Concurrent Systems

Nebenläufige Systeme

III. Processes

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Agenda

Preface

Fundamentals
  Program
  Process

Characteristics
  Physical
  Logical

Summary
Outline

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  Program
  Process

Characteristics
  Physical
  Logical

Summary
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**
- a program in execution
- dynamic sequence of actions conducted by a processor
- of parallel, concurrent, simultaneous, or interacting nature
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explanation of process characteristics in physical and logical terms

- appearance of a process as kernel thread and/or user thread
- sequencing of processes, process states, and state transitions
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explanation of process characteristics in physical and logical terms:
- appearance of a process as kernel thread and/or user thread
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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
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- as coded representation of an algorithm, the program specifies a process
- thereby, the program manifests and dictates a specific process
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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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- 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.

- In both kinds does the program flow consist of actions \(\text{(p. 7 ff.)}\).

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. \([8, 10]\)*

\(^1\)Provided that the operating system offers all necessary commands.
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Program I

Definition

For a certain machine concretised form of an algorithm.
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virtual machine C
- after editing and
- before compilation

```c
#include <stdint.h>

void inc64(int64_t *i) {
    (*i)++;
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virtual machine ASM (x86)
- after compilation
- before assembly

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

\(^2\)gcc -O4 -m32 -static -fomit-frame-pointer -S, also below
Program I

Problem-Oriented/Assembly Language Level

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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

Operating-System Machine Level

- address space and virtual machine SMC
  - text segment
  - Linux
  - after linking/binding and
  - before loading

1. 0x080482f0: mov 0x4(%esp),%eax
2. 0x080482f4: add $0x1, (%eax)
3. 0x080482f7: adc $0x0, 0x4(%eax)
4. 0x080482fb: ret

symbolic machine code: x86 + Linux.
address space and virtual machine SMC$^3$

- text segment
- Linux

<table>
<thead>
<tr>
<th>Line</th>
<th>Address</th>
<th>Instruction</th>
<th>Before Loading</th>
<th>After Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0x080482f0</td>
<td>mov 0x4(%esp),%eax</td>
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</table>

- real machine
  - after loading
  - executable

- same number of actions (lines 1–3, resp.), but different forms of representation

$^3$symbolic machine code: x86 + Linux.
address space and virtual machine SMC

text segment

Linux

after linking/binding and

before loading

real machine

after loading

executable

same number of actions (lines 1–3, resp.), but different forms of representation

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

```assembly
1 0x080481c9: c7 04 24 b0 37 0d 08 movl $0x80d37b0,(%esp)
2 0x080481d0: e8 1b 01 00 00 call 0x80482f0 <inc64>
```

**symbolic machine code:** x86 + Linux.
Definition

A program $P$ specifying actions that allow for parallel flows in $P$ itself.
Non-Sequential Program I

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

an excerpt of $P$ using the example of POSIX Threads [4]:

```c
pthread_t tid;

if (!pthread_create(&tid, NULL, thread, NULL)) {
    /* ... */
    pthread_join(tid, NULL);
}
```

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Non-Sequential Program I

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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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- `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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- the shown actions cause parallel flows within an operating system
- multiprocessing (Ger. *Simultanbetrieb*) of sequential programs requires the operating system in the shape of a non-sequential program
- serviceable characteristic is multithreading within the operating system
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concept “operating system” is epitome of “non-sequential program”

4The exception (strictly cooperative systems) proves the rule.
Multiprocessing of Sequential Programs

address space A

directions

fork()
wait(NULL)
Multiprocessing of Sequential Programs

address space A

parent
fork()
wait(NULL)

address space A'
duplicate

child

fork()
wait(NULL)
exit(0)

non-sequential program flow

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Multiprocessing of Sequential Programs

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sequential program flows
Multiprocessing of Sequential Programs

**address space A**
- parent
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**address space OS**
- operating system

Sequential program flows

Non-sequential program flow

*processor (core) characteristic:*
- Uni
  - operated by a process-based operating system, namely:
    - pseudo-parallelism by means of processor (core) multiplexing

- Multi
  - ditto
  - but also event-based operating system, namely:
    - real parallelism by means of processor (core) multiplication

Both cause parallel processes (p.16) within the operating system.

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A program in execution.
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- the program specifies a sequence of actions that are to be executed
- its kind depends on the particular level of abstraction (cf. p. 34)
  - level₅ ↦ program statement
  - level₄ ↦ assembly mnemonic
  - level₃ ↦ machine instruction
  - level₂ ↦ microprogram directive
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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.
Indivisibility I

Definition

Being indivisible, to keep something appear as unit or entireness.

- a question of the “distance” of the viewer (subject) on an object
Indivisibility I

Definition

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a question of the “distance” of the viewer (subject) on an object

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

<table>
<thead>
<tr>
<th>level</th>
<th>action</th>
<th>sequence of actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>i++</td>
<td></td>
</tr>
<tr>
<td>4–3</td>
<td>incl i*</td>
<td>movl i,%r</td>
</tr>
<tr>
<td></td>
<td></td>
<td>addl %r,i</td>
</tr>
<tr>
<td></td>
<td></td>
<td>movl $1,i</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
<tr>
<td>2–1</td>
<td></td>
<td>read from memory into accumulator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>modify contents of accumulator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>write from accumulator into memory</td>
</tr>
</tbody>
</table>

- typical for a complex instruction of an “abstract processor” (C, CISC)
Entireness or unit of a sequence of actions whose solo efforts all will happen *apparently simultaneous* (i.e., are synchronised)
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- an/the essential non-functional property of an *atomic operation*\(^5\)
  - logical togetherness of a sequence of actions in terms of time
  - by what that sequence appears as *elementary operation* (ELOP)

\(^5\)from (Gr.) *átomo* “indivisible”.

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Fundamentals – Process
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- examples of (critical) actions for incrementation of a counter variable:
  - level $5 \mapsto 3$

```plaintext
C/C++               ASM
1  i++;             2  movl i, %eax
2  movl $1, %eax    3  addl $1, %eax
4  movl %eax, i     5  incl i
```

---

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Indivisibility II

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Examples of (critical) actions for incrementation of a counter variable:

- level\(_5 \mapsto 3\)
  - C/C++
  ```
  i += 1;
  ```

- level\(_3 \mapsto 2\)
  - ASM
  ```
  movl i, % eax
  addl $1 , % eax
  movl %eax , i
  ```
  - ISA
  ```
  incl i
  ```
  - points (i++, incl) in case of merely conditionally atomic execution namely uninterruptible operation (level\(_5 \mapsto 3\)), uniprocessor (level\(_3 \mapsto 2\))

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    - `i++`
  - **ASM**
    - `movl i, %eax`
    - `addl $1, %eax`
    - `movl %eax, i`
  - **ISA**
    - `incl i`
    - `read A from <i>`
    - `modify A by 1`
    - `write A to <i>`

points (*i++*, *incl*) in case of merely **conditionally atomic** execution

- namely uninterruptible operation (*level* 5→3), uniprocessor (*level* 3→2)

- problem: **overlapping in time** of the sequence of actions pointed here

---

5′from (Gr.) átomo “indivisible”.
**Sequential Process**

<table>
<thead>
<tr>
<th>Definition</th>
</tr>
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<td>A process that is composed exclusively of a sequence of temporally non-overlapping actions.</td>
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Sequential Process

Definition

A process that is composed exclusively of a sequence of temporally non-overlapping actions.

- The sequence of actions forms a unique **execution thread**
  - Of which always only a single one exists within a sequential process
  - But which may develop differently with each restart of that process
    - Other input data, program change, ... , transient hardware errors
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  - It is reproducible given unmodified original conditions

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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.*
Non-Sequential Process

Definition

Also referred to as “parallel”, namely a process that is composed of a sequence of temporally overlapping actions.
Non-Sequential Process

**Definition**

Also referred to as “parallel”, namely a process that is composed of a sequence of temporally overlapping actions.

- requirement is a **non-sequential program** (cf. p. 9)
  - that allows for at least one more process incarnation (child process) or
  - that makes arrangements for the handling of events of external processes

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6 Interrupt requests issued by some device (IRQ) or process (signal).
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- whereby sequences of actions may overlap in the first place:
  1. multithreading (Ger. *simultane Mehrfädigkeit*), in fact:
     - pseudo-parallel – multiplex mode of a single processor (core)
     - real parallel – parallel mode of a (multi-core) multiprocessor
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- consequently, the sequence of all actions is defined by a **partial order**
  - as external processes may enable temporal/cause independent actions

---

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Concurrent Processes

Definition (in a broader sense: “simultaneous processes”)

One or more (non-sequential) processes whose sequences of actions will overlap in time and 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

\(^7\) Derived from (Fre.) *s’entreferir* “to brawl each other”.
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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
- 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”.
Definition (also: “depending processes”)

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

Conflicts can arise if at least one of these processes...

- Changes the value of one of the shared variables (access pattern)
- Already occupies a shared non-preemptable resource

This may emerge as a race condition (Wettlaufsituation) for shared variables or (reusable/consumable) resources, respectively.

Conflicts are eliminated by means of synchronisation methods:

- Blocking: prevent from executing an intended sequence of actions
- Non-blocking: let a process abort and retry a started sequence of actions
- Reducing: replace a sequence of actions by an atomic instruction

Founds the coordination of cooperation and competition of processes.

---

8 printer, mouse, plotter, keyboard.
Definition (also: “depending processes”)

Simultaneous processes that, directly or indirectly, interact with each other through a shared variable or by accessing a shared resource. Their actions get into **conflict** if at least one of these processes...

- will change the value of one of the shared variables (access pattern) or
- already occupies a shared non-preemptable resource\(^8\) (resource type)

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- their actions get into **conflict** if at least one of these processes...
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  - already occupies a shared **non-preemptable resource**\(^8\) (**resource type**)
- this may emerge as a **race condition** (Ger. *Wettlaufsituation*)
  - for shared variables or (reusable/consumable) resources, resp.
  - for starting or finishing an intended sequence of actions

\(^8\) printer, mouse, plotter, keyboard.
Interacting Processes I

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- Conflicts are eliminated by means of **synchronisation methods**:
  - **Blocking**
    - Prevent from executing an intended sequence of actions
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    - Let a process abort and retry a started sequence of actions

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  - **reducing**  ■ replace a sequence of actions by an atomic instruction
- **founds coordination** of cooperation and competition of processes

\(^8\) printer, mouse, plotter, keyboard.
```c
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
```c
int64_t cycle = 0;

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

void *thread_minder(void *null) {
    for (;;) {
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    }
}
```

**Which cycle values prints the minder thread (Ger. Aufpasserfaden)?**
```c
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();
    }
}
```

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

inc64: see p. 7
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
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

worker thread

```asm
inc64:
  movl 4(%esp), %eax
  addl $1, (%eax)
  adcl $0, 4(%eax)
  ret
.L6:
  movl $cycle, (%esp)
  call inc64
  jmp .L6
```

inc64 overlaps actions 10–11 then, edx = 0 and eax = 0 effect is, printf displays 0 not 2^{32}, as would have been right
assuming that the non-sequential program runs on a 32-bit machine

- instances of \texttt{int64\_t} then form a pair of 32-bit words: \texttt{double word}
- operations on instances of \texttt{int64\_t} cease to be solo efforts

Worker thread

\begin{verbatim}
inc64:
  movl 4(%esp), %eax
  addl $1, (%eax)
  adcl $0, 4(%eax)
  ret

.L6:
  movl $cycle, (%esp)
  call inc64
  jmp .L6
\end{verbatim}

Minder thread

\begin{verbatim}
movl cycle+4, %edx ; high &
movl cycle, %eax ; low word
movl $.LC0, (%esp)
movl %edx, 8(%esp)
movl %eax, 4(%esp)
call printf
\end{verbatim}
assuming that the non-sequential program runs on a 32-bit machine

- instances of \texttt{int64\_t} then form a pair of 32-bit words: \texttt{double\ word}
- operations on instances of \texttt{int64\_t} cease to be solo efforts

worker thread

1. \texttt{inc64:}
   2. \texttt{movl 4(\%esp), \%eax}
   3. \texttt{addl $1, (\%eax)}
   4. \texttt{adcl $0, 4(\%eax)}
   5. \texttt{ret}

6. \texttt{.L6:}
   7. \texttt{movl \$cycle, (\%esp)}
   8. \texttt{call inc64}
   9. \texttt{jmp .L6}

minder thread

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

- assume \textit{cycle} = 2^{32} - 1

© wosch, thoenig  CS (WS 2018/19, LEC 3)  Fundamentals – Process
Interacting Processes III

1. Race Condition

- 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

**worker thread**

1. inc64:
2. \texttt{movl 4(\%esp), \%eax}
3. \texttt{addl \$1, (\%eax)}
4. \texttt{adcl \$0, 4(\%eax)}
5. \texttt{ret}

6. .L6:
7. \texttt{movl \$cycle, (\%esp)}
8. \texttt{call inc64}
9. \texttt{jmp .L6}

**minder thread**

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

- assume \( \text{cycle} = 2^{32} - 1 \)
- inc64 overlaps actions 10–11
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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minder thread

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  movl cycle+4, %edx ; high &
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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
```
assuming that the development or run-time environment varies
- different compilers, assemblers, linker, or loaders
- different operating systems—but the same real processor (x86)
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GCC 4.7.2, Linux

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1 inc64:
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GCC 4.2.1, MacOSX

6 _inc64:
7   movl 4(%esp), %eax
8   movl (%eax), %ecx
9   movl 4(%eax), %edx
10  addl $1, %ecx
11  adcl $0, %edx
12  movl %edx, 4(%eax)
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pseudo-parallel actions (case 4.2.1)
- (UNIX-) signal
- asynchronous program interrupt
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  movl %edx, 4(%eax)
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```

pseudo-parallel actions (case 4.2.1)
- (UNIX-) signal
- asynchronous program interrupt

real parallel actions: (multi-core) multiprocessor
- the actions in lines 3–4 are critical as well: divisible read-modify-write
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pseudo-parallel actions (case 4.2.1)
- (UNIX-) signal
- asynchronous program interrupt

real parallel actions: (multi-core) multiprocessor
- the actions in lines 3–4 are critical as well: divisible read-modify-write
- 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
Consistency

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

blocking of interacting processes

```c
void mutex_inc64(int64_t *i, pthread_mutex_t *lock) {
    pthread_mutex_lock(lock);   /* indivisible, now */
    inc64(i);                    /* reuse code @ p.7 */
    pthread_mutex_unlock(lock); /* divisible, again */
}
```
prevention of race conditions by the **protection of critical sections**
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blocking of interacting processes: **comparatively long time span**

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Consistency

Coordination of Interacting Processes

- prevention of race conditions by the **protection of critical sections**
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- blocking of interacting processes: **comparatively long time span**
  
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4     pthread_mutex_unlock(lock);        /* divisible, again */
5 }
```

- reducing to a 64-bit ELOP of the real processor
  
```c
6 void inc64(int64_t *i) {                /* renew code @ p.7 */
7     asm ("lock incq %0" : : "m" (*i) : "memory");
8 }
```

- anywhere applicable and by orders of magnitude more efficient solution
anchoring of processes can be different within a computing system
Localisation

- **anchoring** of processes can be different within a computing system
  - namely inside or outside the operating-system machine level:
    - **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
      - incarnation of the process as leaf or inner node (of a graph)
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    - no nowadays known (real) processor is aware of what it is processing
      - particularly, a kernel thread does not know about potential user threads
      - when it gets switched or delayed, all of its user threads will as well
**Localisation**

**Operating-System v. Application Context**

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  - no nowadays known (real) processor is aware of what it is processing
    - particularly, a kernel thread does not know about potential user threads
    - 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”
modes of **process switches** as to partial processor virtualisation:

* inside the same (user/kernel) address space, *ibidem*\(^9\) continuing

** inside kernel address space, same user address space sharing

\(^9\) (Lat.), “at the same place”
modes of **process switches** as to partial processor virtualisation:

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sequencing (Ger. Ablaufplanung) the dispatching (Ger. Einlastung) of processes or, to be precise, process incarnations
Sequencing of Processes

Scheduling v. Synchronisation

- **scheduling** (Ger. *Ablaufplanung*) the **dispatching** (Ger. *Einlastung*) of processes or, to be precise, process incarnations
  - a big theoretical/mathematical side of operating systems [2, 1, 6, 7]
  - but enforcing the scheduling policies faces several practical challenges
Sequencing of Processes

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  - but enforcing the scheduling policies faces several practical challenges
- unpredictable dynamic system behaviour at run-time dashes hopes
  - on the one hand interrupts, on the other hand resource sharing
  - breeds **asynchronism** and, as a result, foregrounds **heuristic**
Sequencing of Processes

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- process **synchronisation** is notorious for producing interference

  - 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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    - 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**
- 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

- **start**
- **seize**
- **yield**
- **cause**
- **await**
- **cease**

- **ready**
- **running**
- **blocked**

**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
Process States and State Transitions

- start
- seize
- yield
- cease
- expect
- awaiting
- allocation
- using
- allocated
- resources
- relevant
- resources:
  - processor
- start
- seize
- yield
- cease
- signal
- await
- cause
- waitlists involved:
  - ready list of runnable processes
  - blocked list of processes unable to run

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**Diagram:***

- States: ready, running, blocked
- Transitions:
  - **start**
  - **seize**
  - **yield**
  - **cause**
  - **await**
  - **cease**

**Using allocated resources**

**Waitlists involved:**
- Ready list of runnable processes
- Blocked list of processes unable to run
Process States and State Transitions

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  - processor
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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 lifetime 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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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 today's computers
- right, the method and (bracketed) program that supports each level