§ 5 Real-time operating systems

5.1	Definition
5.2	Organization tasks of a real-time operating system
5.3	Development of a mini-real-time operating system
5.4	Software system design of the mini real-time operating system
5.5	Examples for real-time operating systems

Chapter 5 - Learning targets

- to know what an operating system is
- to be able to explain what is meant by resources
- to know the functions of an operating system
- to know what interrupts are
- to be able to explain how the memory management is working
- to know the development process of a mini-real-time operating system
- to understand the composition of a mini-real-time operating systems
- to know how the mini operating system is working
- to understand the extensions of the mini operating system
- to understand how the mini operating systems is working
- to get an overview of real-time operating systems

§ 5 Real-time operating systems

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5.4 Software system design of the mini real-time operating system

5.5 Examples for real-time operating systems

What is an operating system?

Definition DIN 44300:

Operating systems are programs of a digital computer system that together with the characteristics of the computer hardware form the basis of the possible operating modes of the digital computer system and especially control and supervise the handling of programs.

Operating system

- Systematically built up collection of control programs and tools
- Allocation of the existing resources to the competing computation processes **Scheduling**
- Simplification of the operating and programming of the computer and its attached devices for the user **Driver**

Characteristic of operating systems

– Realization of the hardware-dependent tasks

– In many cases enclosing from the producer of the computer
  - efficient operating system requires exact knowledge on the hardware structure
  - often for entire computer lines
  - amortization of the high development costs of an operating system

– Size ð **several kilo-bytes in micro computer**
  ð **several mega-bytes in mainframe computer**

– Integration of classical operating systems modules in form of semiconductor chips

Resources

– Objects necessary for the execution of the computer process and for which allocation the computer process has to wait

– Device units
  - Processors
  - Memory
  - Peripheral devices like printers

– System programs

Categories of real-time operating systems (1)

- Real-time - UNIX
  - Compatible to UNIX-System V
  - Used in process control systems
- Real-time - kernels
  - UNIX-compatible micro-kernel with
    Memory management,
    Interrupt handling,
    Scheduler,
    Task management,
    Interfaces on basis of TCP/IP
  - Optimally adapted to requirements
  - Well optimized code for different platforms

Categories of real-time operating systems (2)

– Real-time operating system extensions
  - Extension of MS-DOS-systems
  - Library for the compliance with real time conditions

– Real-time operating systems
  - Very efficient
  - Flexibly configurable
  - Oriented on UNIX

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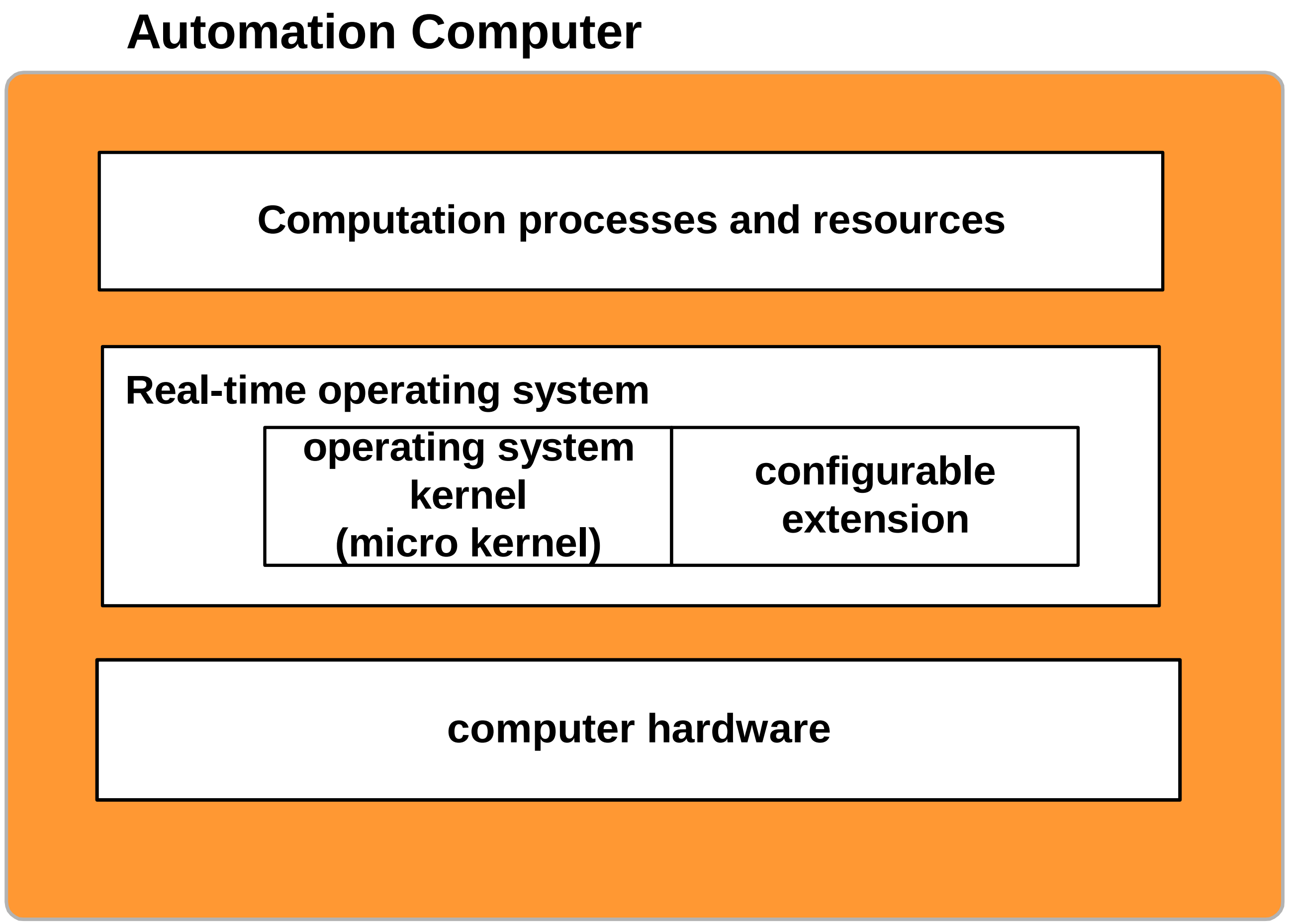
Tasks of a real-time operating system

Management of computer processes and resources in compliance with the requirements for timeliness, concurrency and efficiency

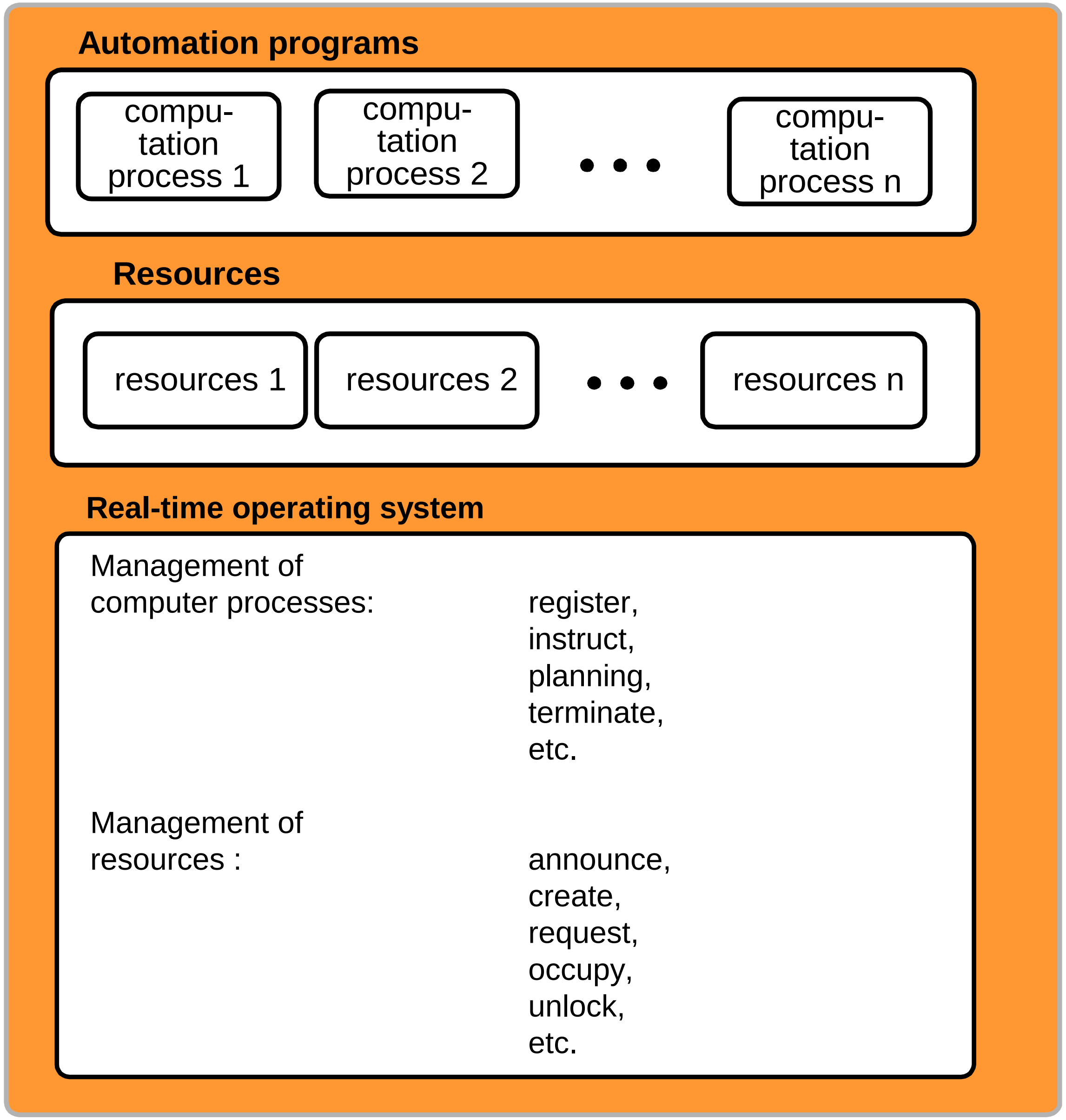
Functions of the operating system

- Organization of the execution of the computation processes (Scheduling)
- Organization of the interrupt handling
- Organization of the memory management
- Organization of the input/output
- Organization of the process in case of irregular operating states and start-up/restart

Layer-architecture of an automation computer system



Automation Computer System



Computation process management

Different kinds of computation processes

- Application processes
- System processes

ð central data logging
ð administration of storage media
ð zero process

Tasks of the computation process management

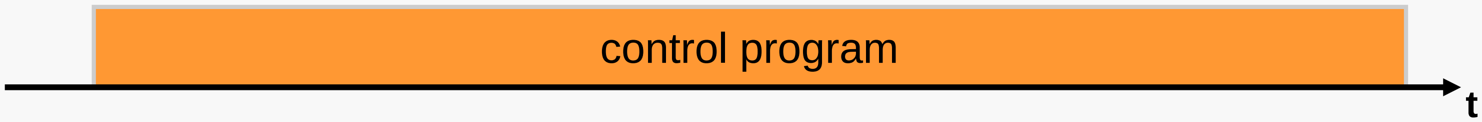
- Coordination of the execution of application and system processes
- Parallel operation of as many resources as possible
- Work of queues for resources
- Synchronization of application system processes
- Avoidance, identification and elimination of deadlocks

Interrupt handling

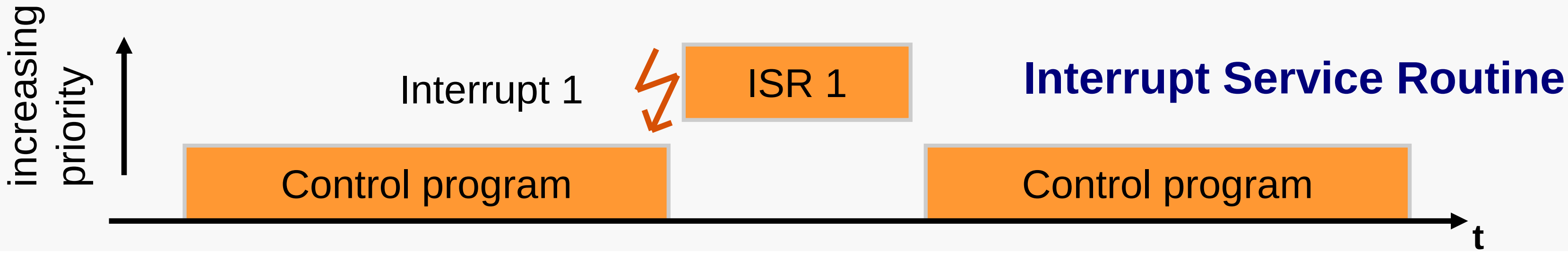
– Interruption of the planned program sequence

– Start of a service routine

Planned program sequence: (without interrupts)



Actual operational sequence: (with interrupts)



Interrupt handling

- Creation and processing of vectorized interrupts

Interrupt vector

- Start of an interrupt service routine while simultaneously interrupting the presently running computation process
- Prioritization of interrupts
- Hardware functions for the interrupt handling (within the range of micro-seconds)

Why memory management?

The cost of memory space is proportional to the access speed

® **optimal usage necessary**

Memory hierarchy levels

- Cache memory (extremely fast semiconductor memory)
- Working memory
- Hard disc memory
- Floppy disc

Tasks of the memory management

- Optimal usage of the “fast” memories
- Coordination of the access on a shared memory area
- Protection of the memory area of different computer processes against false accesses
- Assignment of physical memory addresses for the logical names in application programs

Input/output control

Different kinds of input/output devices

- Distinction in speed
- Distinction in data formats

Realization of the input/output control

Interface hardware-dependent/ hardware-independent

- Hardware-independent level for the data management and the data transport
- Hardware-dependent level, that takes into account all device specific characteristics (driver programs)

Classification of errors (1)

– Faulty user inputs

- Non-valid inputs have to be rejected with error message

– Faulty application programs

- Guaranty, that a faulty application program does not affect other programs

Classification of errors (2)

– Hardware faults and hardware failures

- Recognition of hardware faults and failures
- Reconfiguration without the faulty parts
- Shut-down sequences in case of power failures

– Deadlocks based on dynamic constellations

- Reliable avoidance of deadlocks is not possible

Identification of deadlocks and elimination through withdrawal of operating resources

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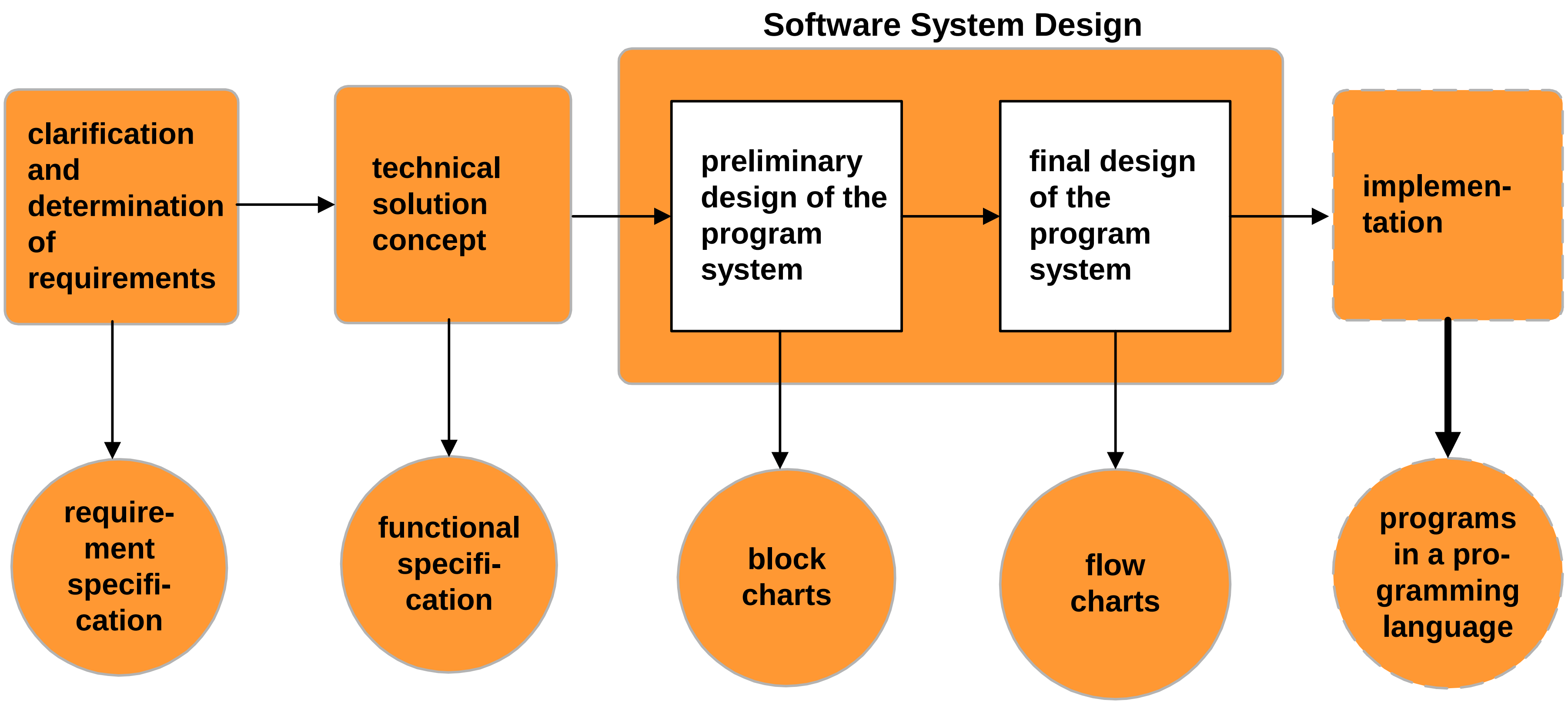
Objective

- Presentation of the structure and the mode of operation of a real-time operating system in strongly simplified form
- Gradual withdraw of the taken simplifications

Development process

- Clarification of the problem formulation, determination of the requirements
- Technical solution concept
- Software system design
- Implementation

Procedure of the development of the mini-real-time operating system



Clarification and determination of the problem formulation and the requirements

– Management of a maximum of n computer processes

- m Computer processes cyclic
- k Computer processes through interrupt signal

  i.e. $n = m + k$

– One processor for the execution of operations

- No optimization of the processes through simultaneous execution of computation operations and I/O operations

– Time signal for cyclic activities through internal clock generator

- Clock impulses at fixed intervals T (i.e.: T = 20ms)
- Different cycle times for the cyclic processes

Simplifications that are withdrawn at a later point

Œ The sum of all computing times of the computation processes is smaller that the interval T

- Assurance that all computation processes are finished at the next clock pulse.

• No tasks that are started by interrupt

Only cyclic tasks

Ž No resource management

- Input/output times are negligibly short

Design of a solution concept

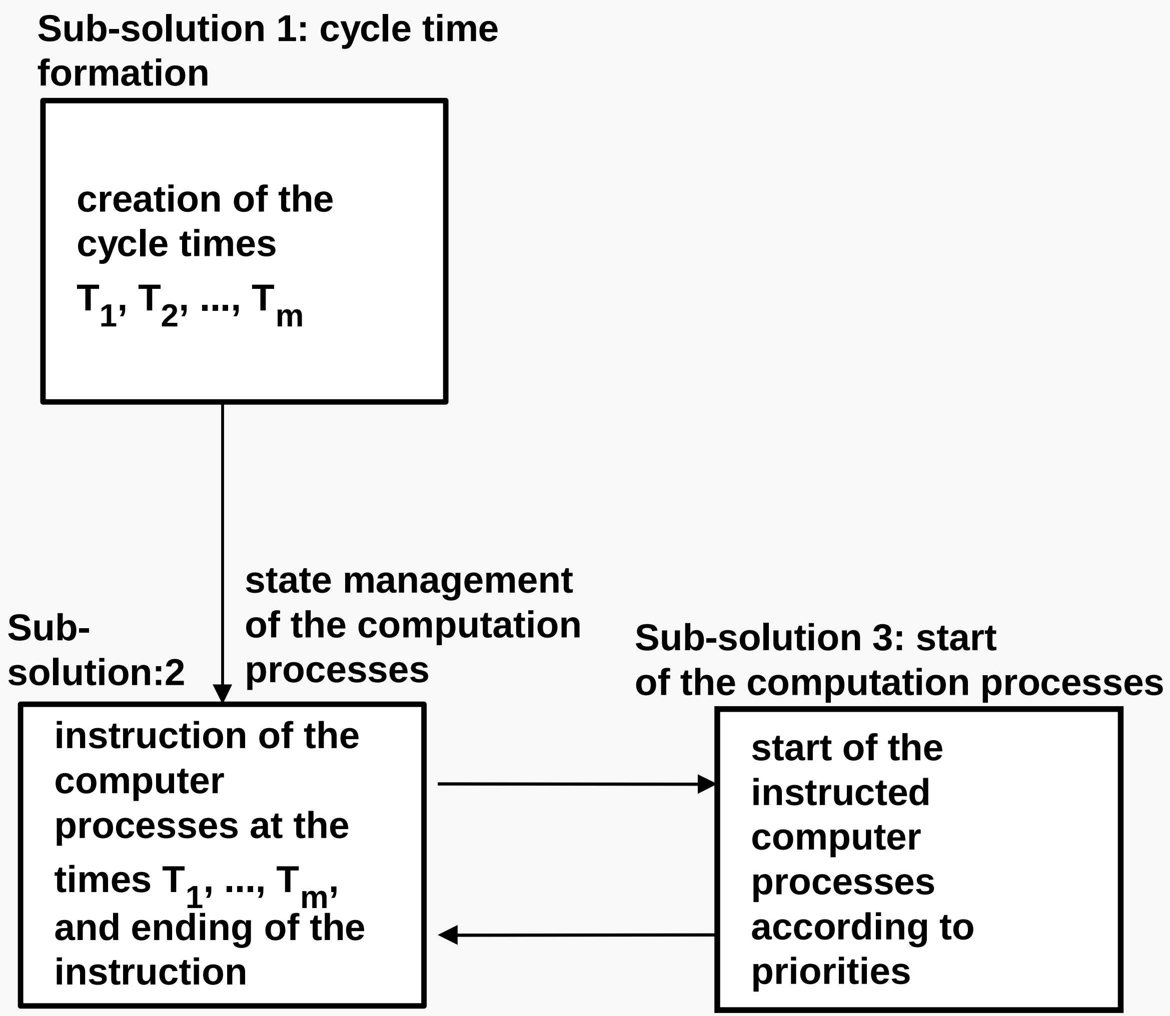
Asynchronous programming method

- Asynchronous instruction of the individual computer processes
- No fixed sequence of tasks
- Conflict strategy according to priority numbers

Sub-solution

- Creation of cycle time
  - Derivation of the different cyclic times of the tasks from the clock impulse
- State management of the computer processes
  - Instruction of the tasks at the corresponding cyclic times and defined termination
- Start of the computation processes
  - Start of the task, which turn it is

Solution concept of the mini operating system



Creation of cycle time

Task:

Formation of the cohesion between the cycle times T_i (i = 1,2,...,m) and the interval T

Assumption: $T_i >> T$

Þ $T_i = a_i \cdot T$

a_i Integral cycle time factors (i=1,2,...,m)

Interval variable Z_i (i=1,2,...,m)

Arrival of the clock impulse reduces Z_i by 1

$Z_i = 0$: Cyclic time T_i is over

Reset of Z_i on initial value a_i

Sub-solution 1: creation of cycle time

introduction of dimensionless, integral cycle time factors

$T_1 = a_1 T$ $\qquad a_1 = \frac{T_m}{T}$

$T_2 = a_2 T$ $\qquad a_2 = \frac{T_2}{T}$

⋮

$T_m = a_m T$ $\qquad a_m = \frac{T_m}{T}$

↓

definition of (dimensionless) interval variables $z_1, z_2, ..., z_m$ with the initial values

$z_1 = a_1$

$z_2 = a_2$

⋮

$z_m = a_m$

↓

clock impulse →

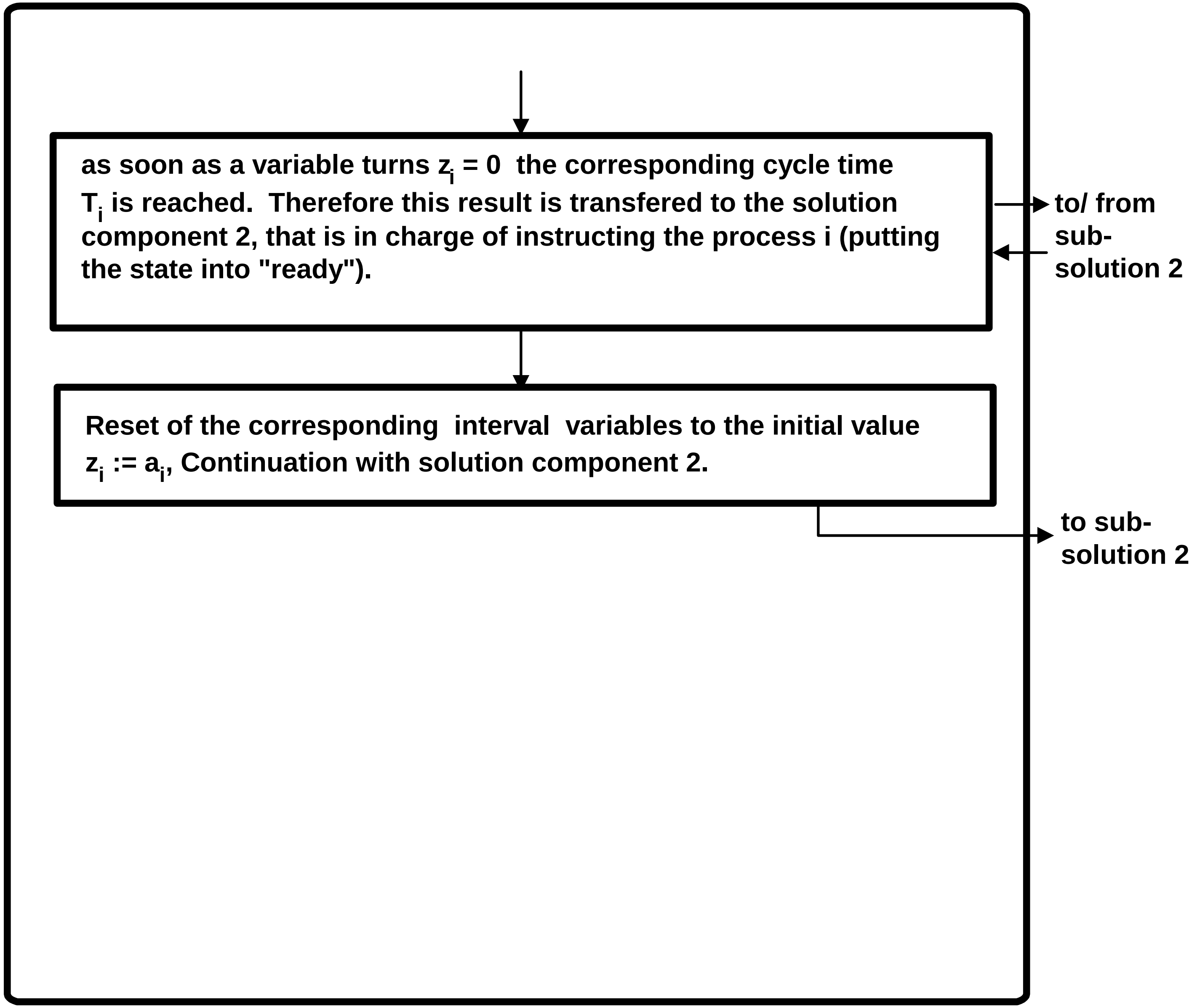
at each arrival of clock impulse in interval T:
decremention of the variable z_i (decrement by 1), i.e. formation of :

$z_1 := z_1 - 1$

$z_2 := z_2 - 1$

$z_m := z_m - 1$

↓


as soon as a variable turns $z_i = 0$ the corresponding cycle time T_i is reached. Therefore this result is transfered to the solution component 2, that is in charge of instructing the process i (putting the state into "ready").
to/ from sub-solution 2
Reset of the corresponding interval variables to the initial value $z_i := a_i$, Continuation with solution component 2.
to sub-solution 2

State management of the computation processes

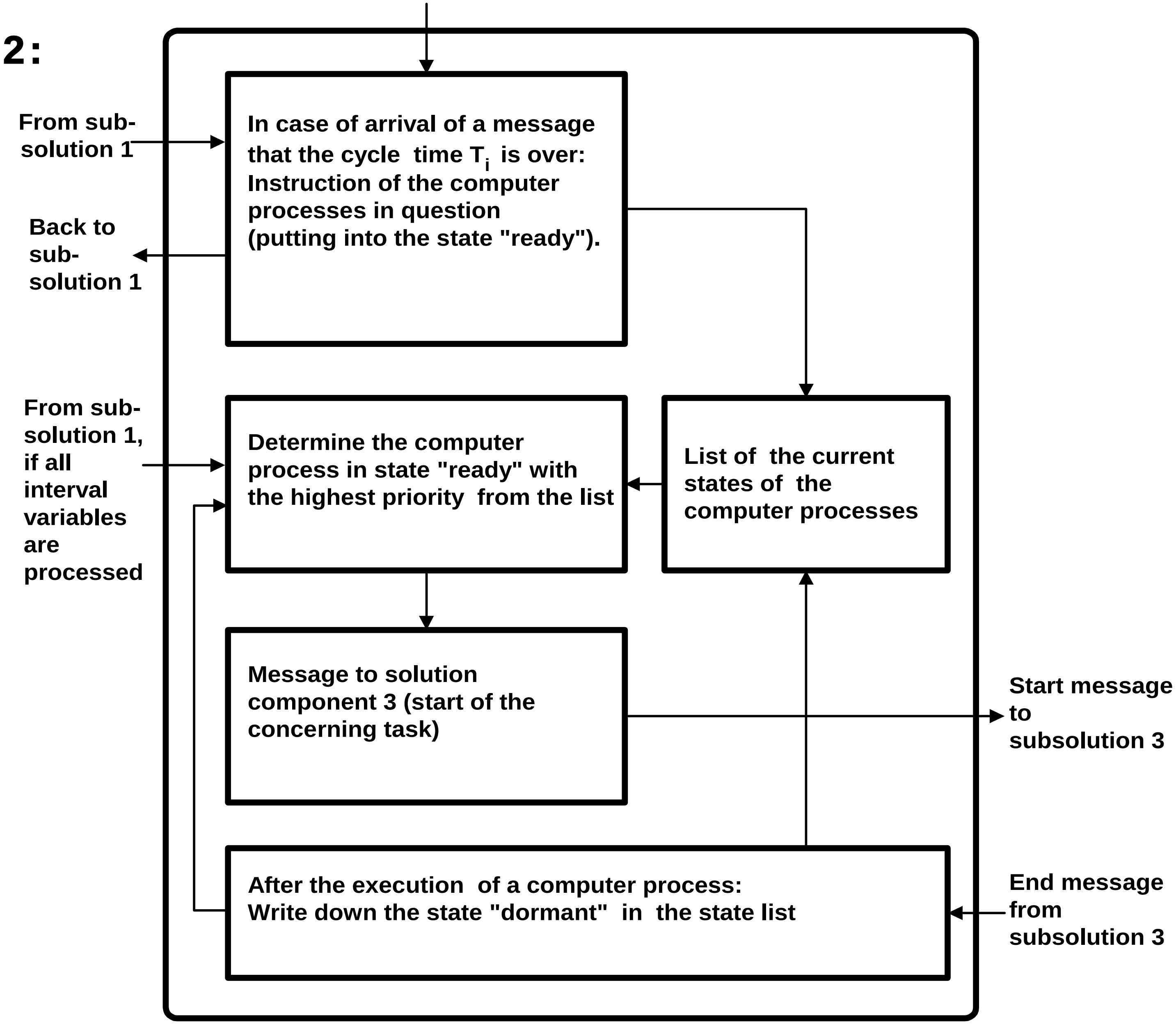
Task:

– Management of the states of the computation processes
  - dormant
  - ready
  - blocked
  - running

– Bookkeeping on the respective states of each process

– Execution of state transitions

Sub-solution 2: State management of the computation processes

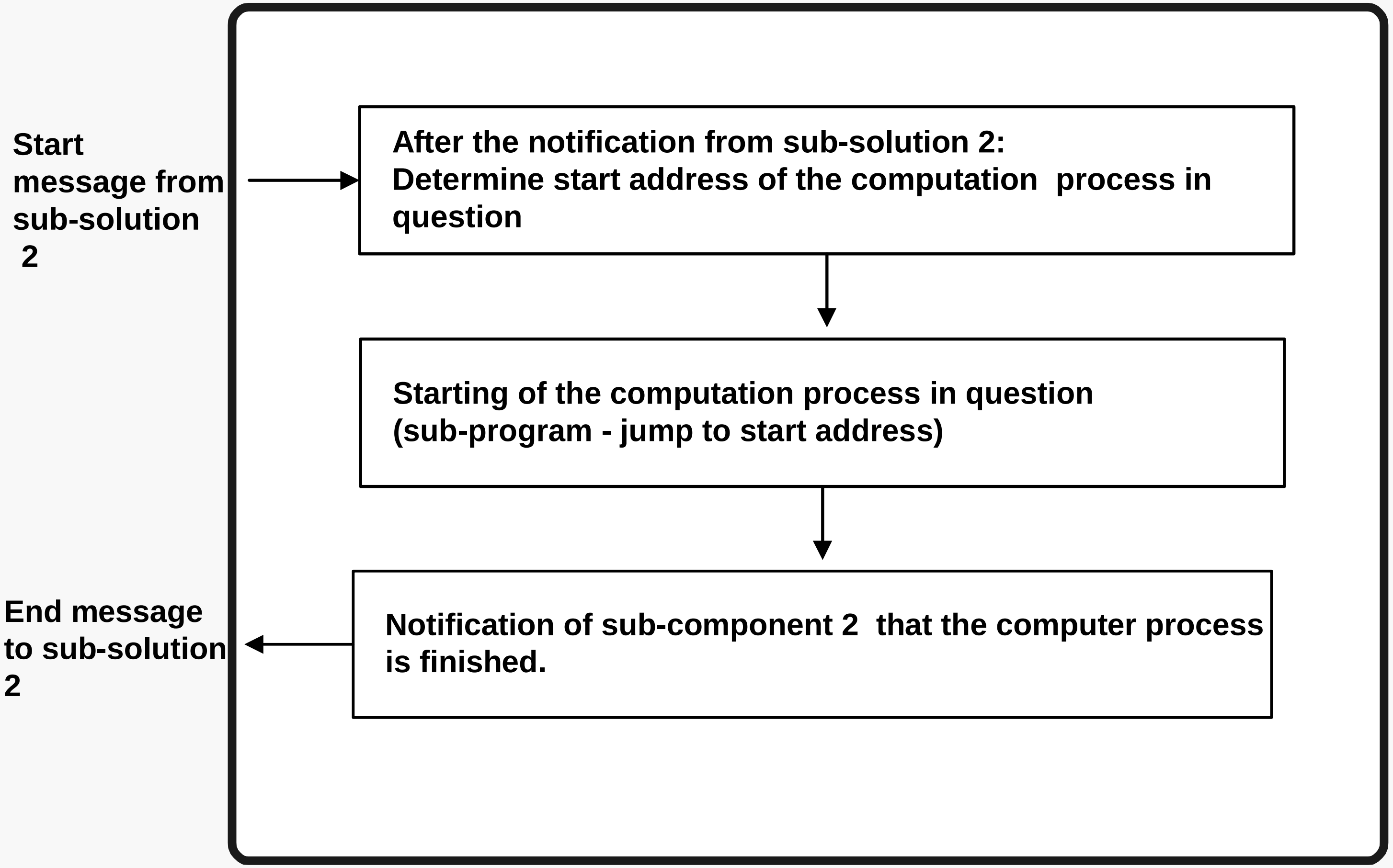


Start of the computation processes

Task:

- Determination of the start address
- Starting of the computation processes
- Supervise the termination of the computer process

Sub-solution 3: Starting of the computation processes



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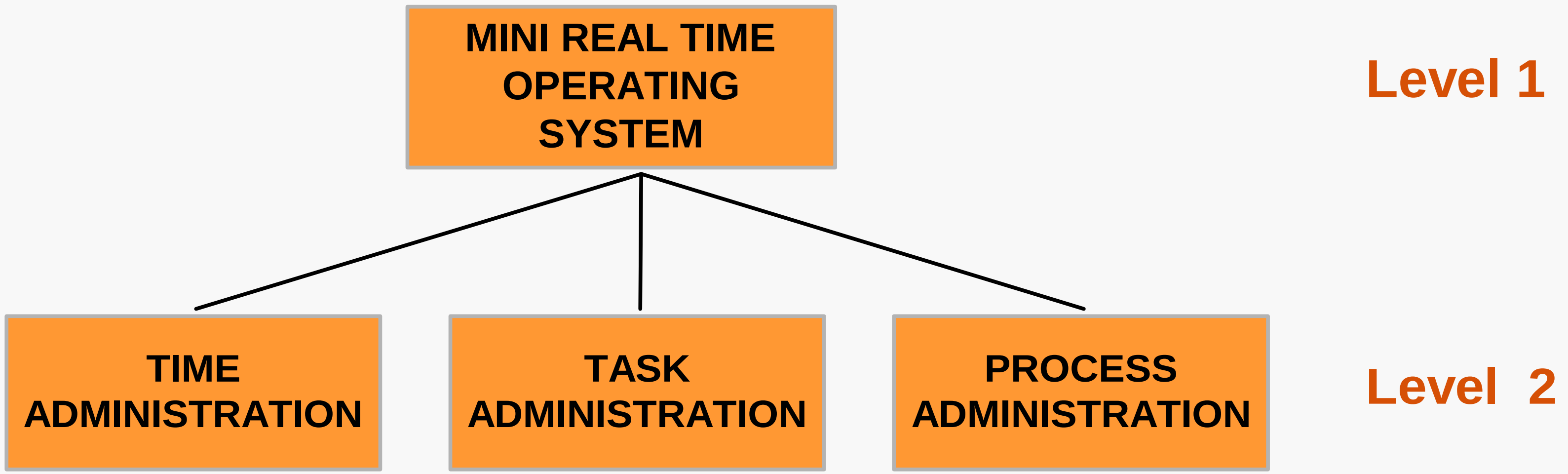
Software system design based on strongly simplified formulation

Principle of the stepwise refinement

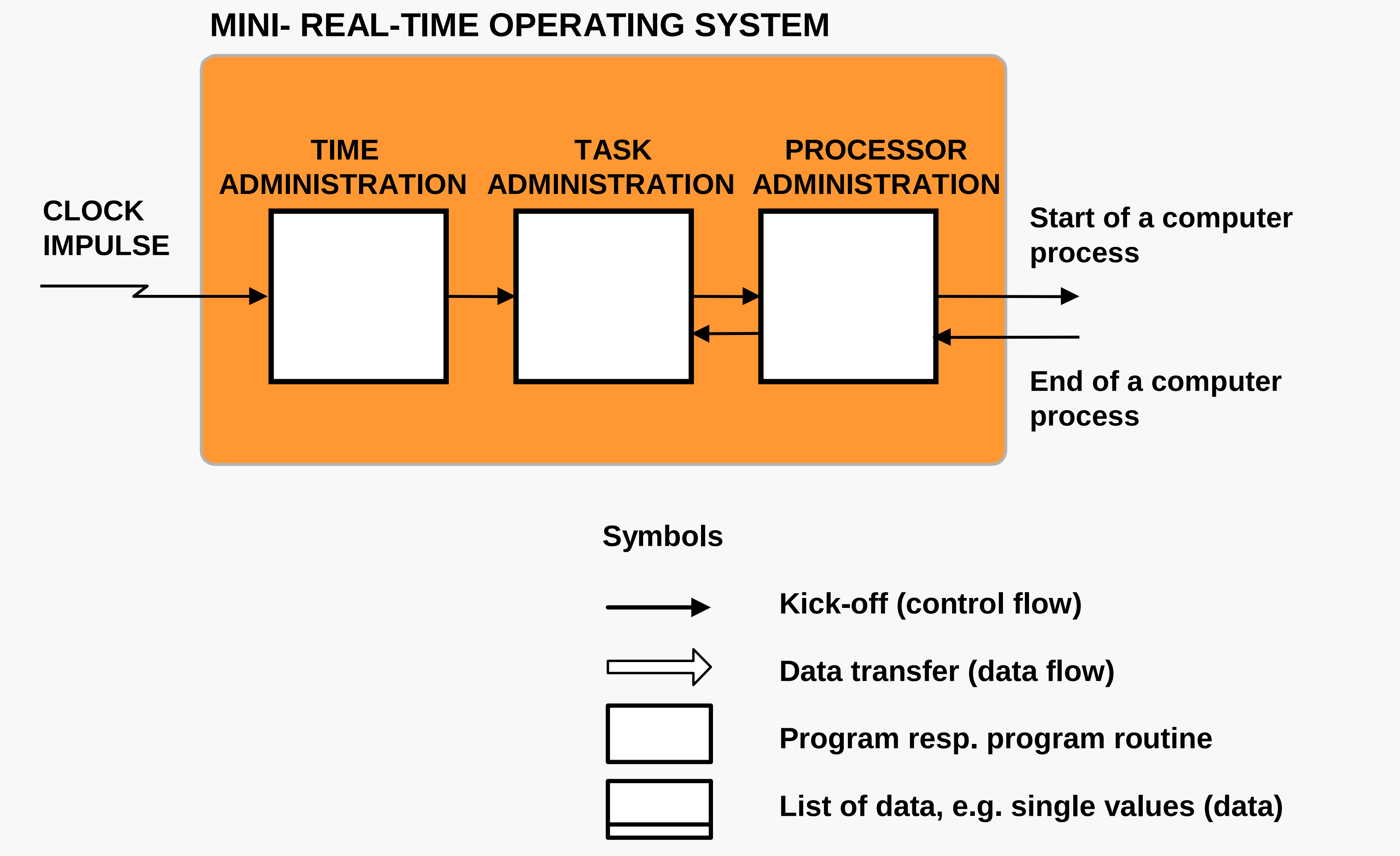
Dissection of the mini operating system in program routines, that are individually refined as well.

Dissection of the mini-real-time operating system program

- Sub-program TIME ADMINISTRATION
  - for the formation of the different cyclic times
- Sub-program TASK ADMINISTRATION
  - for the administration of the computer processes
- Sub-program PROCESSOR ADMINISTRATION
  - allocation of the resource “processor”
  - starting of the computer processes



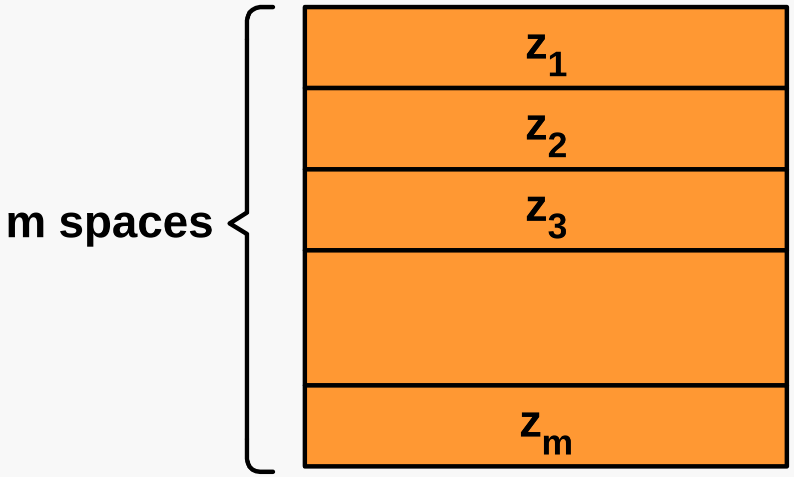
Interaction of the sub-programs of the mini-real-time operating system



Lists necessary for the TIME ADMINISTRATION (1)

– Time span variable Z_i for cyclic time formation
  List TIME COUNTER

Filing of the time-span variables z_i

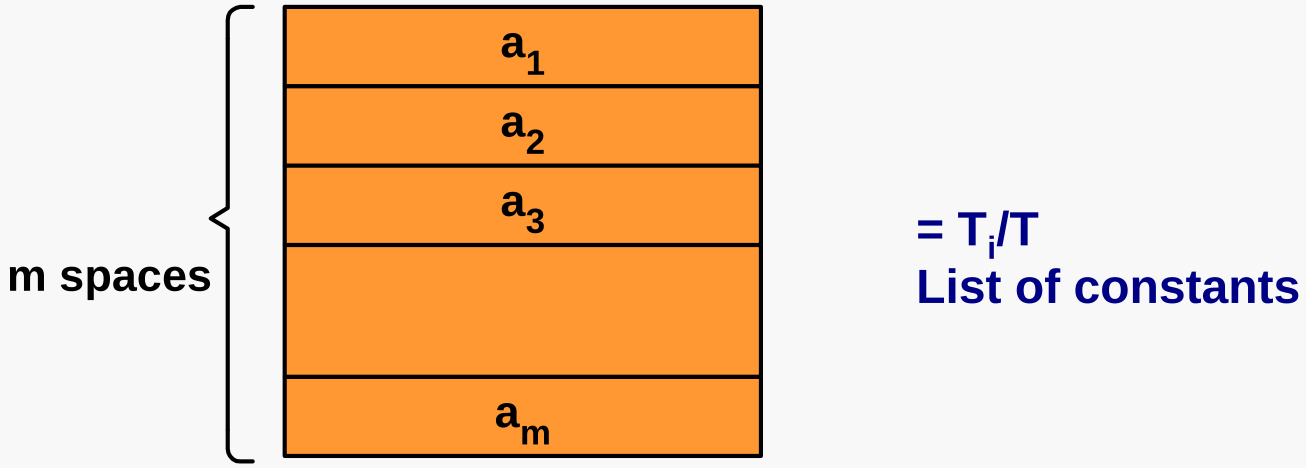


List of variables

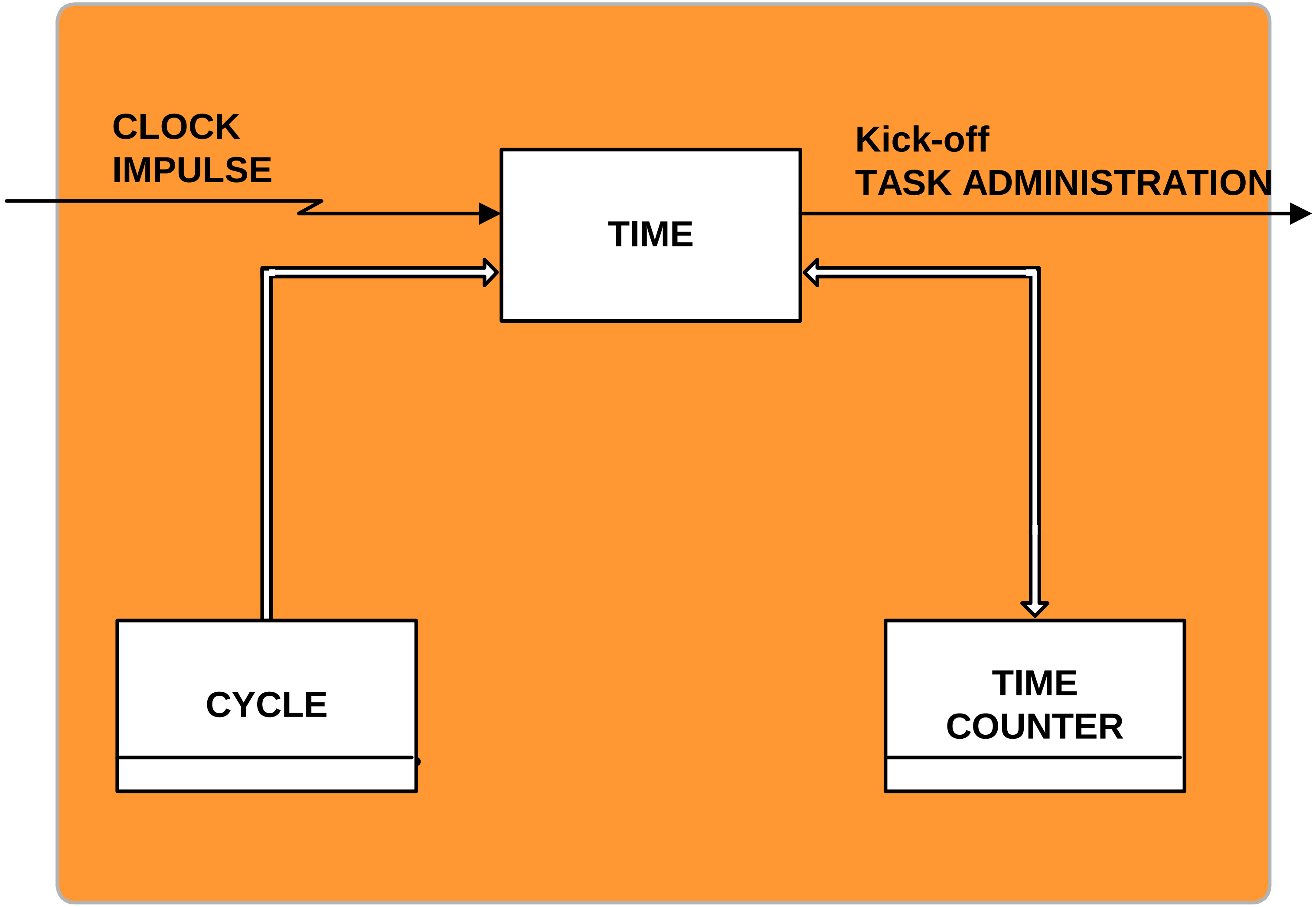
Lists necessary for the TIME ADMINISTRATION (2)

– Cyclic time T_i for each computer process
  List CYCLE

Provision of the cyclic time factors a_i:



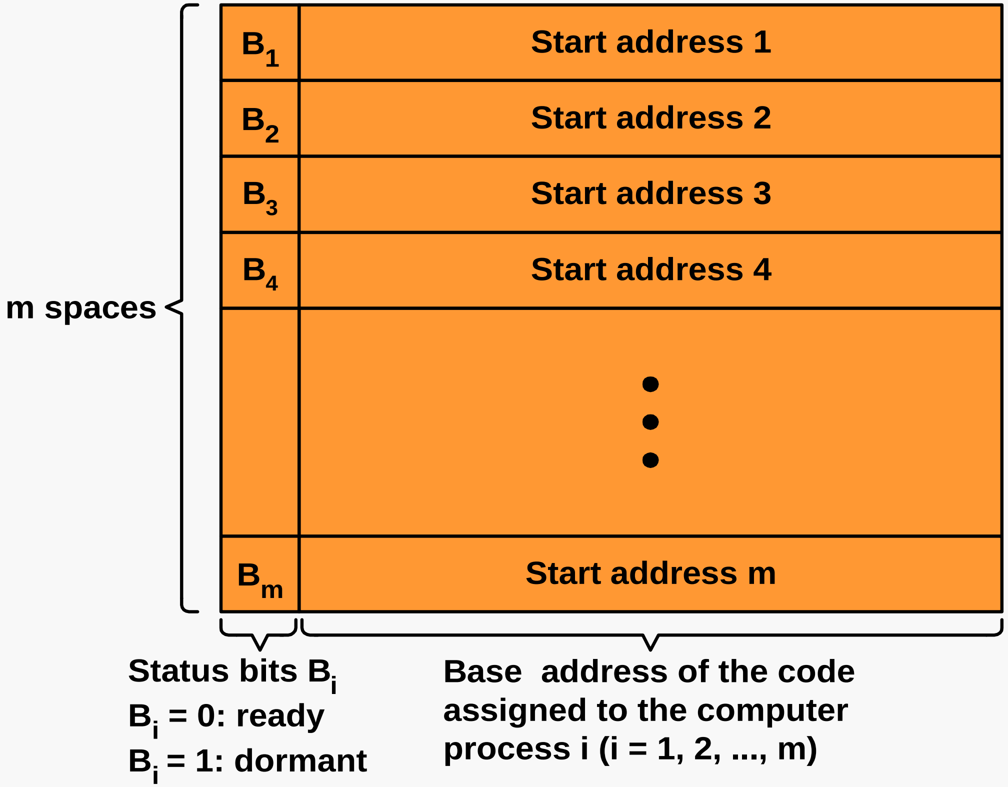
Block chart of the sub-program TIME ADMINISTRATION



List necessary for the TASK ADMINISTRATION and PROCESSOR ADMINISTRATION

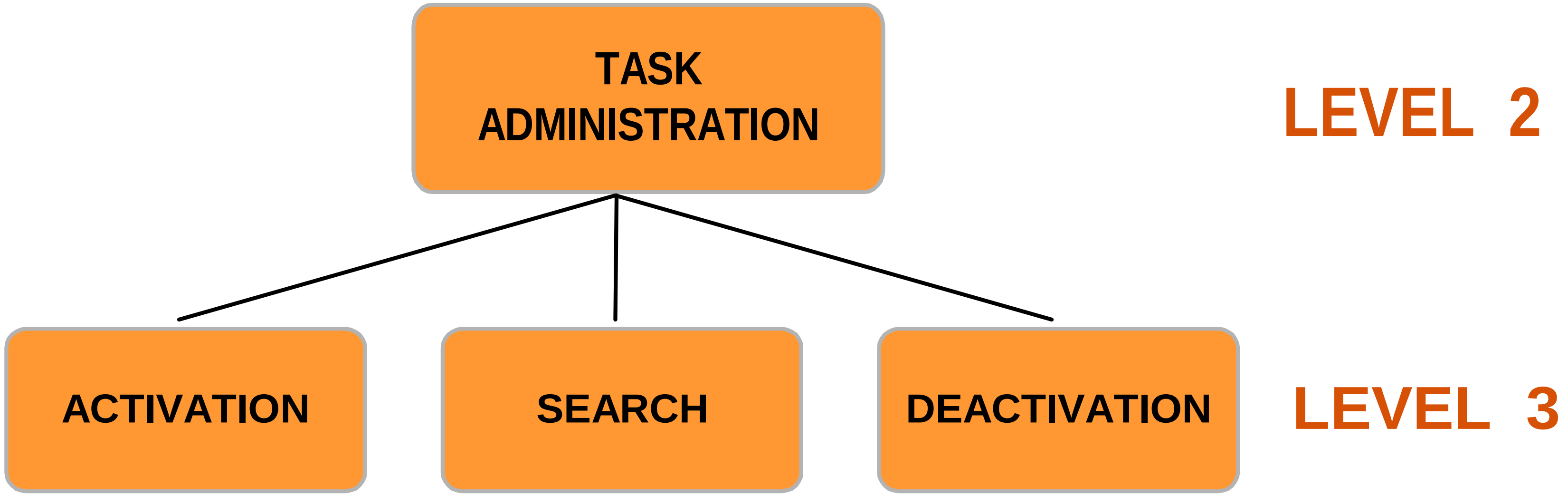
ð Status and base address of the computer process list ADMINISTRATION BLOCK

Structure of the list for the administration of computer processes ADMINISTRATION BLOCK

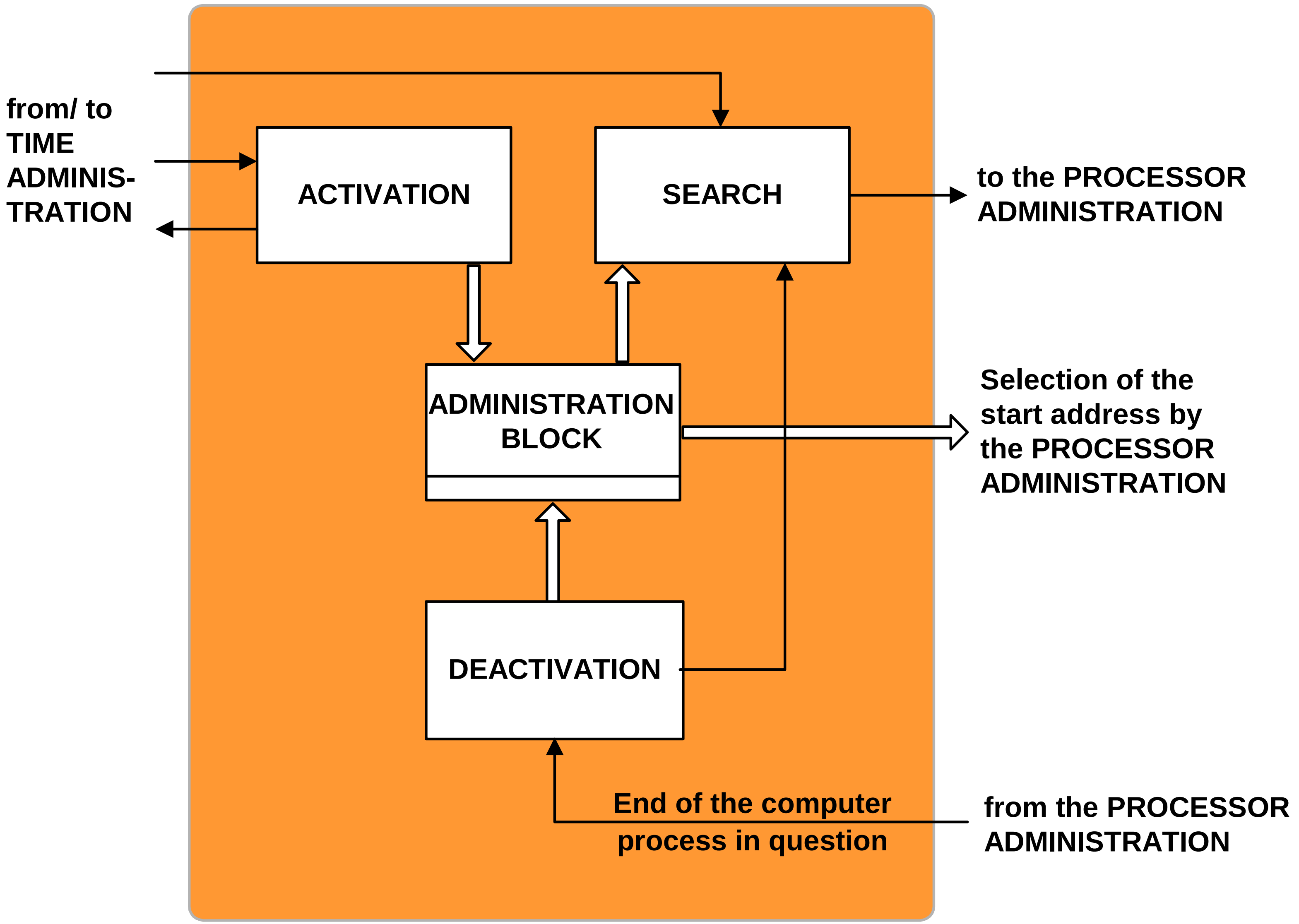


Two-dimensional field

Division of the sub-program TASK ADMINISTRATION



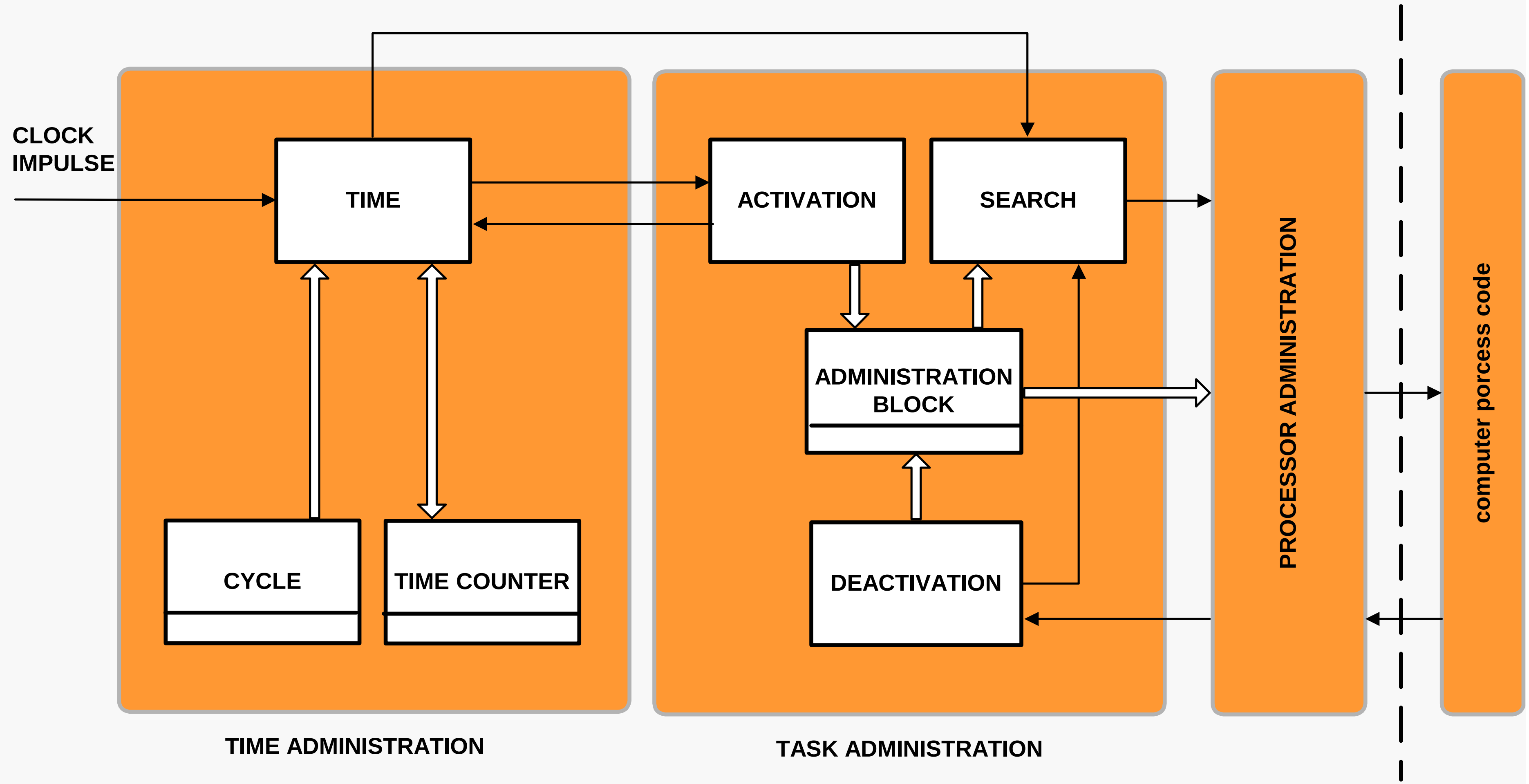
Block chart of the TASK ADMINISTRATION



ACTIVATION:	Modification of the status bits into “ready”
DEACTIVATION:	Modification of the status bits into “dormant”
SEARCH:	Check if there´s a task in state “ready”

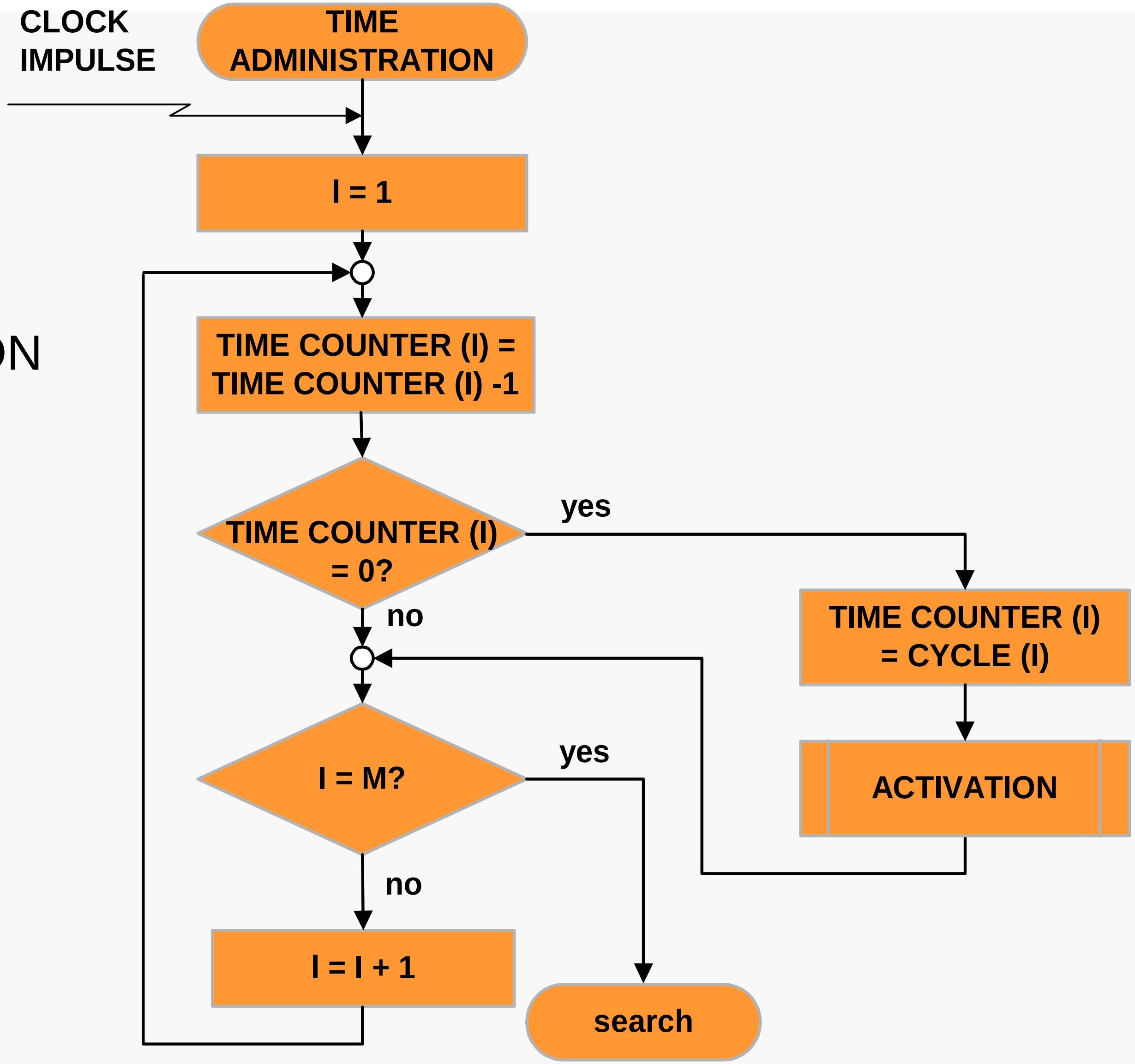
Organizing the list ADMINISTRATION BLOCK allows a simple prioritization.
Subdivision of PROCESSOR ADMINISTRATION is not necessary.

Overall block chart of the mini real time operating system



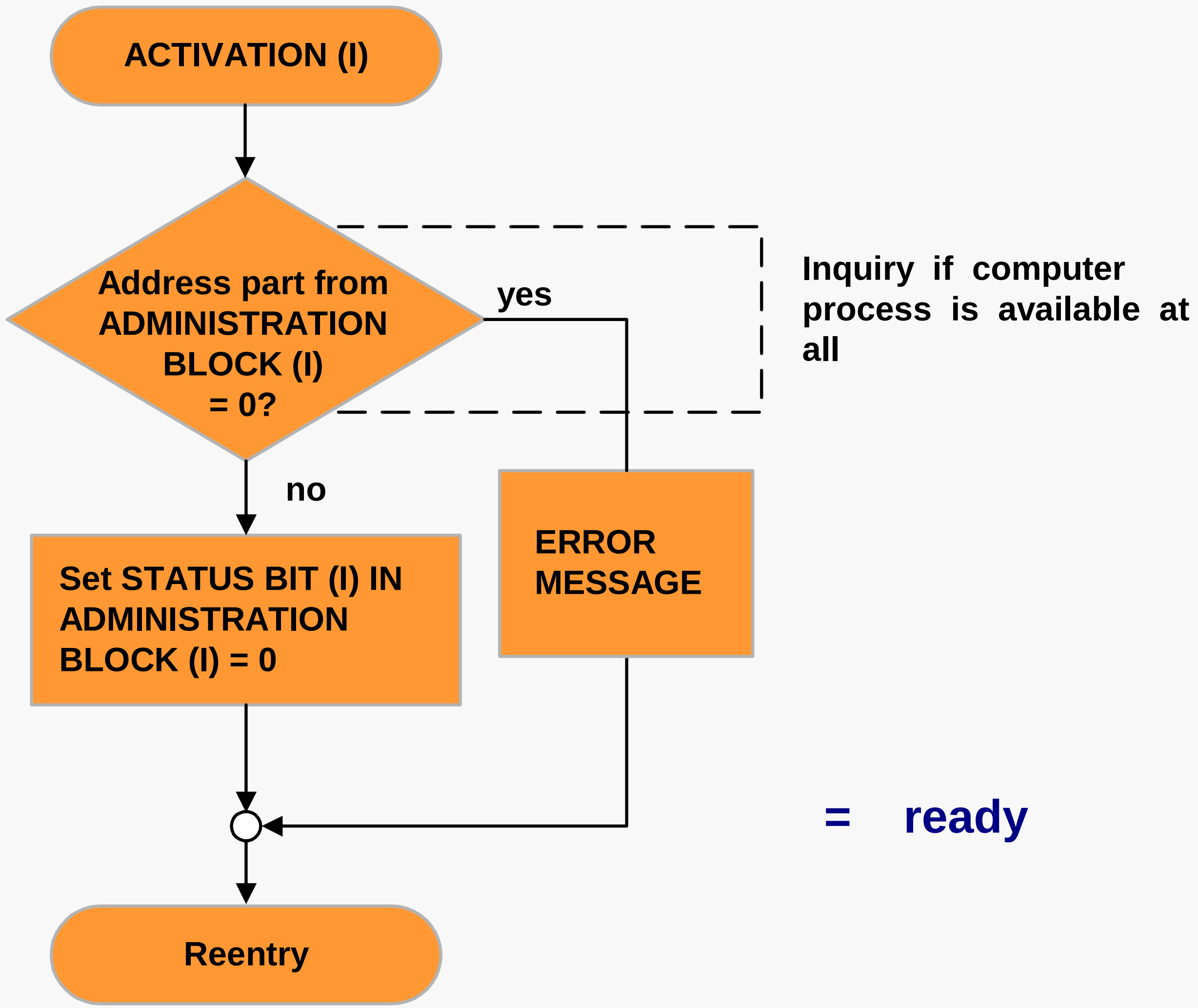
Fine design in form of a flow chart

Flow chart TIME ADMINISTRATION

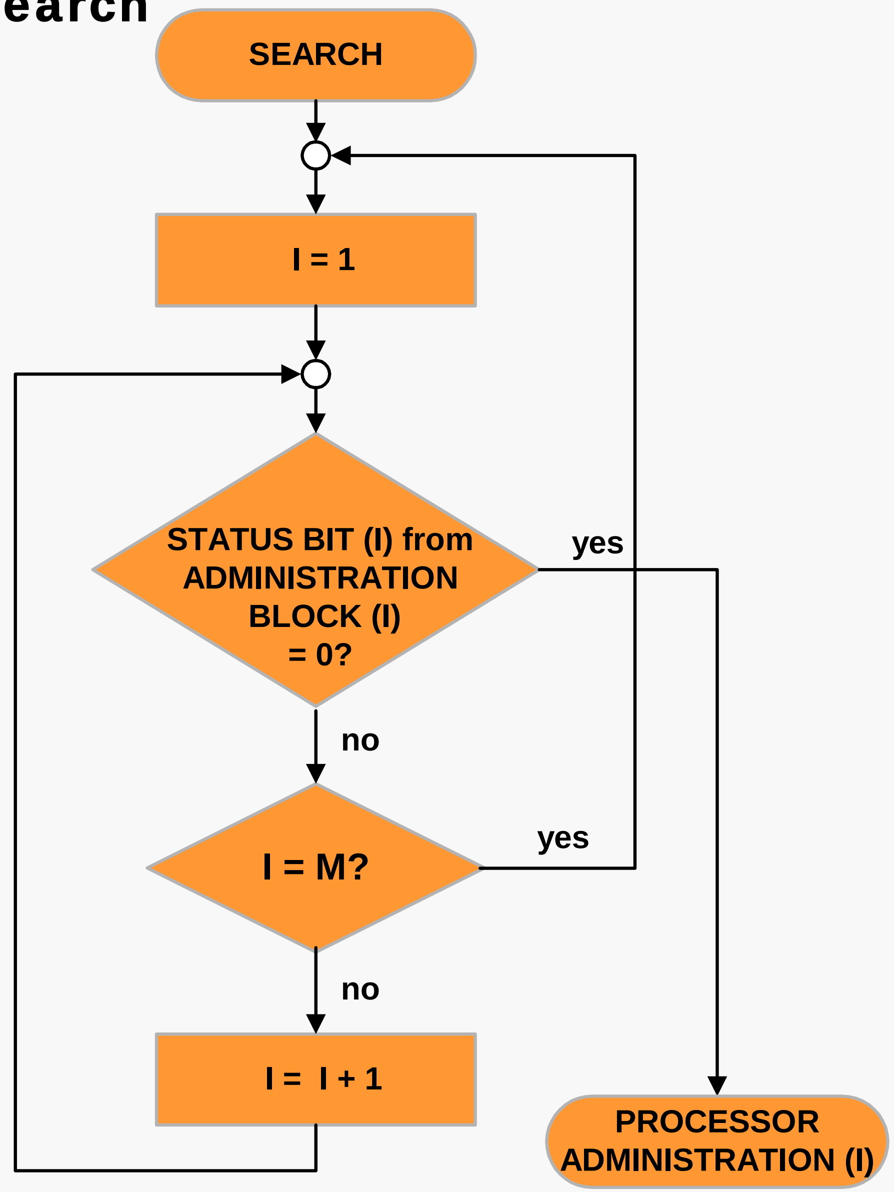


Flow chart of the programs TASK ADMINISTRATION

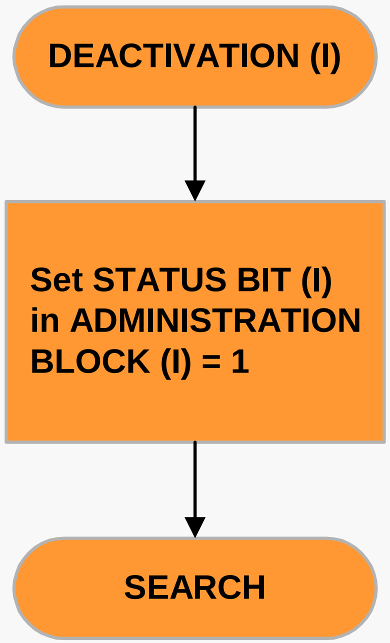
ACTIVATION



Search

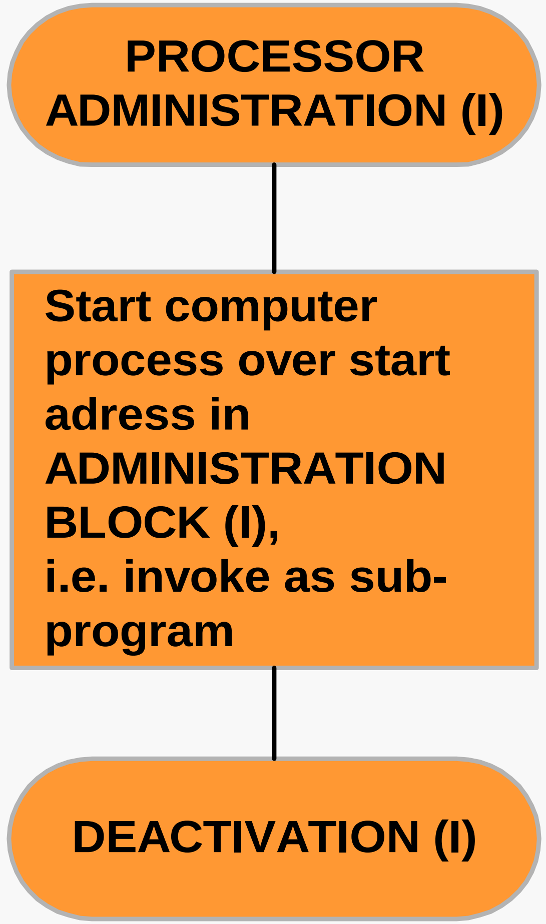


Deactivation



= dormant

Flow chart of the PROCESSOR ADMINISTRATION



First extension of the system design

Admission of longer computing times for the computer processes

é In case of the arrival of a clock impulse it might be necessary to interrupt a (still) running computer process featuring a longer execution time and lower priority, in order to start a computer process with a higher priority.

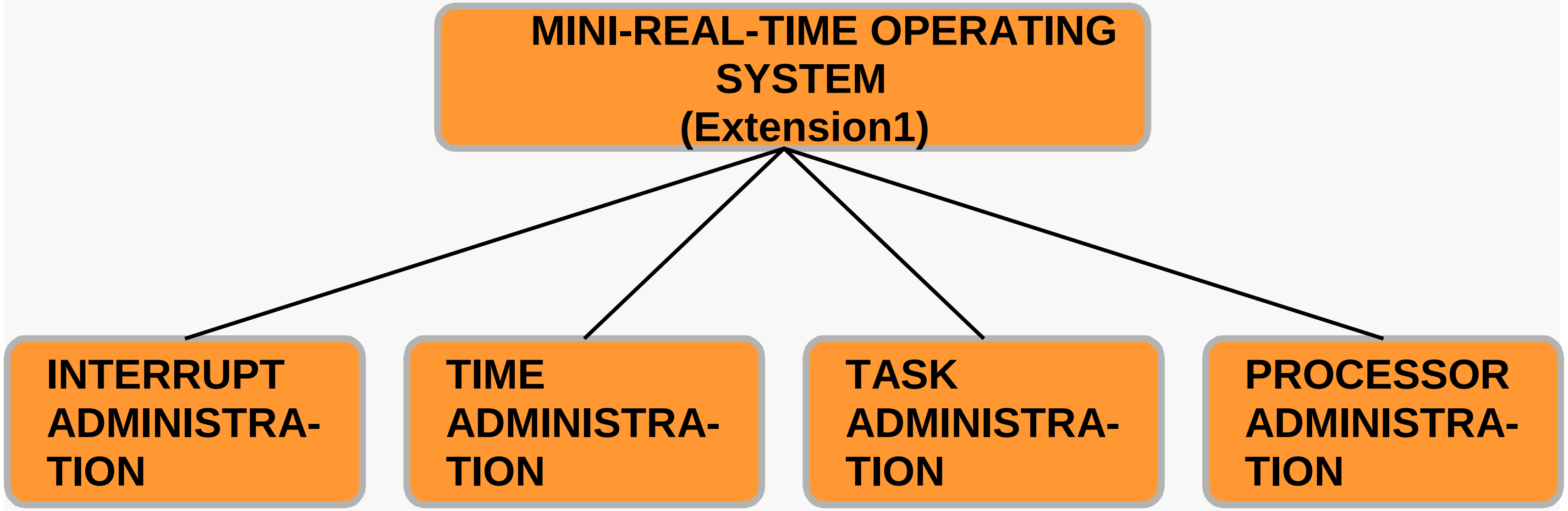
é Program for the interruption administration

Sub-program INTERRUPTION ADMINISTRATION (Administration program)

Task:
Rescue of the registers of the processor of a still running computer process.

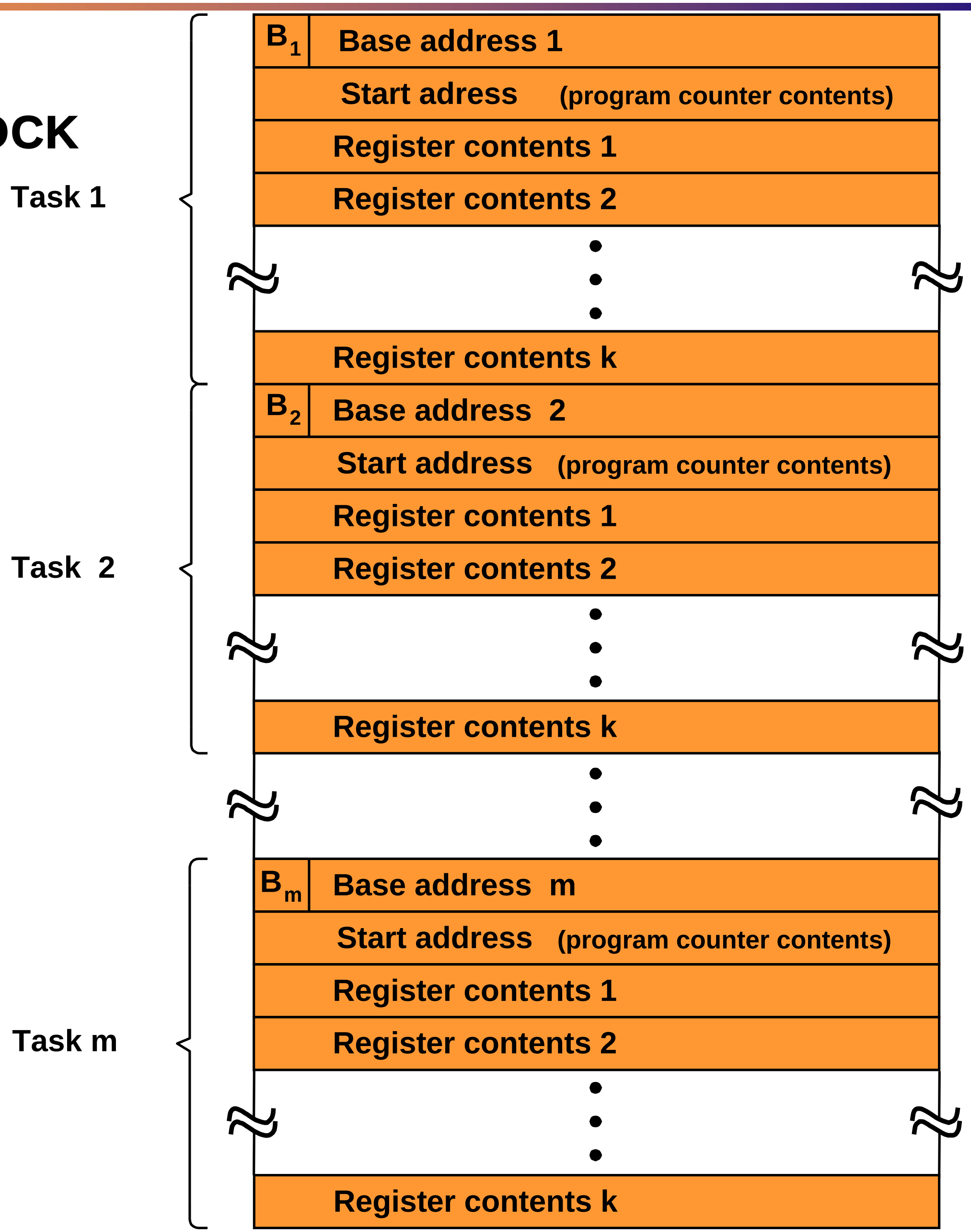
- Program counter
- Accumulator
- Status register
- Working register

Extended hierarchy chart after the admission of longer computing times in computer processes



Extension of the list
ADMINISTRATION BLOCK

– Start address after an interruption
– Register memory location



Extension of the sub-program PROCESSOR ADMINISTRATION

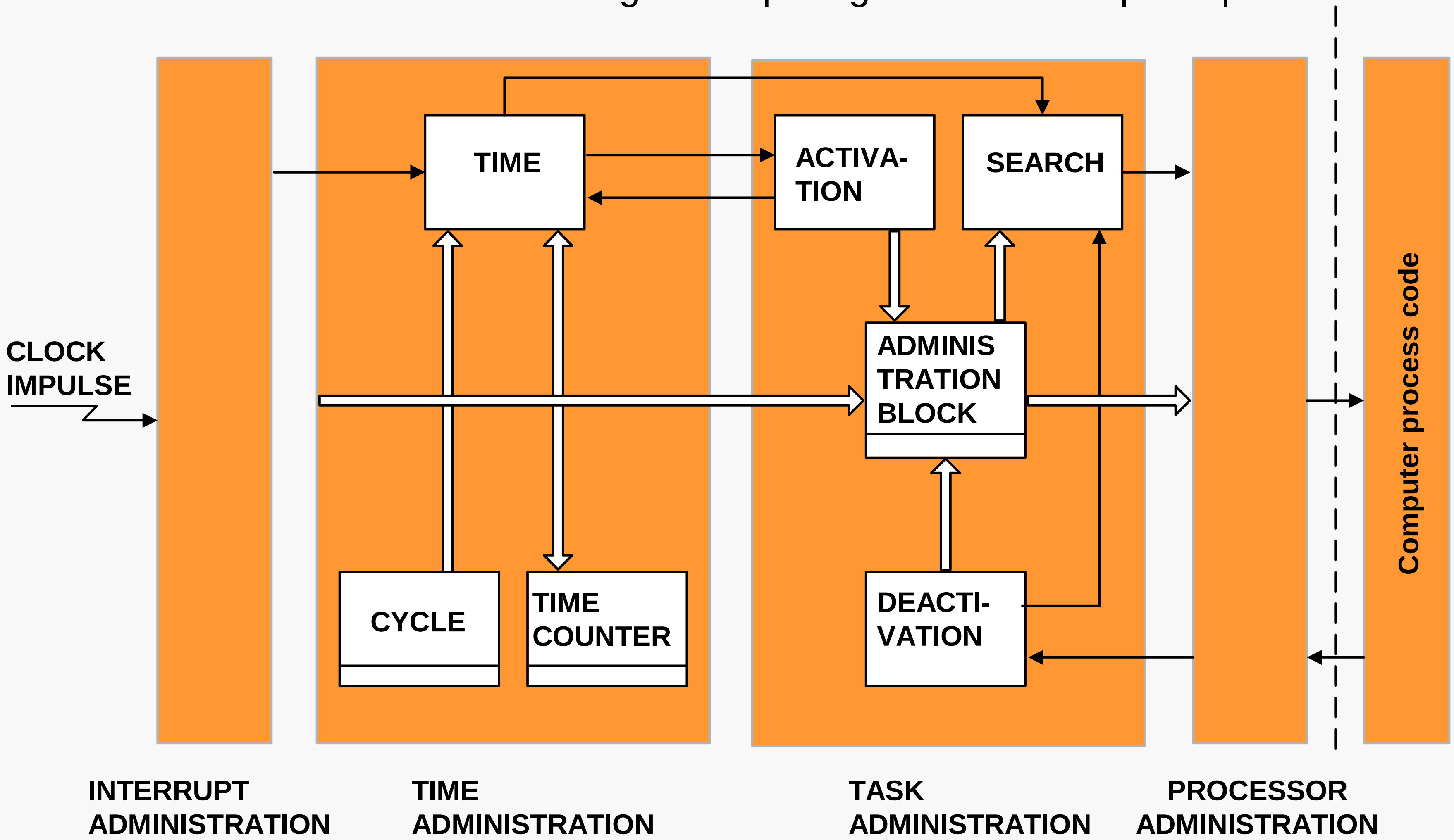
– Right before the start of a ready computer process the register with the contents of the list of the ADMINISTRATION BLOCK has to be loaded.

Extension of the sub-program DEACTIVATION

– After the computer process is finished its base address is loaded into the cell START ADDRESS and the register contents in the ADMINISTRATION BLOCK are to be initialized.

Overall chart of the mini real time operating system

First extension: Admission of longer computing times for computer processes



Second extension of the software system design

Having the possibility of alarm interrupts in mind

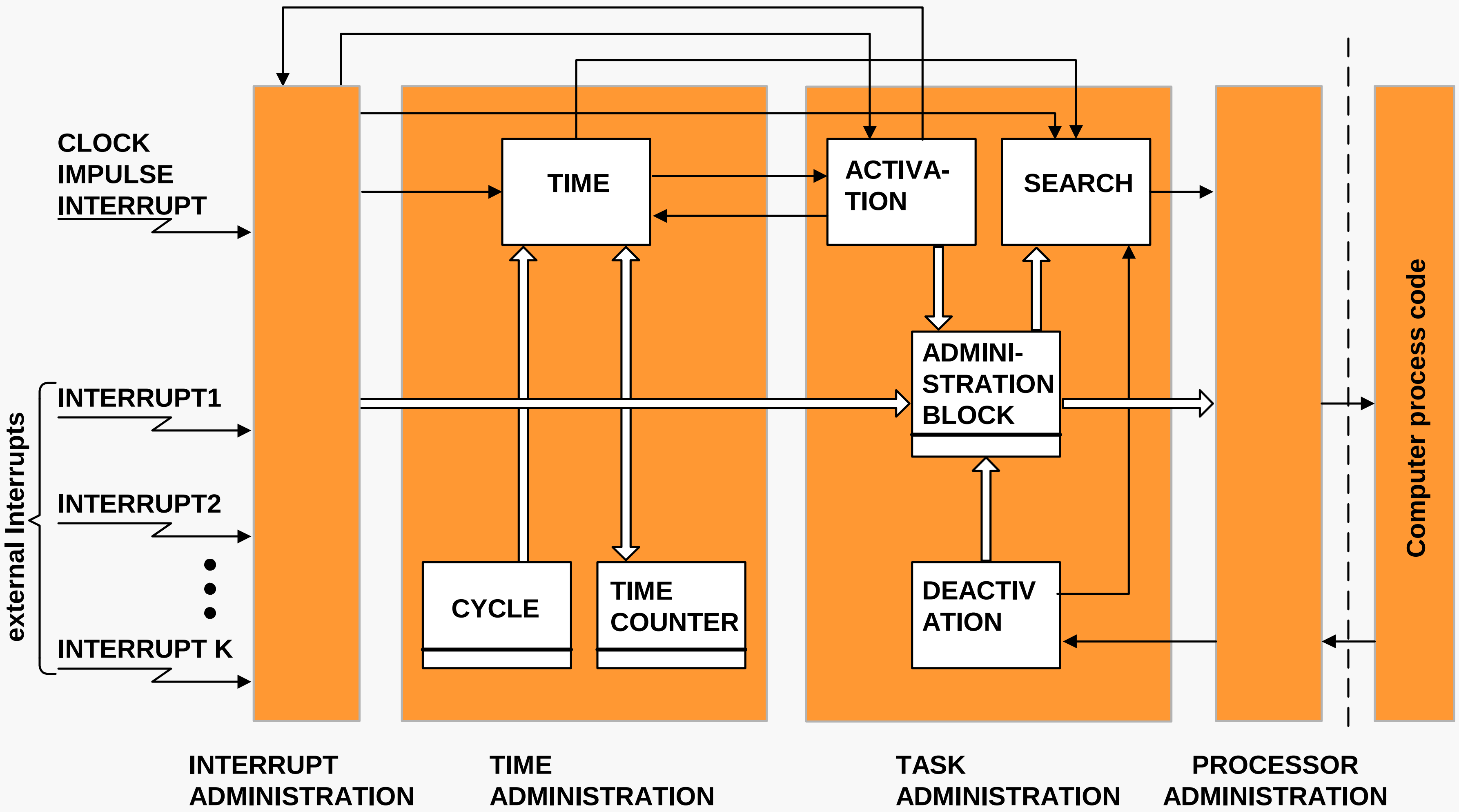
– Up to k computer processes, which activation is triggered by alarm interrupts that are not predictable from the point of view of time.

Extension of the INTERRUPTION ADMINISTRATION

– register rescue
– in case of clock impulse interrupts triggering of TIME ADMINISTRATION
– in case of alarm interrupts invoking of the ACTIVATION, in order to put the corresponding response program in the state “ready”
– kick-off SEARCH

Overall chart for the mini operating system

Second extension: Having the possibility of alarm interrupts in mind



Third extension of the software system design

Operating resource administration for input/output devices
In/output operation are slower than

- analog to digital converter ca. 20 ms

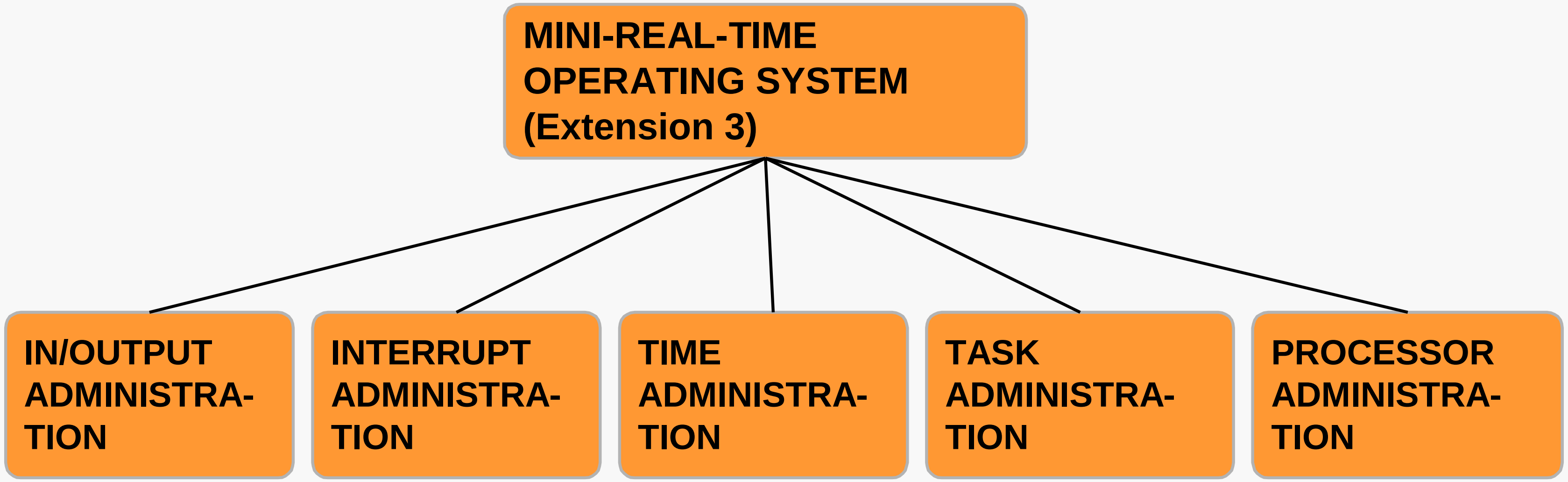
Introduction of a administration program I/O-ADMINISTRATION

Task:

Organization of slow input/output operations

- Computer process is stopped.
- Processor is able to work on other computer processes.
- Finishing the input/output operations allows the continuation of accompanying computer processes.

Hierarchical chart of the mini operating system



Abolition of the simplifications

- Operating system programs themselves are not interruptible.
- The multiple instruction of a computer process, i.e. new instruction before the actual end of a computer process is impossible.
- A mutual instruction of computer processes is not possible.
- A synchronization of computer processes, i.e. through semaphore operations, is not possible.
- No data communication between the computer processes, i.e. no interchange of data, no common use of data.
- No dynamical modifications of the priorities of the computer processes during the program execution.
- Computer processes are located in the working memory, background memories are not available.

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Market survey

Criteria of the selection of real time operating systems

- Development and target environment
- Modularity and kernel size
- Performance data
  - Amount of tasks
  - Priority levels
  - Task switch times
  - Interrupt latency time

- Adaptation to special target environments
- General characteristics
  - Scheduling method
  - Inter-task communication
  - Network communication
  - Design of user interface

Selection of commercial real time operating systems

Product	ERCOS	Lynx-OS	OS/9	OSE Delta	pSOS	PXROS	QNX	VRTX32	VxWorks	Windows CE
Company	ETAS GmbH	Lynx Real-Time System inc.	Microware	ENEA DATA AB	ARS Integrated Systems	HighTec EDV-Systeme	QNX Software Systems LTD	Microtec Research	WindRiver	Microsoft
Type	Embedded		RTOS, RT Kernel, Embedded	RT Kernel, Embedded	RTOS, RT Kernel, Embedded	RT Kernel, Embedded	RTOS, RT Kernel, Embedded	RTOS, RT Kernel, Embedded	RTOS, RT Kernel, Embedded	RTOS Embedded
Target architecture	8016x, PowerPC	680x0, 80x86, PowerPC, 88000, i860, MIPS, SPARC, RS6000	680x0, 80x86, PowerPC, CPU32	680x0, PowerPC, CPU32, AMD29k	680x0, 80x86, 8016x, PowerPC, CPU32, i960, Hitachi SH, MIPS	80x86, 8016x, PowerPC	i386,i486, Pentium, 80286(16 bit)	680x0, 80x86, SPARC, CPU32, AMD29k, i960	680x0, 80x86, PowerPC, CPU32, i960, MIPS, SPARC, AMD29k, Hitachi SH	Pentium 80x86, i486 PowerPC MIPS Hitachi S4, ARM
Host-system	UNIX, Win95, NT	UNIX	UNIX, Windows	UNIX, Windows, NT	UNIX, SUN, Windows, NT, OS/2	UNIX, SUN, Windows, NT, OS/2	QNX	UNIX, SUN, Windows	UNIX, Win95, NT	Windows CE Win 95 NT
Language	ANSI-C, OLT Specification Language	ANSI-C, C++, Pascal, Ada, Modula, Fortran	ANSI-C, C++	C, C++	ASM, ANSI-C, C++, Pascal, Ada	ANSI-C, C++	Watcom C, C++, Inline ASM	ASM, ANSI-C, C++	ANSI-C, C++, Java, Ada	Visual C++ Visual Basic Visual J++
Data system	no	UNIX, FAT, NFS, Real-Time Filesystem	FAT	UNIX, FAT	UNIX, FAT, NFS, Real-Time Filesystem	UNIX, FAT	UNIX, FAT, ISO9660	UNIX, FAT	UNIX, FAT	FAT

Product	ERCOS	Lynx-OS	OS/9	OSE Delta	pSOS	PXROS	QNX	VRTX32	VxWorks	Windows CE
Network		TCP/IP, NFS	TCP/IP, OS/9-net, NeWLink	TCP/IP, PPP, SNMP	TCP/IP, Netware, OSI 1-7, SNMP CMIP, X.25	TCP/IP, NFS	TCP/IP, NFS, SNMP, Streams	TCP/IP, Netware	TCP/IP, NFS, SNMP, Streams	TCP/IP, PPP bzw. SLIP
Field bus	CAN		CAN, PROFI-BUS, Interbus-S		CAN	CAN, PROFI-BUS		CAN, PROFI-BUS, LON		
Others	ROM-able	ROM-able, Multiprocessor, self-hosted	ROM-able, Multi-processor	ROM-able, Multi-processor	ROM-able, Multi-processor, fehlertolerant	ROM-able, Multi-processor	ROM-able, Multi-processor, POSIX 1003 compliant	ROM-able	ROM-able, Multi-processor, POSIX 1003 compliant	ROM-able
Scheduling	preemptive, co-operative, priority controlled	preemptive, priority controlled, Round-Robin	preemptive, co-operative, priority controlled, Round-Robin	preemptive,	preemptive, priority controlled, Round-Robin	preemptive, priority controlled	preemptive, priority controlled, Round-Robin	preemptive, priority controlled, Round-Robin	preemptive, priority controlled, Round-Robin	preemptive, priority controlled
Task switch time	< 54 µs 8016x (20 MHz)						4,7µs Pentium 166, 11,1us 486DX4 (100MHz), 74	17 µs		≥ 100 µs

Question referring to Chapter 5.2

Consider two different automation systems:

- an event-driven system (e.g. a control of a coffee machine)
- a time-driven system (e.g. a trajectory control of a robot)

For which type of system is the interrupt handling of an operating system more important ?

Answer

In event-driven systems most of the processes are started by interrupt signals.

In time-driven systems no interrupts are caused. The events are handled during the next cycle.

Question referring to Chapter 5.4

Scheduling methods for the allocation of the processor are very important in real-time operating systems.

a) What is the purpose of those methods ?

b) In which module of the mini operating system presented in the lecture a scheduling method is used?
How is it called ?

Answer

a) These methods are used to determine the execution sequence of the "runnable" tasks.

b) In the module SEARCH a scheduling method is used. It is the method of fixed priorities in which running tasks can be interrupted (preemptive scheduling).