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
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.
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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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Causality
  Interdependencies
  Dimensions

Resource Sharing
  Principles
  Competition
  Synchronisation

Summary
Principle of Causality

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

- is cause of $e_i$
- is concurrent to $e_i$
- is effect of $e_i$

$A$, $B$ and $C$ denote some computation on a private or shared processor
Principle of Causality

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

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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)

© wosch, thoenig  CS (WS 2018/19, LEC 2)  Causality – Interdependencies
computations can be carried out concurrently provided that:

- **general**
  - none requires a result of the other (cf. p. 10)
  - non-existent **data dependencies**
Order of Precedence

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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** $\sim$ **real-time processing**
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  - Non-existent timing restrictions \( \leadsto \text{real-time processing} \)

- Interrelation of computations/events constrains concurrency

### Event Correlations v. Processing Modes

- "is cause of" \( \mapsto \) sequential (realised before/at run-time)
- "is effect of" \( \mapsto \) sequential (realised before/at run-time)
- "is concurrent to" \( \mapsto \) parallel (realised in logical/real terms)
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**Event correlations v. Processing modes**

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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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su = \frac{r_s + r_p}{r_s + \frac{r_p}{n}} = \frac{1}{r_s + \frac{r_p}{n}}
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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
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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ssu = \frac{r_s + r_p \times n}{r_s + r_p} = r_s + r_p \times n = n + (1 - n) \times r_s
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- \( r_p \) ratio of parallel code, scales with \( n \)
- \( r_s, n \) as with Amdahl’s Law

---

**Graph:**

- Speedup vs. Number of Processors

- Lines for different \( r_s \) values:
  - Green: \( r_s = 80\% \)
  - Cyan: \( r_s = 60\% \)
  - Blue: \( r_s = 40\% \)
  - Black: \( r_s = 20\% \)

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Data management housekeeping (serial part) becomes less important in practice, the problem size scales with the number of processors: HPC
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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
Concurrent Operations of a Computation

Operations can be concurrent if none needs the result of the other.

```c
int foo, bar;

int sample(int tupel[2]) {
    int subtotal, product;
    foo = tupel[0];
    bar = tupel[1];
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    product = bar * foo;
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- which statements **can be** concurrent?
  - 6 and 7
  - 9 and 10
- which statements **are not** concurrent?
  - (6, 7) and (9, 10)
  - (9, 10) and 12

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 © wosch, thoenig
Concurrent Operations of a Computation

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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 \( \sim \) 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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  - a single memory area that is shared by multiple computations
  - a single communication bus that is shared by multiple processing units
- simultaneous executions are constrained by the resource characteristic
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- May result in a performance penalty, non-critical situation.
a sequential operation (in logical terms) at a higher level can be “concurrent” (i.e., non-sequential in real terms) at a lower level
- the operation appears to be complex, consists of multiple sub-steps
  - the \( n \)-bit assignment on a \( \frac{n}{2} \)-bit machine, with \( n = 16, 32, 64 \)
  - the addition of a number to a shared variable located in main memory
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- Simultaneous executions are constrained by the resource characteristic, which may result in a performance penalty.
  - In a non-critical situation, real-time processing, especially in case of hard deadlines.

\[ \rightarrow \]

- A concurrent operation (in logical terms) at a higher level can be sequential (in real terms) at a lower level.
  - Reveals a race condition, substantial critical situation.
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  reveals a race condition, substantial critical situation: error

\(^2\)real-time processing, especially in case of hard deadlines.
Resource Classification

Resource Classification

permanent, limited

reusable

preemptable

non-preemptable

temporary, unlimited

consumable

reusable

preemptable

non-preemptable

Also referred to as “persistent.”
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

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

\(^3\)Also referred to as “persistent”.
# Resource Peculiarities

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

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- **software resources** as to be managed by any other program
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    - data: variable, placeholder
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- reusable data resources are notably **container** for consumable resources
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- availability of the former constrains production/consumption of the latter
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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 manner

- **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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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:

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

void put(char item) {
    buffer[in++ % 80] = item;
}

char get() {
    return buffer[out++ % 80];
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```

in which buffer is a **reusable** and item is a **consumable** resource
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which logical problems exist?

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- values may be read from an empty buffer: underflow

overlapping writes may go to the same memory location similar to overlapping reads, but reverse overlapping auto-increments may manifest wrong values

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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simultaneous computations or operations, resp., are in competition:
- **sharing** of the same **reusable** resource(s)
- **handover** of the same **consumable** resource(s)
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- **handover** of the same **consumable** resource(s)

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

In either case, the chosen synchronisation method should be **minimally invasive**.
Serialisation of Simultaneous Computations

- simultaneous computations or operations, resp., are in competition:
  - **sharing** of the same reusable resource(s)
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- both aspects, in turn, apply against the background of the following:
  1. the moment of an **simultaneous operation** is not predetermined
  2. the operation in question is complex (i.e., consists of multiple steps)
  3. the characteristic of this operation is its **divisibility** in temporal respect

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Divisibility in Temporal Respect

- when the steps of a complex operation may overlap at run-time
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Divisibility in Temporal Respect

when the steps of a complex operation may overlap at run-time
- due to **simultaneous operation** (Ger. *Simultanbetrieb*)
- by way of example an auto-increment operator (cf. p.16):
  - as compiled from C to ASM (x86): `gcc -O3 -m32 -static -S`

```c
in++
1  movl  _in, %ecx
2  leal 1(%ecx), %eax
3  movl %eax, _in
```

```c
out++
4  movl  _out, %ecx
5  leal 1(%ecx), %eax
6  movl %eax, _out
```

non-critical overlapping execution of `in++` and `out++`

ritical self-overlapping execution of `in++` or `out++`, resp.
simultaneous operations work on the same variable

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

Assuming that processor registers are private to each computation.
Divisibility in Temporal Respect

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```assembly
in++
1 movl _in, %ecx
2 leal 1(%ecx), %eax
3 movl %eax, _in

out++
4 movl _out, %ecx
5 leal 1(%ecx), %eax
6 movl %eax, _out
```

**non-critical**
- overlapping execution of \texttt{in++} and \texttt{out++}
- simultaneous operations work on different variables\(^5\)

\(^5\)Assuming that processor registers are private to each computation.
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<table>
<thead>
<tr>
<th></th>
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- when the steps of a complex operation may overlap at run-time  
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- by way of example an auto-increment operator (cf. p.16):
  - as compiled from C to ASM (x86): `gcc -O3 -m32 -static -S`

```plaintext
in++
1 movl _in, %ecx
2 leal 1(%ecx), %eax
3 movl %eax, _in

out++
4 movl _out, %ecx
5 leal 1(%ecx), %eax
6 movl %eax, _out
```

- **non-critical**  
  - overlapping execution of in++ and out++
  - simultaneous operations work on different variables

- **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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5 Assuming that processor registers are private to each computation.
Establishing of Synchronism

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

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 interpret the equivalent computation as elementary operation (ELOP)
  an operation of indivisible cycle (Ger. zeitlicher Ablauf), apparently atomic
Establishing of Synchronism

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- indivisibility of a **cycle** is achieved through **synchronisation**,\(^6\) i.e.:
  - i coordination of the cooperation and competition between processes
  - ii calibration of real-time clocks or data in distributed systems
  - iii sequencing of events along the causal order

\(^6\)(Gr. *sýn*: synced, *chrónos*: time)
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Two fundamental approaches to synchronisation are distinguished:

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

\(^6\)(Gr. *sýn*: synced, *chrónos*: time)
Varieties of Synchronisation

Relevant to Operating Systems

Sequential code

Unilateral

Inhibiting

- Preemption
- Continuation
- Interruption

Blocking

- Semaphore (counting)
- Lock
- Condition variable
- Mutex

Multilateral

Non-sequential code

Non-blocking

- CAS
- LLC
- ATOMIC R/W
- TM

Synchronisation

- The methods are more or less disruptive of the problematic operation.
- Sequential: bracket sequential code by a locking protocol. For the most part, the original code can be reused.
- Non-sequential: reprogram sequential code as a transaction. For the most part, the original code cannot be reused.

Wherever applicable, downsizing sequential code is basic. I.A. Amdahl's Law (cf. p. 8) argues for non-blocking synchronisation.
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Varieties of Synchronisation

Relevant to Operating Systems

the methods are more or less disruptive of the problematic operation:

**sequential**
- bracket sequential code by a **locking protocol**
- for the most part, the original code can be reused
  - _pessimistic_, overlapping is **not** a rare event
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non-sequential
- reprogram sequential code as a **transaction** 😊
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Synchronisation Behaviour

- effect of synchronisation procedures on the computations involved

- inhibiting: prevents other computations from launching irrespective of the eventuality of co-occurrence
- blocking: delays computations subject to resource availability
takes effect only in case of co-occurrence (overlapping)
applies to reusable and consumable resources
loos running computations are possibly delayed

- non-blocking: 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...
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Outline

Preface

Causality
  Interdependencies
  Dimensions

Resource Sharing
  Principles
  Competition
  Synchronisation

Summary
understanding (Ger.) \textit{Gleichzeitigkeit} in its various meanings
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**Concurrency**
- happening together in time and place [7]
- designates the relation of causal independent events
- when none computation depends on results of the other
Abstract Concepts Revisited

concurrency = simultaneity − synchronism

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- synchronism: the individual sub-steps will be strictly executed
  - interim (consecutively)
  - a transaction will take care for consistent (pseudo-) parallel execution

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- fact of being synchronous; simultaneous occurrence \[7\]
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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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  - a simplistic operation (++) at a higher level may translate to a complex operation (*read-modify-write*) at a lower level
    - while multiple invocations of the former will take place sequentially,\(^7\) the corresponding ones of the latter may come about non-sequentially
    - while multiple invocations of the latter discretely can be concurrent, their logical correlation to the former makes them possibly not concurrent

\(^7\)Due to the fact that each one refers to an ELOP (cf. p. 19), logically.
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- 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
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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
[1] **Amdahl, G. M.**:
Validity of the Single-Processor Approach to Achieving Large Scale ComputingCapabilities.

[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.

[4] **Gustafson, J. L.**:
Reevaluating Amdahl’s Law.
In: *Communications of the ACM* 31 (1988), Mai, Nr. 5, S. 532–533
On Deadlock in Computer Systems. 
Ithaca, NY, USA, Cornell University, Diss., 1971

Some Deadlock Properties of Computer Systems. 
In: ACM Computing Surveys 4 (1972), Sept., Nr. 3, S. 179–196

Webster’s New World Dictionary. 
Simon & Schuster, Inc., 1988
bounded buffer using a counting semaphore [3] for unilateral and an ELOP (x86) for multilateral synchronisation

```c
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