Concurrent Systems

Nebenläufige Systeme

II. Concurrency

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October 25, 2016

Agenda

Preface

Causality
- Interdependencies
- Dimensions

Resource Sharing
- Principles
- Competition
- Synchronisation

Summary

Outline

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Subject Matter

- discussion on two fundamental **abstract concepts**:

  concurrency (Ger. *Nebenläufigkeit*)
  - designates the relation of causal independent events
  - is related to events that have no mutual influence

  causality (Ger. *Kausalität*, *Ursächlichkeit*)
  - designates the relation between cause and effect
  - is the causal chain or connection of two events

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Definition (concurrent)

Events occur or are concurrent if none is the cause of the other.

- explanation of the relation of these concepts to **resource sharing**
  - differentiated with respect to various types of resources and sharing
  - classified as to appropriate or necessary synchronisation paradigms

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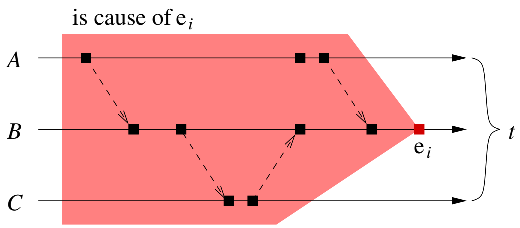
Principle of Causality

- causal chain of events related to some other event e_i:



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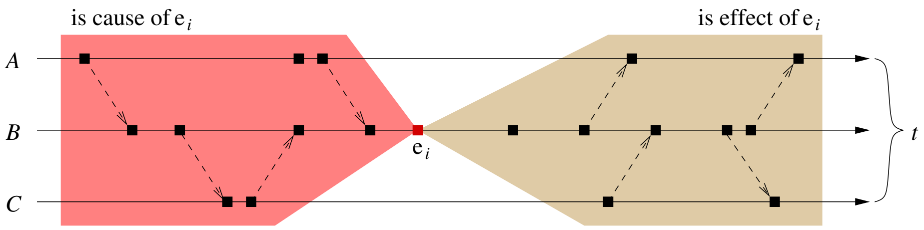

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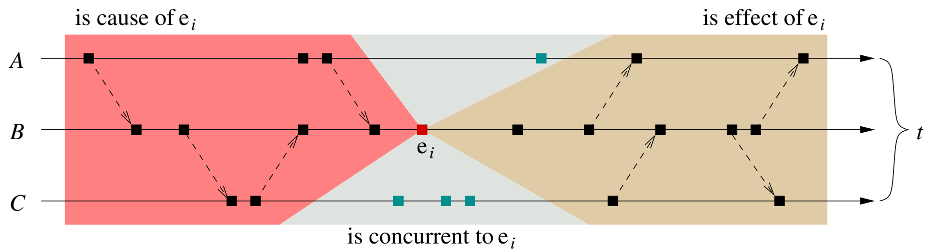

  - A, B and C denote some computation on a private or shared processor
- an event is concurrent to another event (e_i) if it lies in the elsewhere of the other event (e_i)
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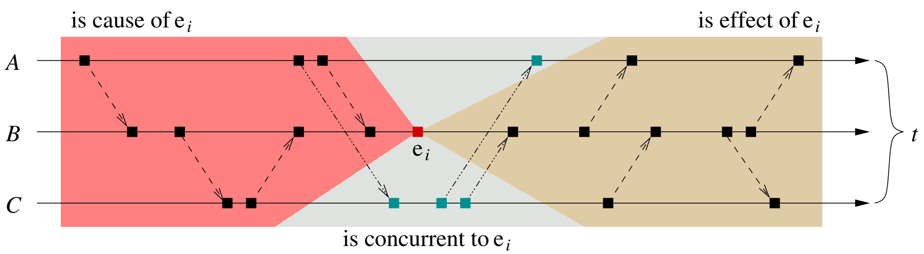

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- the event is neither cause nor effect of the other event (e_i)
  - as the case may be, it is cause/effect of other events (different from e_i) that are lying in the elsewhere (cf. dash-and-dot line)

Order of Precedence

- computations can be carried out concurrently provided that:

general
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  - non-existent **data dependencies**

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- interrelation of computations/events constrains concurrency

Event correlations v. Processing modes

"is cause of"
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"is concurrent to" ↦ parallel (realised in logical/real terms)

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↪ decrease of the portion of **sequential code** is an important aspect

Limits in the Degree of Concurrency

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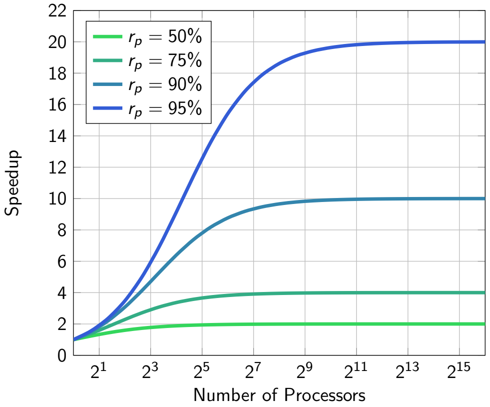
r_s ratio of sequential code

r_p ratio of parallel code, independent of n

n number of processors



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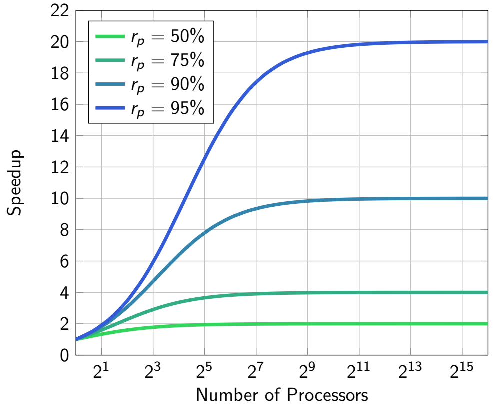

- speed-up will be constrained by **data management housekeeping**
  - the nature of this overhead appears to be sequential

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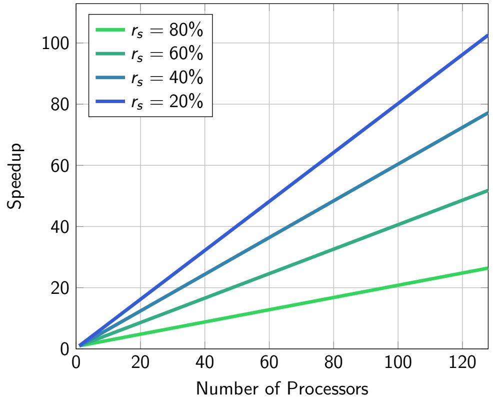

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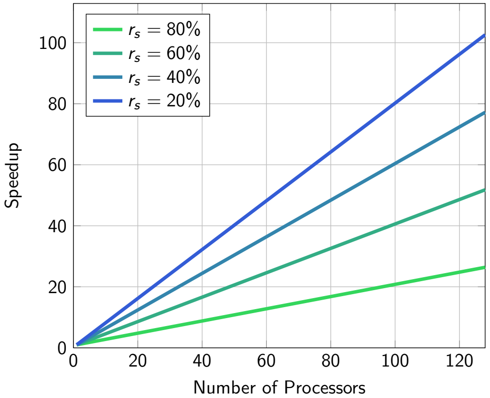

- data management housekeeping (serial part) becomes less important
  - in practise, the problem size scales with the number of processors: **HPC**[1]

[1] High Performance Computing

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- defined by the **causal order** (Ger. *Kausalordnung*) of the statements
  - as far as the logical dimension of a program is concerned
  - but there is also a **physical dimension**, namely when it comes to the execution of that program by a real processor ⇝ *level of abstraction*

Level of Abstraction

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    - the n-bit assignment on a $\frac{n}{2}$-bit machine, with $n = 16, 32, 64$
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↪ reveals a *race condition*, substantial critical situation: **error**

[2] real-time processing, especially in case of hard deadlines.

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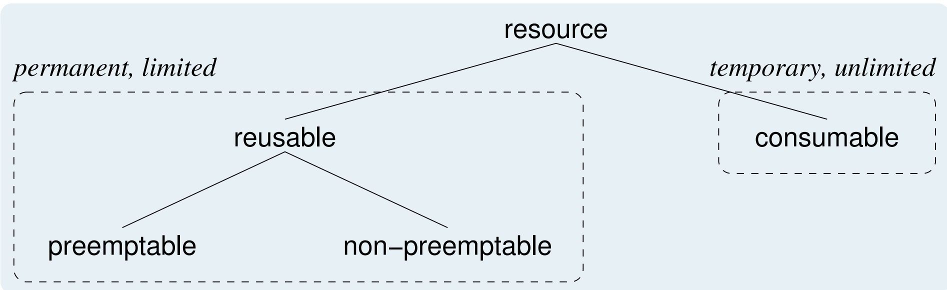
Resource Classification

analogically with [5, 6]



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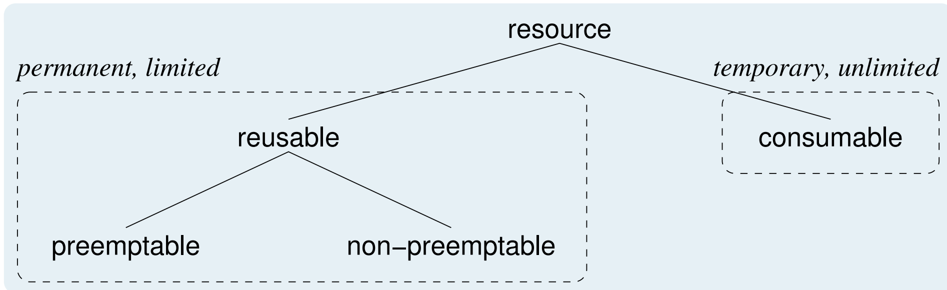

- permanent[3] resources are **reusable**, but always only of limited supply
  - they are acquired, occupied, used, and released (when no longer required)

    in-use resources: are preemptable or non-preemptable, depending on whether allocation to another occupant is possible
  - when non-preemptable, they are exclusively owned by an occupant

[3] Also referred to as "persistent".

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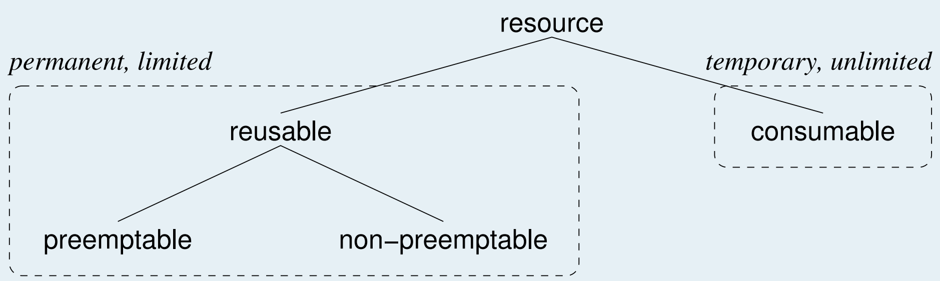

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- temporary resources are of unlimited supply, they are **consumable**
  - i.e. produced, received, used, and destroyed (when no longer required)

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Resource Peculiarities

- **hardware resources** as to be managed, e.g., by an operating system

reusable		consumable	
processor	CPU, FPU, GPU; MMU	signal	IRQ, NMI, trap
memory	RAM, scratch pad, flash		
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- reusable and consumable resources imply different **use patterns**

Resource Use Patterns

- if so, reusable resources are subject to **multilateral** synchronisation

- consumable resources are subject to **unilateral** synchronisation

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  - provided that the following two basic conditions (i.e., constraints) apply:
    - i resource accesses by computations may happen (quasi-) simultaneously
    - ii simultaneous accesses may cause a conflicting state change of the resource
  - simultaneous use of a **shared resource** this way must be coordinated
    - coordination may affect computations in a blocking or non-blocking manner[4]

[4] At the same level of abstraction, use of a shareable resource is exclusive in the blocking case or never refused in the non-blocking case.

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  - generally also referred to as logical or conditional synchronisation:
    - logical – as indicated by the "role playing" of the involved computations
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  - use of a **temporary resource** follows a causal course of events or actions
    - by affecting producers in a non-blocking and consumers in a blocking way
- simultaneous computations **overlap** in time, interfere with each other
  - they become critical in any case if they also overlap in (identical) place

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Consolidating Example

Character Buffer of Limited Size

- assuming that the following subroutines (put and get) are executed in any order and that they may also run simultaneously:

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char buffer[80];
unsigned in = 0, out = 0;

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- `put` and `get` must be subject to uni- and multilateral synchronisation
  - they are not concurrent under the assumption that was made above

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↪ in either case hardware resources and, if applicable, software resources too

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in++

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movl _in, %ecx
leal 1(%ecx), %eax
movl %eax, _in
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- simultaneous operations work on the same variable[5]

- the critical case may result in wrong reading (Ger. *Zählerwert*) of in/out
  - in++ or out++ are not concurrent to oneself, resp.: they are not **re-entrant**

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Establishing of Synchronism

cf. p. 28

- assure a conflict-prone complex operation of (logical) **indivisibility**

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blocking
- ensure synchronism at **operation start**
- lock potential overlapping out in the first place
- synchronised operation is made of sequential code

non-blocking
- ensure synchronism at **operation end**
- allow potential overlapping, achieve consistency afterwards
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- both approaches come in a variety of solutions to the same problem

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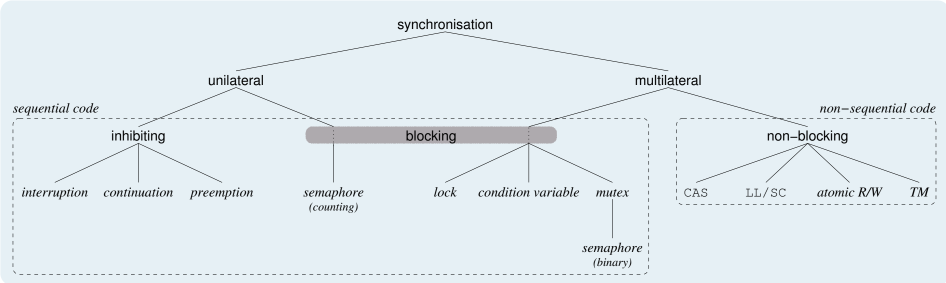

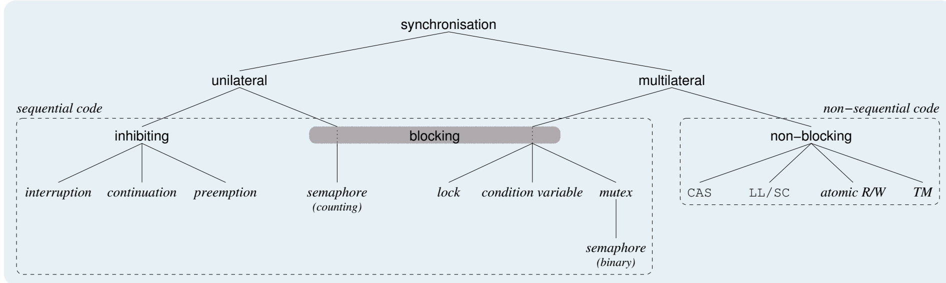

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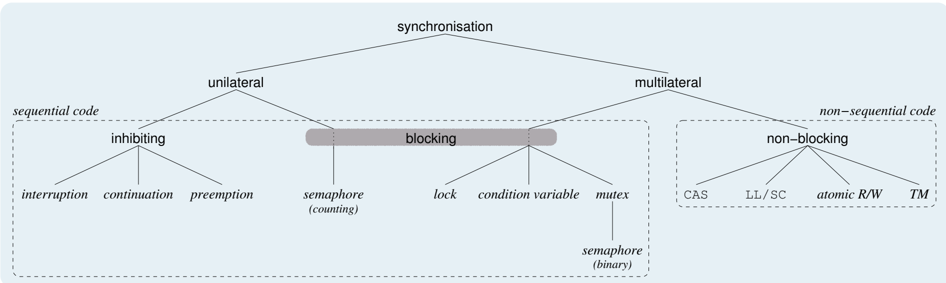

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- for the most part, the original code can be reused ☺

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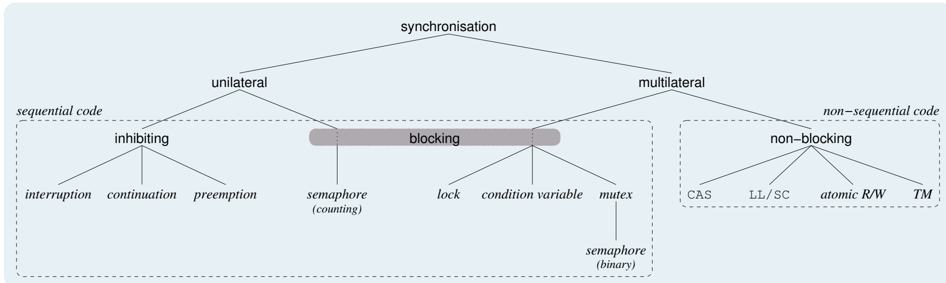

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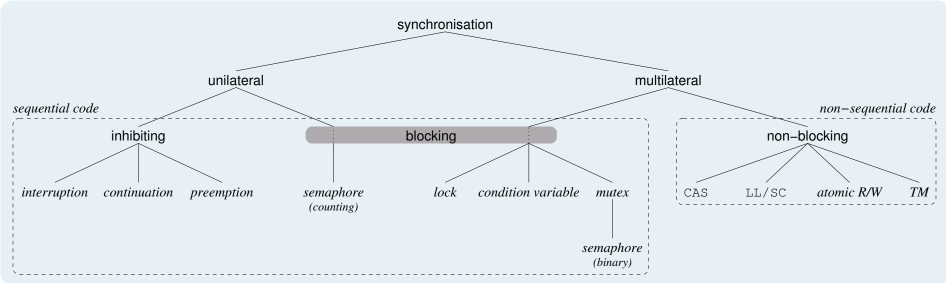
Varieties of Synchronisation



- the methods are more or less disruptive of the problematic operation:
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  - non-sequential
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    - for the most part, the original code cannot be reused ☹
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- wherever applicable, ***downsizing sequential code*** is basic
  - i.a. Amdahl's Law (cf. p. 8) argues for non-blocking synchronization

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    - prevents other computations from launching
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- it bears repeating: ***downsizing sequential code*** is basic
  - where possible, non-blocking synchronisation should be the first choice
- but even then: there is no all-in-one approach for every purpose. . .

Outline

Preface

Causality
- Interdependencies
- Dimensions

Resource Sharing
- Principles
- Competition
- Synchronisation

Summary

Abstract Concepts Revisited

- understanding (Ger.) ***Gleichzeitigkeit*** in its various meanings

concurrency = simultaneity — synchronism

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- happening together in time and place [7]
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  - but simultaneity my also cause overlapping that must be constrained
- synchronism ensures that overlapped complex operations do right
  - the individual sub-steps will be strictly executed *interim* (consecutively) *or*
  - a *transaction* will take care for consistent (pseudo-) parallel execution

Relativity of Simultaneity

Physics figuratively

- the concept of (distant) simultaneity is not absolute, but depends on the **frame of reference** (Ger. *Bezugssystem*) an observer takes
  - moving- and fixed-platform thought experiment [2, p. 768]:

> *The simultaneity of two distant events means a different thing to two different observers if they are moving with respect to each other.*

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    - while multiple invocations of the latter discretely can be concurrent, their logical correlation to the former makes them possibly not concurrent
  - operations must be resolved **cross-level** (from "fixed platform" observed) in order to realise their ability for concurrency or need for synchronism

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Résumé

- computations can be **concurrent** if none needs a result of the other
  - they must be free of data and control-flow dependencies
- in order to be concurrent, computations must be **simultaneous**
  - quasi-simultaneous through partial virtualization (hardware multiplexing) or real simultaneous by multiprocessing (hardware multiplication)
  - both techniques will induce computations to overlap in time and place
- **overlapping** in time cause interference but is the lesser of two evils
  - more critical is overlapping in place relating to the same resource
  - particularly with regard to the same (i.e., shared) memory area
- critical overlapping must be counteracted through **synchronisation**
  - i.e., coordination of the cooperation and competition between processes
  - here: uni- or multilateral synchronisation, depending on the resource type
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Reference List I

[1] Amdahl, G. M.:
Validity of the Single-Processor Approach to Achieving Large Scale Computing Capabilities.
In: *Proceedings of the AFIPS Spring Joint Computer Conference (AFIPS 1967 (Spring)*, AFIPS Press, 1967, S. 483–485

[2] Comstock, D. F.:
The Principle of Relativity.
In: *Science* 31 (1910), Mai 20, Nr. 803, S. 767–772.
`http://dx.doi.org/10.1126/science.31.803.767`. –
DOI 10.1126/science.31.803.767

[3] Dijkstra, E. W.:
Cooperating Sequential Processes / Technische Universiteit Eindhoven.
Eindhoven, The Netherlands, 1965 (EWD-123). –
Forschungsbericht. –
(Reprinted in *Great Papers in Computer Science*, P. Laplante, ed., IEEE Press, New York, NY, 1996)

[4] Gustafson, J. L.:
Reevaluating Amdahl's Law.
In: *Communications of the ACM* 31 (1988), Mai, Nr. 5, S. 532–533

Reference List II

[5] Holt, R. C.:
On Deadlock in Computer Systems.
Ithaca, NY, USA, Cornell University, Diss., 1971

[6] Holt, R. C.:
Some Deadlock Properties of Computer Systems.
In: *ACM Computing Surveys* 4 (1972), Sept., Nr. 3, S. 179–196

[7] Neufeldt, V. (Hrsg.) ; Guralnik, D. A. (Hrsg.):
Webster's New World Dictionary.
Simon & Schuster, Inc., 1988

Consolidating Example Revisited

cf. p. 16

- **bounded buffer** using a counting semaphore [3] for unilateral and an ELOP (x86) for multilateral synchronisation

```
typedef int semaphore_t;

extern void P(semaphore_t*);
extern void V(semaphore_t*);

semaphore_t free = 80;
semaphore_t empty = 0;

static inline int fai(int *ref) {
  int aux = 1;

  asm volatile("lock; xaddl %0,%1"
    : "=r" (aux), "=m" (*ref)
    :  "0" (aux),  "m" (*ref));

  return aux;
}
char buffer[80];
unsigned in = 0, out = 0;

void put(char item) {
  P(&free);
  buffer[fai(&in) % 80] = item;
  V(&empty);
}

char get() {
  char item;

  P(&empty);
  item = buffer[fai(&out) % 80];
  V(&free);

  return item;
}
```

free
- controls the number of unused buffer entries
- *P* prevents from buffer overflow, *V* signals reusable resource

empty
- controls the number of used buffer entries
- *P* prevents from buffer underflow, *V* signals consumable resource

fai
- indivisibly *fetch and increment* specified counter variable