Concurrent Systems

Nebenläufige Systeme

III. Processes

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Agenda

Preface

Fundamentals
  Program
  Process

Characteristics
  Physical
  Logical

Summary

Outline

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  - Process

Characteristics
  - Physical
  - Logical

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Subject Matter

- discussion on **abstract concepts** as to multiplexing machines:

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- a **bridging** of concurrency/simultaneity concepts and mechanisms
  - on the one hand, program as the means of specifying a process
  - on the other hand, process as medium to reflect simultaneous flows

Process – The Course of Being Done

acc. [9], cf. p. 33

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  - if so, it even causes, controls, or terminates other processes[1]

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- in both kinds does the program flow consist of **actions** (p. 7 *ff.*)

Consider: Program Flow and Level of Abstraction

One and the same program flow may be sequential on one level of abstraction and parallel on another. [8, 10]

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  - after compilation[2] and
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inc64:
  movl 4(%esp), %eax
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Definition (Action)

The execution of an instruction of a (virtual/real) machine.

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  - Linux
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0x080482fb:        ret
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Hint (`ret` or c3, resp.)

The action for a subroutine return corresponds to the action of the corresponding subroutine call (`gdb, disas /rm main`):

```
1  0x080481c9:  c7 04 24 b0 37 0d 08  movl  $0x80d37b0,(%esp)
2  0x080481d0:  e8 1b 01 00 00        call  0x80482f0 <inc64>
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- an excerpt of *P* using the example of *POSIX Threads* [4]:

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- the parallel flow allowed in *P* itself:

```c
void *thread(void *null) {
  /* ... */
  pthread_exit(NULL);
}
```

~~Non~~-Sequential Program II

- despite actions of parallelism, **sequential flows** of the same program:

```c
pid_t pid;

if (!(pid = fork())) {
  /* ... */
  exit(0);
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wait(NULL);
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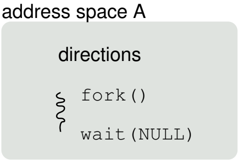
↪ concept "operating system" is epitome of "non-sequential program"[4]

---

[4] The exception (strictly cooperative systems) proves the rule.

Multiprocessing of Sequential Programs


address space A

directions

```
fork()

wait(NULL)
```

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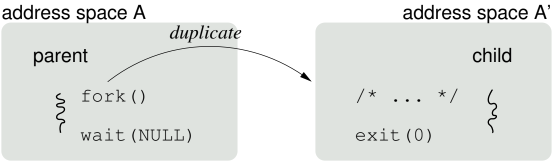

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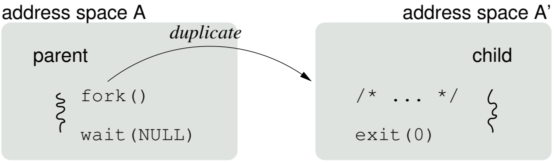

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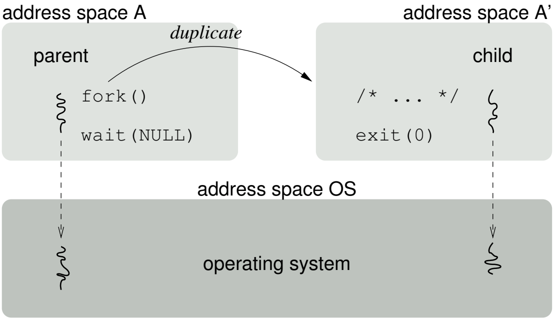

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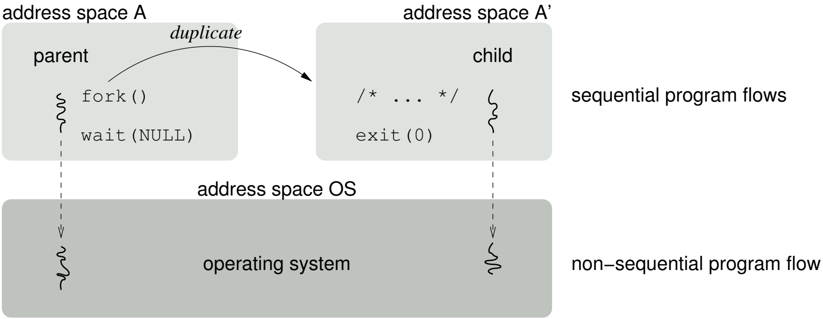

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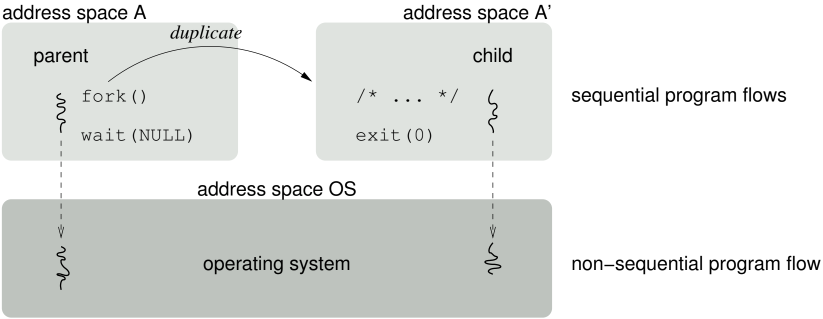

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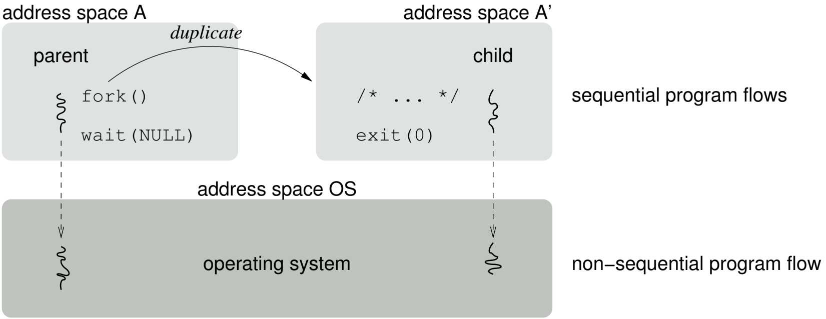

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- both cause **parallel processes** (p. 16) within the operating system

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Hint (Process $\neq$ Process instance)

A process instance (Ger. Exemplar*) is* ***incarnation*** *of a process.*[a]

---

[a] Just as an object is a "core image" of a class.

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  - **action** on higher, **sequence of actions** on lower level of abstraction

level	action	sequence of actions
5	`i++`	

4–3	`incl i`*
	`addl $1,i`*
		`movl i,%r`
		`addl $1,%r`*
		`movl %r,i`

2–1		* ***read*** *from memory into accumulator* ***modify*** *contents of accumulator* ***write*** *from accumulator into memory*

  - typical for a complex instruction of an “abstract processor” (C, CISC)

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  - level$_{5 \mapsto 3}$

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i++;
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    read    A from <i>
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    write   A to <i>
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- points (`i++`, `incl`) in case of merely conditionally atomic execution
  - namely uninterruptible operation (level $_{5 \mapsto 3}$), uniprocessor (Ebene $_{3 \mapsto 2}$)
  - problem: overlapping in time of the sequence of actions pointed here

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Hint (Execution Thread $\neq$ Thread)

Assumptions about the technical implementation of the sequence of actions are not met and are also irrelevant here. A thread *is only one option to put the incarnation of a sequential process into effect.*

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  - that makes arrangements for the handling of events of external processes[6]

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  - i multithreading (Ger. *simultane Mehrfädigkeit*), in fact:
    - pseudo-parallel – multiplex mode of a single processor (core)
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    - pseudo-parallel – multiplex mode of a single processor (core)
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  - ii asynchronous program interrupts
- consequently, the sequence of all actions is defined by a **partial order**
  - as external processes may enable temporal/causal independent actions

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- to proceed, concurrent processes compete for **reusable resources**
  - they share the processor (core), cache (line), bus, or devices
  - outcome of this is **interference**[7] (Ger. *Interferenz*) in process behaviour

---

[7] Derived from (Fre.) *s’entreferir* “to brawl each other”.

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- to proceed, concurrent processes compete for **reusable resources**
  - they share the processor (core), cache (line), bus, or devices
  - outcome of this is **interference**[7] (Ger. *Interferenz*) in process behaviour
- the effective degree of overlapping is irrelevant for the simultaneity
  - apart from time-dependent processes that have to keep deadlines
  - note that the larger the overlapping, the larger the time delay
    - and the more likely will a delayed process miss its deadline
  - just as interference, which may also cause violation of timing constraints

---

[7] Derived from (Fre.) *s'entreferir* "to brawl each other".

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(Ger.) *gekoppelte Prozesse* [3, p. 77]

Definition (also: “depending processes”)

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[8] printer, mouse, plotter, keyboard.

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- founds **coordination** of cooperation and competition of processes

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Interacting Processes II

```
int64_t cycle = 0;

void *thread_worker(void *null) {
  for (;;) {
    /* ... */
    inc64(&cycle);
  }
}

void *thread_minder(void *null) {
  for (;;) {
    printf("worker cycle %lld\n", cycle);
    pthread_yield();
  }
}
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- `inc64`: see p. 7

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- which `cycle` values prints the minder thread (Ger. *Aufpasserfaden*)?
- which are produced by multiple worker threads (Ger. *Arbeiterfäden*)?
  - in case `thread_worker` exists in several identical incarnations

Interacting Processes III

- assuming that the non-sequential program runs on a 32-bit machine
  - instances of `int64_t` then form a pair of 32-bit words: double word
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  movl 4(%esp), %eax
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  adcl $0, 4(%eax)
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- assume $cycle = 2^{32} - 1$
  - `inc64` overlaps actions 10 – 11
  - then, $edx = 0$ and $eax = 0$
  - effect is, `printf` displays 0
    - not 2^{32}, as would have been right

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- a classical error: as the case may be, ineffective numeration

Outline

Preface

Fundamentals
  - Program
  - Process

Characteristics
  - Physical
  - Logical

Summary

Consistency

- prevention of race conditions by the **protection of critical sections**
  - transfer a non-sequential process into a temporary sequential process
    - strictly: the shorter the sequential time span, the better the solution
  - or, if applicable, rewrite conflict-prone program sequences as a transaction

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Lookahead: prevent overlapping by means of **mutual exclusion**

- blocking of interacting processes

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- reducing to a 64-bit ELOP of the real processor

```
void inc64(int64_t *i) {        /* renew code @ p.7 */
  asm ("lock incq %0" : : "m" (*i) : "memory");
}
```

  - anywhere applicable and by orders of magnitude more efficient solution

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	↪ "*kernel thread*", in computer science folklore
outside	– optional, within run-time or even application system
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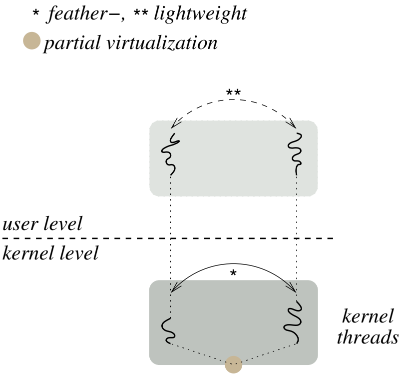
    - when it gets switched or delayed, all of its user threads will as well
- operating systems are aware only of their own "first-class citizens"

Weight Category



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  - * inside the same (user/kernel) address space, *ibidem*[9] continuing
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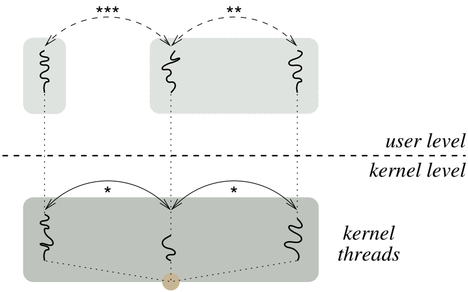
[9] (Lat.), “at the same place”

Weight Category

** feather–, ** light–, *** heavy–weight*

● *partial virtualization*



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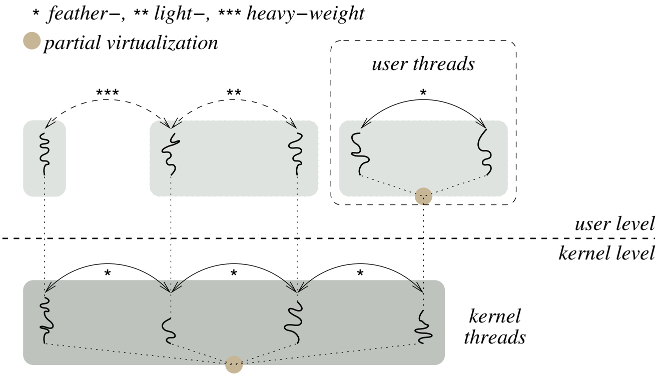

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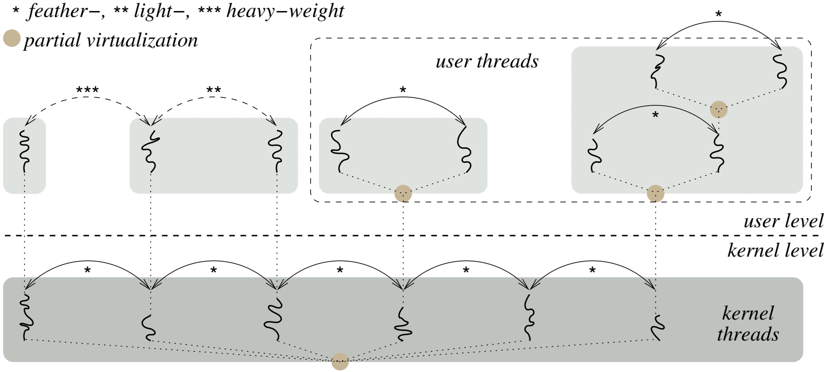

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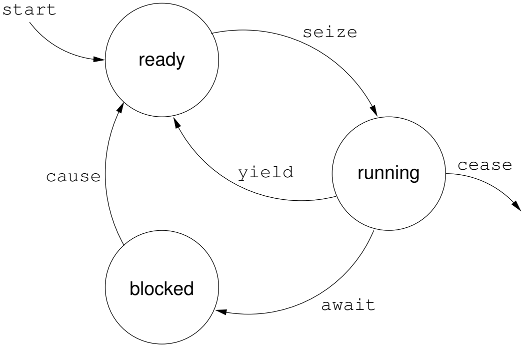
  - especially susceptible for inducing interference is blocking synchronisation
- to **control resource usage**, processes pass through logical states
  - whereby synchronisation emerges jointly responsible for state transitions
  - taken together, scheduling *and* synchronisation are cross-cutting concerns

Process States and State Transitions



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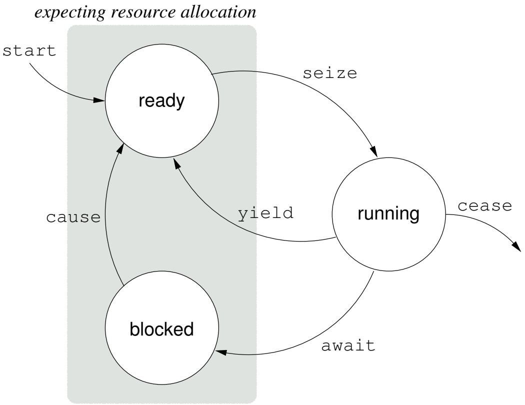

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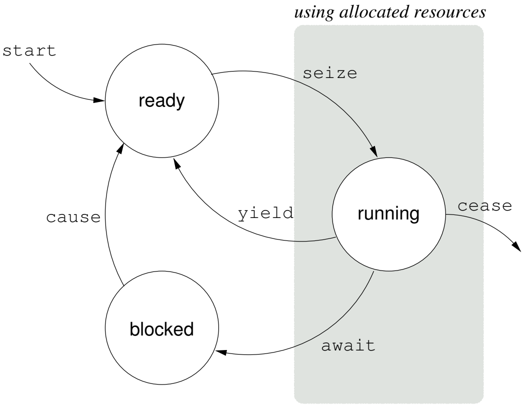
Process States and State Transitions



- typical **life time cycle** of processes:

ready	ready to run, but still waiting for a processor (core)
running	executing on a processor (core), performing a CPU burst
blocked	waiting for an event (being in sync), performing an I/O burst

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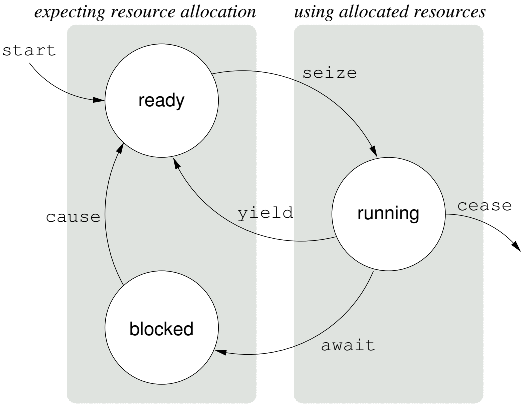

- relevant resources:
  - processor
    - `start`
    - `seize`
    - `yield`
    - `cease`
  - signal
    - `await`
    - `cause`

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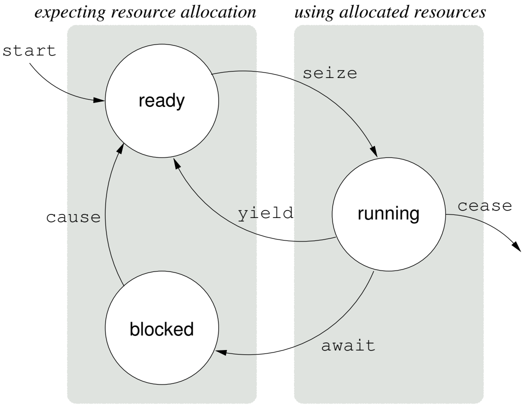

- relevant resources:

processor	▪ `start` ▪ `seize` ▪ `yield` ▪ `cease`
signal	▪ `await` ▪ `cause`

- waitlists involved:
  - ready list of runnable processes
  - blocked list of processes unable to run

- typical **life time cycle** of processes:

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Outline

Preface

Fundamentals
- Program
- Process

Characteristics
- Physical
- Logical

Summary

Résumé

- a process is **predetermined by a program** that is to be executed
  - the process inherits the static characteristics of its program
  - when being existent, the process adds dynamic characteristics
    - as a function of data processing and interaction with the environment
- a process may be **sequential or non-sequential** (as to its program)
  - that is to say, composed of non-overlapping or overlapping actions
  - whereby overlapping is caused by multiprocessing in a wider sense
    - real parallelism, but also pseudo-parallelism in its various forms
- processes are **parallel, concurrent, simultaneous, or interacting**
  - simultaneous processes comprise concurrent and interacting periods
  - each of these can be parallel on their part, i.e., if their actions overlap
    - by either multiplexing or multiplication of the necessary processing units
- as to implementation, processes may be **kernel or user threads**
  - regardless of which, logical states report on the life time cycle of a process
  - whereby synchronisation emerges jointly responsible for state transitions
    - taken together, scheduling *and* synchronisation need to be complementary

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Reference List I

[1] Coffman, E. G. ; Denning, P. J.:
Operating System Theory.
Prentice Hall, Inc., 1973

[2] Conway, R. W. ; Maxwell, L. W. ; Millner, L. W.:
Theory of Scheduling.
Addison-Wesley, 1967

[3] Hansen, P. B.:
Concurrent Processes.
In: *Operating System Principles*.
Englewood Cliffs, N.J., USA : Prentice-Hall, Inc., 1973. –
ISBN 0–13–637843–9, Kapitel 3, S. 55–131

[4] IEEE:
POSIX.1c Threads Extensions / Institute of Electrical and Electronics Engineers.
New York, NY, USA, 1995 (IEEE Std 1003.1c-1995). –
Standarddokument

[5] Kleinöder, J. ; Schröder-Preikschat, W. :
Rechnerorganisation.
In: Lehrstuhl Informatik 4 (Hrsg.): *Systemprogrammierung*.
FAU Erlangen-Nürnberg, 2014 (Vorlesungsfolien), Kapitel 5

Reference List II

[6] Kleinrock, L. :
Queuing Systems. Bd. I: Theory.
John Wiley & Sons, 1975

[7] Liu, J. W. S.:
Real-Time Systems.
Prentice-Hall, Inc., 2000. –
ISBN 0–13–099651–3

[8] Löhr, K.-P. :
Nichtsequentielle Programmierung.
In: Institut für Informatik (Hrsg.): *Algorithmen und Programmierung IV*.
Freie Universität Berlin, 2006 (Vorlesungsfolien)

[9] Neufeldt, V. (Hrsg.) ; Guralnik, D. A. (Hrsg.):
Webster's New World Dictionary.
Simon & Schuster, Inc., 1988

[10] Schröder-Preikschat, W. :
Concurrency.
In: Lehrstuhl Informatik 4 (Hrsg.): *Concurrent Systems*.
FAU Erlangen-Nürnberg, 2014 (Lecture Slides), Kapitel 2

Reference List III

[11] TANENBAUM, A. S.:
Multilevel Machines.
In: *Structured Computer Organization*.
Prentice-Hall, Inc., 1979. –
ISBN 0–130–95990–1, Kapitel Introduction, S. 1–17

[12] WIKIPEDIA:
Process.
`http://en.wikipedia.org/wiki/Legal_process`, Apr. 2014

Originally as a Concept of Law

acc. [12, Legal process]

> Process “particularly, describes the formal notice or writ used by a court to exercise jurisdiction over a person or property”

- analogy in computer science or operating-system concepts, resp.:

writ	▪ order to abandon rivalry[10] in the claiming of resources ▪ direction to resolve competition of resource contenders
court	▪ incarnation of the function of scheduling or coordination ▪ point of synchronisation in a program
jurisdiction	▪ sphere of authority of contention resolution ▪ zone of influence of the synchronisation policy
property	▪ occupancy/ownership of resources, ability to proceed ▪ functional or non-functional attribute

- generally, the action or trial, resp., follows a hierarchical jurisdiction
  - thereby, the process step related to a certain level is denoted as *instance*
    - in informatics, translation to (Ger.) “Instanz” however was rather unept **!!!**
  - operating systems often command a multi-level processing of processes

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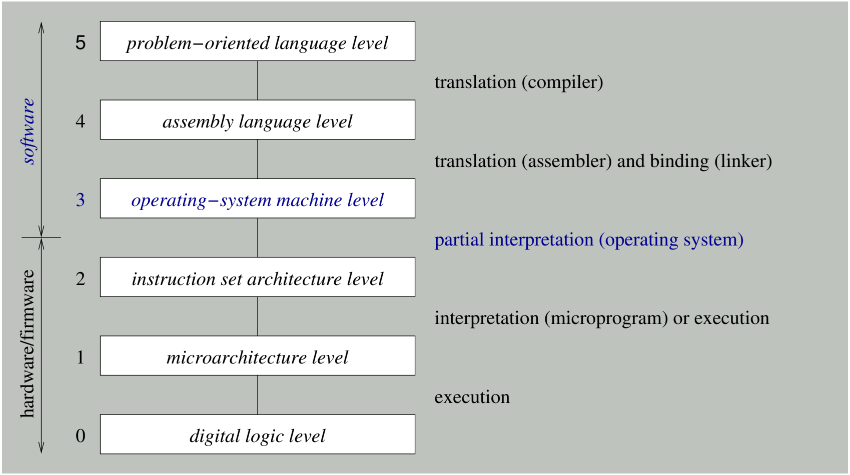
[10] Lat. *rivalis* “in the use of a watercourse co-authored by a neighbour”

Structured Computer Organisation



- refinement of [11, p. 5]: levels present on todays computers
  - right, the method and (bracketed) program that supports each level