§ 6 Programming Languages for Process Automation

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Basic Terms</td>
</tr>
<tr>
<td>6.2</td>
<td>High Level Programming Languages for Process Automation</td>
</tr>
<tr>
<td>6.3</td>
<td>Programming Programmable Logic Controllers (PLC) (PLC)</td>
</tr>
<tr>
<td>6.4</td>
<td>Real-time Programming Language Ada 95</td>
</tr>
<tr>
<td>6.5</td>
<td>The Programming Languages C and C++</td>
</tr>
<tr>
<td>6.6</td>
<td>The Programming Environment Java</td>
</tr>
</tbody>
</table>
Chapter 6 - Learning targets

– to know the modus operandi when doing process automation programming
– to be able to differ programming languages referring to the language level
– to know the programming languages for PLC
– to program simple examples using PLC-languages
– to know the most important real-time concepts for programming languages
– to know how real-time concepts are realized in Ada 95
– to be able to design a real-time program in Ada 95
– to be able to rank C/C++ referring to real-time aspects
– to know what the fundamentals of the portability of Java
– to understand the real-time extensions of Java
§ 6 Programming Languages for Process Automation

6.1 Basic Terms
6.2 High Level Programming Languages for Process Automation
6.3 Programming Programmable Logic Controllers (PLC)
6.4 Real-time Programming Language Ada 95
6.5 The Programming Languages C and C++
6.6 The Programming Environment Java
6.1 Basic Terms

Procedures for program generation

Programmable Logic Controllers
- Textual programming languages
- Graphical programming languages

Micro controller
- Assembler
- Low machine-independent programming languages

PC and IPC
- Software package
- Universal real-time programming language

Process control system
- Functional module technology
### Programming language types

#### Classification according to notation type
- **textual programming languages**: Ada, C, PLC instruction list
- **graphical programming languages**: PLC ladder diagram

#### Classification according to programming language paradigm
- **procedural programming languages**: C, Ada 83
- **functional programming languages**: LISP
- **logical programming languages**: PROLOG
- **object-oriented programming languages**: C++, Smalltalk, Ada 95

#### Classification according to language level
- **high**: focus on the understandability for the user
- **low**: focus on the hardware characteristics of a computer
Classification according to language level

- Program generators
  - Application-specific programming languages
  - Universal programming languages
- Macro assembler languages
- Assembler languages
- Machine languages
- Microprogramming languages

Machine-independent programming languages
Machine-oriented programming languages
Machine languages
Microprogramming languages

- Sequence control realization for the execution of machine commands
  - Permanently wired logic elements
  - Microprograms
- Microprograms (firmware)
  - Storage in fast random access memory (RAM’s) or in read only memory (ROM’s)
  - Not accessible for mask programming
- Machine languages
  - Language elements:
    Commands and data in form of bit patterns
    - Combination of octal or hexadecimal numbers
    - Difficult handling
    - Not suitable for application programming
6.1 Basic Terms

Assembler languages

Goals: Avoid the difficult handling of machine languages while keeping the characteristics of machine commands

- Replacement of the octal/hexadecimal notation on the operation part of the commands by symbolic, mnemonically convenient letter abbreviations
- Introduction of a symbolic name instead of the numerical depiction of the address part
- Non-ambiguous assignment of commands in the assembler languages to commands in the machine languages
- Dependency on device-technical characteristics of the corresponding computer
Macro assembler languages (macro languages)

– Further auxiliary means for simpler handling: macros

**Macro:** Abbreviation for a certain instruction sequence

– Distinction
  • Macro definition
  • Macro call
  • Macro expansion

– Setup of a macro definition
  MACRO Macro name \((P_1, P_2, ..., P_N)\)
  Macro body
  Final mark

Macro call
  Macro name \((A_1, A_2, ..., A_N)\)

– Non-ambiguous assignment of macro assembler commands to
  commands of the machine language

– One macro command corresponds to several machine commands
Example: macro threeaddressadd

Macro definition:  
MACRO Threeaddressadd (P₁, P₂, P₃)  
LOAD P₁  
ADD P₂  
STORE P₃  
END

Macro call:  
Threeaddressadd (A, B, SUM)

Macro expansion:  
...  
LOAD A  
ADD B  
STORE SUM  
...
6.1 Basic Terms

**Difference between subprogram calls and macros**

- A subprogram is only stored once but can be called and executed several times
- Each time a macro is called it is expanded

**Classification of macros**

- Standard macros: predefined (fix)
- User macros: the user is able to define macros for instruction sequences that are needed often
### Universal programming languages

**Universal**

- **Purpose**: Generation of system programs
  - Compiler
  - Operating systems
  - Editors
  - Driver programs
- **Objective**: 1. Utilization of the hardware characteristics
  2. Portability
- **Example**: C

#### Universal low programming languages

- **Purpose**: Generation of system programs

#### Universal higher programming languages

- **Purpose**: Generation of general/common programs
- **Objective**: 1. Simple formulation
  2. Extensive compiler checks
  3. Portability
- **Example**: Ada, Java, Smalltalk
Application-specific languages

Descriptive languages, non-procedural higher languages, very high level languages

Difference to procedural languages:
- No description of the solution approach, instead: description of the problem definition
- Limited to certain application areas:

  e.g.:  
  SFC  Sequential Function Chart
  LD   Ladder Diagram
  IL   Instruction List
  EXAPT For machine tool control
  ATLAS For automatic device tester

Advantages/disadvantages:
+  comfortable, application-specific mode of expression
-  inflexibility
Program generator (fill-in-the-blanks-languages)

– Formulation method for programs

– User replies to questions in the form of menus on screen (user configuration)

– Conversion of the answers in an executable program through the program generator

– Advantage: no programming skills necessary

– Disadvantage:
  - Limitation to certain application areas
  - Dependency in regard to a certain manufacturer
Application areas of program generators in the process automation field

- Instrumentation and control systems in energy and process engineering
  - TELEPERM-M (Siemens)
  - PROCONTROL-B (ABB)
  - CONTRONIC-P (Hartmann & Braun)

- Programmable logic controller in the form of instruction lists or ladder diagrams
  - SIMATIC (Siemens)
### § 6 Programming Languages for Process Automation

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Basic Terms</td>
</tr>
<tr>
<td><strong>6.2</strong></td>
<td>High Level Programming Languages for Process Automation</td>
</tr>
<tr>
<td>6.3</td>
<td>Programming Programmable Logic Controllers (PLC)</td>
</tr>
<tr>
<td>6.4</td>
<td>Real-time Programming Language Ada 95</td>
</tr>
<tr>
<td>6.5</td>
<td>The Programming Languages C and C++</td>
</tr>
<tr>
<td>6.6</td>
<td>The Programming Environment Java</td>
</tr>
</tbody>
</table>
**Difficulties regarding real-time programming**

- High-level programming languages like BASIC, FORTRAN, COBOL and PASCAL are *not suitable* for real-time programming:
  - no real-time language resources
  - no single bit operations
  - no instructions for process input/output

- The operation of higher programming languages in comparison to assembler languages also causes higher demands on memory and computing times:
  - Product automation: memory usage and computing times critical
  - Plant automation: computing times might be critical

**Availability**

- Compiler for target computer
- Real-time operating system
Deployment comparison of higher programming languages

Higher level programming languages for technical, scientific and commercial applications

Higher level programming languages for process automation

Proportion of the application of higher level programming languages

© 2004 IAS, Universität Stuttgart
Advantages and disadvantages of assembler programming

+ memory and computing time efficiency
- higher program development costs
- lower maintainability
- problems concerning reliability
- bad readability, low documentation value
- missing portability

Operation of assembler languages

yes: automation of devices or machines with serial or mass application, small programs
no: long-lasting, big processes that ought to be automated
6.2 High Level Programming Languages for Process Automation

Legend:
- object-oriented programming language
- real-time programming language
- higher level programming languages
§ 6 Programming Languages for Process Automation

6.1 Basic Terms
6.2 High Level Programming Languages for Process Automation

6.3 Programming Programmable Logic Controllers (PLC)
6.4 Real-time Programming Language Ada 95
6.5 The Programming Languages C and C++
6.6 The Programming Environment Java
Programming Languages for PLC-Systems (1)

– no fixed programming languages for PLC-systems
– different kinds of programming, also depending on the manufacturer
– IEC 1131 is defining graphical and text-based basic-languages

IEC 1131 is not defining any instructions!

δ as well german as english identifier for operators
Programming Languages for PLC-Systems (2)

- base of all programming languages are logical connections
- addition of possibilities for time processing
- suitable kind of representation depends on problem
  - state-oriented program parts are more suitable for FBD or LD
  - flow-oriented program parts are more suitable for IL or AS
- the different representations can be converged into each other

Be aware:
Some operations can only be programmed using IL (e.g. bit shifting)!

Example:
Exit 1 (exit1) and exit 2 (exit2) are only true, if either entry 3 (entry3) is true or if both entries 1 (entry1) and 2 (entry2) are simultaneously true
Instruction List (IL)

– similar to assembler
– all functionality of a PLC can be programmed using IL
– consistent structure of every statement

\[
\text{Mark (opt.): } \quad \text{Operator} \quad \text{Operand} \quad \text{comment (opt.)}
\]

– the programming is done by connecting signals

Realization of the example using AWL (chalkboard writing)
Structured Text (ST)

- high-level language, similar to Pascal
  - declarations
    e.g.: 
    alarm := on AND off;
  - sub program calls
    e.g.: 
    alarmlamp(S:=on, R:=off);
  - control statements
    e.g.: 
    IF alarm
    THEN alarmlamp(S:=on, R:=off);
    END_IF;

- additional language constructs for time processing and process data access
- suitable for programming large systems

Realization of the example using ST (chalkboard writing)
Ladder Diagram (LD)

– simple illustration
– similar to the circuit diagram of the relay technology
– symbols for „normally open contact“, „normally closed contact“, und „relay coil“ (output)

– symbolized current flow from left to right
– I/O states are mapped onto switch-states
– the program is read from top to bottom

Realization of the example using LD (chalkboard writing)

Disadvantage: difficult representation of complex mathematic functions
Function Block Diagram (FBD)

- similar to the well known symbols for function blocks (DIN40900)
- amount of symbols is not confined to logical basic elements
  - memory marks, counter, timer and freely definable blocks possible
- I/O states are directly used as Input-/Outputsignals
- clearly arranged representation

Realization of the example using FBD (chalkboard writing)
§ 6 Programming Languages for Process Automation

6.1 Basic Terms
6.2 High Level Programming Languages for Process Automation
6.3 Programming Programmable Logic Controllers (PLC)
6.4 **Real-time Programming Language Ada 95**
6.5 The Programming Languages C and C++
6.6 The Programming Environment Java
Lady Ada Lovelace

Ada

Name of the 1. female programmer

Named in the honor of the mathematician Augusta Ada Byron, Countess of Lovelace, daughter of Lord Byron. Ada Lovelace (1815-1851) worked with Charles Babbage on his “Difference-and Analytic-Engine”. The idea of programming this machine with punched cards can be traced back to Ada Lovelace.
6.4 Real-time Programming Language Ada 95

Characteristics of Ada

- Suitable for the development of extensive software systems (> \(10^7\) lines)
  - Modularization concepts
  - Separation between specification and implementation of units
  - Support to reuse of software components
  - Exception handling as part of the module’s code

- Real time specific features
  - Fulfillment of absolute and relative time requirements
  - Execution of parallel activities
  - Prioritization and scheduling of parallel activities

- Extensive validation of each Ada95 compiler against compliance standards
  - Several thousand test programs
Ada 95 program units

- Subprograms
  - Specific functionality encapsulated in executable pieces of code
    - Functions and procedures
- Concurrently executing programs
  - Different program sequences that are executed at the same time
    - Tasks
- Shared resources with synchronized access
  - Data structures with access protected by monitors
    - Protected variables
- Reusable libraries
  - Group of functionality related subprograms, tasks and protected units
    - Packages
Ada 95 basic program structure

Ada program

Main routine

```ada
procedure main is
   ... end main;
```

Libraries

```ada
package A is
   ... end A;
```

- No explicit superordinate program
  - Definition of a subprogram as main routine
- Execution of program units from the main routine
- Programs units stored in libraries or directly declared
Example of unit structure

- Specification  = external interface
- Implementation = realization of the program unit

**Specification (package declaration)**

```ada
package package_name is
    declaration
    (types, subprograms, tasks, protected units, ...)
    private
    private part (declaration)
end package_name;
```

**Implementation (package body)**

```ada
package body package_name is
    further declaration
    subprograms’ bodies
    begin
    instructions
end package_name;
```
Declaration and implementation of units

– Separation of specification and implementation in different files

Specification (File General.ads)

```ada
package General is

protected Variable is

  function read return Float;

private
  protectedData: Float := 0.0;

end Variable;

end General;
```

Implementation (File General.adb)

```ada
package body General is

protected body Variable is

  function read return Float is
  begin
    return protectedData;
  end read;

end Variable;

end General;
```
Concurrent programming concepts

- Requirement to enable the reaction to simultaneous events
  - Concept of parallel tasks to perform parallel activities
- Support of concurrent programming

Task unit

- Task as a concurrent, parallel running sequences of commands
- Task as a encapsulated unit
  - Declarations made within a task are not visible outside it
- Communication between task units
  - Message passing and via shared variables
6.4 Real-time Programming Language Ada 95

Realization of tasks

- Declaration and implementation of tasks in a library or directly in the program unit
- Planning of tasks done at the **begin** of the superordinate program unit
- End of execution and deletion after reaching the task’s **end** statement

```ada
package package_name is
  task T1;
  task T2;
end package_name;

package body package_name is
  task body T1 is
    begin
      ...
    end T1;
  task body T2 is
    begin
      ...
    end T2;
end package_name;
```

```ada
with package_name; use package_name;

procedure main_procedure_name is
  task T3;
  task body T3 is
    begin
      ...
    end T3;

  task body T2 is
    begin
      ...
    end T2;
end main_procedure_name;
```
Task types and objects

- Task types provide a template for the instantiation of task objects
- Tasks of the same type have similar properties and functionality
- Individual task objects can be parameterized during instantiation

```ada
package General is

  task type monitorValue(X: Integer);
  taskbody monitorValue(X: Integer) is
  begin
    -- Implementation code
    ...
  end monitorValue;

end General;

With General; use General;
procedure main is
  M1 : monitorValue(1);
  M2 : monitorValue(2);
  M3 : monitorValue(3);
begin
  -- Main code
  ...
end main;
```
Synchronization of tasks

Synchronization concepts in Ada 95

– Logical synchronization
  • Establish a timely sequence of the tasks’ execution

  Œ Rendezvous concept

– Resource oriented synchronization
  • Establish rules to access shared resources

  Œ Protected units
The rendezvous concept (1)

- Handshake method
  - Definition of timely synchronization points between the tasks
  - Mutual wait of the tasks
- Rendezvous has on the calling side the form of a procedure call
- Definition of calling declaration (entry) and calling point (accept)
The rendezvous concept (2)

- Declaration of entry points declared in the task’s specification
- Calls and accept statements in the tasks’ implementation code
- Function principle: task calls the entry point another task

```ada
task T1 is
  entry sync;
end T1;

task body T1 is
  begin
    ...
    T2.sync;
    accept sync;
  end T1;

task T2 is
  entry sync;
end T2;

task body T2 is
  begin
    ...
    accept sync;
    T3.sync;
  end T2;

task T3 is
  entry sync;
end T3;

task body T3 is
  begin
    ...
    accept sync;
    T1.sync;
  end T3;
```

Execution sequence T1, T2, T3, T1, ... is guaranteed in the code above
Dynamic run of the multitask program example

T1

T2

T3

T2.sync;

accept sync;

T3.sync;

T1.sync;

accept sync;
The select statement

- Alternative sequence with the select statement
  - Conditional synchronization
  - Timed waiting

**Conditional synchronization**

```
select
    accept entryName1;
or
    accept entryName2;
... else
    -- Alternative code
end select;
```

```
select
    Receiver.entryName;
else
    -- Alternative code
end select;
```

**Timed waiting**

```
select
    accept entryName1;
or
    accept entryName2;
... or
    delay time_out;
    -- Alternative code
end select;
```

```
select
    Receiver.entryName;
or
    delay time_out;
    -- Alternative code
end select;
```
Protected units and resource synchronization (1)

- Problem of accessing shared variables
- Monitors for exclusive access

- Interface as protected operations
- Access to the shared variable controlled by an intern monitor
  - Protected operations are not executed in parallel
  - Sequential ordering of simultaneous requests

Tasks access the shared variable exclusively
Protected units and resource synchronization (2)

protected S is

entry P;
procedure V;
function G return Boolean;

private
Sem : Boolean := True;
end S;

protected body S is
entry P when Sem = True is
Sem := False;
end P;

procedure V is
begin
Sem := True;
end V;
...
end S;

– Protected operations are mutually exclusive
– A procedure can manipulated the shared variable in any way
   – Functions have only read access
– The entries are protected operations
– All variables of a protected unit have to be declared private
Communication between tasks (1)

- Synchronous communication
  - Extension of the rendezvous synchronization with data exchange
    - Mutual wait
    - Data exchange during the rendezvous
    - Data only valid within the rendezvous

Example of synchronous communication

```ada
task body T1 is
begin
  T2.entryName(I:Integer);
end T1;
```

```ada
task body T2 is
begin
  accept entryName(I:Integer) do
  ...
  end entryName;
end T1;
```

Message passing principle
Communication between tasks (2)

- Asynchronous communication
  - Data exchange via shared variables
    - Protected operation for access
    - No waiting/blockage during communication

Example of asynchronous communication

```ada
protected body M is
  procedure write(I:Integer); begin M.write(I:Integer); end T1;
  function read return Integer; temp := M.read; ...
private
  Val:Integer;
end T1;
```

```ada
task body T1 is
  begin
  M.write(I:Integer);
end T1;
```

```ada
task body T2 is
  temp: Integer;
  begin
    temp := M.read;
    ...
  end T1;
```

- Shared variables and protected operations
6.4 Real-time Programming Language Ada 95

Time operations

- Possible delay of the execution
  - Until a defined point in time
  - For a fixed time period
- Ada 95 statements **delay** and **delay until**
- Time units and operations defined in the core packages
  - For standard applications, **second**
  - For real time applications **ms, µs, ns**
  - Operations
    - Add and subtract time variables
    - Read the current system time
- During a delay, the processor is occupied by another process ready to run
- After a delay, a task may have to wait to receive the processor
  - Preemption by a **higher priority task**
Example of timed operations

```ada
task T1 is
  ms: Duration := 0.001;
  begin
    loop
      read_sensor;
      delay 10*ms;
    end loop;
  end T1;

task T2 is
  ms: Duration := 0.001;
  next_call: Time;
  begin
    loop
      next_call := Clock + 10*ms;
      read_sensor;
      delay until next_call;
    end loop;
  end T2;
```

Task T1
running
blocked

---

– Task T1 activates read_sensor **after a 10ms time delay**
  - The subprogram activation time is relative to the previous execution

– Task T2 activates the read_sensor **every 10ms**
  - The subprogram is activated at fixed times
Modularized exception handling

- Exceptions due to irregular operations possible
  - Treatment of exceptions (exception handling)

Ada 95 exception handling concept:

- Exception handling blocks are implemented as part of the unit’s code
- If an exception occurs, control is given to the exception handling blocks
- Several exceptions can be handled in a single handling block
- Any exception not handled is propagated to the calling unit, if there is any
- Exceptions are raised by the runtime environment or by the program code
  - Runtime environment: predefined exceptions
  - Program code: custom defined exceptions
Exception handling example

```ada
procedure main is
begin
    A := readSensor(1);
    B := readSensor(2);

    rate := A / B;
    -- Could be a division by 0
    exception
        when Constraint_Exception =>
            -- Handles divisions by 0
            ...
        when others =>
            -- Handles all other exceptions
            ...
    end main;
end main;
```

```ada
function readSensor (X: Integer) return Float is
begin
    temp := read(X);
    if (temp < 0.0) then
        raise Sensor_Exception;
        -- Custom defined exception
    else
        return temp;
    end if;
    exception
        when Sensor_Exception =>
            -- Handles sensor exceptions
            ...
    end readSensor;
end readSensor;
```

- Handling blocks implement the exception handling
  - Sensor exceptions handled within the function `readSensor`; others are propagated
  - Activation of specific code by constraint exceptions
  - **Predictable** system behavior also under exception conditions
Real time extensions to Ada 95 (1)

- Tasks with dynamic priorities
  - **Base priority** is established on its specification
  - **Active priority** can differ from the above
  
  â Priority inheritance

- **Hint:** In Ada, a lower number means a lower priority!

**Specification**

```
task T1 is
  pragma Priority(10);
end T1;

task T2 is
  pragma Priority(1);
  entry sync;
end T1;
```

**Implementation**

```
task body T1 is
  begin
    T2.sync;
  end T1;

task body T2 is
  begin
    accept sync do
      ...
      end sync;
    begin
      Set_Priority(20);
    end T2;
```

Note: The `Set_Priority` function is not a standard Ada 95 capability. It is added here for demonstration purposes.
Real time extensions to Ada 95 (2)

- Scheduling methods
  - The method used to schedule tasks can be specified
    - The `pragma Task_Dispatching_Policy`
    - Default method: fixed priorities; FIFO within the priorities
  - Further scheduling methods can be implemented and used

- Access to protected units and the Priority Ceiling Protocol
  - Ceiling priority of protected units can be defined in its specification
    - Default value: system’s highest priority
  - Ceiling priority rules guarantee that there is no chance of deadlock
Further language extensions in Ada 95

- System programming
- Real-time processing
- Distributed systems
- Information system
- Numerics
- Security

- Core language + base library
- Inline-machine-language
- Interrupts
- Flexible scheduling
- Flexible priorities
- Flexible queues
- Partitions
- Inter-partition communication
- Static and dynamic RPCs
- Decimal format
- "PIC" format
- Control over internal numeric formats
- Complex numbers
- Code revision and code inspection
- Reduction of available language constructs
- Dynamic character strings
- Interfaces to other PL
- I/O

© 2004 IAS, Universität Stuttgart
§ 6 Programming Languages for Process Automation

6.1 Basic Terms
6.2 High Level Programming Languages for Process Automation
6.3 Programming Programmable Logic Controllers (PLC)
6.4 Real-time Programming Language Ada 95
6.5 The Programming Languages C and C++
6.6 The Programming Environment Java
## History of C and C++

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1978</td>
<td>Development of the operating system UNIX by Dennis Richie in the programming language C.</td>
</tr>
<tr>
<td>1986</td>
<td>Extension of C for the object-oriented programming to the programming language C++.</td>
</tr>
</tbody>
</table>
Development objectives for C and C++

**C:**
- efficient system programming language for hardware
- flexible like assembler
- control flow possibilities of higher programming languages
- universal usability
- restricted language size

**C++:**
- C is enhanced with object orientation
- the efficiency of C is kept
- improvement of productivity and quality

**Hybrid programming language**

**Concurrent C:**
C is enhanced with concepts dealing with real-time processing.
Language concepts of C

- Four data types: char, int, float, double
- Combination of data: vectors, structures
- Control structures: if, switch, while, do-while, for, continue, break, exit, goto
- Input/Output: Library functions
- Large variety of bit manipulation possibilities
- Weak type concept
- Separate compiling of source files
- Weak exception handling
- No explicit tools for parallel processing
Program setup

Insertion of certain libraries or files;
Definition of names for constants and macros;

Declaration of global variables;

main ( )
{
    Variables that are known within the function “main” have to be declared;
    Instructions;
}

Function type function name (list of parameters)
{
    Variables that are known within the function have to be declared here;
    Different instructions;
    Return (value);
}
Example

```c
#include <stdio.h> // Standard input/output library

main () // Marker for program start
{
    printf ("My first program") // Output instruction
}
```
Language concepts of C++

- **Class**
  - Data structure with data and methods (member function)
- **Constructor**
  - Creation of an instance of a class (object)
- **Destructor**
  - Release of class objects
- **Overloading of functions**
- **Encapsulation of data**
- **Inheritance**
- **Polymorphism**
  - Triggering of different processing steps by messages
### Structure of a C++ program

```cpp
class Wash_machine {
    int rotspeed1, rotspeed2;
    float capacity;
    void calculate (rotspeed1, rotspeed2);
    void type (float);
};
```

Wash_machine Drum;
Suitability of C and C++ for real-time systems (1)

- C and C++ contain no real-time language constructs.
- Deployment of real-time operating system to realize real-time systems.

Call of operation system functions in a C coded program

- Libraries are provided.
Suitability of C and C++ for real-time systems (2)

Programming languages C and C++

Most often used program languages for real-time applications

- Great number and variety on support tools
- Well extended programming environment
- Compilers are available for most micro processors
- Connection to real-time operating systems like QNX, OS9, RTS, VxWorks

Caution with object-oriented language tools

- non-deterministic run-time behavior
- inefficient memory space usage
§ 6 Programming Languages for Process Automation

| 6.1  | Basic Terms          |
| 6.2  | High Level Programming Languages for Process Automation |
| 6.3  | Programming Programmable Logic Controllers (PLC)    |
| 6.4  | Real-time Programming Language Ada 95               |
| 6.5  | The Programming Languages C and C++               |
| 6.6  | **The Programming Environment Java**                |
History of Java

1990  Concept of the programming language Java by the Sun Corp. (James Gosling, Bill Joy)

Objective: Programming language for entertainment electronics (interactive TV)

Named after coffee beans known as Java

1995  Reorientation of the development direction towards a language that could be used for transmitting and carrying out programs in the World Wide Web.

Freely available for non-commercial purposes
Language concepts of Java

- Object-oriented concepts
- Interpretation of the code
  - fast development cycle
  - bad run-time behavior and high demand on storage space
  - higher portability
- A storage manager is provided.
- Conventional pointer methods were not integrated.
- Strict type control at compile and run-time
- Lightweight processes
- GUI class library
Portability of Java through a two-stage translation method

First step of the translation

- Source Program (Java-Code)
- Translation Computer
- Java Byte Code
- Java Compiler

Second step of the translation

- Translator for the target computer 1
  - Target Computer 1
  - Output

- Translator for the target computer 2
  - Target Computer 2
  - Output

- Translator for the target computer n
  - Target Computer n
  - Output
Differences to C++

- No pre-processor instructions like `#define` or `#include`
- No typedef clauses
- Structures and unions in the form of classes
- No functions
- No multiple inheritance
- No `goto`
- No overloading of operators
- Extensive class libraries
  - Base classes (object, float, integer)
  - GUI classes
  - Classes for input/output
  - Classes for network support
Suitability of Java for the development of real-time systems

Application fields

- rapid prototyping in client/server area
- multimedia presentations (video, sound, animation)
- intranet applications
- real-time applications

- Storage management (garbage collection)
- High demand on storage space
- Bad run-time behavior
Real-time language constructs in Java

- Input and output of process values
  - comparable with C/ C++
- Parallelism
  - no process support
  - lightweight processes
  - Round Robin Method
- Synchronization
  - monitors
  - semaphore variables
- Inter-process communication
  - only for lightweight processes on common data
- Bit operations
  - comparable with C/ C++
Examples for Java

Java application
class HelloWorldApplication
{
    public static void main(String argv[])
    {
        System.out.println(„Hello World!“);
    }
}

Java applet
import java.applet.*;
import java.awt.Graphics;
public class HelloWorldApplet extends Applet
{
    public void paint(Graphics g)
    {
        g.drawString(„Hello World!“),5,25);
    }
}
**Real-Time Java**

Extension in the Java language, to realize real-time requirements

### Extensions (1)

- **1. Scheduling:**
  Ensure the timely or predictable execution of sequences of *schedulable objects*

- **2. Memory management:**
  Extend the memory model in order to allow real-time code to deliver deterministic behaviour

- **3. Synchronisation:**
  Specification of the dispatching algorithms; avoidance to the priority inversion problem; support to priority inheritance and priority ceiling policies.

- **4. Asynchronous Event Handling:**
  Ensure that the program can cope with a large number (ten of thousands) of simultaneous events
6.6 The Programming Environment Java

Extensions (2)

- 5. Asynchronous Transfer of Control (ATC):
  Possibility to transfer the control from a thread upon an asynchronous event, e.g. a timer going off

- 6. Asynchronous Thread Termination:
  Ensure an orderly clean up and termination of threads without danger of deadlocks

- 7. Physical Memory Access:
  Special API to directly access memory areas

- 8. Exceptions:
  Definition of new exceptions and new treatment of exceptions surrounding ATC and memory allocators
The control of a central locking system in a car is to be realized using a micro controller based control device.

Give reasons why it might be advantageous to implement the software in an assembler language.

**Answer**

Code generated from an assembler program is very efficient and requires less memory space.

Thus, the cost for the series production can be lowered, as a cheaper micro controller and less memory is required.

If the product is produced in high quantities this is more important than the higher development cost caused by the assembler programming.
**Question referring to Chapter 6.4**

State some of the differences between the real-time programming language Ada95 and the PLC language FBD concerning:

**Answer**

<table>
<thead>
<tr>
<th></th>
<th>Ada</th>
<th>FBD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Notation</strong></td>
<td>text-based language</td>
<td>graphical language</td>
</tr>
<tr>
<td><strong>Language level</strong></td>
<td>universal high level</td>
<td>language specific for</td>
</tr>
<tr>
<td></td>
<td>language</td>
<td>control application</td>
</tr>
<tr>
<td><strong>Application areas</strong></td>
<td>suitable for large projects</td>
<td>suitable for small</td>
</tr>
<tr>
<td></td>
<td></td>
<td>projects only</td>
</tr>
<tr>
<td><strong>Real-time features</strong></td>
<td>extensive real-time</td>
<td>only restricted real-time</td>
</tr>
<tr>
<td></td>
<td>features</td>
<td>capabilities</td>
</tr>
</tbody>
</table>
Question referring to Chapter 6.4

Due to its language features, Ada 95 is called a real-time programming language. Why is Ada so suitable for real-time issues? Because...

Answer

- Ada has no object-orientation.
- Ada supports Tasks.
- Ada is faster than other programming languages.
- Ada is been interpreted.
- Ada is a hybrid programming language.
- Ada supports a rendezvous concept.
- Ada offers methods for run-time checking and exception handling.
The following procedure should be implemented in Ada using two tasks:

A pedestrian is waiting for a taxi and wants to get to the church. He pays the ride and enters the church.

On the next slide there are three different code examples for this problem. Which is the correct one and what are the others doing?
Question referring to Chapter 6.4 - code examples

Alternative 1

task passant;
task body passant is begin
  -- do something
taxi.drive;
  -- do something
end passant;
task taxi is entry drive;
end taxi;
task body taxi is begin
  -- do something
  accept drive;
drive.to(church);
  -- drive away
end taxi;

f - Implements only the timing synchronization without joint code execution

Alternative 2

task passant;
task body passant is begin
  -- do something
taxi.drive;
  -- do something
end passant;
task taxi is entry drive;
end taxi;
task body taxi is begin
  -- do something
  accept drive do
  drive.to(church);
  -- drive away
end taxi;

_ - Implements the timing synchronization with joint code execution

Alternative 3

task passant is entry taxi;
end passant;
task body passant is begin
  -- do something
  accept taxi;
  -- do something
end passant;
task taxi is entry passant;
end taxi;
task body taxi is begin
  -- do something
  accept passant;
drive.to(church);
  -- drive away
end taxi;

f - Does not implement the mutual synchronization
Crosswords to Chapter 6
Crosswords to Chapter 6

Across
3  Program unit of Ada (7)
5  Low-level programming language (9)
8  Real time programming language (3)
9  Basis for the machine independence of Java (3)

Down
1  Ada concept for synchronization (10)
2  Definition of timely synchronization points between the tasks (9)
4  Abbreviation of a PLC programming language which uses building blocks (3)
6  Auxiliary mean to simplify assembler languages (5)
4  Representation of a PLC program similar to a circuit diagram (6,7)