 18.3: Legal Executions

- ◇ **Visibility** - When does a memory write become visible to other threads?
- ◇ **Reordering** - In what order can the operations be rearranged?

18.4.1 Atomicity

An operation is **atomic** if, from the point of view of any other thread, its effects are seen in full, or not at all (but never "half").But then...
Which operations are naturally atomic, even in the absence of mutual exclusion mechanisms?
JLS and JMM guarantee that:

- ◇ Reads and writes of `reference` variables are atomic
- ◇ Reads and writes of `primitive` variables are atomic, *except* for `long` and `double` variables
  Modification of a long variable can occur in two distinct operations which may be interrupted by the scheduler, separately modifying the 32 most significant bits and the 32 least significant bits.
  "Implementations of the Java Virtual Machine are encouraged to avoid splitting 64-bit values where possible. Programmers are encouraged to declare shared 64-bit values as volatile or synchronize their programs correctly to avoid possible complications." — JSL 17
- ◇ Reads and writes of `volatile` variables are atomic

```
int x, y;
long n;
volatile long m;
Object a, b;
volatile Object c, d;

1. x = 8;                    // Atomic
2. x = y;                    // Atomic
3. n = 0x1122334455667788;   // Not Atomic
4. m = 0x1122334455667788;   // Atomic
5. m++;                      // Not Atomic
6. a = null;                 // Atomic
7. a = b;                    // Atomic
8. c = d;                    // Atomic
```

Note that volatile modifier makes only a single write to the variable in question atomic: even if `a` and `b` are both `volatile`, `a = b` is **not** atomic.

18.4.2 Visibility

In absence of synchronization, the operations (writes to memory) performed by a thread can remain hidden from other threads **indefinitely**. In particular, some operations may remain hidden, and others may be visible.

Visibility is guaranteed by the following operations:

- ◇ Acquiring a **monitor** (i.e., entering a `synchronized` method or block) makes visible the operations performed by the last thread that owned that monitor, up until the moment it released it
- ◇ Reading the value of a `volatile` variable makes visible the operations carried out by the last thread that modified that variable, up to the moment in which it modified it
- ◇ Invoking `t.start()` makes visible to the new thread `t` all the operations carried out by the calling thread, up to the invocation of start
- ◇ Returning from a `t.join()` invocation makes visible all the operations carried out by thread t until its termination

18.4.3 Reordering

s said, the compiler, the JVM and the CPU can reorder any sequence of instructions as long as the result does not change for the single thread. Clearly, `synchronized` and `volatile` constructs reduce the possibility of reordering, but we can dig deeper.

Consider two subsequent instructions `x1` and `x2` having no dependencies between them from the point of view of a single thread. In which cases may they be —reversed— reordered?

Type of x1 \ Type of x2	Normal	Volatile read / Synchronized start	Volatile write / Synchronized end
Normal	Yes	Yes	No
Volatile read / Synchronized start	No	No	No
Volatile write / Synchronized end	Yes	No	No

Figure 18.4: Reodering `x1,x2`cases

- ◇ Normal instructions can always be interchanged
- ◇ Normal instructions can be brought into a synchronized block
- ◇ The normal instructions that precede the reading of a volatile can be moved after the reading
- ◇ The normal instructions that follow the writing of a volatile can be moved before the writing

Chapter 19

RUST

Rust is a general purpose, system programming language with a focus on safety, especially **safe concurrency**, supporting both *functional* and *imperative* paradigms. Its main goal is to *ensure safety without penalizing efficiency*. `C/C++` provide more control but less safety, while `Python/Haskell` provide less control but more safety. **Rust** aims to get the best of both worlds, providing both **control** and **safety**.

Despite its syntax resemblance to C/C++, in a deeper sense Rust is closer to the ML family languages; in fact almost every part of a function body is an expression, include `if-then-else` constructs, which returns a value.

19.1 Statically enforcing memory safety

Rust, similarly to C, compiles to **object code** for bare-metal performance, but it supports **memory safety**: programs can *dereference* only previously allocated pointers that have not been freed, and *out-of-bound* array accesses not allowed; besides, the **overhead** introduced is very low, since it's the *compiler* which checks that memory safety rules are followed, and there's *no garbage collection*, so zero-cost abstraction in managing memory.
This is achieved through and **advanced type system** and three key concepts to prevent memory corruption:

1. **Ownership**
2. **Borrowing**
3. **Lifetime**

Again, Rust is designed to be **memory safe** even in the presence of **concurrency**, and guarantees the following properties **statically**, meaning that if the program *compiles* it will *never manifest a violation* of these properties:

- ◇ No `null` pointers
  ⟶ accessing a variable which does not hold a value
- ◇ No dangling pointers
  ⟶ Pointers to invalid memory location
  - Pointers to explicitly deallocated objects;
  - Pointers to locations beyond the end of an array;
  - Pointers to objects allocated on the stack;
- ◇ No double frees
  ⟶ A memory location in the heap is reclaimed twice
- ◇ No data races
  ⟶ unpredictable results in concurrent computations
- ◇ No iterator invalidation

19.2 `null` and Primitive types in Rust

A `null` value does **not** exist in Rust, so in some way it must address the problem of accessing a variable which does not hold a value.
Data values can only be initialized through a fixed set of forms, requiring their inputs to be already initialized, and if any branch of code fails to assign a value to the variable, we get a **compile time error**.

Static/global variables must be initialized at declaration time.

Nullable types, are managed with a generic `Option<T>`, playing the role of Haskell's `Maybe` or Java's `Optional`

```
enum std::option::Option<T> {
    None,
    Some(T)
}
```

19.2.1 Primitive Types

Listing 19.1: Rust primitive types

```
// Numeric types:
i8 / i16 / i32 / i64 / isize
u8 / u16 / u32 / u64 / usize
f32 / f64

bool
char // (4-byte unicode)
```

- **Type inference** for variables declarations with `let`
- **No overloading** for literals: type annotations to disambiguate
- **Tuples** like in Haskell
- **Arrays** with fixed length.
  out-of-bound access is checked at **runtime**, but it's just a single comparison, its overhead is negligible

19.3 Memory Management

As usual, Rust uses a **stack** of activation records, and a **heap** for dynamically allocated data structures.

The user is forced to be *aware of where* the data are stored: there is no **implicit boxing**[1].

```
fn main() {
    let x = 3; // 'let' allocates a variable on the stack
    let y = Box::new(3); // y is a reference to 3 on the heap
    println!("x == y is {}", x == *y); // "x == y is true"
    }
```

To avoid the overhead of a Garbage collection mechanism and the possible subtle errors introduced a programmer to whom memory management is delegated, Rust provides *deterministic management of resources*, with very low overhead, using **RAII** (*Resource Acquisition Is Initialization*).

19.3.1 Variables Immutability and `RAII`

By *default*, Rust variables are **immutable**, and their usage is statically checked by the compiler. `mut` is used to declare a resource as mutable.

Listing 19.2: Compilation *error* ✗

```
fn main() {
    let a: i32 = 0;
    a = a + 1;
    println!("a == {}", a);
}
```

Listing 19.2: Compilation ok ✓

```
fn main() {
    let mut a: i32 = 0;
    a = a + 1;
    println!("a == {}", a);
}
```

The *Resource Acquisition Is Initialization* (**RAII**) programming idiom states that Resource *allocation* is done during object *initialization*, by the constructor, while resource *deallocation* (**release**) is done during object destruction (specifically **finalization**), by the destructor.

Large resources are on the heap (or elsewhere) and are owned by an object on the stack. The object is then responsible for releasing the resource in its destructor. The object is **bound** to the **scope** (function, block) where it is declared; when the scope closes it is reclaimed, together with any owned resource.

Not sure i corretly understood this

[1] Act of *boxing* an `int` in `Integer`, or extracting an `int` from `Integer`

19.3.2 Ownership

This approached is adopted in modern C++: small objects are allocated on *stack*, while larger resources are on the *heap* –or elsewhere– and are **owned** by an object on the *stack*, who is responsible for *releasing* the resource in its destructor.
Each resource has a **unique owner**.

Rust supports RAII in a *strict* way through an **ownership system**, based on the concepts of *ownership* and *borrowing*.

Ownership

O1 - Every value is *owned* by a variable, identified by a name (possiby a path);
O2 - Each value has *at most one owner at a time*;
O3 - When the owner goes *out-of-scope*, the value is *reclaimed* / destroyed.

By default, an assignment between variables has a **move semantics**: the ownership is moved from the Right Hand Side (RHS) to the Left Hand Side (LHS) of the assignment.

Listing 19.3: O2 violated

```
fn main() {
    let x = Box::new(3);
    let _y = x; // underscore to avoid 'unused' warning
    println!("x = {}", x); // error! x is no longer owner of Box
    }
```

Box is a *heap-allocated* type that does not implement the Copy trait.

For primitive types and types implementing the **Copy trait**, assignment has a **copy semantics**;

Here O2 is satisfied because a new value is created

```
fn main() {
    let x = 3;
    let _y = x;
    println!("x = {:?}", x); // OK
}
```

```
fn main() {
    let x = Option::Some(3);
    let _y = x;
    println!("x = {:?}", x); // OK
}
```

The same move semantics apply also for parameter passing: any value passed to the function will be reclaimed when it returns, as the formal parameters gets out of scope; only returned values can survive.

tuples allow to return more

```
struct Dummy { a: i32, b: i32 }
fn foo() {
    let mut res = Box::new(Dummy {
        a: 0,
        b: 0
    });
    take(res);
    println!("res.a = {}", res.a); // compilation error
}
fn take(arg: Box<Dummy>) {...}
```

When invoking `take(res)` the ownership of `Dummy` is moved from `res` to `arg`: when `take()` returns `arg` goes out of scope, so the resource gets freed automatically, making it no longer usable in `println`: this result in a **compilation error**. To use again the resource, we would have to make take return it, i.e. `res = take(res)`.

This looks rather limiting, but allows to completely avoid the *Double-free* problem: memory is freed automatically when the owner goes out of scope, and by rule O2, each value has only one owner.

Rust does **not** allow explicit memory allocation

19.3.3 Borrowing

Since Ownership rules in some case may be too restrictive, **borrowing** is introduced: a resource can be *borrowed* from its owner via assignment or parameter passing. To guarantee memory safety, borrowing rules ensure that *aliasing*[2] and *mutability cannot* ***coexist***.
Values can be passed

1. by immutable reference ⟶ `x = &y`
2. by mutable reference ⟶ `x = &mut y`
3. or by value ⟶ `x = y`

Borrowing

About mutable and immutable references:

`B1` - At most **one** *mutable* reference to a resource can exist at any time
`B2` - If there is a *mutable* reference, **no** *immutable* references can exist
`B3` - If there is **no** *mutable* reference, **several** *immutable* references to the same resource can exist

During borrowing, ownership is reduced or suspended:

`B4` - Owner *cannot* free or **mutate** its resource while it is *immutably borrowed*
`B5` - Owner *cannot* even **read** its resource while it is *mutably borrowed*

```
let mut s = String::from("example");
let r1 = &mut s;
let r2 = &mut s;
println!("{} {}", r1, r2); // does not compile by rule B1

let r1 = &s;
let r2 = &mut s;
println!("{} {}", r1, r2); // does not compile by rule B2

let r1 = &s;
let r2 = &s;
println!("{} {}", r1, r2); // ok by rule B3
```

19.3.4 Strings

String types

1. `String` does not require to know the length at compilation time, thus allocated on the *heap*.
2. `&str` size must be known statically, allocated on the *stack*.

Method `String::from()` allocates memory on the heap: it takes an argument of type `&str` and returns a `String`.

A String object has three components:

1. a reference to the heap location containing the character sequence
2. capacity (unsigned integer)
3. length (unsigned integer)

`String` does not implement `Copy`, thus assignment is subject to move semantics; assignment creates a copy of length, capacity and reference, but not of the char sequence in the heap.

19.3.5 Lifetime

A **lifetime** is a construct that the borrow checker uses to ensure the validity of the *borrowing rules* 19.3.3. Lifetimes are associated with each individual ownership and borrowing: a lifetime *begins* when the **ownership** starts, and *ends* when it is moved / destroyed, while for **borrowings**, it ends where the borrowed value is accessed the last time.

```
fn main() {
    let mut s= String::from("ex-1");
    println!("s-0 == {}", s);
    let t = &mut s;
    *t = String::from("ex-2");
    // println!("s-1 == {}", s); // what happens if uncommented?
    // Error because we violate B2
    println!("t == {}", t);
    println!("s-2 == {}", s);
```

[2]Both the owner and the borrower can access the resource. More generally indicates that there are multiple ways to access a resource on the heap.

```
    let z = &s;
    println!("s-3 == {}", s);
    let w = z;
    println!("{},{},{}",z,w,s);
}
```

Lifetimes are mostly *inferred*, but sometimes they must be made explicit using the same syntax of generics. Using lifetimes, the compiler checks the validity of the rules of ownership and borrowing in the expected way; in particular, it ensures that –the *owner* of– every borrowed variable/reference has a lifetime that is longer than the borrower [B4,B5].

Borrowed (reference) formal parameters (arguments, return value) of a function have a lifetime, and if borrowed values are returned, each *must* have a lifetime.
The compiled tries to infer output lifetimes according to the following rules, but when not sufficient explicit lifetimes are necessary:

Lifetime

R1 - The lifetimes of the borrowed paramers are, by default, all **distinct**
R2 - If there is exactly **one input** lifetime, it will be assigned to **each output** lifetime
R3 - If a method has **more than one input** lifetime, *but* **one** of them is `&self` or `&mut self`, then this lifetime is assigned to **all output** lifetimes

```
fn longest(s1: &str, s2: &str) → &str { //does not compile
    if s1.len() > s2.len() { s1 }
    else { s2 }
}
```

Here the lifetime of the parameters depends on whether `s1` or `s2` is returned, so the compiler cannot infer the lifetime of the output parameters; hence, an **explicitly named lifetime** for input parameters is requires, as in the following snippet.

```
fn longest<'a>(s1: &'a str, s2: &'a str) → &'a str {
    if s1.len() > s2.len() { s1 }
    else { s2 }
```

19.4 More on Types

19.4.1 Enums

Enums (Algebraic Data Types) are similar to unions in C, but with a more powerful type system. They are similar to Haskell.

```
enum RetInt {
      Fail(u32),
      Succ(u32)
   }
fn foo_may_fail(arg: u32) → RetInt {
      let fail = false;
      let errno: u32;
      let result: u32;
      ...
      if fail {
            RetInt::Fail(errno)
         } else {
            RetInt::Succ(result)
         }
   }
```

Listing 19.4: Trees as ADT

```
#[derive(Debug)] // needed to print
enum Tree<T> {
   Empty,
   Node(T, Box<Tree<T>>, Box<Tree<T>>)
}

fn main() {
   let tree = Tree::Node(
      42,
      Box::new(Tree::Node(
         0,
         Box::new(Tree::Empty),
         Box::new(Tree::Empty)
      )),
      Box::new(Tree::Empty));
   println!("{:?}", tree);
   //>Node(42, Node(0, Empty, Empty), Empty)
}
```

`println!("{:?}", tree);` indicates to print `tree` in *"debug mode"*.

19.4.2 Pattern Matching

Compiler enforces that matching is complete. Pattern matching is useful for enums, but also for integral types

```
   let x = 5; // try others...
   match x {
      1               => println!("one"),
      2               => println!("two"),
      3|4             => println!("three or four"),
      5..=10          => println!("five to ten"),
      e @ 11..=20     => println!("{}", e),
      i32::MIN..=0    => println!("less than zero"),
      21..            => println!("large"),
      _               => println!("???"),
   }
```

19.4.3 Classes

Rust is **not** *Object Oriented* and there is **no inheritance**, instead it pushes for composition over inheritance.

```
#[derive(Debug)]
struct Rectangle { // class
      width: u32, // instance variable
      height: u32,
   }
impl Rectangle { // methods
      fn area(&self) → u32 { // first argument is this
            self.width * self.height
            // self.width = 20; // <- illegal, self is immutable
         }
   }
fn main() {
      let rect1 = Rectangle {
            width: 30,
            height: 50,
         };
      println!(
      "The area of the rectangle is {} square pixels.", rect1.area()
```

```
    );
}
```

19.4.4 Traits

Traits are equivalent to *Type Classes* in Haskell and to *Concepts* in C++20, similar to Interfaces in Java. A trait can include *abstract* and *concrete* (default) **methods**, but not fields or variables. A struct can implement a trait providing an implementation for at least its abstract methods

```
impl <TraitName> for <StructName>{ ... }
```

The *#[derive]* clause can be used –if possible– to derive automatically an implementation of a trait.

Rust supports **bounded universal explicit polymorphism** with **generics**, as in Java, where bounds are one or more traits. Generic functions may have the generic type of parameter bound by one or more traits, so within such a function, the generic value can only be used through those traits, allowing for generic function to be **type-checked** when defined, as it happens in Java, unlike C++ templates.
• However, implementation of Rust generics uses *monomorphization* and is similar to typical implementation of C++ templates, where a separate copy of the code is generated for each instantiation, in contrast with the type erasure scheme of Java.

- ◇ `Clone` - allows to create a deep copy of a value using the method clone(). The duplication process might involve running arbitrary code
- ◇ `Copy` - allows to duplicate a value by only copying bits stored on the stack; no arbitrary code is necessary. Marker trait
- ◇ `Debug` - support default conversion to text, for printing (marker)
- ◇ `Display` - programmable conversion to text, `fmt()`
- ◇ `Deref` and `Drop` - implemented by Smart Pointers
- ◇ `Synchkz` and `Send` - declare if a data type can be moved to another thread (marker)

19.5 Smart Pointers

Smart pointers act as a pointer but with additional metadata and capabilities, and are typically structs, implementing `Deref` (`*`) and `Drop` (*reclaiming* when out of scope).

```
fn main() {
    let b = Box::new(5);
    println!("b = {}", b);
    }
```

19.5.1 Smart Pointer and Deref Coercion

`Box<T>` Allow to store a data of type T on the heap, with no performance overhead. Deref (`*`) returns the value, but it is optional when using coercion: Deref coercion automatically converts a `Box<T>` (smart pointer) to `&T` (regular reference) when needed.

Listing 19.4: Basic reference and dereference

```
fn main() {
    let x = 5;
    let y = &x;
    ley z = Box::new(x);

    assert_eq!(5, x);
    assert_eq!(5, *y);
    assert_eq!(5, *z);
}
```

The variable `x` holds an `i32` value `5`. We set `y` equal to a reference to `x`. We can assert that `x` is equal to `5`. However, if we want to make an assertion about the value in `y`, we have to use `*y` to follow the reference to the value it's pointing to (hence *dereference*) so the compiler can compare the actual value. Once we dereference `y`, we have access to the integer value `y` is pointing to that we can compare with `5`.

Writing `assert_eq!(5, y);` instead, results in compilation error

With `z` we can use the dereference operator to follow the pointer of the `Box<T>` in the same way that we did `when` y was a reference.

Implementing `Deref` Trait

To implement the `Deref` trait, we need to implement a method named `deref` that borrows self and returns a reference to the inner data. An example of implementing the `Deref` trait is shown in Listing 19.5.

Having implemented the `Deref` trait, we can use the `*` operator on an instance of `MyBox<T>`, which will first call the `deref` method to get a reference, and then dereference that reference to access the inner value, allowing us to invoke `assert_eq!(5,*y)` with `y = MyBox::new(x)`. When doing so, Rust behind the scenes actually does `*(y.deref())`.

`self.0` is the syntax to access the first value inside a tuple struct, without exploiting names.

Listing 19.5: Implementing `Deref` Trait

```
use std::ops::Deref;
struct MyBox<T>(T);
impl<T> MyBox<T> {
    fn new(x: T) → MyBox<T> {
        MyBox(x)
    }
}
impl<T> Deref for MyBox<T> {
    type Target = T;
    fn deref(&self) → &T {
        &self.0
    }
}
```

The reason the deref method returns a reference to a value, and that the plain dereference outside the parentheses in `*(y.deref())` is still necessary, is to do with the ownership system. If the deref method returned the value directly instead of a reference to the value, the value would be moved out of self. We don't want to take ownership of the inner value inside `MyBox<T>` in this case or in most cases where we use the dereference operator.

More on the topic at doc.rust-lang.org/book/ch15-02-deref.html

Deref coercion converts a reference to a type that implements the Deref trait into a reference to another type. For example, deref coercion can convert `&String` to `&str` because `String` implements the Deref trait such that it returns `&str`.

Deref coercion was added to Rust so that programmers writing function and method calls don't need to add as many explicit references and dereferences with `&` and `*`. The deref coercion feature also lets us write more code that can work for either references or smart pointers.

19.5.2 RC and RefCell

`Rc<T>` supports **immutable** access to resource with reference counting. Method `Rc::clone()` *doesn't clone!* It simply returns a new reference, incrementing the counter, whose value can be obtained by `Rc::strong_count`; when the counter is 0 the resource is reclaimed.

`RefCell<T>` supports shared access to a mutable resource through the **interior mutability** pattern. It provides two methods `borrow()` and `borrow_mut()` which return a smart pointer (`Ref<T>` or `RefMut<T>`). `RefCell<T>` keeps track of how many `Ref<T>` and `RefMut<T>` are active, and *panics* if the ownership/borrowing rules are invalidated. Its implementation is single-threaded, and it is typically used with `Rc<T>` to allow multiple accesses.

Type	Sharable?	Mutable?	Thread Safe?
&	yes *	no	no
&mut	no *	yes	no
Box	no	yes	no
Rc	yes	no	no
Arc	yes	no	yes
RefCell	yes **	yes	no
Mutex	yes, in Arc	yes	yes

* but doesn't own contents, so lifetime restrictions.
** while there is no mutable borrow

Figure 19.1: Pointers comparison

19.6 Functional elements

Closures can capture non-local variables in three ways, corresponding to ownership, mutable and immutable borrowing; this is reflected in the trait they implement: `FnOnce`, `FnMut` and `Fn`. The trait implemented is inferred. With `move` before `|| FnOnce` is enforced.

```
let x = 5;
let greater_than_x = |y| y > x; // Parameters within ||
println!("{}",greater_than_x(3)); // prints "false"
let vector = vec![1, 2, 3, 4, 5]; // stream-like
vector.iter()
    .map(|x| x + 1)
    .filter(|x| x % 2 == 0)
    .for_each(|x| println!("{}", x));
```

19.6.1 Race conditions

Listing 19.6: Broken Rust code

```
// Rust: does not compile
fn main() {
    let mut counter = 0;
    let task = || {
      // closure
      for _ in 0..100000 {
       counter += 1;
      }
    };
    let thread1 = thread::spawn(task);
    let thread2 = thread::spawn(task);
    thread1.join().unwrap();
    thread2.join().unwrap();
    println!("{}", counter);
}
```

Looking at Listing 19.6 on the right:

- `Arc` is used to share ownership of the Mutex across multiple threads. It ensures that the `Mutex` is not deallocated while it is still in use
- `Mutex` ensures that only one thread can access the counter at a time, preventing data races.
- `counter.lock().unwrap()` locks the `Mutex` to gain mutable access to the counter. The `unwrap()` is used to handle the possibility of the lock being poisoned by a panic in another thread.

Listing 19.6: Fixed code with `Arc<Mutex<T>>` and `move`

```
use std::sync::{Arc, Mutex};
use std::thread;

fn main() {
    let counter = Arc::new(Mutex::new(0));
    let counter1 = Arc::clone(&counter);
    let counter2 = Arc::clone(&counter);

    let task1 = move || {
      for _ in 0..100000 {
       let mut num = counter1.
           lock().unwrap();
       *num += 1;
      }
    };

    let task2 = move || {
      for _ in 0..100000 {


       let mut num = counter2.
           lock().unwrap();
       *num += 1;
      }
    };

    let thread1 = thread::spawn(task1);
    let thread2 = thread::spawn(task2);

    thread1.join().unwrap();
    thread2.join().unwrap();

    println!("{}", *counter.lock().unwrap());
}
```

Listing 19.6 does not compile because Rust does not allow shared mutable state between threads. The closure `task` tries to capture `counter` by mutable reference because it needs to increment it, but Rust notices it may outlive the borrowed value `counter`, so it does not compile.

Rust's borrowing rules prevent multiple mutable references to the same data at the same time. When you try to spawn two threads with the same closure, both threads would need mutable access to `counter`, which is not allowed.

Rust prevents this bug by forcing us to make our intentions explicit. We can fix this by using the `Arc<Mutex<T>>`, along with the `move` keyword to move the ownership of the closure to the thread.

Notice that using only `move` to move the ownership of the closure to the thread is not enough, because the closure still captures `counter` by mutable reference. We need to use `Arc<Mutex<T>>` to fix this issue, as in Listing 19.6.

19.6.2 Sync and Send

`Send` and `Sync` are two strongly related traits regarding multithreading: an error is signaled by the compiler if the ownership of a value *not* implementing `Send` is passed to another thread; for a value to be referenced by multiple threads, it has to implement `Sync`.

$$\texttt{T}\ \textit{implements}\ \texttt{Send} \Leftrightarrow \texttt{\&T}\ \textit{implements}\ \texttt{Sync} \tag{19.1}$$

Examples

- `Arc<T>` is the thread-safe version of `Rc<T>` which implements Send and Sync
- `Mutex<T>` supports mutual exclusive access to a value via a lock. It is both Send and Sync, and typically wrapped in Arc

19.6.3 Unsafety

Mutable sharing is *inevitable* in the real world, and Rust provides a way to handle it through **unsafe blocks**.

Rust does **not** check the memory safety of most operations with raw pointers, they should be encapsulated in a `unsafe{}` synctatic structure.

```
struct Node {
    prev: option<Box<Node>>,
    //next: option<Box<Node>>,
    next: *mut Node // raw pointer
}
```

```
let a = 3;
unsafe {
    let b = &a as *const i32 as *mut i32; \\ "I know what I'm doing"
    *b = 4;
}
println!("a = {}", a); // prints "a = 4"
```

All *foreign* functions are *unsafe* because Rust cannot guarantee their safety.

```
extern {
    fn write(fd: i32, data: *const u8, len: u32) → i32;
}
fn main() {
    let msg = "Hello, world!\n";
    unsafe {
        write(1, &msg[0], msg.len());
    }
}
```

Chapter 20

Python

Python is very concise and good for scripting. It is the most used general purpose language, and there are many nice Machine Learning libraries.

Its two key aspects are that it is **interpreted** ($\neq$ *compiled*) and **dynamically typed**.

Aside from these two main aspects, we can discuss a few others:
even if not as much as Java, it's **object** oriented; Python supports both **imperative** and **functional** paradigms.
Python **Iterators** can be associated with `Lists` in Haskell and `Streams` in Java. Other Python features are:

- ◇ Powerful subscripting (slicing)
- ◇ Higher-order functions
- ◇ Flexible signatures, which compensate the lack of complex polymorphism
- ◇ Java-like exceptions
- ◇ (bad) Multithreading support

Let's discuss how Python addresses **typing**:

1. Variables come into existence when first assigned to
2. Variables are *not typed*, but Values are!
3. A variable can refer to an object of any type
4. It is **Strongly typed** in the sense that the *value type* does not change in unexpected ways
5. It is **Type-safe** since no conversion or operation can be applied to values of the **wrong** type

Variables come into existence when first assigned and a variable can refer to an object of any type, besides all types are (almost) treated the same way. Even if this allows for concise syntax and intuitive code writing, it also implies a main drawback: **type errors** are only caught at *runtime*.

20.1 Some Python aspects

- ◇ **Indentation** matters, and is used opposed to brackets {}
- ◇ A variable is created when some value is assigned to it
- ◇ Assignments in Python **do not** create a copy
  Even for `Integers`!
- ◇ Objects are deleted by the garbage collector once they become unreachable
  - `CPython` uses *reference counting* along with `Mark & Sweep` for garbage collection
- ◇

20.2 Data Types and operators

Integers are **unbounded**, while `Floats` are represented with 64 bits.
There are no logical symbols, the operators are `and, or, not`.
Strings can be enclosed in `''`, `""`, `""" """`, with the third that allows multiline strings (*cool!*).

20.2.1 Sequence types

`Tuples`, `Strings` and `Lists` are the sequence types in Python, they are *immutable* except for Lists.

They all support **slicing**, concatenation (`+`) and membership (`in`).

Slicing returns a subsequence of the original sequence, a **copy**. Start copying at the first index, and stop copying *before* the second index.

```
>>> t = (23, 'abc', 4.56, (2,3), 'def')
>>> t[1:4] # ('abc', 4.56, (2,3))
>>> t[1:-1] # negative indices ('abc', 4.56, (2,3))
>>> t[1:-1:2] # optional argument: step ('abc', (2,3))
>>> t[:2] # no first index: from beginning (23, 'abc')
>>> t[2:] # no second index: to end (4.56, (2,3), 'def')
>>> t[:] # no indexes: creates a copy (23, 'abc', 4.56, (2,3), 'def')
```

Lists, since they are **mutable**, support some specific operators `append(),insert(),extend(),index(),count(),remove(),sort()...`

Lists also support **List Comprehension** pretty similarly to Haskell, allowing also filtered and nested comprehensions.

```
>>> li = [3, 2, 4, 1]
>>> [elem*2 for elem in
    [item+1 for item in li] if elem > 1]
[8, 6, 10]
```

20.2.2 Sets and Dictionaries

Sets support membership, and common set operations, but not indexing:

```
>>> a = set('abracadabra')
>>> b = set('alacazam')
>>> a # unique letters in a
{'a', 'r', 'b', 'c', 'd'}
>>> a - b # letters in a but not in b
{'r', 'd', 'b'}
>>> a | b # letters in a or b or both
{'a', 'c', 'r', 'd', 'b', 'm', 'z', 'l'}
>>> a & b # letters in both a and b
{'a', 'c'}
>>> a ^ b # letters in a or b but not both
{'r', 'd', 'b', 'm', 'z', 'l'}
```

Dictionaries are very similar to `maps` in Java, and they map a key of an *immutable hashable* type, and support the following operations on the $\langle key, value \rangle$pairs:

1. define
2. modify
3. view
4. lookup
5. delete

20.3 Higher-order functions

Functions can be returned as result and passed as arguments to other functions, for example the predefined `map` and `filter` combinators. When handling higher-order functions there's a heavy use of iterators, which support laziness.

Typically List comprehensions can replace the `map` and `filter` combinators.

```
map(func, *iterables) --> map object
Make an iterator that computes the function using
arguments from each of the iterables. Stops when the
shortest iterable is exhausted

>>> map(λ x:x+1, range(4))  # lazyness:
<map object at 0x10195b278>      # returns an iterator
```

20.3.1 Decorators

A **decorator** is any callable Python object that is used to modify a function, method or class definition. A decorator is passed the original object being defined and returns a modified object, which is then bound to the name in the definition. The basic idea is to **wrap a function**, and the use cases may vary a lot, and may include *measuring execution time*, caching *intermediate results*, and so on.

```
def do_twice(func):
def wrapper_do_twice():
    func() # the wrapper calls the
    func() # argument twice
    return wrapper_do_twice
```

20.4 Namespaces and Scopes

A **namespace** is a mapping from *names* to *objects*, typically implemented as a dictionary.

1. builtin names (predefined functions, exceptions,...)
    i. Created at intepreter's start-up
2. global names of imported modules
    i. Created when the module definition is read
    ii. Note: names created in interpreter are in module `__main__`
3. local names of a function invocation class names, object names,...

A **scope** is a textual region of a Python program where a namespace is directly accessible, i.e. reference to a name attempts to find the name in the namespace.

Scopes are *determined statically*, but are *used dynamically*, at runtime at least three namespaces are directly accessible, searched in the following order:

1. the scope containing the **local names**
2. the scopes of any *enclosing functions*, containing both **non-local** and **non-global** names
3. the *next-to-last* scope containing the current **module's global names**
4. the outermost scope is the namespace containing **built-in names**

Python supports **closures**: even if the scope of the outer function is reclaimed on return, the non-local variables referred to by the nested function are saved in its attribute `__closure__`

```
def counter_factory():
    counter = 0
    def counter_increaser():
        nonlocal counter
        counter = counter + 1
        return counter
    return counter_increaser
>>> f = counter_factory()
>>> f()
1
>>> f()
2
>>> f.__closure__
(<cell at 0x1033ace88: int object at 0x10096dce0>,)
```

20.4.1 Scope issues

```
def test(x):
    print(x)
    for x in range(3):
        print(x)
    print(x)
>>> test("Hello!")
Hello!
0
1
2
2  # 'x' changed!
```

20.5 Classes

A **class** is a *blueprint* for a new data type with specific internal **attributes** (like a struct in C) and internal functions (**methods**).

```
class className:
    <statement-1>
    ...
    <statement-n>
```

Where `statements` are either assignments or function definitions

Class instances introduce a new **namespace** nested in the class namespace; Python's visibility rules make all names of the class *visible*.

An **instance method** is a class method which takes `self` (*"implicit parameter"*, similar to `this` in Java) as first argument, and it must access the object's attributes through the self reference (eg. `self.x`) and the class attributes using `className.<attrName>` (or `self.__class__.<attrName>`)

Since it is bound to the target object, the first parameter must not be passed when the method is called with dot-notation on an object, but it can be passed explicitly if using the `className` alternative syntax.

```
obj.methodname(args)
className.methodname(obj,args)
```

In Python a **constructor** is a special instance method with name `__init__`, and since there is *no overloading* for constructors, there can be only *one constructor* per class.

Since instances are themselves namespaces, so we can add functions (and variables?) to them; and by applying the usual rules, they can hide *"instance methods"*.

```
class Point:
    def __init__(self, x, y):
        self.x = x
        self.y = y
    def move(z,t):
        self.x -= z
        self.y -= t
        self.move = move
        def move(self,dx,dy):
        self.x += dx
        self.y += dy
```

```
>>> p = Point(1,1)
>>> p.x
1
>>> p.move(1,1)
>>> p.x
0
>>> p.__class__.move(p,2,2)
>>> p.x
2
```

The two `move()` invocations result in different behaviours

20.5.1 Overloading and Inheritance

A class may overload the default python operators `+,-,in, ...`, by defining methods like `__sub__(self, other)`, `__add__(self, other),...`

A class can be defined as a derived class, resulting in its namespace to be nested in the one of `baseClass`, which is used as the next scope for non-local resolutions:

```
class derived(baseClass):
    statements
    statements
```

Python supports **multiple inheritance**, i.e.

```
class derived(baseClass1,baseClass2,...):
```

This induces the *Diamond problem*, solved by an algorithm that linearizes the set of all directly or indirectly inherited classes.

20.5.2 Encapsulation and Name Mangling

Private instance variables do *not* exist in Python, so there are two main workarounds for this:

1. names prefixed with **underscore** (e.g. `_spam`) are treated as non-public part of the API and should be considered an implementation detail and subject to change without notice
2. **Name mangling**: Any name with at least two leading underscores and at most one trailing underscore like e.g. `__spam` is textually replaced with `_class__spam`, where class is the current class name.

20.5.3 Class and Static methods

Static methods are simple functions defined in a class with no self argument, preceded by the `@staticmethod` decorator. They are defined inside a class but they *cannot* access instance attributes and methods.

Class methods are similar to static methods but they have a first parameter which is the class name. Definition must be preceded by the `@classmethod` decorator.

20.5.4 Iterators

An **iterator** is an object which allows a programmer to traverse through all the elements of a collection (iterable object), regardless of its specific implementation.

1. `__iter__` returns the iterator object itself
2. `next` method returns the next value of the iterator or throws `StopIteration` exception if not possible.

Generators are a simple and powerful tool for creating iterators: they are written like regular functions but use the `yield` statement whenever they want to return data. What makes generators so compact is that the `__iter__()` and `next()` methods are created automatically

```
def reverse(data):
    for index in range(len(data)-1, -1, -1):
        yield data[index]
```

20.6 Typing

Python provides dynamic strong **duck** typing.

Listing 20.1: Code can be annotated with types

```
def greetings(name: str) → str:
    return 'Hello ' + name
```

The module `typing` provides runtime support for *type hints* which can be checked statically by external tools, like `mypy`, but are ignored by **CPython**.

20.6.1 Polymorphism

- **Overloading**
  forbidden, but its absence alleviated by
  - Default parameters for functions
  - Dynamic typing
  - Duck typing
- **Overriding**
  ok, thanks to nesting of namespaces
- **Generics**
  type hints (module `typing` + `mypy` support generics)

20.6.2 Multithreading and Garbage collection

CPython manages memory with a *reference counting* and a *mark&sweep cycle* collector scheme;

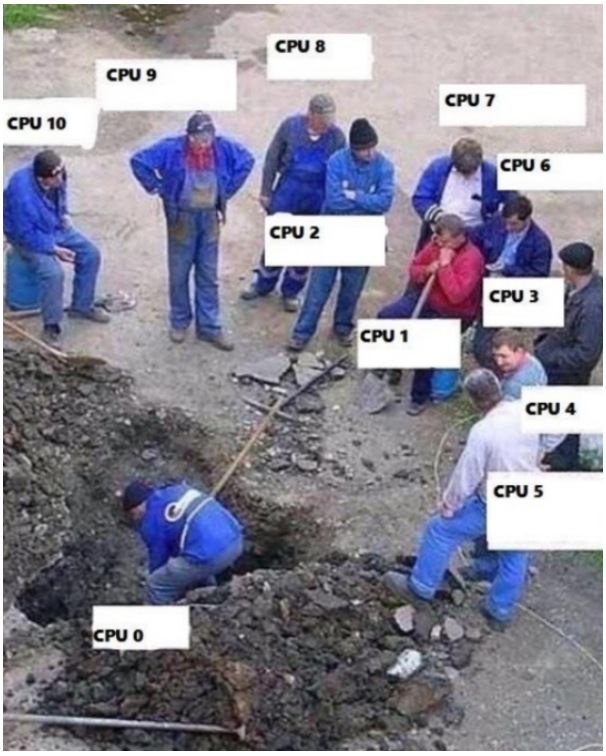
"Reference counting" means that each object has a counter storing the number of references to it. When it becomes 0, memory can be reclaimed.

Updating the *refcount* of an object has to be done **atomically**, in case of *multi-threading* all refcount updates must be **synchronized** otherwise there may be wrong values. Since *almost every operation* in CPython can cause a refcount to change somewhere, and since synchronization primitives are quite *expensive* on contemporary hardware, handling refcounts with some kind of synchronization would cause spending almost all the time on synchronization.

The CPython interpreter assures that *only one thread* executes Python bytecode at a time, thanks to the **Global Interpreter Lock**: the current thread must hold the **GIL** before it can safely access Python objects.
Locking the entire interpreter makes it easier for the interpreter to be multi-threaded, at the **expense** of much of the **parallelism** afforded by multi-processor machines.

Besides the GIL can **degrade performance** even when it is not a bottleneck: the system call **overhead is significant**, especially on multicore hardware.

Two threads calling a function may take twice as much time as a single thread calling the function twice.



20.6.2.1 Alternatives

It is believed that overcoming the GIL performance issue would make the implementation much more complicated and therefore costlier to *maintain*. **Jython** and **IronPython** have no GIT and fully exploit multiprocessor architecture capabilities. In Cython the GIL may be released temporarily using the `with` statement.

20.7 Criticism

Tuples are made by the commas, not by `( )` with the exception of the empty tuple...

```
>>> type((1,2,3))
<class 'tuple'>
>>> type(())
<class 'tuple'>
>>> type((1))
<class 'int'>
>>> type((1,))
<class 'tuple'>
```

Lack of brackets makes the syntax *"weaker"* than in other languages: accidental changes of indentation may change the semantics, leaving the program syntactically correct.

Will Python change on this matter?

```
>>> from __future__ import braces
   File "<stdin>", line 1
SyntaxError: not a chance
```