Programming in Java

2. Functional Programming

Programming Paradigms

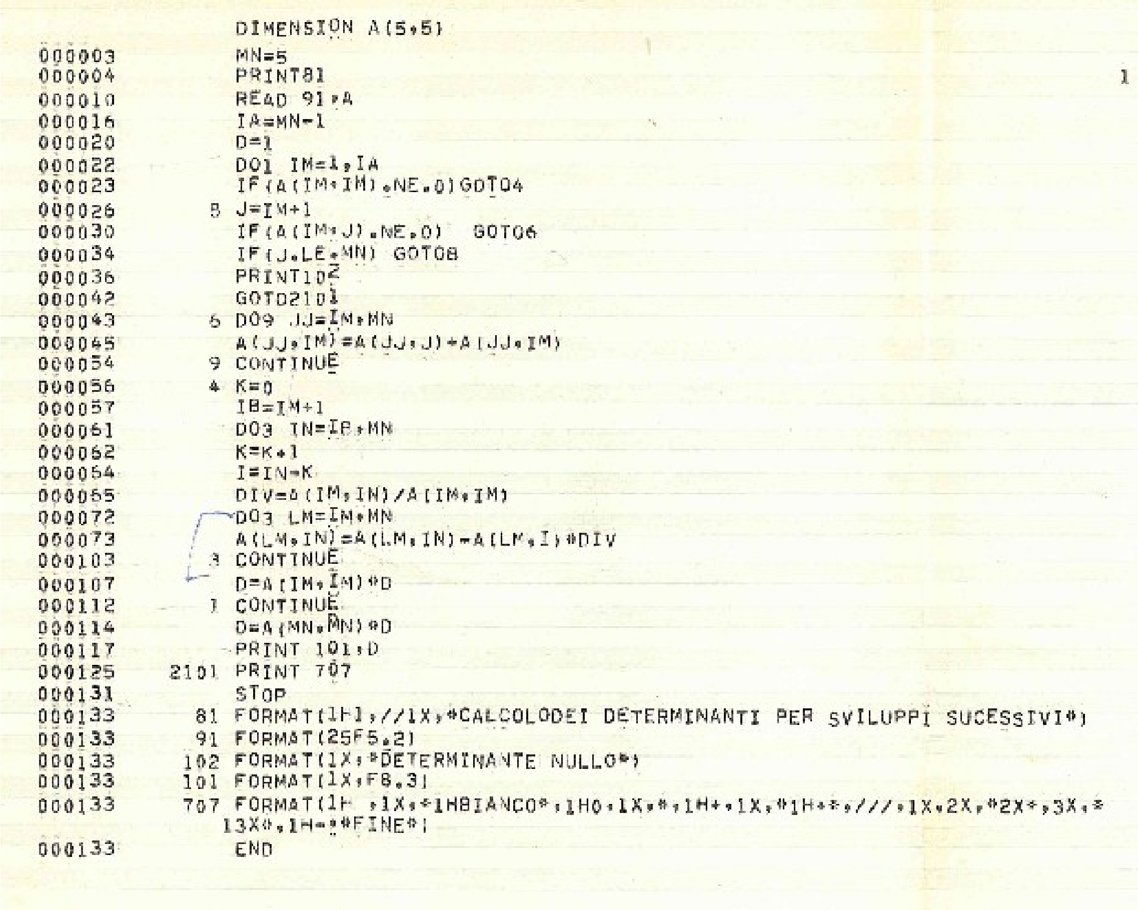
- A programming paradigm is a set of:
  - Assumptions about what the components of a program should be
  - Techniques and principles for building programs
  - Assumptions about what sort of problems are solved best by that paradigm
- There are multiple programming paradigms
  - Most have been around since the start of high level programming in the 1960s
  - A paradigm becomes “main-stream” and supported in programming languages when a set of problems arise that the paradigm is better suited to solve than the other paradigms in use
- The main-stream paradigms in use today:
  - Structured or procedural programming
  - Object Oriented Programming
  - Functional Programming

Programming Style

- Imperative programming
  - Code is a series of instructions that specify how a program execution is to be done
  - Intended to be easily compiled into assembly code
  - Procedural and OO programming tend use the imperative style
- Declarative programming
  - Code is a description of what a final result should be
  - Described as a series of transformation
  - The transformations are turned into executable code by the language
  - Requires a layer of abstraction to hide the imperative code
  - Functional and symbolic programming tend to use the declarative style

Procedural Code

- An abstraction of low level assembly code
  - Was often coupled to the hardware and OS environment it ran in
  - Eg. C was written for OS development
- In Java
  - Executable code in methods is procedural code
  - OO is more about how the code is organized and managed at run-time
  - OO programming extends procedural programming



```
                  DIMENSION A(5,5)
000003            MN=5
000004            PRINT81                                                1
000010            READ 91,A
000016            IA=MN-1
000020            D=1
000022            DO1 IM=1,IA
000023            IF(A(IM,IM).NE.0)GOTO4
000026          5 J=IM+1
000030            IF(A(IM,J).NE.0)   GOTO6
000034            IF(J.LE.MN) GOTO8
000036            PRINT102
000042            GOTO2101
000043          6 DO9 JJ=IM,MN
000045            A(JJ,IM)=A(JJ,J)+A(JJ,IM)
000054          9 CONTINUE
000056          4 K=0
000057            IB=IM+1
000061            DO3 IN=IB,MN
000062            K=K+1
000054            I=IN-K
000065            DIV=A(IM,IN)/A(IM,IM)
000072            DO3 LM=IM,MN
000073            A(LM,IN)=A(LM,IN)-A(LM,I)*DIV
000103          3 CONTINUE
000107            D=A(IM,IM)*D
000112          1 CONTINUE
000114            D=A(MN,MN)*D
000117            PRINT 101,D
000125       2101 PRINT 707
000131            STOP
000133         81 FORMAT(1H1,//1X,*CALCOLODEI DETERMINANTI PER SVILUPPI SUCESSIVI*)
000133         91 FORMAT(25F5.2)
000133        102 FORMAT(1X,*DETERMINANTE NULLO*)
000133        101 FORMAT(1X,F8.3)
000133        707 FORMAT(1H ,1X,*1HBIANCO*,1H0,1X,*,1H+,1X,*1H+*,///,1X,2X,*2X*,3X,*
                13X*,1H-,*FINE*)
000133            END
```

OO Code

- An abstraction of low level assembly code
  - Was often coupled to the hardware and OS environment it ran in
  - Eg. C was written for OS development
- In Java
  - Methods are procedural code
  - Designed that way for easy adoption by programmers used to writing procedural code (mostly C and C++ developers)
  - Almost 30 years old and reflects the tech of the times
  - OO is about program design and organization
  - Example is from 1967 Simula code

```
Begin
   Class Glyph;
      Virtual: Procedure print Is Procedure print;;
   Begin
   End;

   Glyph Class Char (c);
      Character c;
   Begin
      Procedure print;
        OutChar(c);
   End;

   Glyph Class Line (elements);
      Ref (Glyph) Array elements;
   Begin
      Procedure print;
      Begin
         Integer i;
         For i:= 1 Step 1 Until UpperBound (elements, 1) Do
            elements (i).print;
         OutImage;
      End;
   End;

   Ref (Glyph) rg;
   Ref (Glyph) Array rgs (1 : 4);

   ! Main program;
   rgs (1):- New Char ('A');
   rgs (2):- New Char ('b');
   rgs (3):- New Char ('b');
   rgs (4):- New Char ('a');
   rg:- New Line (rgs);
   rg.print;
End;
```

Functional Code

- Uses a declarative style
  - Support for functional programming is common with most modern programming languages
  - Modeled after math notation
- One of the first languages to use functional programming was LISP
  - Dates from the 1950s
  - Earlier than FORTRAN
- Shown is a listing in APL for computing the determinant of a matrix
  - Developed in the 1960s

```
      ∇DET[⎕]∇
     ∇ Z←DET A;B;P;I
[1]   I←⎕IO
[2]   Z←1
[3]  L:P←(|A[;I])⍳⌈/|A[;I]
[4]   →(P=I)/LL
[5]   A[I,P;]←A[P,I;]
[6]   Z←-Z
[7]  LL:Z←Z×B←A[I;I]
[8]   →(0 1 ∨.=Z,1↑⍴A)/0
[9]   A←1 1 ↓A-(A[;I]÷B)∘.×A[I;]
[10]  →L
[11] ⍝EVALUATES A DETERMINANT
     ∇
```

Programming Paradigms

- Most programming languages support more than one paradigm
  - Languages are often revised to add support for a paradigm
    - *COBOL added object oriented support*
    - *Java added support for functional programming in Java 8*
  - Modern languages like Rust, Go and Julia are designed to support multiple paradigms
- Why paradigms go mainstream
  - Most of the different paradigms have existed for over 50 years
  - They are designed to solve a particular class of problems
  - The types of problems industry deals with change over time
  - Changes often result from changes in technology and the market place
  - Existing paradigms may not be able to solve these new problems
  - A different paradigm is main-streamed that can solve the problems

Paradigm Focus

- Procedural programming
  - Was the ideal tool to support the automation of business processes in the 1960s
  - A data set was read in, algorithms used to process it, the results written out
  - Typically done in batch mode on a mainframe
  - There is still a massive installed based of COBOL and other imperative code still running business operations in the public and private sector
- Object Oriented programming
  - Ideal tool to handle distributed computing with the rise of the Internet in the 1990s
  - Enabled different nodes of computing to collaborate
- Functional programming
  - Ideal tool to handle streaming data at scale
  - The need for arose in the 2010s with the rise of big data
  - Cannot be done easily or efficiently with procedural or object oriented approaches

Functional Programming

- Dates back to Church’s Lambda calculus in the 1930s
- Procedural and OO code update the state of the running program
- Functional code is based on the idea of a mathematical function
  - e.g. Square function: f(x) = x * x
  - Functions do not change the input data but transform it to a new value
  - In pure functional programming languages, variables are immutable, they just bind to new values
  - A functional program maps a set of data to a new set of data
- Complex computations are done by functional composition
  - e.g. f(g(x)) produces an output where f() takes as input the result of applying g() to an input x
  - Algorithms are expressed as a series of functions representing the steps of the algorithms
  - Each step of the algorithm is implemented as a function
  - A program can be represented as a series of function calls

Functional Programming in Java

- Functions are first class objects
  - A function body is data, called a function literal, just like “Hi There” is a string literal.
  - A function can be assigned to a variable
  - A function can be passed as an argument to another function
  - A function can be the return value from another function
- A function literal is written using Lambda notation
- Java is a strongly typed language
  - Every variable must have a type that can be checked at compile time
  - That means functions have to have types
  - Defined to be the type of return value plus the number and types of arguments
  - Similar to the signature of a method, but includes the return value

Functional Programming in Java

```
public class Main {

// Define several static variables to hold different function types
    public static Function<Integer,Integer> square;
    public static Predicate<Integer> isEven;
    public static BiFunction<Integer,Integer,Integer> sum;
    public static Supplier<String> today;
    // This variable is initialized
    public static Consumer<String> printLength = (s) -> System.out.print(s.length());

    public static void main(String[] args) {
        // Assign the variables values in the form of Lambda expressions
        // since the lambda expression is one line, we omit the {} by convention
        square = (x) -> x * x ;
        System.out.println("The square of 7 is " + square.apply(7));
```

Functions

- Functions are stored in memory like other Java objects
  - They have addresses and types
  - Functional variables are references to Lambda expressions on the heap
  - Methods are NOT functions, they are stored completely differently
  - Functions are objects, methods are not objects
  - Function bodies can be used in the same way that other data is used in Java
- Java is not a functional language - it has functional support
- Functional languages have the following requirements
  - Variables are immutable
  - Functions are pure - they have no side effects
  - Functions do not rely on anything that can change
  - These specific requirements cannot be implemented in Java

Functional Programming in Java

- The different types of functional interfaces are defined in java.util.function
- Some basic types are:
  - Function<R,T>: takes one argument of type T and returns an value of type R
  - BiFunction<R,T,U>: takes two arguments of types T and U and returns a value of type R
  - Predicate<T>: takes one argument of type T and returns a Boolean
  - Consumer<T>: takes one argument of type T and does not return a value
  - Supplier<R>: takes no arguments and returns a value of type R
- There a number of different types that are variations of the above
  - Consult the documentation
- To execute the body of the function, we use different methods, for example
  - **apply()** for functions
  - **test()** for predicates
  - **get()** for suppliers and **accept()** for consumers

Lab 2-1

Functional Programming

Functions as Parameters

- Functions can be passed as parameters
  - However, the type of function that can be passed is strictly checked
  - For example, we can’t pass a Predicate<T> with a parameter expecting Function<T,T>
- This a functional programming implementation of a strategy pattern
  - A specific piece of code to be executed is provided to a function at execution time
  - This is often called “meta-programming” where code can modify itself at run time
  - The decision on what specific code should be executed is decided at run time
- This makes for simpler code in many cases
  - Otherwise all possible alternatives would have to be provided at compile time with the correct option determined by some sort of test in the program environment
  - This can result in large blocks of conditional code that are hard to write, read and maintain

Functions as Return Values

- This is often used to implement a dispatch table
  - During execution, depending on some condition, a number of different functions could be called
  - A dispatch table or function, checks some condition and returns the function to be executed
  - This is useful when we don’t know which function we will need to call at runtime
  - The required function is selected at runtime
- Another use is to assemble a function at run-time
  - Recall this is referred to meta-programming
  - Often uses what we call factory method
  - Assembles the body of the function from different alternatives
  - Usually specified by parameters passed to the factory function

Lab 2-2

Meta-programming

Functional Interfaces

- A functional interface in Java is an interface with one abstract method
  - A functional interface must have exactly one abstract method that is the “exposed functionality” of that interface
  - Also called SAM or a “single abstract method” interface
  - It may have other static and default methods but usually they don’t
  - A Lambda function implements the Runnable interface implicitly
  - Specifically, the code defined in the Lamba funcction *is* the implementation of the `run();` method
- The standard Java OO process for using interfaces is
  - Define the interface with an abstract method
  - Write a class that implements the interface
  - Provide an implementation that overrides the interface definition
  - This is a lot of extra coding, especially when we might use the class only once

Functional Interfaces

- Inner classes allow us to create disposable objects that implement an interface
  - Like a Lamba function, we are essentially created a class literal or class implementation and not assigning it to a variable
- Functional Interfaces have only one abstract method
  - In order to create an implementation, all we have to do is provide a Lambda to act as the body of the abstract method
  - The compiler knows which method the Lambda implements because there is only one abstract method in a functional interface
  - As long as we provide a single Lambda to override the abstract method, Java can do all the rest of the work to create a class implementation under the hood
- Many of the interfaces in the Java library are functional interfaces
  - The Runnable interface for example

Lab 2-3

Functional Interfaces

The Closure Problem

- In a pure functional language
  - Functions do not depend on anything that changes
  - Functions do not change things
- Java does not support these two properties
- In a functional language
  - There may be variables used in the body that are <u>not</u> either
    - *declared in the function body*
    - *passed as parameters*
  - These are call free variables
  - If they change, then the function will behave differently
  - The function result now depends on an external variable that can change

The Closure Problem

- In a functional language
  - Then the function is created, it binds the free variables to the value it had when the function was created
  - In other words, it evaluates the variable at assignment time
- This is called a “closure”
  - A closure is an object containing the function body and the bound values of the free variables
  - A closure closes the function to outside changes that could be introduced by free variables
- Java does not do this
  - It uses the value of the free variable at execution time, not at assignment tim

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