Concurrent Systems

Nebenläufige Systeme

III. Processes

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October 30, 2018

Outline

Preface

Fundamentals
  Program
  Process

Characteristics
  Physical
  Logical

Summary

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

- 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

- 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

Operating systems bring programs to execution by creation, releasing, controlling and timing of processes

- in computer sciences, a process is unimaginable without a program
  - 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

- a program (also) describes the kind of flow (Ger. Ablauf) of a process
  - sequential: a sequence of temporally non-overlapping actions
  - parallel: non-sequential

- 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]

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.

- virtual machine C
  - after editing and
  - before compilation

- virtual machine ASM (x86)
  - after compilation
  - before assembly

1 #include <stdint.h>
2
3 void inc64(int64_t *i) {
4     (*i)++;
5 }

- one action (line 4)

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

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

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

- real machine
  - after loading
  - executable

8b 44 24 04
83 00 01
83 50 04 00
c3

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

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 mov 0x80d37b0 , (%esp)
2 0x080481d0 : e8 1b 01 00 00 call 0x80482f0 <inc64>

3 symbolic machine code: x86 + Linux.
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
1 pthread_t tid;
2 if (! pthread_create(&tid, NULL, thread, NULL)) {
3     /* ... */
4     pthread_join(tid, NULL);
5 }
```

the parallel flow allowed in $P$ itself:

```c
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:

```c
1 pid_t pid;
2 if (!(pid = fork())) {
3     /* ... */
4     exit(0);
5 }
6 wait(NULL);
```

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

independent of the degree of parallelism within $P$, fork sets it to 1 for $A'$

sequential flows can establish parallel ones within a domain that logically comprises those sequential flows

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

The exception (strictly cooperative systems) proves the rule.

Multiprocessing of Sequential Programs

address space $A$

parent

fork()

child

duplicate

sequential program flows

address space OS

address space $A'$

operating system

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

Process

Definition (Program flow)
A program in execution.

the program specifies a sequence of actions that are to be executed

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

  level $5 \mapsto$ program statement $\geq 1$ assembly mnemonics
  level $4 \mapsto$ assembly mnemonic $\geq 1$ machine instructions
  level $3 \mapsto$ machine instruction $\geq 1$ microprogram directives

- the actions of a processor thus are not imperatively indivisible (atomic)
  - this particularly holds both for the abstract (virtual) and real processor

this sequence is static (passive), while a process is dynamic (active)

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
- 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 $1, %r*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>movl %r, i</td>
</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)

Indivisibility II

Entireness or unit of a sequence of actions whose solo efforts all will happen apparently simultaneous (i.e., are synchronised)

- an/the essential non-functional property of an atomic operation
- logical togetherness of a sequence of actions in terms of time
- by what that sequence appears as elementary operation (ELOP)

- examples of (critical) actions for incrementation of a counter variable:

<table>
<thead>
<tr>
<th>level 5→3</th>
<th>level 3→2</th>
</tr>
</thead>
<tbody>
<tr>
<td>C/C++</td>
<td>ASM</td>
</tr>
<tr>
<td>i++;</td>
<td>incl i</td>
</tr>
<tr>
<td>movl i, %eax</td>
<td>read A from &lt;i&gt;</td>
</tr>
<tr>
<td>addl $1, %eax</td>
<td>modify A by 1</td>
</tr>
<tr>
<td>movl %eax, i</td>
<td>write A to &lt;i&gt;</td>
</tr>
</tbody>
</table>

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

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
- the sequence is defined by a total order of its actions
  - it is reproducible given unmodified original conditions

Hint (Execution Thread ≠ 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.

- 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
  - whereby sequences of actions may overlap in the first place:
    - multithreading (Ger. simultane Mehrfachdurchführung), in fact:
      - pseudo-parallel - multiplex mode of a single processor (core)
      - real parallel - parallel mode of a (multi-core) multiprocessor
    - 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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5from (Gr.) átomo "indivisible".

6Interrupt requests issued by some device (IRQ) or process (signal).
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. _nebenläufig_).

- areas are concurrent (Ger. _nebenläufig_) only if they are independent
- none of these concurrent processes is cause or effect of the other
- none of these 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 (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

_interactive processes_ (Ger.) _gleichzeitige Prozesse_ [3]

Interacting Processes I

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 (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
- conflicts are eliminated by means of _synchronisation methods_:
  - blocking non-blocking
  - prevent from executing an intended sequence of actions
  - let a process abort and retry a started sequence of actions
  - replace a sequence of actions by an atomic instruction
- _founds coordination_ of cooperation and competition of processes

Interacting Processes II

Race Conditions

```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

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

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

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

- minder thread

```c
    movl cycle+4, %edx ; high &
    movl cycle, %eax ; low word
    movl $.LC0, (%esp)
    movl %edx, 8(%esp)
    movl %eax, 4(%esp)
    call printf
```

- 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

2. Race Condition

assuming that the development or run-time environment varies
different compilers, assemblers, linker, or loaders
different operating systems—but the same real processor (x86)

GCC 4.7.2, Linux

GCC 4.2.1, MacOSX

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

Consistency

Coordination of Interacting Processes

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

Lookahead: prevent overlapping by means of mutual exclusion

Localisation

Operating-System v. Application Context

anchoring of processes can be different within a computing system

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)
− partial virtualisation of the root process as an abstract processor
− *user thread*, in computer science folklore

usually, a processor (core) is entirely unaware of being multiplexed
threads evolve from time sharing their underlying processor (core)
− a kernel thread may serve as an abstract processor for user threads

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”
Weight Category Interruption and Resumption Overhead

- feather−, **light−**, ***heavy−weight
- partial virtualization

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
- *** inside kernel address space, at other user address space landing

9(Lat.), “at the same place”

Process States and State Transitions

- relevant resources:
  - processor
    - start
    - seize
    - yield
    - cease
    - await
    - cause
  - signal
- 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)
- running: executing on a processor (core), performing a CPU burst
- blocked: waiting for an event (being in sync), performing an I/O burst

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
- 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**
- 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
  - 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**

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© wosch, thoenig CS (WS 2018/19, LEC 3) Characteristics – Physical
© wosch, thoenig CS (WS 2018/19, LEC 3) Characteristics – Logical
© wosch, thoenig CS (WS 2018/19, LEC 3) Summary
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 multiprocesing in a wider sense
- 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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**Résumé**

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**Reference List II**


**Reference List III**


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\(^\text{10}\) 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 \textit{instance}.
    - in informatics, translation to (Ger.) “Instanz” however was rather unept \(^!!!\)
  - operating systems often command a multi-level processing of processes

\(^{10}\)Lat. \textit{rivalis} “in the use of a watercourse co-authored by a neighbour”

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Structured Computer Organisation

| 5 | problem-oriented language level | translation (compiler) |
| 4 | assembly language level | translation ( assembler ) and binding ( linker ) |
| 3 | operating-system machine level | partial interpretation ( operating system ) |
| 2 | instruction set architecture level | interpretation ( microprogram ) or execution |
| 1 | microarchitecture level | execution |
| 0 | digital logic level | |

Refinement of [11, p.5]: levels present on today’s computers

- right, the method and (bracketed) program that supports each level