Concurrent Systems

Nebenläufige Systeme

I. Introduction

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Abstract Concept

- meaning of the lecture labelling in linguistic terms [3]:
  - **con·cur·rent** (lat.) *concurrens*: preposition of *concurrere*
    1. occurring at the same time; existing together
    2. meeting in or going toward the same point; converging
    3. acting together; cooperating
    4. in agreement; harmonious
    5. exercised equally over the same area

- **sys·tems** plural of (gr.) *systēmas*: to place together
  1. a set of arrangements of things so related or connected as to form a unity or organic whole
  2. a set of facts, principles, rules, etc. classified or arranged in a regularly, orderly form so as to show a logical plan linking the various parts
  3. a method or plan of classification or arrangement

- in terms of computer science: a system of several computations which are executing simultaneously, potentially interacting with each other
Concurrency as a System Property

- **Simultaneous execution** of potentially interacting computations with the latter being logical (cooperating) or incidental (contending)

- **Concurrency in the program flow** is due to:
  - **Multiplication** of processing units, but also
    - real parallelism
    - instruction set architecture level
    - partitioning in space
  - **Multiplexing** (partial virtualisation [2])
    - pseudo-parallelism
    - operating-system machine level
    - partitioning in time

- Functionally equal, but non-functionally unequal, characteristics
  - however, each of the two “concurrency dimensions” originates in different functions to coordinate/synchronise concurrent processes

- Focus is on **parallel processing** of the same non-sequential program
Parallel Processing

master/slave
Parallel Processing

unclustered & symmetric
Multiplication of Processing Units

- parallel-computer engineering is pervasive
  - multi-core: conventional characteristic
  - uni-core: rather unconventional, but rife

- by the way: multi-core \(\subset\) many-core
  - multi: little tens ("handful") of cores
  - many: several tens of cores and more
    - hundreds or even thousands

- exposure to parallelism is indispensable [4]
  - mandatory at least for operating systems

- many-core processors make core multiplexing almost superfluous
  - unless latency hiding becomes an issue within a parallel process

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Parallel Processor: CPU

2 cores  4 cores  8 cores  16 cores

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Parallel Processor: GPU

512 cores

1536/3072 cores
Parallel System: HPC

Tianhe-2

3 120 000 cores
Parallel System: HPC

Sunway TaihuLight

10 649 600 cores
Characteristic

- **nature** of the overall processor architecture
  - **homogeneous**
    - in functional terms: instruction set architecture (ISA)
    - but also non-functional: latency, clock speed, energy use
  - **heterogeneous**
    - different in at least one of those aspects

- **address-space organisation**
  - **shared**
    - globally direct memory access: load/store operations
    - maybe partitioned global address space (PGAS)
  - **distributed**
    - globally indirect memory access: message passing

- **cache coherency**: memory *property*
  - **coherent**
    - any read evaluates to the last write to the same address
    - temporary (memory/cache) inconsistencies are tolerated
  - **non-coherent**
    - else

- **memory (also: cache) consistency**: memory *state*
  - **strict**
    - all accesses are seen in order in which they were issued
  - **otherwise**
    - loosened models, differentiate between read and write
    - sequential, processor, weak, entry, or release consistency
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Introduction:

1. overview, organisation—today’s lecture...

General topics and basic principles:

2. notion of “concurrency” against the background of resource sharing
   - causality (“cause and effect”), synchronisation, indivisibility

3. notion of “process” and difference to “program”
   - sequential, non-sequential, concurrent, interacting

4. critical (program) sections and their typical patterns
   - race conditions/hazards: lost update, lost wakeup

5. elementary operations and other hardware aspects
   - TAS, CAS, and LL/SC versus caches, coherence, and interference
Synchronisation: Blocking

Pessimistic methods

Classic and folklore:

6. lock algorithms
   - contention, backoff, ticket, interference

7. semaphore
   - binary (vs. “mutex”), general/counting, bolt, set

8. monitor and condition variable
   - signalling semantics: Hansen, Hoare, Mesa, Java

9. deadlock and livelock
   - prevention, avoidance and detection & resolution
Synchronisation: Non-Blocking

Avant-garde and other:

10. algorithms based on indivisible memory-write instructions
   - assuming vertical (stack-like) overlapping
   - interrupt-transparent synchronisation

11. algorithms based on dedicated machine instructions
   - assuming horizontal (congeneric) overlapping
   - compare and swap (CAS), load linked (LL) and store conditional (SC)

12. transactional memory
   - AMD’s advanced synchronisation facility (ASF)
   - Intel’s transactional synchronisation extensions (TSX)
Recapitulation:

13. wrap-up and words in a personal matter
   - retrospection and lessons learned
   - research projects on these topics at the chair
   - perspectives for advanced training: bachelor, master, doctoral thesis

Hint (Lecture)

Main objective is to impart knowledge on concurrent systems from the **system programming point of view**. Wide emphasis is on the internals of synchronisation concepts and primitives as well as the implications of the respective implementations. Application of these methods for parallel programming takes a back seat.
Language of Instruction

- depends on the German linguistic abilities of the participants
  - English  ■ preferred working language
  ■ strict choice if at least one attendee does not agree on German
  - German  ■ in case of doubt or missing answer, German is fallback position\(^1\)

- written material (slides or handouts, resp.) will be English
  ■ with technical terms also stated in German, where applicable

\(^1\)Studying abroad also means *living* abroad—and to take part and share in Franconian social life. The latter *soft skills* cannot be overestimated.
Meaningful Learning

- acquire new knowledge
  - prepare next reading on one's own initiative
  - attend presentation, listen, and discuss topics treated
  - reinforce learning matter, reflect

- relate it with previous knowledges
  - parallel programming (PFP)
  - computer architecture (GRA)
  - system programming (SP, SPiC, GSPiC)
  - operating systems (BS), operating-systems engineering (BST)
  - real-time systems (EZS)

- teaching material presented in the lecture room:
  - follow “Lehre” (Eng. teaching) at https://www4.cs.fau.de
  - copies of the slides are made available as handouts free of charge
  - supplemented by secondary literature as and when required
    - see the bibliography at the bottom of each handout
  - glossary of terms at https://www4.cs.fau.de/~wosch/glossar.pdf
deepen knowledge by means of direct experience

Acquisition of virtuous behaviour and operational ability is less a matter of easy instruction but rather functional copy, practise, and use. (Aristotle [1])

- discussion of assignments, outline of approaches
- consolidation of the lecture, clarification of open questions

blackboard practice under guidance of an exercise instructor
- registration through WAFFEL\(^2\) (URL see CS web page)
- assignments are to be processed in teamwork: discretionary clause
  - depending on the number of participants

computer work under individual responsibility
- registration is not scheduled, reserved workplaces are available
- in case of questions, a CS exercise instructor is available

\(^2\) abbr. for (Ger.) Webanmeldefrickelformular Enterprise Logic
Requirements

- **hard skills** *(computer-science expertise)*
  - mandatory
    - structured computer organisation
    - algorithm design and development
    - principles of programming in C or C++
  
  → knowledge gaps will not be closed actively: no extra tuition

- optional
  - assembly language (absolute) programming
  - system programming
  - operating systems
  
  ↔ as appropriate, knowledge gaps will be closed on demand by the instructors

- **soft** *(personal, social, methodical)* **skills**
  - staying power, capacity of teamwork, structured problem solving
Major Course Assessment

- achievable credit points
  - 5 ECTS (*European Credit Transfer System*)
  - corresponding to a face time of 4 contact hours per week
    - lecture and practice, with 2 SWS\(^3\) (i.e., 2.5 ECTS) each

- German or English (cf. p. 22) **oral examination**
  - date by arrangement: send e-mail to wosch@cs.fau.de
  - propose desired date within the official audit period
    - the exception (from this very period) proves the rule...

- examination subjects
  - topics of lecture, blackboard practice, but also computer work
  - brought up in the manner of an “expert talk”
    - major goal is to find out the degree of understanding of inter-relations

- registration through “mein campus”: https://www.campus.fau.de

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\(^3\) abbr. for (Ger.) *Semesterwochenstunden*
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Subject Matter

- coordination of cooperation and concurrency
  - between interacting (i.e., control- or data-flow dependent) processes
  - with emphasis on explicit synchronisation

- against the background of two dimensions of concurrency
  - **vertical**
    - overlapped execution at operating-system machine level
    - process preemption (partial virtualisation)
  - **horizontal**
    - overlapped execution at instruction set architecture level
    - processor (core) multiplication

- in-depth study of approaches suitable (not only) for operating systems
  - advanced studies to the range of topics on system programming
  - basic studies to concurrent (i.e., non sequential) programming

- fundamental understanding of different synchronisation paradigms
  - blocking versus non-blocking synchronisation
  - where is what paradigm mandatory, optional, beneficial, or adversely…
[1] **Aristotle**:  
*Nicomachean Ethics*.  
c. 334 BC

[2] **Corbató, F. J.; Merwin-Daggett, M.; Daley, R. C.**:  
An Experimental Time-Sharing System.  

*Webster’s New World Dictionary*.  
Simon & Schuster, Inc., 1988

[4] **Sutter, H.**:  
The Free Lunch is Over: A Fundamental Turn Toward Concurrency in Software.  
In: *Dr. Dobb’s Journal 30* (2005), Nr. 3, S. 202–210