

Concurrent Systems

Nebenläufige Systeme

II. Concurrency

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Agenda

Preface

Causality

Interdependencies

Dimensions

Resource Sharing

Principles

Competition

Synchronisation

Summary



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Causality

- Interdependencies

- Dimensions

Resource Sharing

- Principles

- Competition

- Synchronisation

Summary



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



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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



Outline

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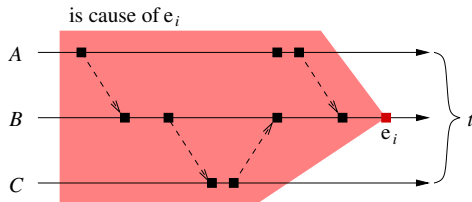
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Principle of Causality

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

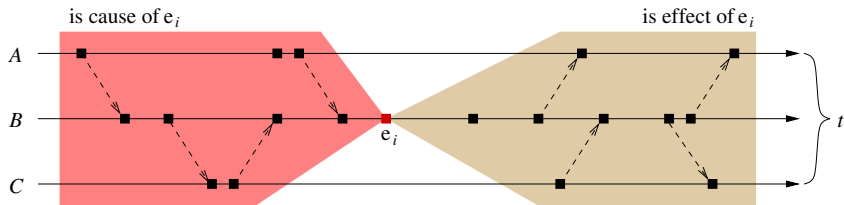


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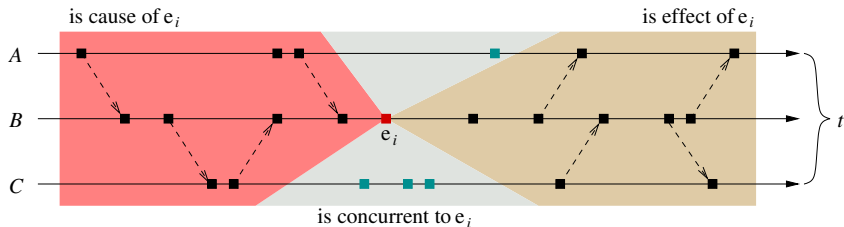


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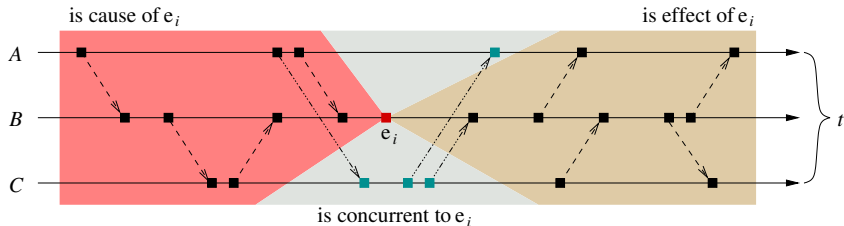


- A , B and C denote some computation on a private or shared processor
- an event is concurrent to another event (e_i) if it lies in the elsewhere of the other event (e_i)
- the event is neither cause nor effect of the other event (e_i)



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- an event is concurrent to another event (e_i) if it lies in the elsewhere of the other event (e_i)
- 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 ■ none requires a result of the other (cf. p. 23)
 - non-existent **data dependencies**



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 - special** ■ none depends on delays brought forth by the other
 - deadlines may be missed rarely or under no circumstances
 - periods may be stretched up to a certain limit or not at any time
 - non-existent **timing restrictions** $\leadsto$ *real-time processing*



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- interrelation of computations/events constrains concurrency

Event correlations v. Processing modes

$\left. \begin{array}{l} \text{"is cause of"} \\ \text{"is effect of"} \end{array} \right\} \mapsto \text{sequential} \text{ (realised before/at run-time)}$

$\text{"is concurrent to"} \mapsto \text{parallel} \text{ (realised in logical/real terms)}$



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Event correlations v. Processing modes

“is cause of”
“is effect of” } $\mapsto$ **sequential** (realised before/at run-time)

“is concurrent to” $\mapsto$ **parallel** (realised in logical/real terms)

$\hookrightarrow$ decrease of the portion of **sequential code** is an important aspect



Limits in the Degree of Concurrency

- Amdahl's Law [1]: speed-up (su) achievable by parallel processors
 - work load remains constant with the varying number of processors
 - aim at reducing overall computation time for a given fixed-size problem



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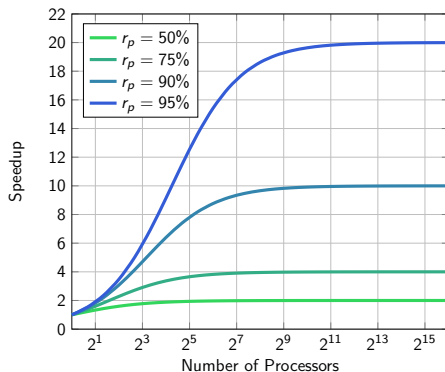
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$$\begin{aligned} su &= (r_s + r_p) / (r_s + \frac{r_p}{n}) \\ &= \frac{1}{r_s + \frac{r_p}{n}} \end{aligned}$$

r_s ratio of sequential code

r_p ratio of parallel code,
independent of n

n number of processors



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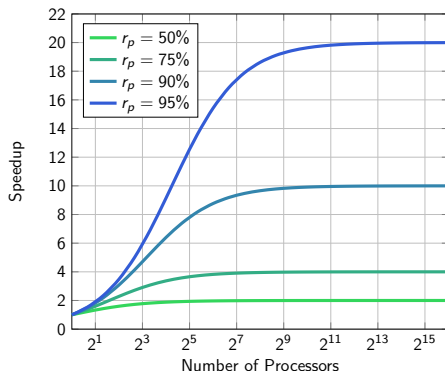
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- speed-up will be constrained by **data management housekeeping**
 - the nature of this overhead appears to be sequential



Limits in the Degree of Concurrency



Adapting the Work Load

- Gustafson's Law [4]: scaled speed-up (ssu), “hands-on experience”
 - work load varies linearly with the number of processors
 - aim at getting better results for a given fixed computation time



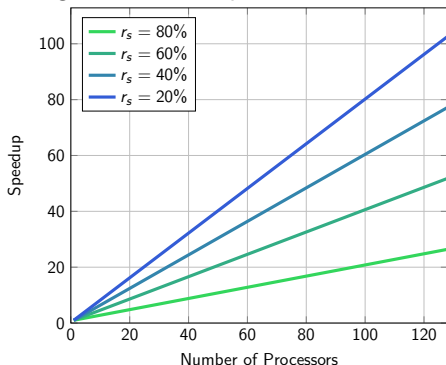
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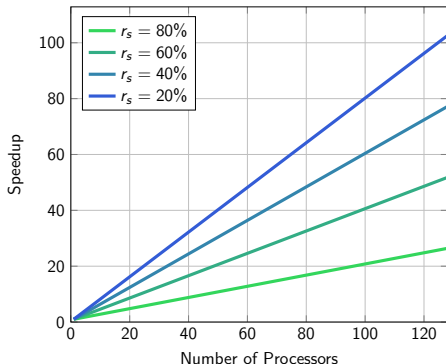
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- data management housekeeping (serial part) becomes less important
 - in practise, the problem size scales with the number of processors: **HPC**¹

¹High Performance Computing



Concurrent Operations of a Computation

- operations can be concurrent if none needs the result of the other



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1  int foo, bar;
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 - 6 and 7
 - 9 and 10
- which statements are not concurrent?
 - (6, 7) and (9, 10)
 - (9, 10) and 12



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 - as far as the logical dimension of a program is concerned



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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 $\leadsto$ *level of abstraction*



Level of Abstraction

- a concurrent operation (in logical terms) at a higher level can be sequential (in real terms) at a lower level

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Level of Abstraction

- a concurrent operation (in logical terms) at a higher level can be sequential (in real terms) at a lower level
 - the operation handles a resource that can be used only consecutively
 - a single memory area that is shared by multiple computations
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 - simultaneous executions are constrained by the resource characteristic



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- may result in a *performance penalty*, non-critical situation



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 - the operation appears to be complex, consists of multiple sub-steps
 - 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**

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



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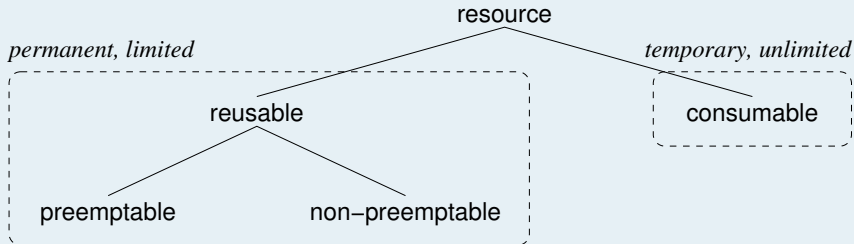
Principles

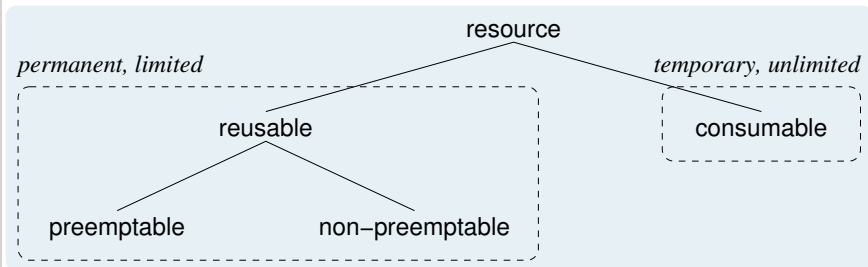
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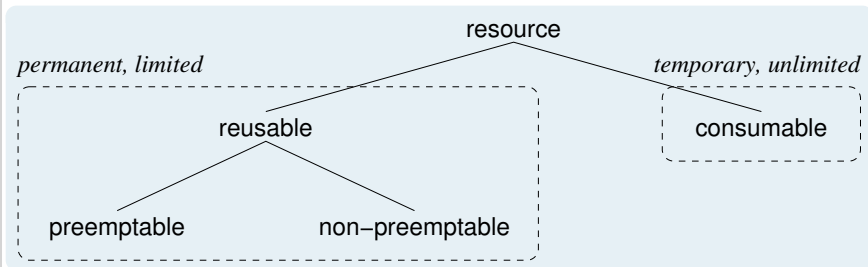




- permanent³ resources are **reusable**, but always only of limited supply
 - they are acquired, occupied, used, and released (when no longer required)
 - **in-use resources** are preemptable or non-preemptable, depending on whether allocation to another occupant is possible
 - when non-preemptable, they are exclusively owned by an occupant

³Also referred to as “persistent”.





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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

- processor ■ CPU, FPU, GPU; MMU
- 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



Resource Use Patterns

- if so, **reusable resources** are subject to **multilateral** synchronisation
 - 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 manner⁴

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



- **consumable resources** are subject to **unilateral** synchronisation
 - generally also referred to as logical or conditional synchronisation:
 - logical** – as indicated by the “role playing” of the involved computations
 - conditional** – as indicated by a condition for making computational progress
 - 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



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

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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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- both aspects, in turn, apply against the background of the following:
 - i the moment of an **simultaneous operation** is not predetermined
 - ii the operation in question is complex (i.e., consists of multiple steps)
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- simultaneous computations or operations, resp., are in competition:
 - they compete for the **sharing** of the same reusable resource(s)
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- the chosen synchronisation method should be *minimally invasive*



Divisibility in Temporal Respect

- when the steps of a complex operation may overlap at run-time
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 - as compiled from C to ASM (x86): `gcc -O3 -m32 -static -S`

`in++`

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1  movl  _in, %ecx
2  leal  1(%ecx), %eax
3  movl  %eax, _in
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- overlapping execution of `in++` and `out++`
 - simultaneous operations work on different variables⁵

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- critical** ■ self-overlapping execution of `in++` or `out++`, resp.
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- 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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 - 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
 - synchronised operation is made of non-sequential code

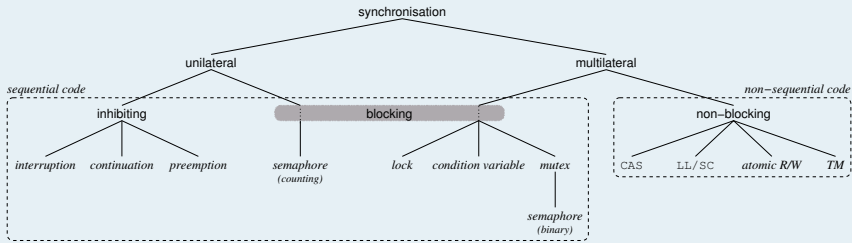
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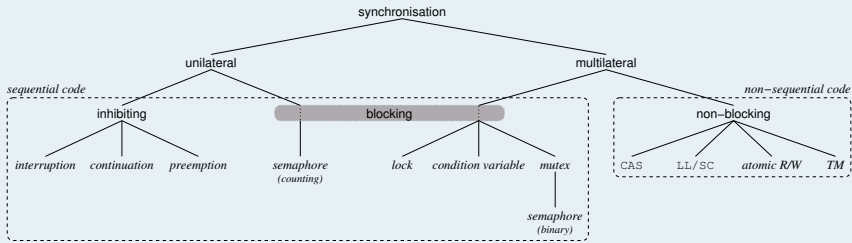


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- both approaches come in a variety of solutions to the same problem

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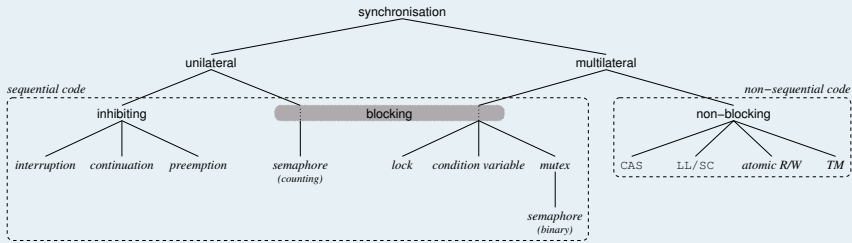






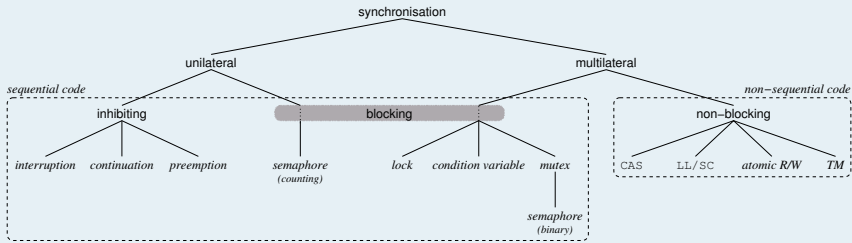
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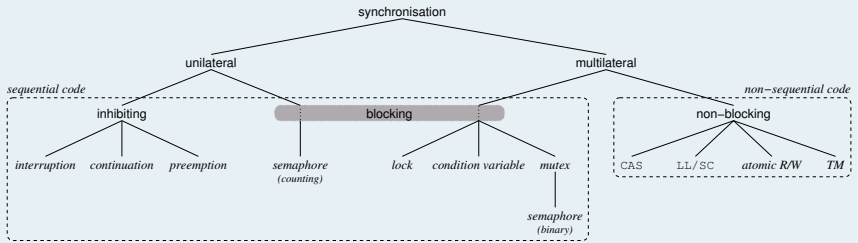
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non-sequential ■ reprogram sequential code as a **transaction** ☺

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- wherever applicable, **downsizing sequential code** is basic
 - i.a. Amdahl's Law (cf. p.16) argues for non-blocking synchronization



Synchronisation Behaviour

- effect of synchronisation procedures on the computations involved



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- effect of synchronisation procedures on the computations involved:
 - inhibiting
 - prevents other computations from launching
 - irrespective of the eventuality of co-occurrence
 - applies to consumable resources, only
 - running computations are not delayed



- effect of synchronisation procedures on the computations involved:

- blocking
 - delays computations subject to resource availability
 - takes effect only in case of co-occurrence (overlapping)
 - applies to reusable and consumable resources
 - running computations are possibly delayed



- effect of synchronisation procedures on the computations involved:

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- may force non-dominantly running computations to repeat
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 - 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



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



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 - concurrency ■ happening together in time and place [7]
 - designates the relation of causal independent events
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- occurring, done, existing together or at the same time [7]
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 - concurrency implies unconstrained overlapping in time and place
 - but simultaneity may 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



- 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 former will take place sequentially,⁷ the corresponding ones of the latter may come about non-sequentially
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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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- 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 virtualisation (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
- synchronisation ensures for **indivisibility** of a computation cycle
 - at the outset: physical, in blocking manner, by being pessimistic ☹️
 - at the road's end: logical, in non-blocking manner, by being optimistic 😊



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

```
1  typedef int semaphore_t;
2
3  extern void P(semaphore_t*);
4  extern void V(semaphore_t*);
5
6  semaphore_t free = 80;
7  semaphore_t empty = 0;
8
9  static inline int fai(int *ref) {
10     int aux = 1;
11
12     asm volatile("lock; xaddl %0,%1"
13         : "=r" (aux), "=m" (*ref)
14         : "0" (aux), "m" (*ref));
15
16     return aux;
17 }
18
19 char buffer[80];
20 unsigned in = 0, out = 0;
21
22 void put(char item) {
23     P(&free);
24     buffer[fai(&in) % 80] = item;
25     V(&empty);
26 }
27
28 char get() {
29     char item;
30
31     P(&empty);
32     item = buffer[fai(&out) % 80];
33     V(&free);
34
35     return item;
36 }
```

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

