Concurrent Systems
*Nebenläufige Systeme*

I. Introduction

Wolfgang Schröder-Preikschat

October 9, 2014
Agenda

Preface

Contents

Organisation

Summary
Preface
meaning of the lecture labelling in linguistic terms [3]:

con·cur·rent (lat.) concurrens: preposition of concurrere

sys·tems plural of (gr.) systēmas: to place together
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
meaning of the lecture labelling in linguistic terms [3]:

**systems** 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
Abstract Concept

in terms of computer science: a system of several computations who are executing simultaneously, potentially interacting with each other
Abstract Concept

- meaning of the lecture labelling in linguistic terms [3]:
  
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- in terms of computer science: a system of several computations who 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 contending (incidental)
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Concurrence in the program flow is due to:

- **Multiplication** of processing units
  - real parallelism
  - instruction set architecture level
  - partitioning in space
Concurrency as a System Property

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- concurrence 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
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  - however, each of the two “concurrency dimensions” originates in different functions to coordinate/synchronise concurrent processes
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- focus is on **parallel processing** of the same non-sequential program
Parallel Processing
Parallel Processing

clustered & symmetric
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

28 cores, uniformly distributed across four tiles 😊
parallel-computer engineering is pervasive

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exposure to parallelism is indispensable [4]

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many-core processors make core multiplexing almost superfluous

- unless latency hiding becomes an issue within a parallel process

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28 cores, uniformly distributed across four tiles 😊
Parallel Processor: CPU

AMD, Intel, Tilera

2 cores
Parallel Processor: CPU

2 cores  4 cores
Parallel Processor: CPU

AMD, Intel, Tilera

2 cores 4 cores 8 cores
Parallel Processor: CPU

AMD, Intel, Tilera

<table>
<thead>
<tr>
<th>2 cores</th>
<th>4 cores</th>
<th>8 cores</th>
<th>16 cores</th>
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Parallel Processor: CPU

AMD, Intel, Tilera

2 cores  4 cores  8 cores  16 cores  32 cores
### Parallel Processor: CPU

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<td>8</td>
<td>![Image](128x152 to 223x199)</td>
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<td>![Image](230x142 to 353x219)</td>
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<td>100</td>
<td>![Image](37x41 to 163x135)</td>
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Parallel Processor: GPU

512 cores
Parallel Processor: GPU

NVIDIA

512 cores

1536 cores
Parallel System: HPC

Tianhe-2

3 120 000 cores
Characteristic

- **nature** of the overall processor architecture

- address-space **organisation**

- cache **coherency**: memory **property**

- memory (also: cache) **consistency**: memory **state**
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
Characteristic  Parallel Systems

- **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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Outline

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Contents

Organisation

Summary
Introduction:

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

**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)

13. progress guarantees
   - obstruction-, lock- and wait-free behaviour
   - constructive (favoured) and analytical (neglected) approaches
State of the art and recapitulation:

14. right from the rummage table...
   - software combining, procedure chaining, combining funnels
   - read-copy update, remote-core locking

15. 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
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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.
Outline

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Organisation

Summary
Language of Instruction

- depends on the German linguistic abilities of the participants

*Note: The language of instruction can be English if all attendees agree on a German-speaking class. In case of doubt or missing answer, German is the fallback position.*

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

Studying abroad also means living abroad—and to take part and share in Franconian social life. The latter soft skills cannot be overestimated.
depends on the German linguistic abilities of the participants

- **German**
  - if all attendees do agree on a German-speaking class
  - will be asked for at the beginning of each lesson

- **English**
  - if at least one attendee does not agree on German
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Lecture

Meaningful Learning

- acquire new knowledge
- relate it with previous knowledges
acquire new knowledge

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

- relate it with previous knowledges
  - parallel programming (PFP) I2
  - computer architecture (GRA) I3
  - system programming (SP, SPiC, GSPiC) I4
  - operating systems (BS), operating-systems engineering (BST) I4
  - real-time systems (EZS) I4
Lecture

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- 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
Exercise

- 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])
Exercise

Experimental Learning

depthen knowledge by means of direct experience

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

\(^2\)abbr. for (Ger.) Webanmeldefrickelformular Enterprise Logic
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- **computer work** under individual responsibility
  - registration is not scheduled, reserved workplaces are available
  - in case of questions, a CS exercise instructor is available

²abbr. 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
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- **soft** (personal, social, methodical) **skills**
  - staying power, capacity of teamwork, structured problem solving
achievable credit points
- 5 ECTS (*European Credit Transfer System*)

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

abbr. for (Ger.) Semesterwochenstunden
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

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registration through “mein campus”: [https://www.campus.fau.de](https://www.campus.fau.de)

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³ abbr. for (Ger.) *Semesterwochenstunden*
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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...
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[1] Aristotle:  
*Nicomachean Ethics.*  
c. 334 BC

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