Concurrent Systems

Nebenläufige Systeme

III. Processes

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November 8, 2016

Agenda

Outline

Subject Matter

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

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

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

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  - appearance of a process as kernel thread and/or user thread
  - sequencing of processes, process states, and state transitions
- 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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  - 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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- a program (also) describes the kind of flow (Ger. *Ablauf*) of a process

sequential
- a sequence of temporally non-overlapping actions
- proceeds deterministically, the result is determinate

parallel
- non-sequential

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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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Definition (Action)

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

[2] gcc -O4 -m32 -static -fomit-frame-pointer -S, also below

Program II

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  - text segment
  - Linux
  - after linking/binding and
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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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Definition

A program *P* specifying actions that allow for parallel flows in *P* itself.

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- the parallel flow allowed in P itself:

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


~~Non~~-Sequential Program II

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

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pid_t pid;

if (!(pid = fork())) {
  /* ... */
  exit(0);
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wait(NULL);
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- fork duplicates the address space A of P, creates A' as a copy of A
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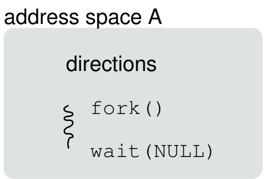
↪ concept "operating system" is epitome of "non-sequential program"[4]

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

Multiprocessing of Sequential Programs



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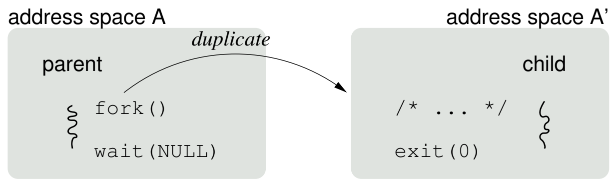

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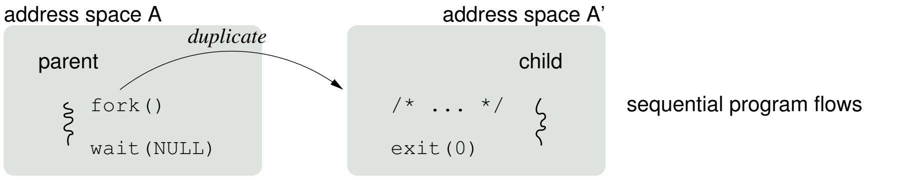

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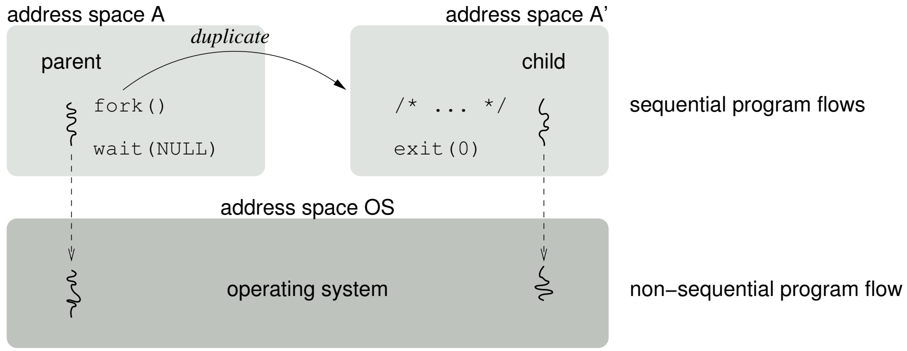

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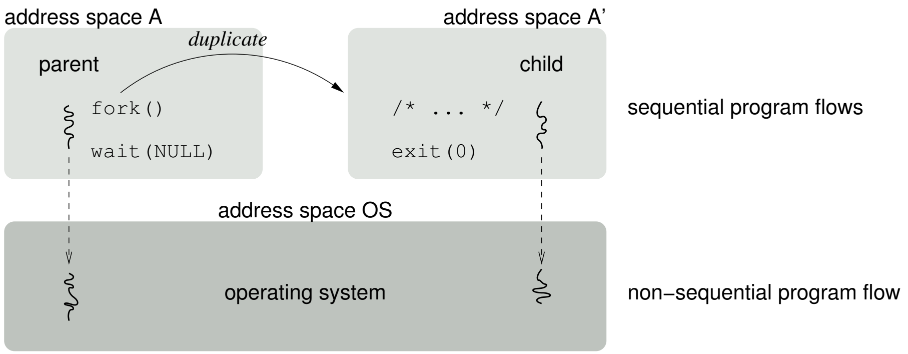

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  - Multi
    - ditto

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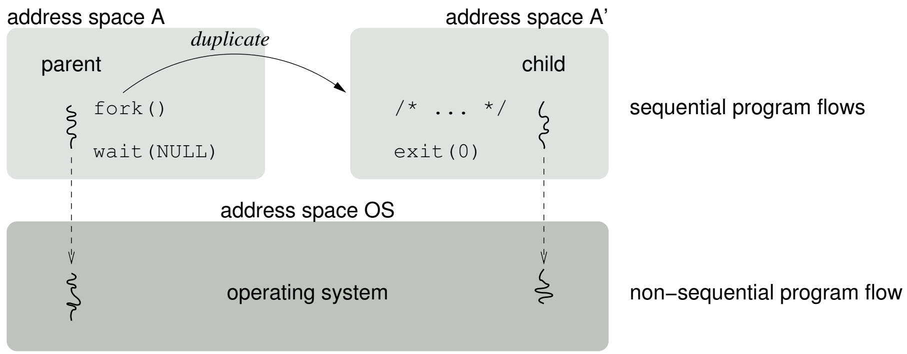

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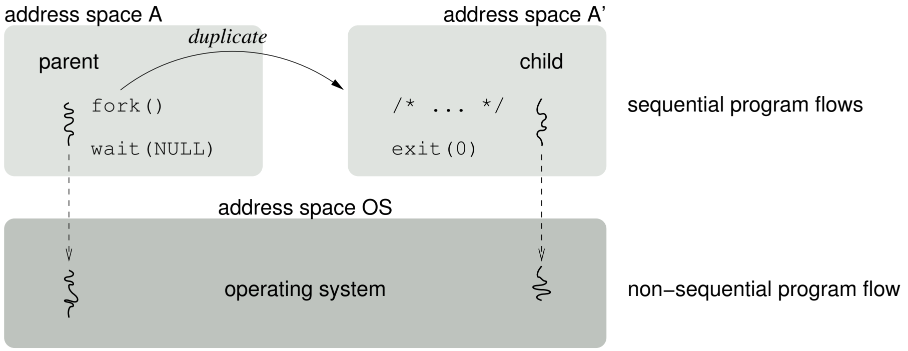

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- both cause **parallel processes** (p. 16) within the operating system

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  - its kind depends on the particular **level of abstraction** (cf. p. 34)

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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`*	`movl i,%r`
	`addl $1,i`*	`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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  - logical togetherness of a sequence of actions in terms of time
  - by what that sequence appears as **elementary operation** (ELOP)

[5] from (Gr.) *átomo* "indivisble".

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- examples of (critical) actions for incrementation of a counter variable:
  - level $_{5 \mapsto 3}$

C/C++

```
i++;
```

ASM

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movl i, %eax
addl $1, %eax
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ASM	ISA
`incl i`	*read A from <i>*
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- points (`i++`, `incl`) in case of merely conditionally atomic execution
  - namely uninterruptible operation (level$_{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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- requirement is a **non-sequential program** (cf. p. 9)
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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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  - 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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Concurrent Processes (Ger.) *gleichzeitige Prozesse* [3]

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One or more (non-sequential) processes whose sequences of actions will overlap in time area by area (Ger. *bereichsweise*).

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  - they share the processor (core), cache (line), bus, or devices
  - outcome of this is **interference**[7] (Ger. *Interferenz*) in process behaviour

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  - 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

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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.

Interacting Processes I

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

Definition (also: "depending processes")

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Interacting Processes I

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

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Interacting Processes II

Race Conditions

```
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();
  }
}
```

- inc64: see p. 7

Interacting Processes II


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- inc64: see p. 7

- 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

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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
  - operations on instances of `int64_t` cease to be solo efforts

Interacting Processes III

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- worker thread

```asm
inc64:
  movl 4(%esp), %eax
  addl $1, (%eax)
  adcl $0, 4(%eax)
  ret

.L6:
  movl $cycle, (%esp)
  call inc64
  jmp  .L6
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9    jmp  .L6
```

- minder thread

```
10 movl cycle+4, %edx ; high &
11 movl cycle, %eax   ; low word
12 movl $.LC0, (%esp)
13 movl %edx, 8(%esp)
14 movl %eax, 4(%esp)
15 call printf
```


Interacting Processes III 1. Race Condition

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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

Interacting Processes IV

- assuming that the development or run-time environment varies
  - different compilers, assemblers, linker, or loaders
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- a classical error: as the case may be, ineffective numeration

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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

```
void mutex_inc64(int64_t *i, pthread_mutex_t *lock) {
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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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    - inside
      - originally, within the operating system or its kernel
      - incarnation of the process is root of possibly other processes
      - partial virtualisation of the CPU as the real processor (core)
      - ↪ "*kernel thread*", in computer science folklore
    - outside
      - optional, within run-time or even application system
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- operating systems are aware only of their own "first-class citizens"

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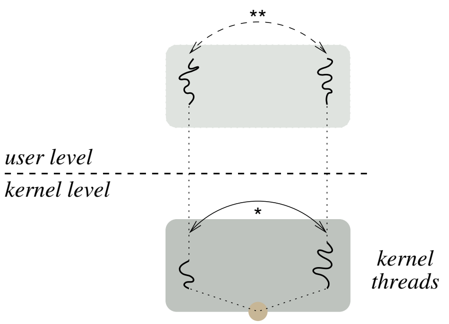
Weight Category

* *feather–*, ** *lightweight*
partial virtualization



- modes of **process switches** as to partial processor virtualisation:
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[9] (Lat.), "at the same place"

Weight Category

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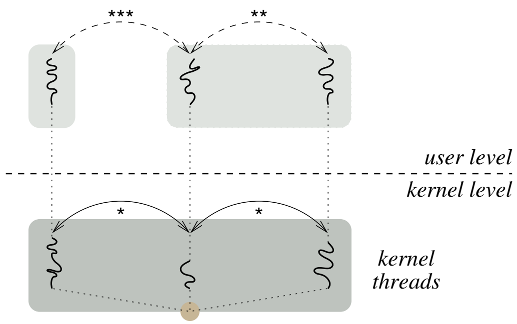

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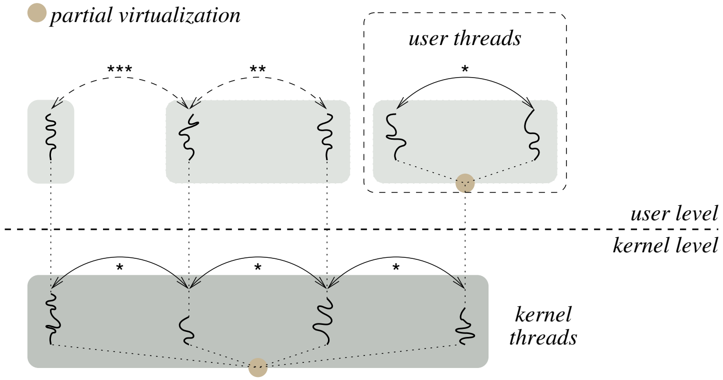

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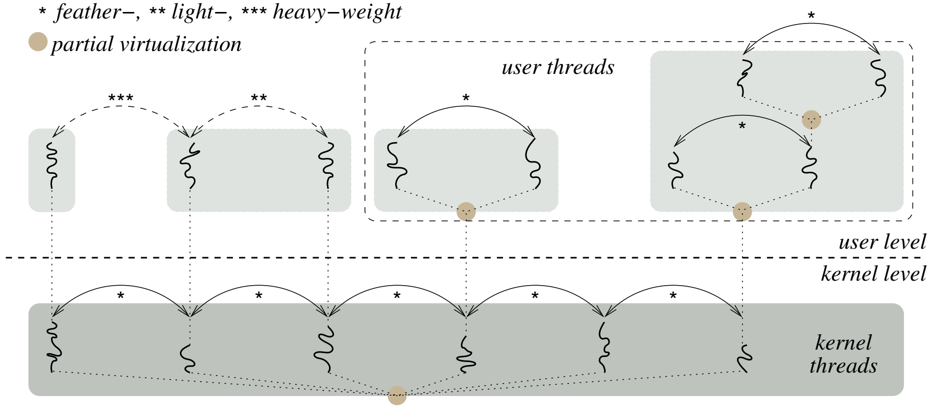

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Sequencing of Processes Scheduling v. Synchronisation

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  - a big theoretical/mathematical side of operating systems [2, 1, 6, 7]
  - but enforcing the scheduling policies faces several practical challenges

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  - on the one hand interrupts, on the other hand resource sharing
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  - once it comes to contention resolution, which **implies sequencing**

    blocking – in matters of allocating consumable and/or reusable resources
    non-blocking – pertaining to indivisible machine (CPU) instructions
  - especially susceptible for inducing interference is blocking synchronisation

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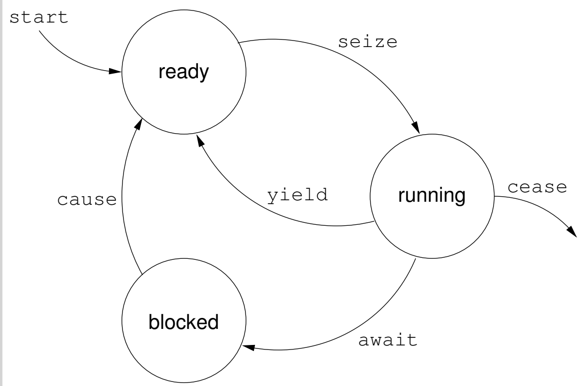
  - especially susceptible for inducing interference is blocking synchronisation
- to **control resource usage**, processes pass through logical states
  - whereby synchronisation emerges jointly responsible for state transitions
  - taken together, scheduling *and* synchronisation are cross-cutting concerns

Process States and State Transitions



- 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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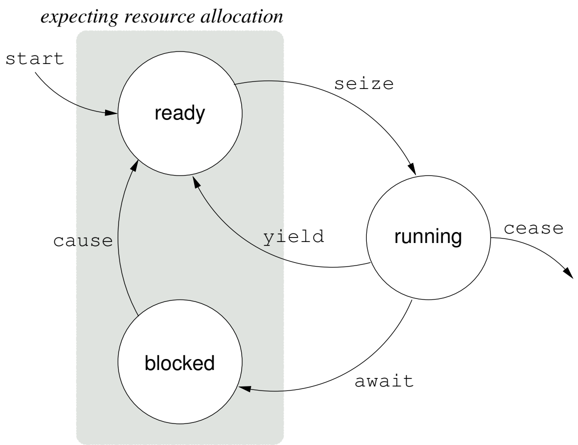

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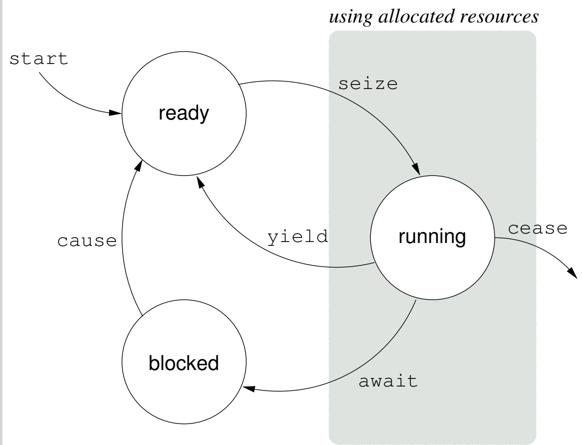

- typical **life time cycle** of processes:

  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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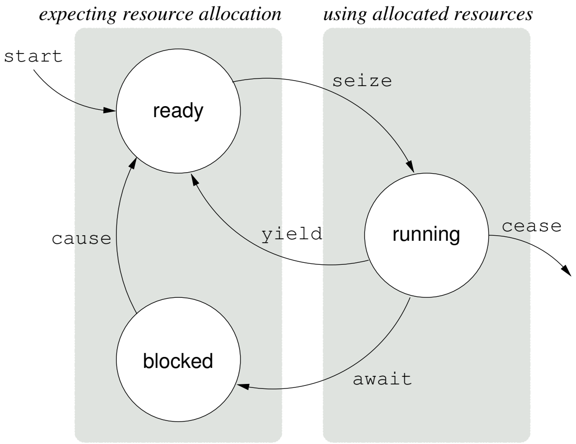

- relevant resources:
  - processor
    - start
    - seize
    - yield
    - cease
  - signal
    - await
    - cause

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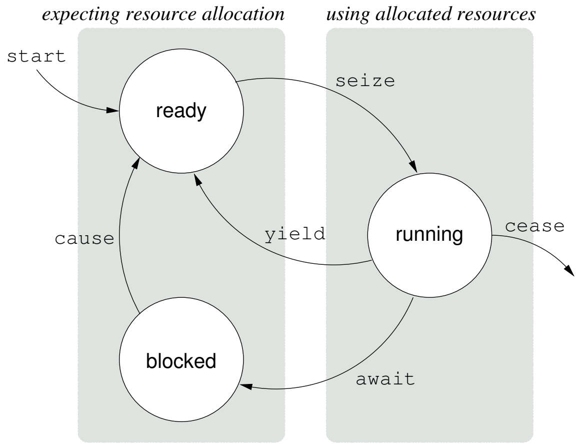

- relevant resources:
  - processor
    - start
    - seize
    - yield
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    - await
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- waitlists involved:
  - ready list of runnable processes
  - blocked list of processes unable to run

- typical **life time cycle** of processes:
  - ready — ready to run, but still waiting for a processor (core)
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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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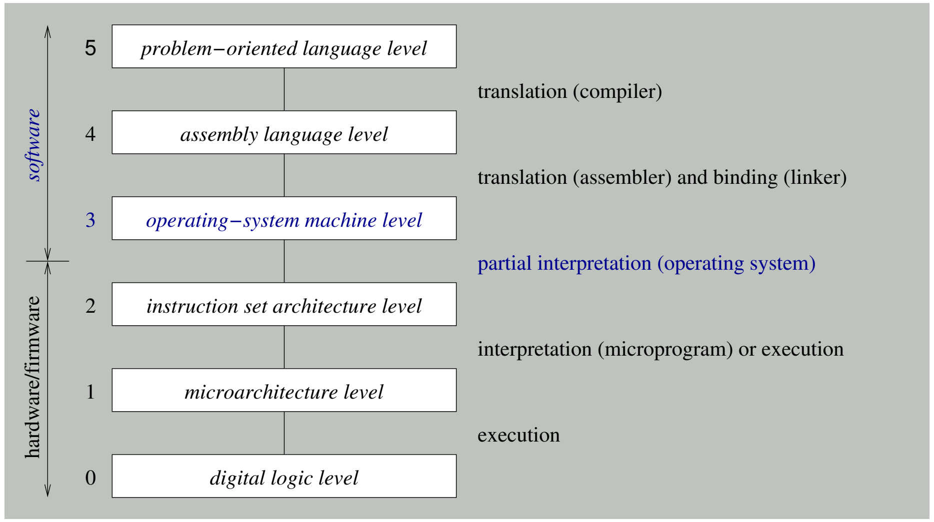
Originally as a Concept of Law

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"



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