Concurrent Systems

Nebenläufige Systeme

III. Processes

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Agenda

Preface

Fundamentals
- Program
- Process

Characteristics
- Physical
- Logical

Summary

Outline

Subject Matter

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

  program
  - concretized form of an algorithm
  - static sequence of actions to be conducted by a processor
  - of sequential or non-sequential structure

  process
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  - dynamic sequence of actions conducted by a processor
  - of parallel, concurrent, simultaneous, or interacting nature

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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. 112

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  - as coded representation of an algorithm, the program specifies a process
  - thereby, the program manifests and dictates a specific process
  - if so, it even causes, controls, or terminates other processes[1]

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- proceeds deterministically, the result is determinate

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- in both kinds does the program flow consist of **actions** (p. 12 *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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7    movl 4(%esp), %eax
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Definition (Action)

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

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  - text segment
  - Linux
  - after linking/binding and
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1 0x080482f0:    mov 0x4(%esp),%eax
2 0x080482f4:    add $0x1,(%eax)
3 0x080482f7:    adc $0x0,0x4(%eax)
4 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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- the parallel flow allowed in P itself:

```
7  void *thread(void *null) {
8    /* ... */
9    pthread_exit(NULL);
10 }
```

~~Non-~~Sequential Program II

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

```
1  pid_t pid;
2
3  if (!(pid = fork())) {
4    /* ... */
5    exit(0);
6  }
7  wait(NULL);
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- `fork` duplicates the address space A of P, creates A' as a copy of A
- within A as source address space arises thereby no parallel flow, however
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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

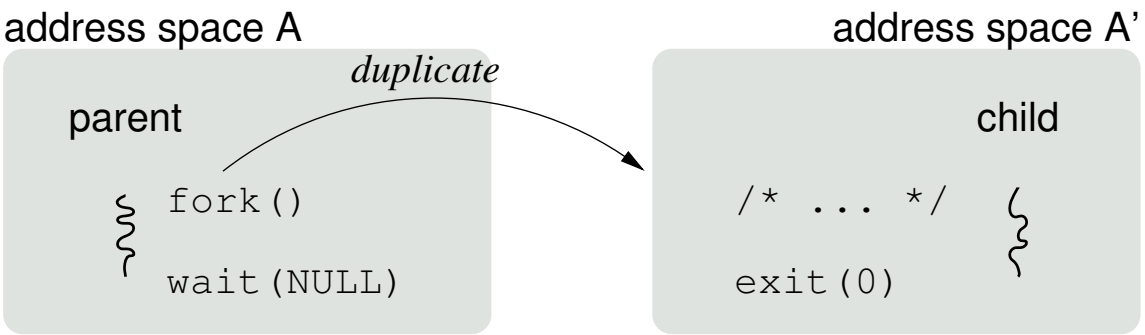
address space A

directions

```
fork()

wait(NULL)
```

Multiprocessing of Sequential Programs



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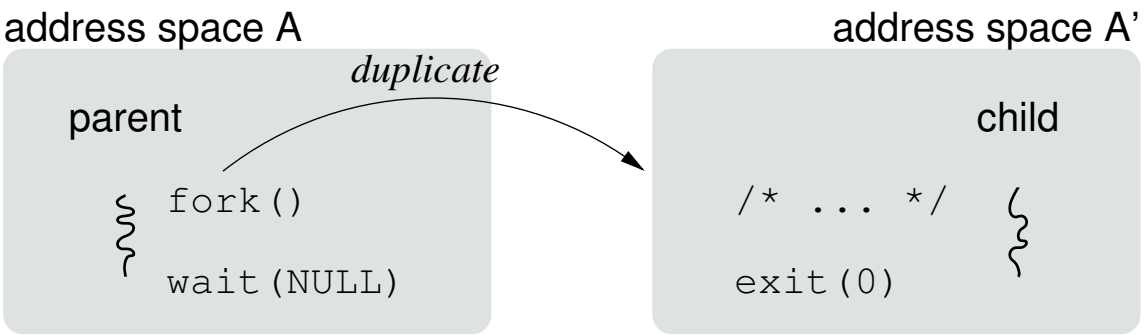

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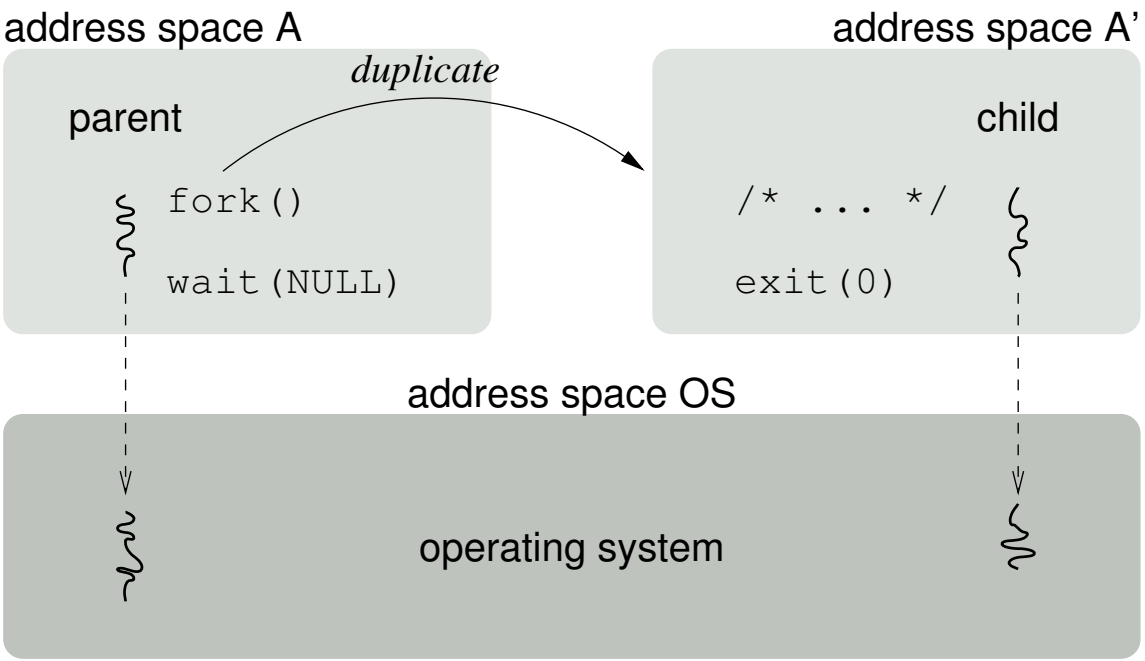

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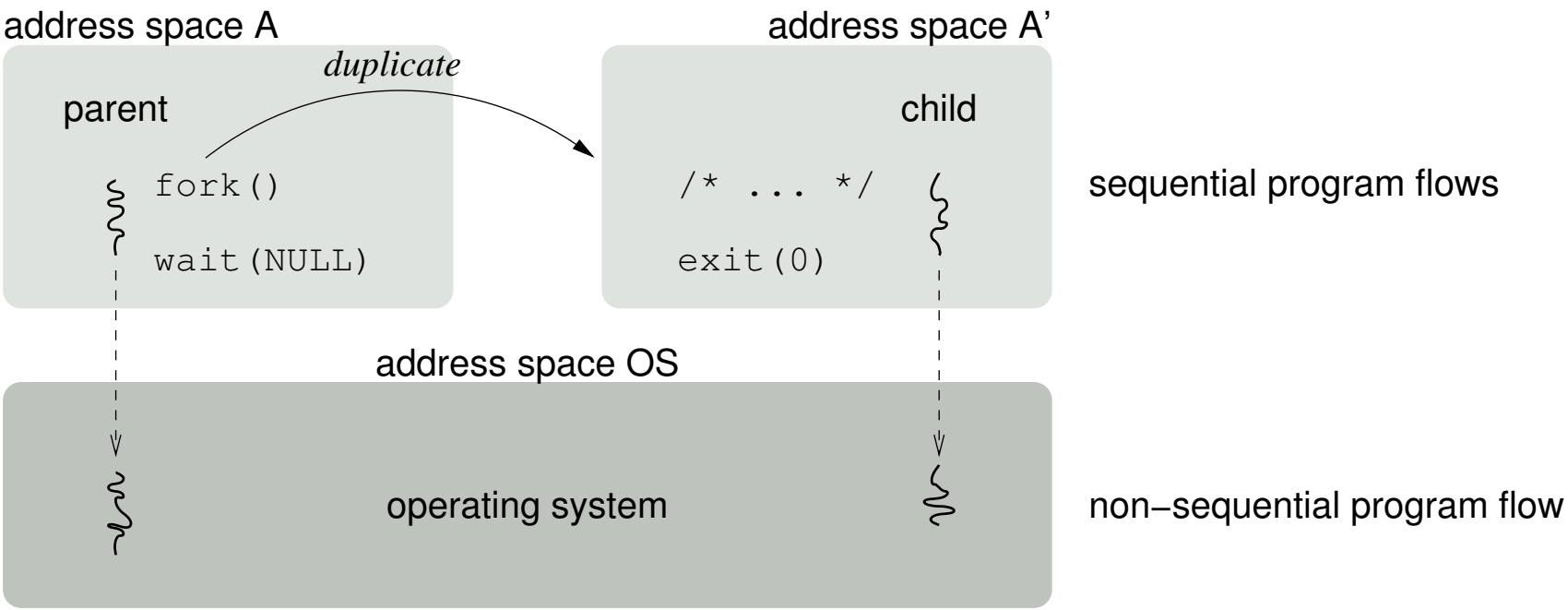

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    - ditto

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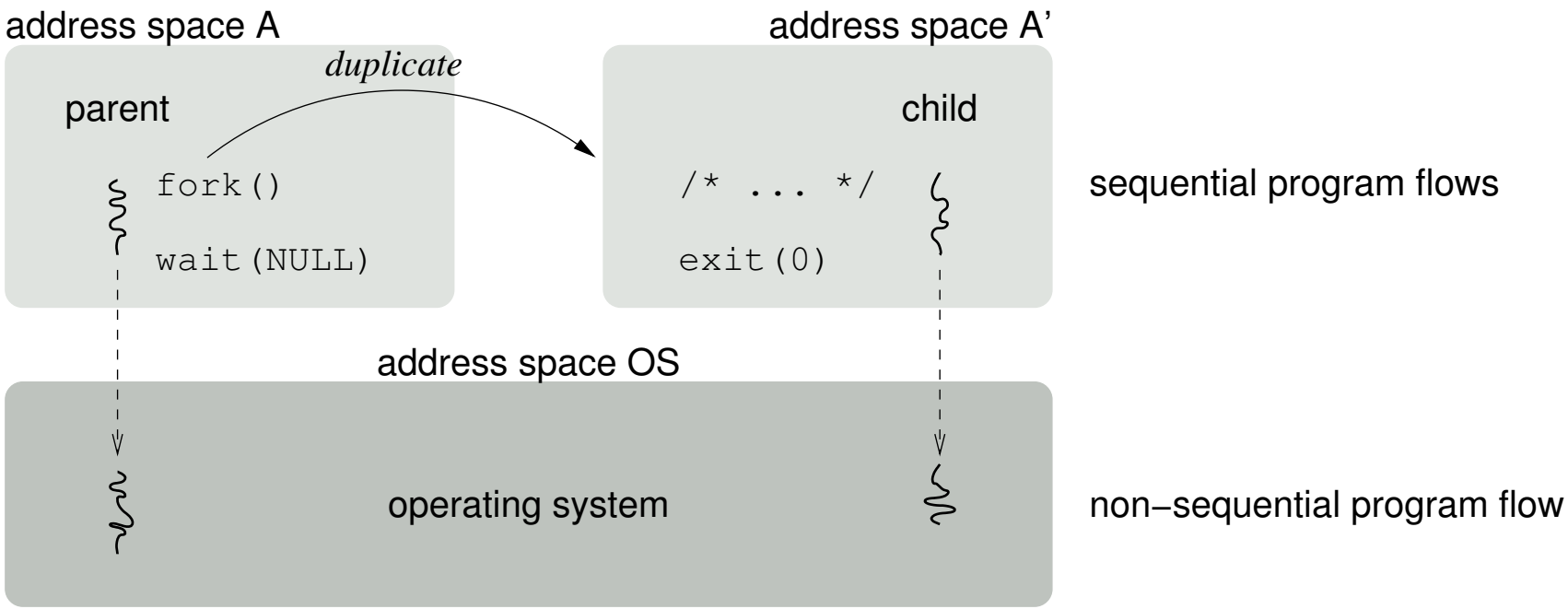

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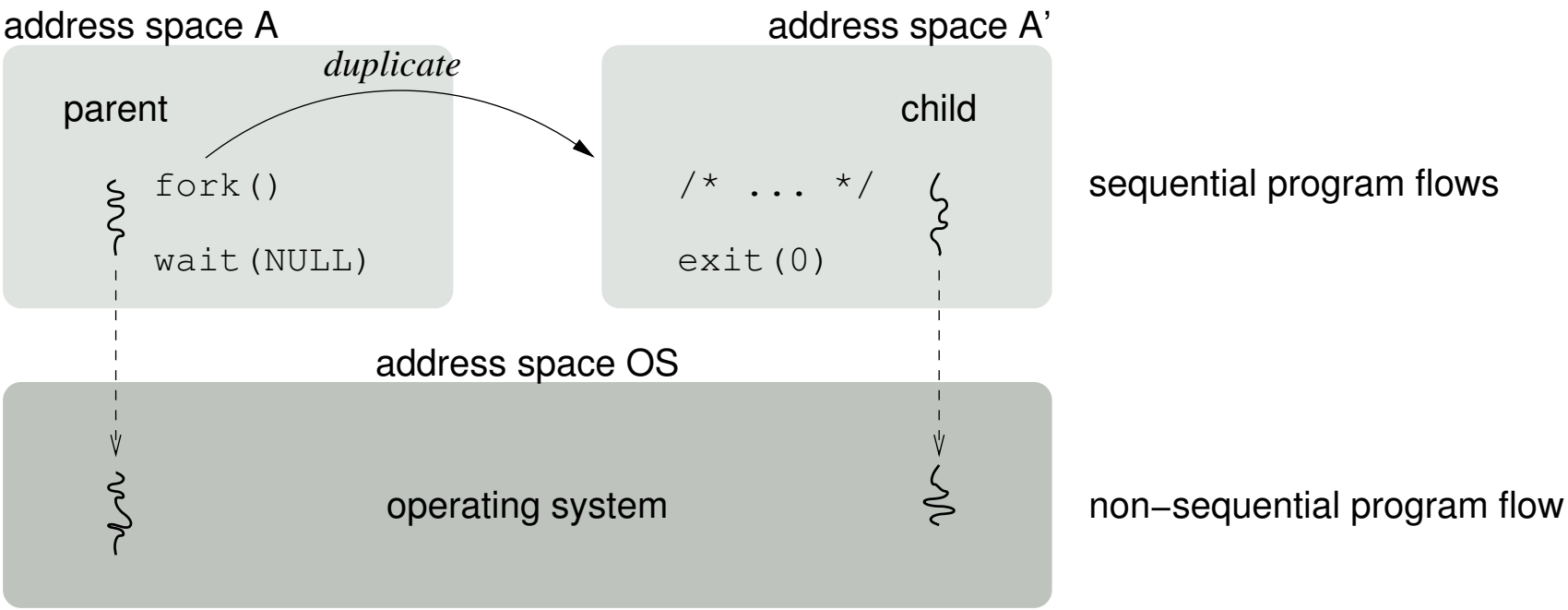

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Hint (Process $\neq$ Process instance)

A process instance (Ger. Exemplar*) is an* ***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`*	`movl i,%r`
		`addl $1,%r`*
		`movl %r,i`

	`addl $1,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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  - by what that sequence appears as **elementary operation** (ELOP)

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- points (`i++`, `incl`) in case of merely conditionally atomic execution
  - namely uninterruptible operation (level $5 \mapsto 3$), uniprocessor (level $3 \mapsto 2$)
  - 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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- requirement is a **non-sequential program** (cf. p. 20)
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  - that makes arrangements for the handling of events of external processes[6]

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- 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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(Ger.) *gleichzeitige Prozesse* [3]

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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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- areas are **concurrent** (Ger. *nebenläufig*) only if they are independent
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  - none of theses actions of these processes requires the result of any other
- 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".

Interacting Processes I

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

Definition (also: "depending processes")

Simultaneous processes that, directly or indirectly, interact with each other through a shared variable or by accessing a shared resource.

[8] printer, mouse, plotter, keyboard.

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  - for shared variables or (reusable/consumable) resources, resp.
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  - reducing: replace a sequence of actions by an atomic instruction
- founds **coordination** of cooperation and competition of processes

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Interacting Processes II

```
1  int64_t cycle = 0;
2
3  void *thread_worker(void *null) {
4    for (;;) {
5      /* ... */
6      inc64(&cycle);
7    }
8  }
9
10 void *thread_minder(void *null) {
11   for (;;) {
12     printf("worker cycle %lld\n", cycle);
13     pthread_yield();
14   }
15 }
```

- inc64: see p. 12

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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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- 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

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

```
6  void inc64(int64_t *i) {         /* renew code @ p.12 */
7    asm ("lock incq %0" : : "m" (*i) : "memory");
8  }
```

  - anywhere applicable and by orders of magnitude more efficient solution

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      - ↪ "*kernel thread*", in computer science folklore
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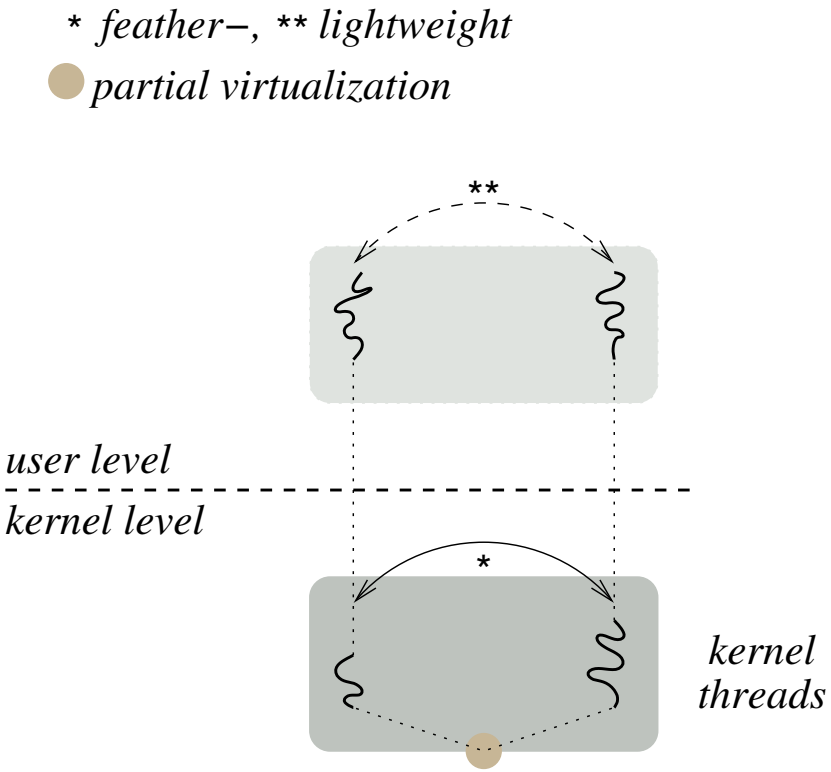
- operating systems are aware only of their own "first-class citizens"

Weight Category



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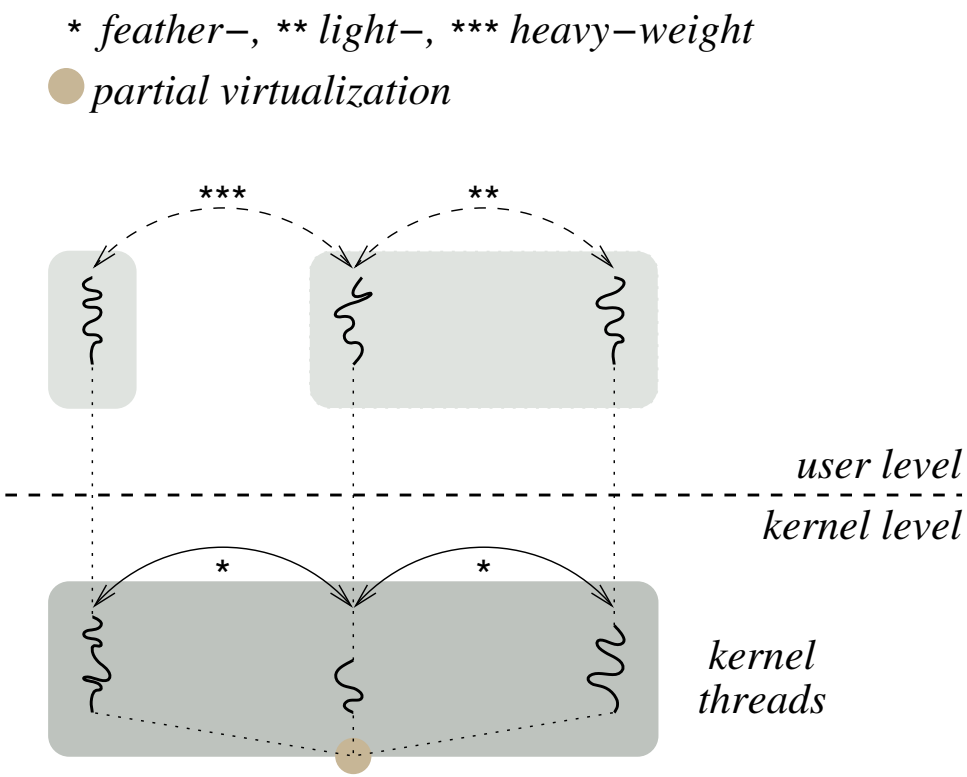

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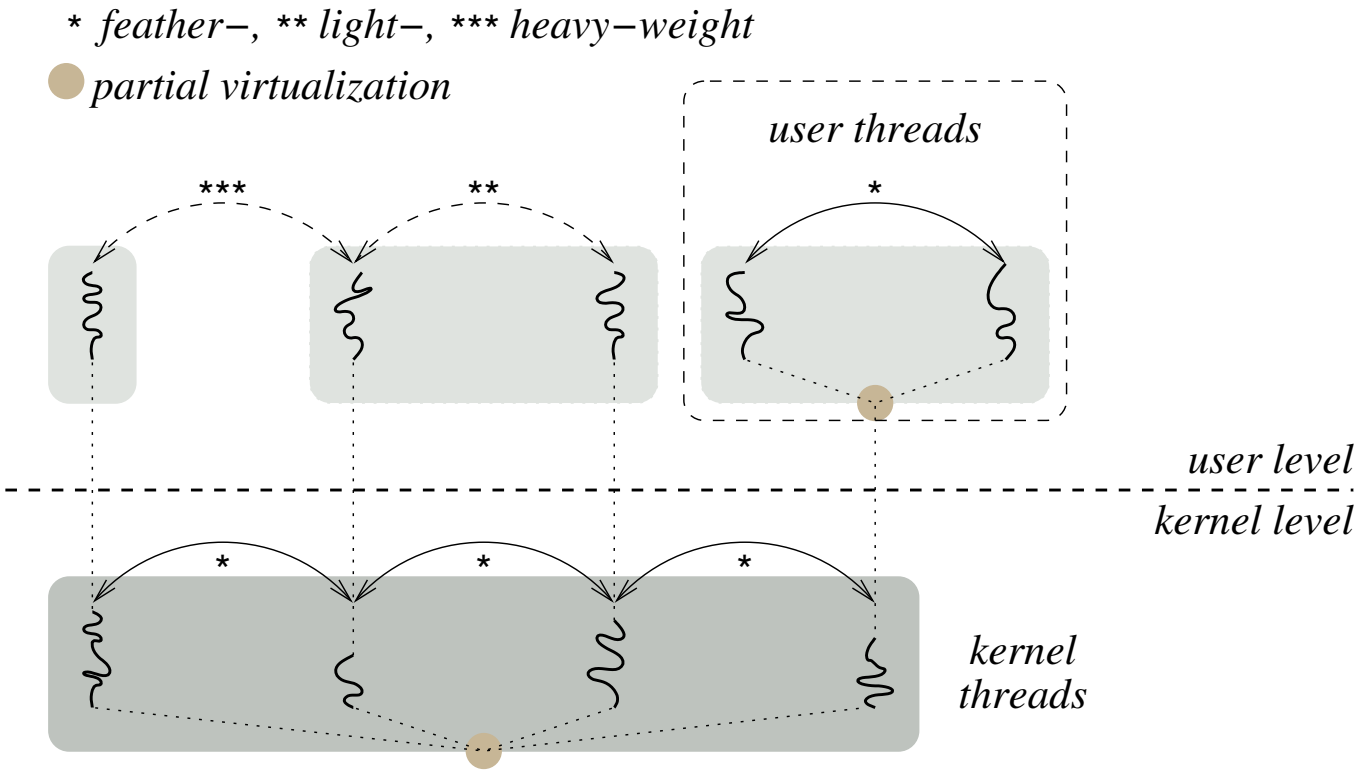

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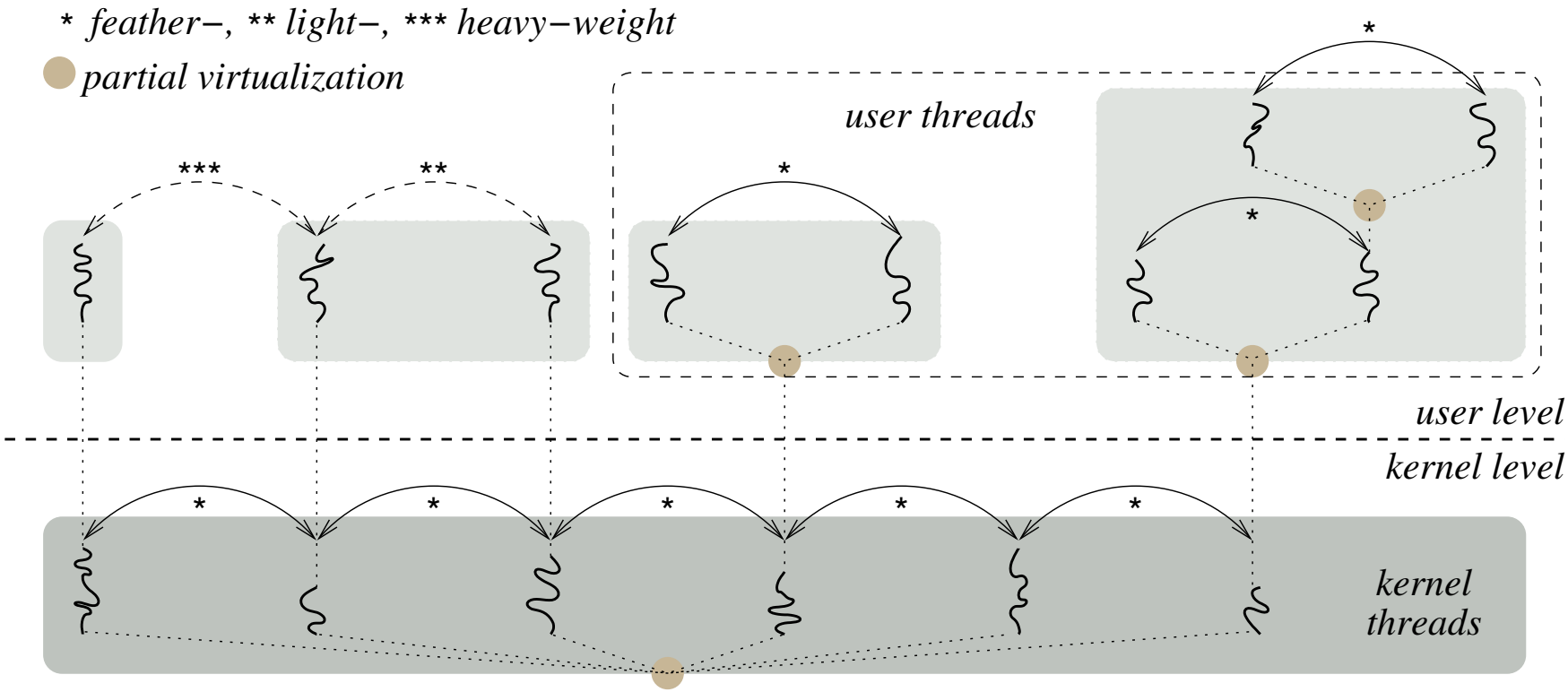

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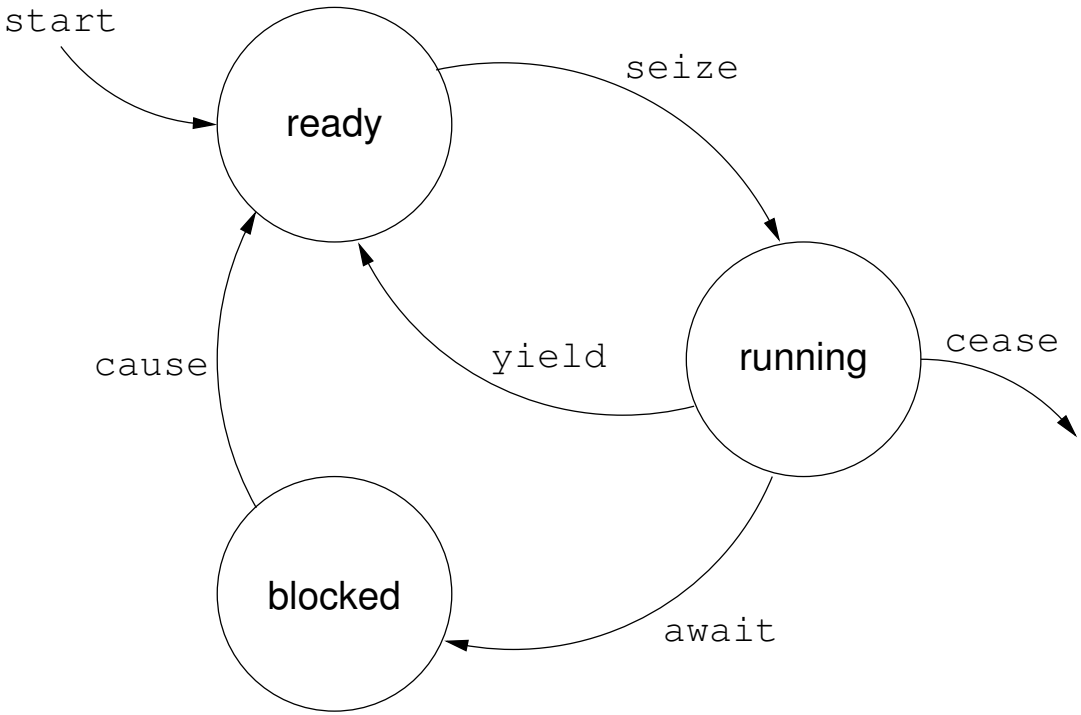
- to **control resource usage**, processes pass through logical states
  - whereby synchronisation emerges jointly responsible for state transitions
  - taken together, scheduling *and* synchronisation are cross-cutting concerns

Process States and State Transitions



- typical **life time cycle** of processes:
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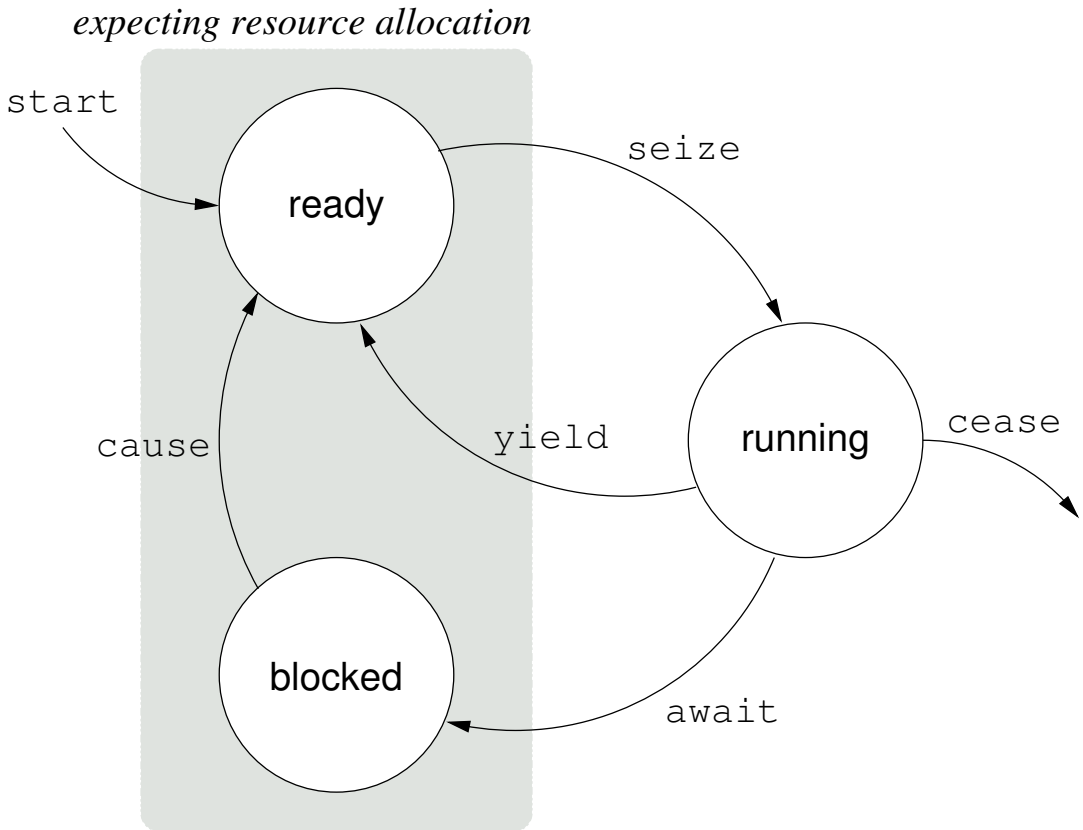
Process States and State Transitions



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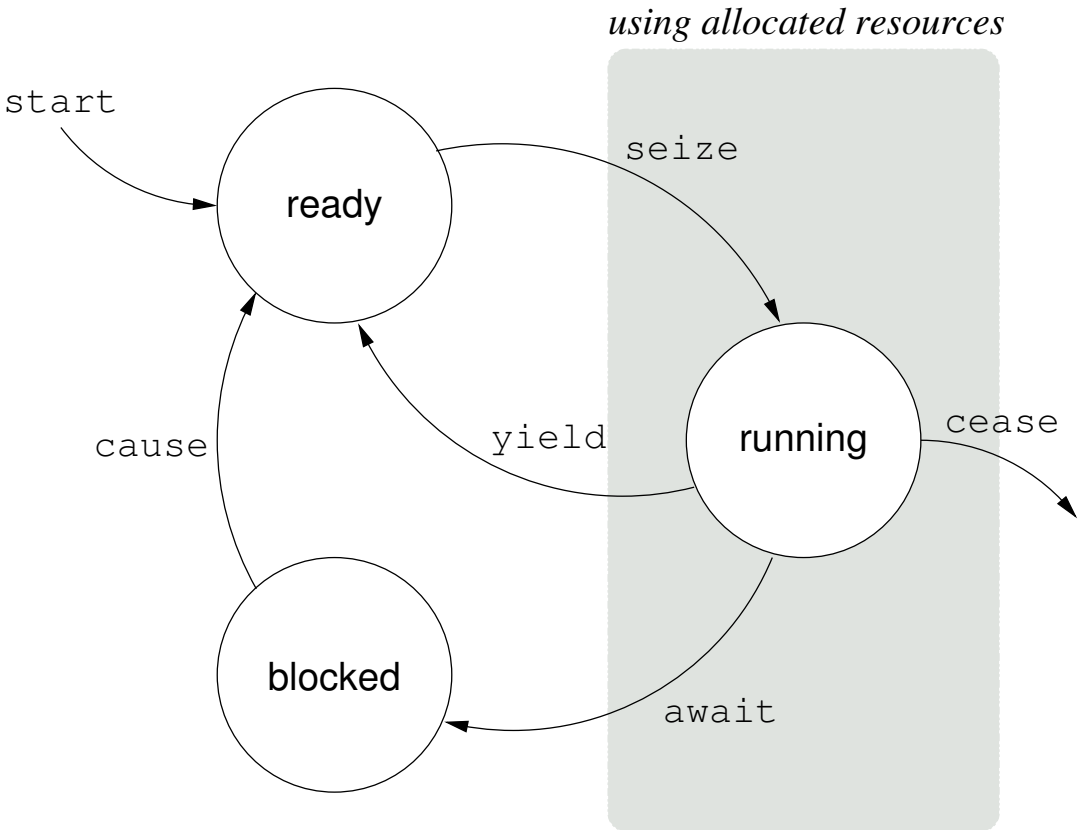

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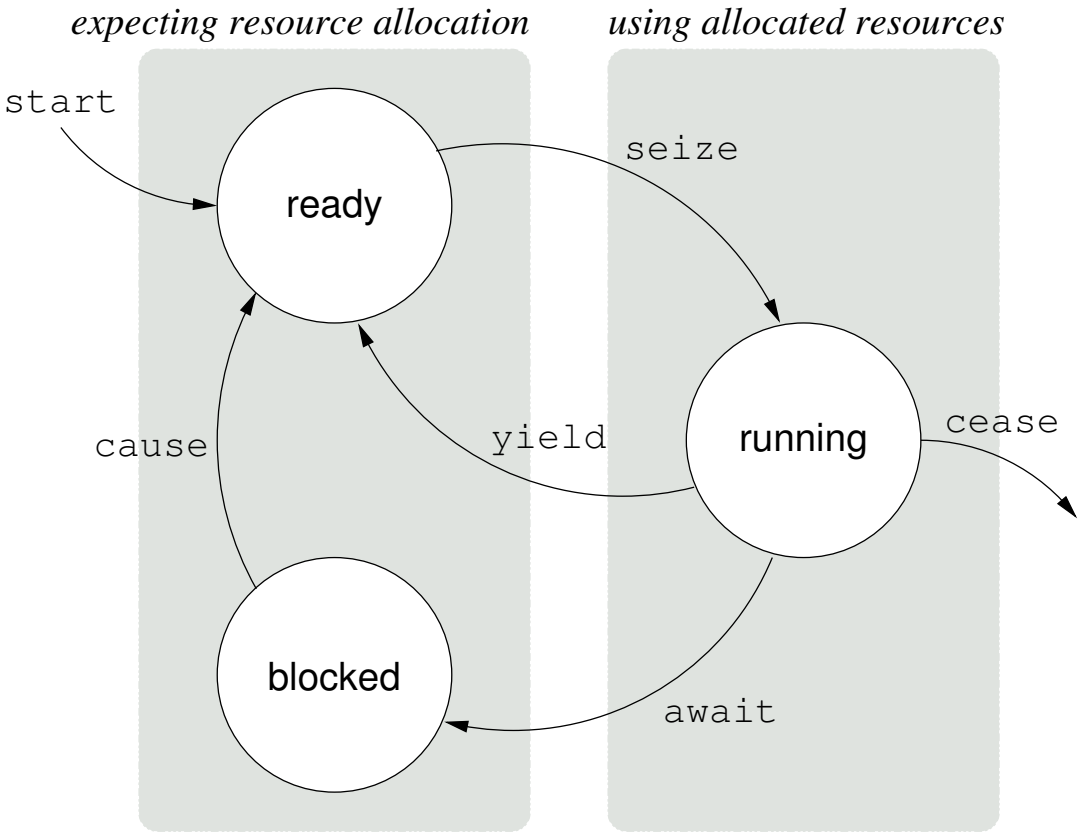

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  - processor
    - start
    - seize
    - yield
    - cease
  - signal
    - await
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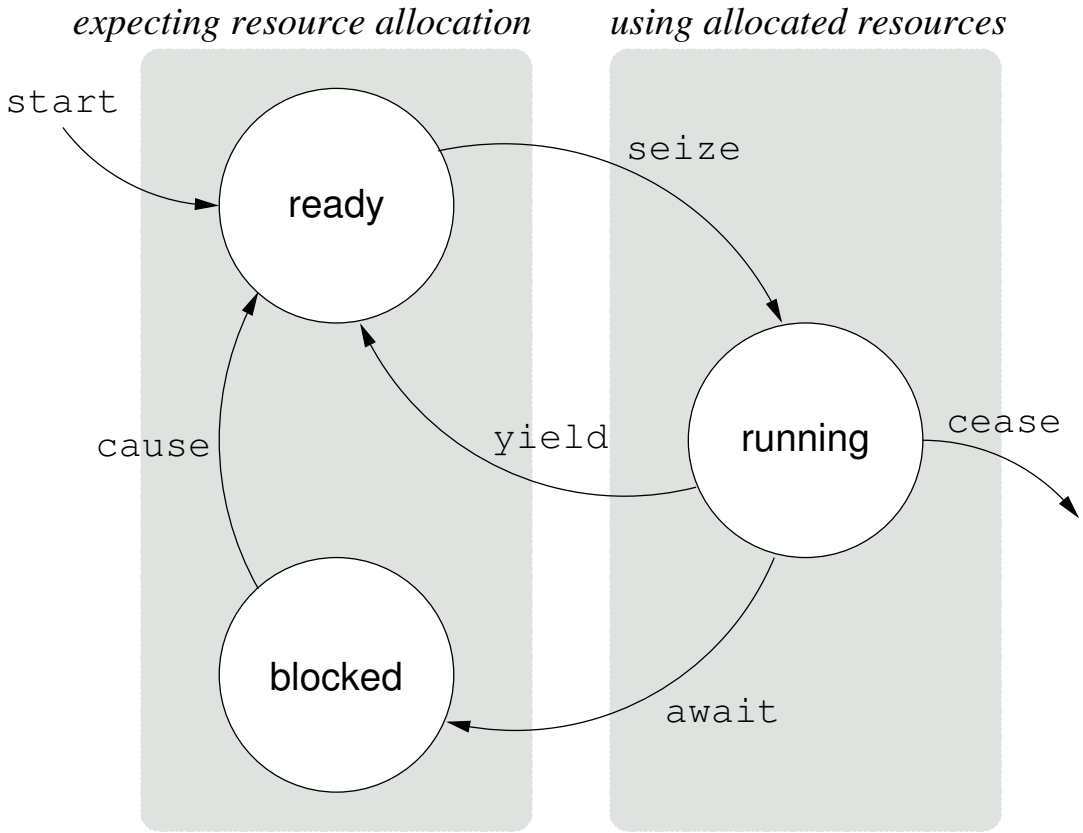

- relevant resources:
  - processor
    - `start`
    - `seize`
    - `yield`
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  - signal
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    - `cause`
- waitlists involved:
  - ready list of runnable processes
  - blocked list of processes unable to run

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Outline

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

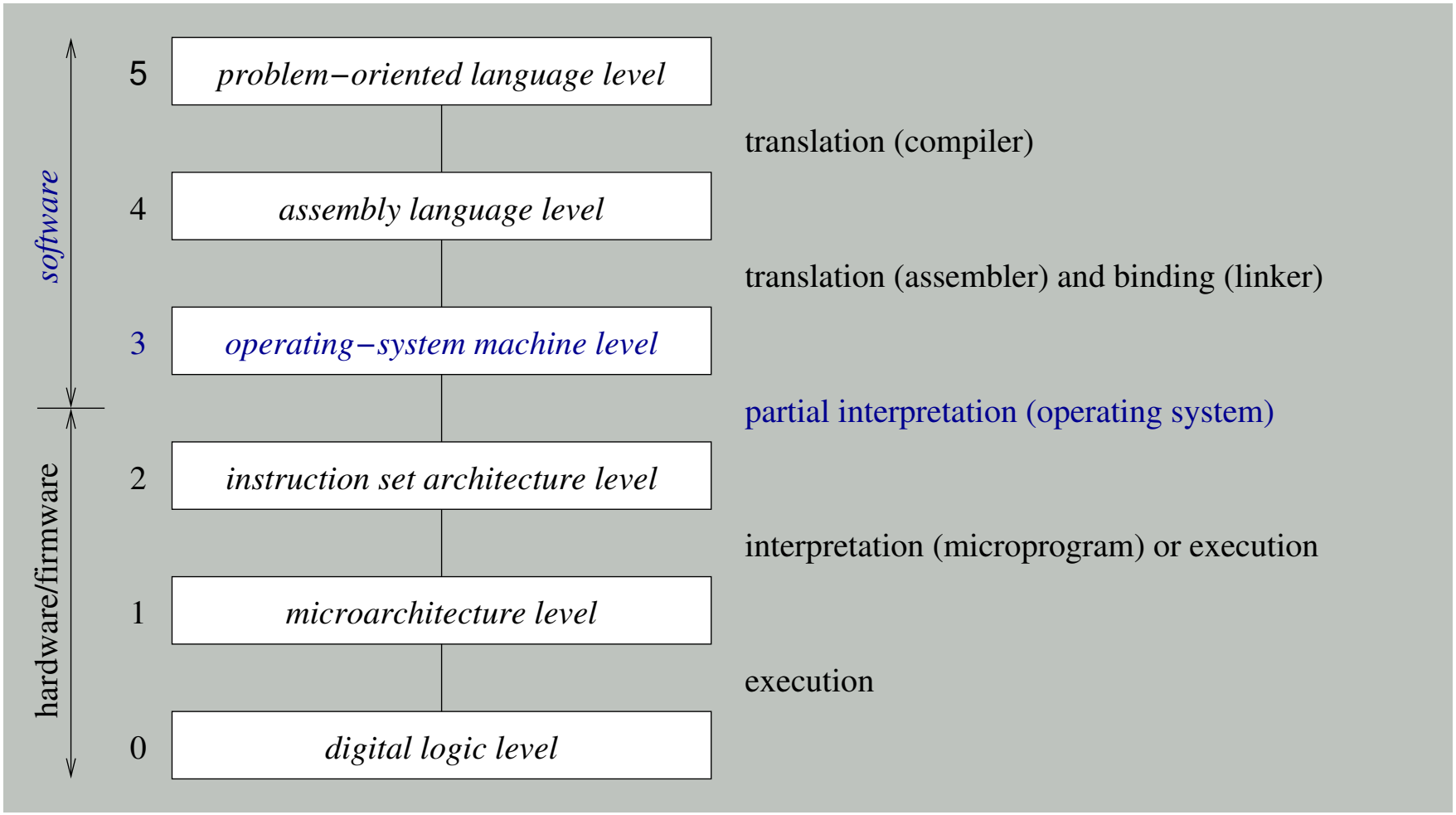
acc. [12, Legal process]

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

[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