Fundamentals of Programming Languages

PL families

Lecture 02

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Lecture outline

- Imperative PLs
- Functional PLs
- Declarative PLs

The three PL families

- There are several criteria of PL classification…
- Imperative
- Functional
- Declarative
- Inside each family there is a diversity of languages
- They have the same basic principles

Imperative PLs

- Imperative = based in instructions
- Most widespread
  - Fortran, Cobol, Basic, Pascal, Ada, Modula-2, C, C++, C#, Java
- Their conception is based on the traditional von Neumann architectures
- The computer is made out of
  - Memory (holding data and instructions)
  - Command unit
  - Execution unit

Imperative PLs

- Based on 2 concepts
  - Sequential (step by step) execution of instructions
  - Keeping a modifiable set of values during program execution
    - Those values define the state of system

Imperative PLs

- The 3 essential components:
  - Variables
    - Major component in imperative PLs
    - Memory cells with names assigned and values stored
  - Assignment instruction
    - Memorizing the computed value
  - Iteration
    - Typical way to do complex computation
    - To execute repeatedly a set of instructions

Example of a C imperative language
Prime number testing

```
#include <stdio.h>

#include <math.h>


int prime(unsigned long n)

{

    unsigned long i;

    if(n<=1) return 0;

    for(i=2;i<sqrt(n);i++)

        if(n%i==0) return 0;

    return 1;

}


int main()

{

    unsigned long n;

    printf("N=");

    scanf("%ld",&n);

    if(prime(n)) printf("The number %ld is prime!",n);

    else printf("The number %ld is not prime!",n);

}
```

Functional PLs

- Are based on mathematical concepts of
  - function
  - function apply
- Applicative languages
- Free from the von Neumann concept
- LISP, SML, Miranda

Functional PLs 4 essential components

- The set of predefined primitive functions
- The set of functional forms
  - Mechanisms that allow combining functions in order to create new ones
- The apply operation
  - Allows applying a function on arguments and producing as a result new values
- The data set (objects)
  - The set of arguments and function values

Example of Lisp functional language
List atom counting

```
(defun count(x)
   (COND ((NULL x) 0)
        ((ATOM x) 1)
        (T (+ count (CAR x))
            (count (CDR x))))))
```

Declarative PLs

- In the development process of a software system
  - Requests and specifications phase
    - What must the system do
  - Design and implementation phase
    - How the system works

What's new in declarative PLs?

- To stop at the specification phase
- To describe what we expect from a system
- Not to define the implementation of the system
- To specify only
  - Problem properties
  - Problem conditions
- The system will automatically find the answers

Declarative PLs

- To focus the effort and creativity in the request definition phase
- Very high level languages
- SNOBOL4
- SQL
  - Structures Query Language
  - for database interrogation
- Prolog
  - declarative and logic
  - problem conditions are expressed through predicate calculus

Example of declarative program in Prolog

```
parent(helen,ralph).
parent(peter,ralph).
parent(peter,mary).
parent(ralph,anna).
parent(ralph,dan).
```

```
? - parent(peter,mary).
yes

? - parent(x,anna).
x=ralph

? - parent(peter,x).
x=ralph;
x=mary;
no

? - parent(y,anna),parent(x,y).
x=helen;
x=peter;
y=ralph;
no
```

Generally, PLs

- are not pure
  - Imperative or functional or declarative
- ML
  - functional with imperative facilities
- C
  - programs defining and using functions intensively
- F#
  - functional with imperative facilities

PLs and machines

- Imperative languages
  - optimal on actual computers
- Functional and declarative languages have
  - solid theoretical foundations
  - automatic checking
  - high level programming

Functional and declarative PL domains

- Artificial intelligence
- List processing
- Databases
- Symbolic calculus
- Natural language processing
- Knowledge bases
- Program checking
- Theorem provers

Sequential programming vs. concurrent programming

- Imperative program
  - actions
  - data
- Next action initiated when the current action has finished
- The program becomes a process
- The programming activity is sequential programming

Parallel vs. concurrent processes

- a process uses computer resources
  - one at a time
- if only 1 process in a system using all resources
  - weak usage performance
  - multiple processors are useless
- multiple processes in memory to use the CPU in time division is useful
  - logic parallelism
  - virtually the processes are executed in parallel

Multiprogramming operating systems

- Multiple programs in the memory
- Parallel execution
- The physical parallelism depends on
  - The number of CPUs
  - The type of CPUs
- Windows, Unix, OS/2
  - Allow multi programmed process management
  - Great improvement in resource usage rate

Programs on multiprogramming OS

- Parallel processes
- Executed independently
  - As if they ran on a mono programmed system
- Resource conflicts are
  - handled by the OS
  - Transparent to the application programmer

Processes with communication

- Isolated processes are not always a solution
- The solution may be multiple processes
  - asynchronous
  - with Message exchange
  - with Data transfer
  - sharing in common the system resources
- Concurrent processes
- Sometimes they need synchronization

Synchronization cases

- Mutual exclusion
- Cooperation

Mutual exclusion

- Multiple processes use the same resource
- The access is permitted to one process at a time
- The access requests must be sequenced
- Synchronization based on a condition
  - Delaying a process until a condition becomes true
- Critical resource
  - A resource that may be used in a single process at one time
- Critical section
  - The code section manipulating the critical resource

Mutual exclusion

Definition:

- Mutual exclusion is a synchronization form for concurrent processes allowing that only one process to be in the critical section at one time
- a language construction to solve this issue is the critical region
  - Added by CAR Hoare and P. Brinch Hansen in 1972
  - To emphasis program text and variables which denote the critical resource
  - To add new keywords like region, when for the access of such resources
  - Adding a synchronization condition -> conditional critical region

Cooperation

- Messages or data are exchanged between processes
- Keep a producer/consumer relationship
- The information produced by a process are used/consumed by the other
- Describing concurrent processes and their relationship -> concurrent programming
- Resources
  - Shared between authorized processed
  - Protected from unauthorized processes
- When the time factor involved -> real-time processes
- Concurrent processes programming languages

Distributed systems

- Concurrent systems
- The most widespread because of the Internet and networking
- Communication based on message transmission

Concurrent programming languages

- Are developed in the last 30 years
- Have special facilities to describe
  - parallel and concurrent processes
  - synchronization and communication
- Edison defined by P. Brinch Hansen 1980
- To describe concurrent programs of small and medium sizes for micro and mini computing systems

“when” instruction

- The processes
  - communicate through common variables
  - synchronize through conditional critical regions

```
when b_1 do instr_list_1
else b_2 do instr_list_2
…
else b_n do instr_list_3
```

“when” instruction

- the common variable for the critical region is not specified
- Edison solution
  - Mutual exclusion of all critical regions
  - Only one critical sequence is executed at one time
- thus, it results
  - Simplified language implementation
  - Complex restrictions regarding process concurrency

“when” instruction

- Is executed in two phases
  - Synchronization phase
    - The process is delayed until no other process executes the critical phase of a when instruction
  - Critical phase
    - Logical expressions are evaluated b_1, b_2,…,b_n
    - If one of them is true the corresponding instruction list is executed
    - If all are false the synchronization phase is repeated

“cobegin” instruction

- describes the concurrent activities

```
cobegin const_1 do instr_list_1
also const_2 do instr_list_2
…
also const_n do instr_list_n
end
```

- the instruction list represents processes to be executed in parallel
- processes start at cobegin
- cobegin ends when all processes end
- each process has a constant attached
- the constant semantic is PL implementation dependent
  - necessary memory space
  - the processor number
  - the priority etc.

Edison program

- Has the form of a procedure
- Is launched by activating the procedure instructions
- Is formed out of several modules
- The exported identifiers are preceded by the star * symbol

The “Philosophers” problem

- 5 philosophers spend their life eating and meditating
- When a philosopher is hungry goes to the dining room, sits at the table and eats
- To eat from the spaghetti dish he needs 2 forks
- On the table there are only 5 forks
- There is only one fork between two places
- Each philosopher can access the forks at his right and left hand-side
- After eating (a finite amount of time) the philosopher puts back the forks and leaves the room

The solution program

- the philosophers behavior is modeled by concurrent processes
- the forks are modeled by the shared resources
- philosophers wait until both forks are free
- the “forks” table stores the number of forks available to a philosopher
- it can occur the starvation situation when the neighbors are eating alternatively
- the 5 philosophers represent the 5 activations of the “philosopherlife” procedure in each cobegin branch
- each branch launches one parallel process

The Philosophers program

```
proc philosophers
    module
     array tforks[0..4] (int)
     var forks:tforks; i:int;

     proc philoright(i:int):int
     begin
          val philoright:=(i+1) mod 5
     end

     proc philoleft(i:int):int
     begin
          if i=0 do val philoleft:=4
          else true val philoleft:=i-1
     end
```

The Philosophers program

```
*proc get(philo:int)
begin
   when forks[philo] = 2 do
      forks[philoright(philo)]:=
         forks[philoright(philo)]-1;
      forks[philoleft(philo)]:=
         forks[philoleft(philo)]-1;
   end
end
```

The Philosophers program

```
*proc put(philo:int)
   begin
      when true do
         forks[philoright(philo)]:=
            forks[philoright(philo)]+1;
         forks[philoright(philo)]:=
            forks[philoleft(philo)]+1;
      end
   end
```

The Philosophers program

```
begin
 i:=0
 while i<5
     forks[i]:=2
     i:=i+1;
 end
end
```

The Philosophers program

```
proc philosopherlife(i:int)
begin
 while true do
    -think-
    get(i);
    -eat-
    put(i);
 end
end
```

The Philosophers program

```
begin
   cobegin
    1 do philosopherlife(0) also
    2 do philosopherlife(1) also
    3 do philosopherlife(2) also
    4 do philosopherlife(3) also
    5 do philosopherlife(4) also
   end
end
```

Distributed systems programming

- Distributed system
  - a set of computers capable of information exchange
  - computers are called nodes
  - can be programmed to solve problems involving
    - concurrency
    - parallelism

Typical algorithmic problems

- Synchronization on condition
- Message broadcasting to all nodes
- Process selection for fulfilling special actions
- Termination detection
  - A node performing an action must be capable of detecting its ending moment
- Mutual exclusion
  - Using resources by mutual exclusion
  - Files, printers, etc
- Deadlock detection and prevention
- Distributed file system management
- a PL for distributed systems must have all facilities: Java
- example: a chat system

The client/server model

- Server processes
  - managing resources
- Client processes
  - Accessing resources managed by severs
- The message is limited to only one text line
- The server
  - must be started first
  - developed in the compilation unit Server.java
- The client
  - send a message
  - waits for an answer
  - sends the STOP command
  - developed in the compilation unit Client.java

Client.java

```
import java.net.*; import java.io.*;
class Client
{
   public static void main(String[] args) throws
   IOException
   {
    Socket cs=null;
    DataInputStream is=null; DataOutputStream os=null;
    try
    {
        cs=new Socket("localhost",5678);
        is=new DataInputStream(cs.getInputStream());
        os=new DataOutputStream(cs.getOutputStream());
    }
    catch(UnknownHostException e)
    {
        IO.writeln("No such host");
    }
```

Client.java

```
  DataInputStream stdin=new DataInputStream(System.in);
  String line;
  for(;;)
  {
   line=stdin.readLine()+"\n";
   os.writeBytes(line);
   IO.writeln("Transmission:\t"+line);
   if(line.equals("STOP\n")) break;
   line=is.readLine();
   IO.writeln("Receiving:\t"+line);
  }
  IO.writeln("READY");
  cs.close();
  is.close();
  os.close();
 }
}
```

Server.java

```
import java.net.*;
import java.io.*;
class Server
{
 public static void main(String[] args) throws
   IOException
 {
  ServerSocket ss=null; Socket cs=null;
  DataInputStream is=null;
  DataOutputStream os=null;
  ss=new ServerSocket(5678);
  IO.writeln("The server is running!");
  cs.ss=accept();
  is=new DataInputStream(cs.getInputStream());
  os=new DataOutputStream(cs.getOutputStream());
  DataInputStream stdin=new DataInputStream(System.in);
  String line;
```

Server.java

```
  for(;;)
  {
   line=is.readLine(); IO.writeln("Receiving:\t"+line);
   if(line.equals("STOP")) break;
   line=stdin.readLine()+"\n";
   os.writeBytes(line);
  }
  cs.close();
  is.close();
  os.close();
 }
}
```

The socket

- An IP address identifies a computer in Internet
- A port number identifies a program running on a computer
- A combination between an IP address and a port is a final point for a communication path
- Two communicating applications must find themselves in the Internet
- Typically the client must find the server

The socket

- The client connects to the server by initiating a socket connection
- The first client message to the server contains the client socket
- The server transmits its socket address to the client in the first reply message
- Data transmission is done through socket input/output streams
- The streams can be accessed through getInputStream() and getOutputStream() from class Socket

Short history of PL development

- First high level PL were created in 1950
- In this period the efficiency was the main goal
- Fortran
  - Designed by a group from IBM lead by John Bachus 1954
- Algol 60
  - 1958-1960
  - Block structures
  - Recursive procedures

Short history of PL development

- Cobol
  - Financed by Department of Defense in 1959
  - Economical applications
  - Files
  - Data description facilities
    - record
    - struct
  - Used in current days in an evolved version

Short history of PL development

- Late 50s and early 60s
- Functional PLs
  - Lisp
    - John McCarthy MIT 1955
    - The main PL in artificial intelligence
  - APL
    - Iverson IBM 1962
- Declarative PL
  - Snobol
    - Bell Laboratories 1964

Short history of PL development

- Mid 60s
- Large diversity of programming languages
- IBM project
  - To gather all concepts in a single PL
  - To replace all other PLs
  - PL/I 1964
    - Limited success
    - Complex
    - Heavy

Short history of PL development

- In the 60s
- Algol 68 1968
  - Perfect orthogonality
  - Defined using formal methods
- Simula 67 1967
  - Simulation facilities
  - Uses the class concept for
    - Modularization
    - Abstract data description

Short history of PL development

- Pascal 1971
  - N. Wirth
  - Expressivity
  - Simplicity
- ML 1973
  - University of Edinburgh
  - Functional PL
  - Strongly typed

Short history of PL development

- C 1974
  - One of the most widespread PL
  - Dennis Ritchie at Bell Labs
  - Portable implementation for the Unix operating system
  - C programs have good portability

Short history of PL development

- In the 70s
- Abstract data types
- Program checking
- Exception handling
- Concurrent programming

Short history of PL development

- Mesa (Terax, 1974)
- Concurrent Pascal (Hansen, 1975)
- CLU (Liskov, MIT 1974)
- Modula 2 (Wirth, 1977)
- Ada (DoD, 1979)
- Prolog (Colmerauer, 1972)
  - Logic programming
  - Artificial intelligence

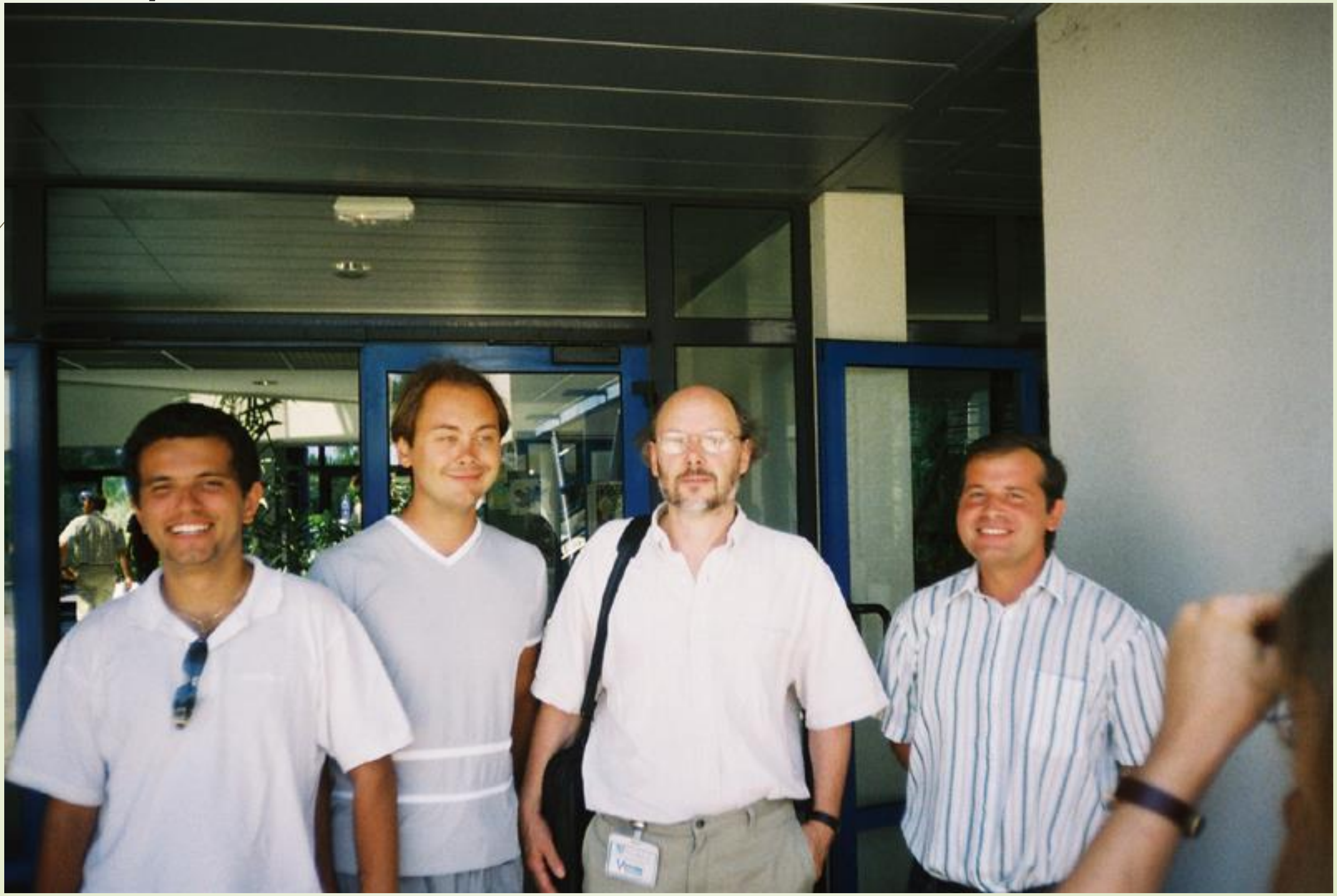
Short history of PL development

- In the 80s
- Common Lisp 1984
  - Was used and consolidated
- Standard ML
  - SML, Milner, Edinburgh, 1984
- Miranda
  - Turner, Kent, 1985
- Haskell
  - Hudak, 1988

Short history of PL development

- Imperative languages
- Object-oriented programming languages
- SmallTalk
  - PL and IDE
  - Xerox late 70s
- C++
  - Bjarne Stroustrup, Bell Labs, 1988
  - C with object-oriented concepts
  - Widely used in present

Bjarne Stroustrup seminar at INRIA, Sophia Antipolis, France, July, 2003



Short history of PL development

- Object Oberon
  - Zurich, 1989
- Eiffel
  - Bertrand Meyer, 1988
- Java
  - Sun Microsystems Inc., 1995
  - OOP
  - interactivity
  - Animation
  - Internet applications
  - Distributed applications

Short history of PL development

- Java
  - Anti C++
    - no pointer arithmetic
    - no manually releasing memory
    - no multiple inheritance between classes
- other object-oriented PL
  - Object Pascal (Delphi, Borland 1995-2000)
  - CLOS (Common Lisp Object System)
  - OCAML (object oriented ML)

Short history of PL development

- Microsoft C#
  - Alpha release 2000
  - Microsoft team lead by Andres Hejlsberg
  - Derived from C, C++ and Java
  - Portability taken from Java
  - Can be mixed with other PL
  - Full integration with MS Windows OS
- Java vs. C#
  - time will tell…