

Concurrent Systems

Nebenläufige Systeme

I. Introduction

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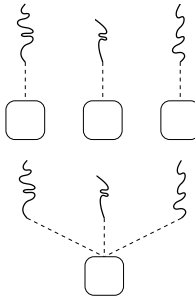
Abstract Concept

- meaning of the lecture labelling in linguistic terms [?]:
con·cur·rent (lat.) *concurrrens*: 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.) *systemas*: 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)
- 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 [?])
 - 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

asymmetric



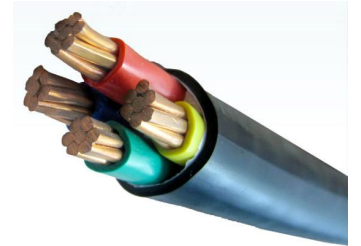
Parallel Processing

clustered & symmetric





- 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 [?]
 - mandatory at least for operating systems
- many-core processors make **core multiplexing** almost superfluous
 - unless **latency hiding** becomes an issue within a parallel process



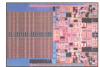
28 **cores**, uniformly distributed across four **tiles** 😊



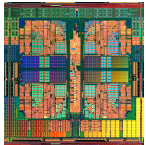
Parallel Processor: CPU

AMD, IBM, Intel, Tiler

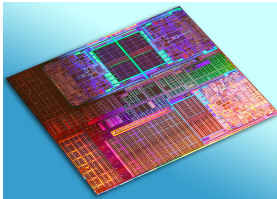
2 cores



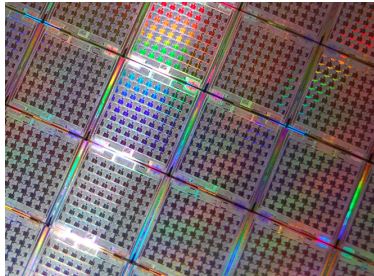
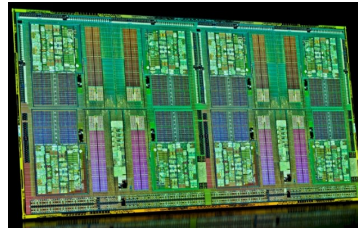
4 cores



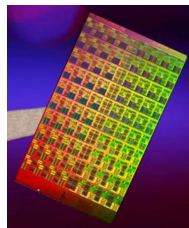
8 cores



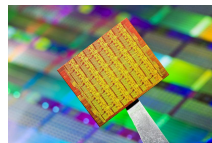
16 cores



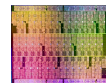
100 cores



80 cores



48 cores

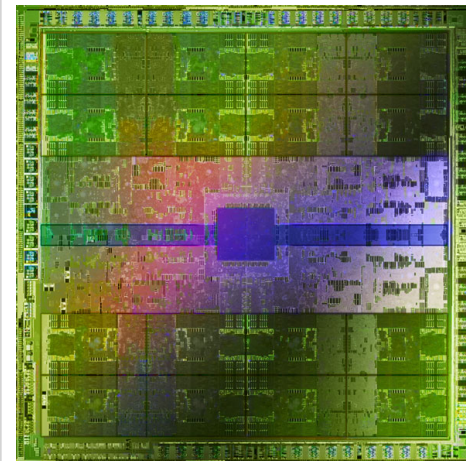


32 cores

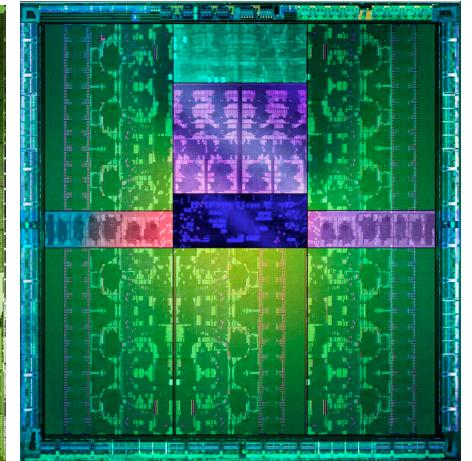


Parallel Processor: GPU

NVIDIA



512 cores

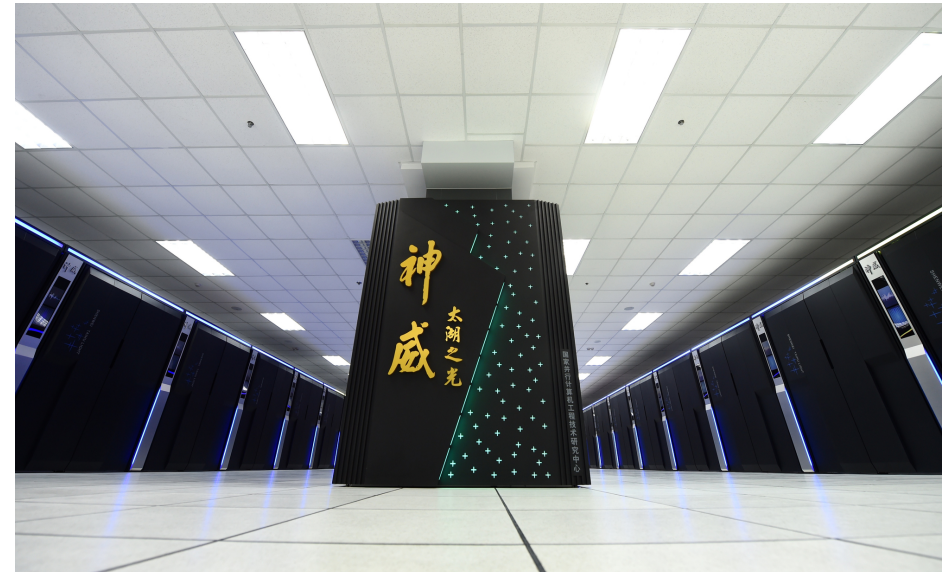


1536/3072 cores





3 120 000 cores



10 649 600 cores



Characteristic

Parallel Systems

- **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



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

Optimistic methods

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. current research work and advances in modern operating systems
 - remote-core locking [?], unlocking energy [?]
 - read-copy update [?], big kernel lock
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.*



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- 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 position¹
- written material (slides or handouts, resp.) will be English
 - with technical terms also stated in German, where applicable

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



Lecture

Meaningful Learning

- 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) 12
 - computer architecture (GRA) 13
 - system programming (SP, SPiC, GSPiC) 14
 - operating systems (BS), operating-systems engineering (BST) 14
 - real-time systems (EVS) 14
- 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>



Exercise

Experimental Learning

- 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 [?])

 - 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

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
- **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 SWS³ (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>

³abbr. 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...



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