Concurrent Systems

Nebenläufige Systeme

I. Introduction

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Agenda

Preface

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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

  ⋮

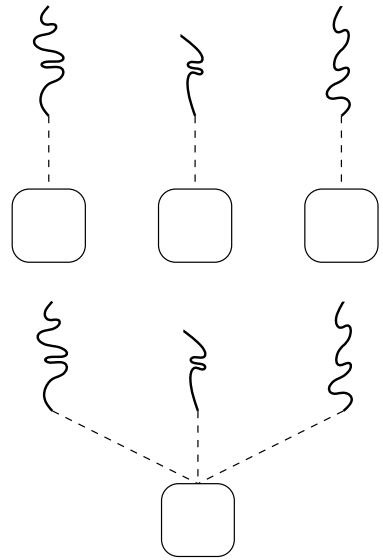
- in terms of computer science: a system of several computations who are executing simultaneously, potentially interacting with each other

Concurrency as a System Property

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

Parallel Processing

Parallel Processing

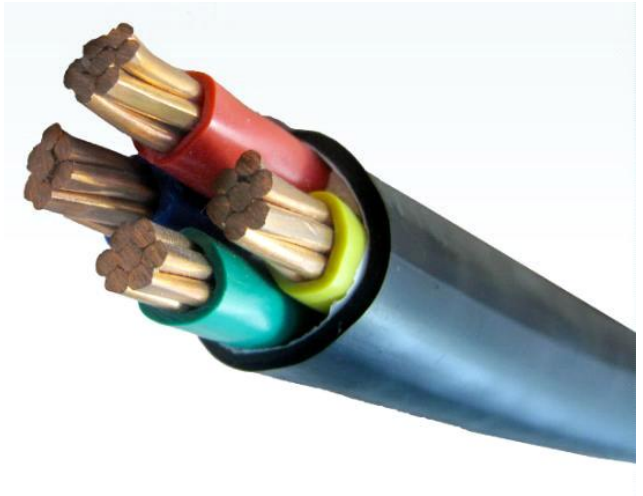
clustered & symmetric

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



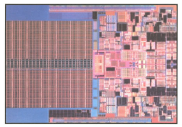
28 cores, uniformly distributed across four tiles ☺

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

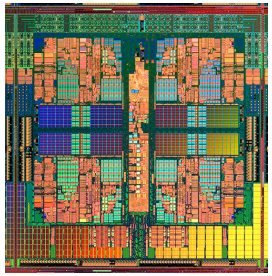
Parallel Processor: CPU

AMD, Intel, Tilera

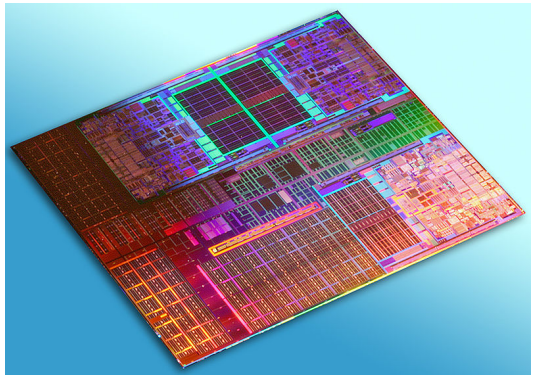
2 cores



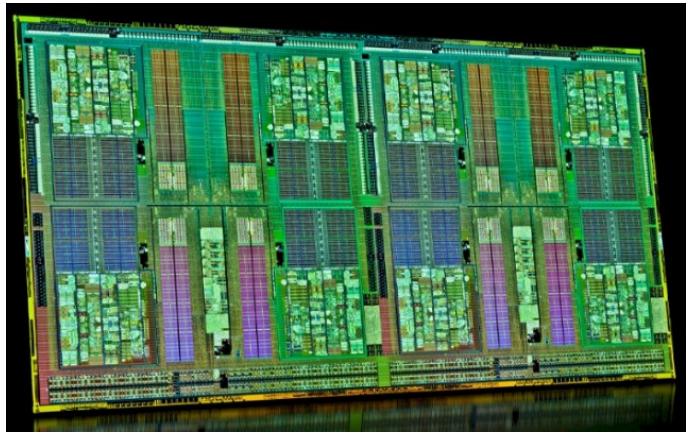
4 cores

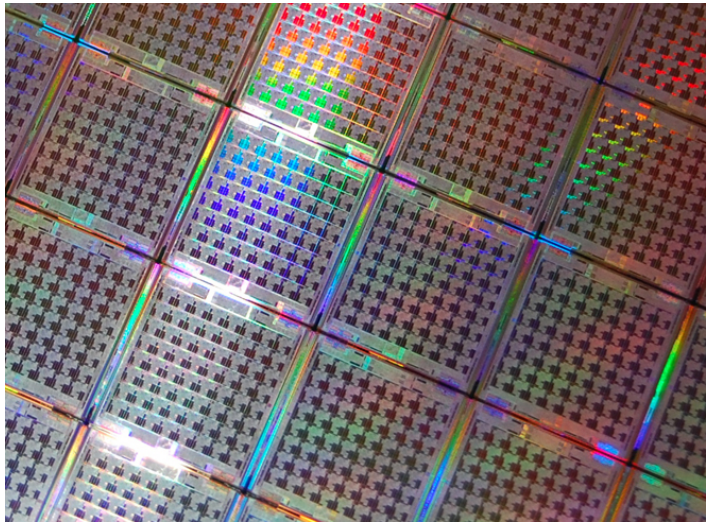


8 cores

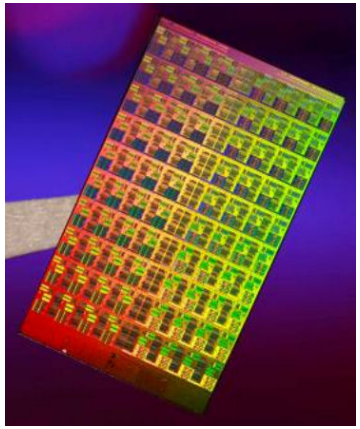


16 cores

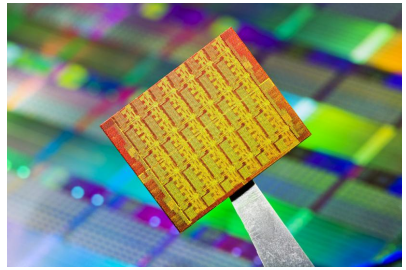




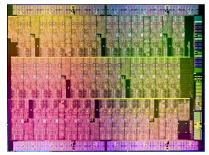
100 cores



80 cores



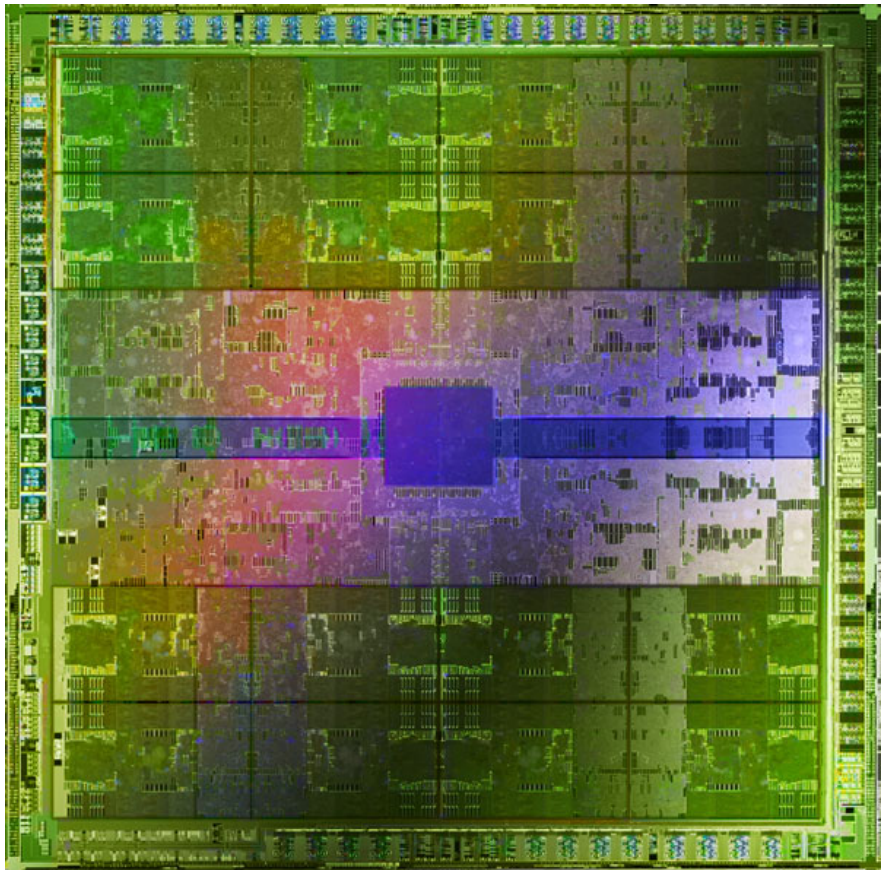
48 cores



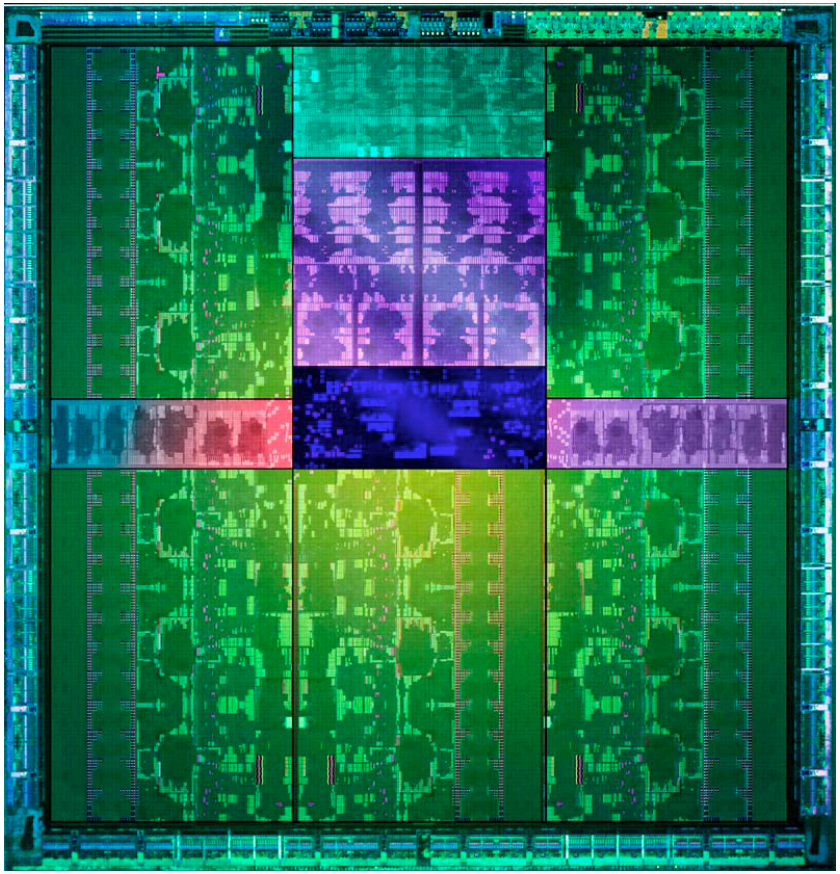
32 cores

Parallel Processor: GPU

NVIDIA



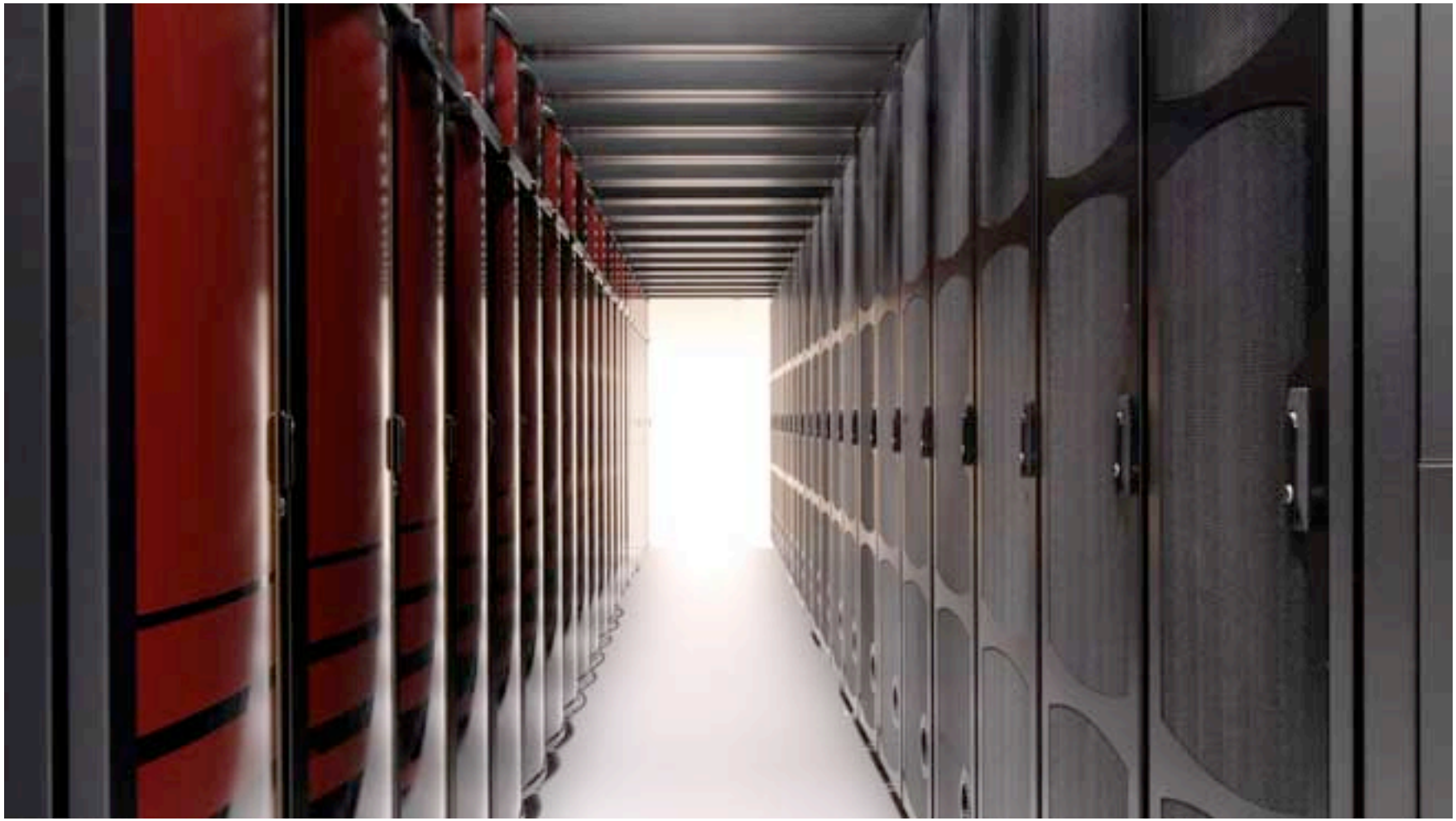
512 cores



1 536 cores

Parallel System: HPC

Tianhe-2



3 120 000 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

Outline

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

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

Pickings

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

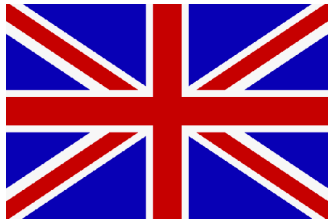
Hint (Lecture)

*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

Language of Instruction

(Ger.) *Unterrichtssprache*



- 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

- 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.

Lecture

- acquire new knowledge
  - prepare next reading on ones own initiative
  - attend presentation, listen, and discuss topics treated
  - reinforce learning matter, reflect
- 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
- 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])*

  - 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. 21) **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`

[3] abbr. for (Ger.) *Semesterwochenstunden*

Outline

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...

Reference List

[1] Aristotle:
Nicomachean Ethics.
c. 334 BC

[2] Corbató, F. J. ; Merwin-Daggett, M. ; Daley, R. C.:
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[3] Neufeldt, V. (Hrsg.) ; Guralnik, D. A. (Hrsg.):
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[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