Concurrent Systems

Nebenläufige Systeme

X. Guarded Sections

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Agenda

Preface

Hardware Events
  Fundamentals
  Sequencing
  Implementation

Process Events
  Fundamentals
  Sequencing
  Implementation

Summary
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Summary
discussion on abstract concepts as to structural measures suited in paving the way for non-blocking synchronisation

**guarded sections**  
- synchronise process-originated events

**pre-/postlude sections**  
- synchronise hardware-originated events

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both approaches common is the fact that processes of whichever kind will never be blocked at entrance to a critical section

■ however their requests to enter and pass through may be delayed

■ an **alternating sequencer** takes care of retroactive request processing

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Subject Matter

- discussion on abstract concepts as to **structural measures** suited in paving the way for non-blocking synchronisation
  - **guarded sections**  synchronise process-originated events\(^1\)
  - **pre-/postlude sections**  synchronise hardware-originated events
- both approaches common is the fact that processes of whichever kind will never be blocked at entrance to a critical section
  - however their requests to enter and pass through may be delayed
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  - this constrains overlapping and, thus, eases non-blocking request queues
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similar to an explicit (“eventual values” [8, 9]) or implicit **future** [2], it is shown how to deal with “direct-result critical sections”
- using concepts such as the **promise** [6] or promise pipelining [11]
- functional programming meets distributed computing for synchronisation

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one learns that guarded sections largely resemble conventional critical sections, but with a much more relaxed execution model

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Outline

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Interrupt Handling

Definition (Interrupt)

Mechanism of a (soft- or hardware) processor to prompt software to draw attention to an external process asynchronously, unpredictable, and unrepeatable.
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- a **sudden upcall** (acc. [3]) performed by a processor in the middle of or between actions, depending on the processor model
  - start of a simultaneous process on this very processor in **stacking** mode
  - most notably, this process is characteristic of a **run-to-completion** flow
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- as to operating systems, usually a **trinity** of problem-specific routines is to be considered—and assumed in the following:
  - **guardian**  
    - *interrupt-handler dispatcher* running at CPU priority
  - **prelude**  
    - *first-level interrupt handler* (FLIH) running at CPU/OS priority
  - **postlude**  
    - *second-level interrupt handler* (SLIH) running at OS priority
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  - **prelude** ✷ *first-level interrupt handler* (FLIH) running at CPU/OS priority
  - **postlude** ✷ *second-level interrupt handler* (SLIH) running at OS priority
- what all have in common is the **asynchronism** to the current process that was interrupted and will be delayed by their particular actions
In order to make **loss of interrupts** improbable, **CPU priority**⁴ must be cancelled and **OS priority**⁵ must be taken in minimum time.

⁴Interrupt requests of the same and lower priority are disabled.
⁵All interrupt requests are enabled.
**Hint (Interrupt Latency)**

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**prelude**  
- operates and “unloads” the device to satisfy the IRQ source  
- starts immediately if enabled by the CPU priority  
- as the case may be, releases its postlude for post-processing
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Relevance of Postlude

**Hint (Asynchronous System Trap, AST [10, p. 414])**

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- a mechanism that forces an interrupted process back into system mode:
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prelude

risk of race conditions and system-stack overflow

postlude

risk of race conditions $\leadsto$ synchronisation or reentrancy

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    2. in the moment when the interrupt handler guardian terminates (i.e., returns)
  - as if this very process performs a system call to the interrupt postlude
- caution is advised when an **interrupt-handler control flow** expands
  - guardian: not applicable, controls prelude and postlude (i.e., an AST)
  - prelude: risk of race conditions and system-stack overflow
  - postlude: risk of race conditions $\rightsquigarrow$ **synchronisation** or reentrancy
- purpose of the postlude is to safely allow such control-flow expansions
  - its activation is controlled similar to the control of guarded sections
heading for postlude execution depends on the particular prelude

- a prelude is a **function**, its return value indicates the postlude to be run
- a return value of **NULL** indicates that this prelude asks for no postlude
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according to the model, an interrupt indeed causes a new process but not a new process instance
- the guardian is such a process, it operates in the name of the interrupted process instance and commands no own context
- same applies for the sequencer, it is an optional **guardian continuation** and takes care for safe postlude processing
Overlapping Pattern

not unlike the guarded section as to process events described below (cf. p. 20), but with the following fundamental differences:

- simultaneous requests to run through a guarded section occur stack-wise
- processing start as to delayed (i.e., pending) passage requests is AST-like
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regarding the whole processing chain and the involvement of guardian and sequencer process one may realise:

- the guardian (incl. prelude) enqueues postludes possibly simultaneously, but never dequeues them
- the sequencer dequeues postludes possibly overlapped by enqueues, but these dequeues will never overlap enqueues performed by the guardian
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- this **multiple-enqueue/single-dequeue** mode of operation eases the design of a non-blocking synchronised postlude queue
__attribute__((fastcall)) void guardian(long irq) {
    static usher_t tube = { 0, {0, &tube.load.head} };
    extern remit_t *(*flih[])(usher_t *);
    remit_t *task;

    #ifdef __FAME_INTERRUPT_EDGE_TRIGGERED__
    pivot(&tube.busy, +1); admit(IRQ); /* take OS priority */
    #endif

    task = (*flih[irq])(&tube); /* activate prelude & satisfy IRQ source */

    #ifdef __FAME_INTERRUPT_LEVEL_TRIGGERED__
    pivot(&tube.busy, +1); admit(IRQ); /* take OS priority */
    #endif

    if (tube.busy > 1) { /* sequencer is already on duty */
        if (task != 0) deter(&tube, task); /* enqueue postlude & */
        avert(IRQ); /* leave with CPU priority */
    } else { /* bring sequencer into service */
        if ((task != 0) && (tube.load.head.link == 0)) remit(task);

        avert(IRQ);
        while (tube.load.head.link != 0) {
            admit(IRQ); /* take OS priority, again */
            flush(&tube); /* forward pending postludes */
            avert(IRQ); /* leave with CPU priority */
        }
    }

    pivot(&tube.busy, -1); /* leave critical section */
}
assuming that simultaneous enqueues can happen only in a **stacking arrangement**, then the following is “thread safe”:

```c
void chart_ms_lfs(queue_t *this, chain_t *item) {
    chain_t *last;

    item->link = 0; /* terminate chain: FIFO */

    last = this->tail; /* settle insertion point */
    this->tail = item; /* create new partial list */

    while (last->link != 0) /* overlapping enqueue! */
        last = last->link; /* find end of orig. list */

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idea is to create a new partial list using an **atomic store** and, thus, isolate the original list for later safe manipulation

- but simultaneous enqueues then may shift the **actual insertion point**
Lock-Free Synchronised Dequeue

chain_t *fetch_ms_lfs(queue_t *this) {
    chain_t *item;

    if ((item = this->head.link) /* next item fetched */
        && !(this->head.link = item->link)) {
        this->tail = &this->head; /* is last one, reset */
        if (item->link != 0) { /* overlapping enq.! */
            chain_t *help, *lost = item->link;
            do { /* recover latecomers */
                help = lost->link; /* remember next & */
                chart_ms_lfs(this, lost); /* rearrange */
            } while ((lost = help) != 0);
        }
    }

    return item;
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        }
    }

    return item;
}
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- critical is dequeuing as to the **last element** and overlapped by one or more enqueues, thus, filling up the queue again
- one moment the fetched item was last, now latecomers must be recovered
Lock-Free Synchronised Dequeue

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Some process will complete an operation in a finite number of steps, regardless of the relative execution speeds of the processes. [7, p. 142]

Hint (Lock Freedom)

```
```
void chart_ms_wfs(queue_t *this, chain_t *item) {
    chain_t *last;
    item->link = 0;  /* terminate chain: FIFO */
    last = FAS(&this->tail, item);
    last->link = item;  /* eventually append item */
}

chain_t *fetch_ms_wfs(queue_t *this) {
    chain_t *item = this->head.link;
    if (item) {  /* check for last item */
        if (item->link)  /* is not, non-critical */
            this->head.link = item->link;
        else if (CAS(&this->tail, item, &this->head))
            CAS(&this->head.link, item, 0);
    }
    return item;
}

with the following mapping to GCC atomic intrinsic functions:

#define FAS(ref,val) __sync_lock_test_and_set(ref, val)
#define CAS __sync_bool_compare_and_swap
in the **pre-/postlude model**, sequencer becomes that process in the context of which interrupt handling is carried out

- more precisely, the process at the bottom of an interrupt-handler stack
- put differently, the interrupted process that “activated” the guard (p. 9)
Recapitulation

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Hint (Pro-/Epilogue [14, 13])

At first glance, interrupt handler pre-/postludes seemingly resemble the pro-/epilogue model. While this is quite true for preludes, it does not hold for postludes. Epilogue execution is a synchronous event as to the interrupted kernel-level process, in contrast to postludes.
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- postlude guide through is not unlike **procedure chaining** [12, p. 10], a technique to serialize execution of conflicting threads
  - differences are due to the constrained pre-/postlude overlapping pattern
  - unless stack-based scheduling [1], any process overlapping is assumed
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This similarity gives reason to think about a **generalisation** of the pre-/postlude model to synchronise **process-instance** events
in structural respect not unlike conventional critical sections, but as
to its flow model very different and non-blocking

```c
{ future tobe; /* value container & promise */

  guarded(tobe) *task = { /* future as parameter */
    /* compute promised value 'item', part 1 */

    if (!phase(ewd)) break; /* conditional synchr. */

    /* compute promised value 'item', part 2 */

    task->tobe.prove(item); /* fulfil promise */
  }

  tobe.exact(); /* await fulfilment of promise */
}
```

key aspect is that a process never blocks incoming a guarded section,
but its request to pass through that section may be delayed
Conditional Fire-and-Forget Pattern

- processes heading for passing through a critical section will proceed unstopped, though simultaneous **passage requests** are serialised
- at the end of a critical section, these requests will be processed one a time
processes heading for passing through a critical section will proceed unstopped, though simultaneous passage requests are serialised at the end of a critical section, these requests will be processed one at a time accordingly, the exit protocol does not have to take care of blocked processes but rather intermediately incurred passage requests the particular leaving process attends to handle accumulated entry calls thus, critical-section execution is asynchronous to its requesting process
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1. as additional element of the corresponding passage request, a placeholder for the computation result (\textit{consumable resource}) and
2. a signalling mechanism to indicate result delivery (\textit{logical synchronisation})
Conditional Fire-and-Forget Pattern

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  - at the end of a critical section, these requests will be processed one at a time accordingly, the exit protocol does not have to take care of blocked processes but rather intermediately incurred passage requests.
  - the particular leaving process attends to handle accumulated entry calls.
  - thus, critical-section execution is asynchronous to its requesting process.

- in case of data dependencies as to the computation within a critical section, synchronisation on result delivery becomes necessary.
  - thereto, computation results need to be returned and accepted by proxy.
  - to this end, the following measures have to be provided:
    - as additional element of the corresponding passage request, a placeholder for the computation result (consumable resource) and
    - a signalling mechanism to indicate result delivery (logical synchronisation).

- in the final analysis, critical sections are twofold, namely one that is procedure- and another one that is function-like.
  - with the former delivering no direct result, in contrast to the latter.
fall back on known **linguistic concepts** in order to pattern a solution for the above-mentioned problem:

**future**  ■ the *promise* to deliver a value at some later point in time [2]
■ read-only placeholder object created for a not yet existing result
■ the result is computed concurrently and can be later collected
Handling of a Critical-Section Function

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  - **promise**  - traced back to [6], a writeable, single-assignment container\(^2\)
    - can be used to successfully complete a future with a value

\(^2\)Refined for *promise pipelining* [11] to overcome latency in distributed systems.
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- each future instance has a dedicated **resolver** taking care of (a) value assignment and (b) **promise states**:

  - **kept**
    - value computed, assignment took place
  
  - **broken**
    - computation aborted, assignment ceases to take place
  
  - **pending**
    - process in progress, assignment did not just yet take place

\(^2\)Refined for *promise pipelining* [11] to overcome latency in distributed systems.
Handling of a Critical-Section Function

- fall back on known **linguistic concepts** in order to pattern a solution for the above-mentioned problem:
  - **future** - the *promise* to deliver a value at some later point in time [2]
  - read-only placeholder object created for a not yet existing result
  - the result is computed concurrently and can be later collected

- **promise** - traced back to [6], a writeable, single-assignment container\(^2\)
  - can be used to successfully complete a future with a value

- each future instance has a dedicated **resolver** taking care of (a) value assignment and (b) **promise states**:
  - **kept** - value computed, assignment took place
  - **broken** - computation aborted, assignment ceases to take place
  - **pending** - process in progress, assignment did not just yet take place

- based on these states, a process is able to synchronise on the **event** that the promise to deliver a value was either kept or broken
  - the resolver (process inside the critical section) acts as producer
  - the future using process acts as consumer ↦ **signalling semaphore**

\(^2\)Refined for *promise pipelining* [11] to overcome latency in distributed systems.
Execution Sequencing of Critical Sections

- **Requester**
- **Guard**
- **Guarded Section**
- **Queue**
- **Critical Section**
- **Sequencer**

**Guarded Section**

- **Guard**
- **Queue**

**Sequence of Events**

1. **Unoccupied**
   - Guard grants requester access to the critical section.
   - The critical section becomes occupied by the requester.

2. **Occupied**
   - Guard denies requester access to the critical section.
   - The request gets queued and the requester bypasses the critical section depending on the request-queue state.

3. **Empty**
   - Critical section becomes unoccupied, the process continues.

4. **Full**
   - The actual leaving process becomes sequencer and re-enters the critical section for each queued request.
heading for a critical section depending on the state of occupancy:

- **unoccupied**
  - guard grants requester access to the critical section
  - the critical section becomes occupied by the requester

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leaving a critical section depending on the **request-queue state**:

- **empty**
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- **full**
  - the actual leaving process becomes sequencer and re-enters the critical section for each queued request
A passage request may refer to a multi-elementary future object:

i. A promise indicator (kept, broken, pending)
ii. A placeholder of problem-specific type as to the critical section
iii. A binary semaphore that is used in producer/consumer mode, i.e., a signalling semaphore applicable by different processes.

In case of a direct-result critical section, the sequencer takes the part of a resolver that also have to signal the "kept" or "broken" state. V does the signalling and by means of P the signal can be consumed.

Guarded section

Critical section

Queue

Sequencer

Requester

Future
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- $V$ does the signalling and by means of $P$ the signal can be consumed
Execution Characteristics of the Critical Section

- Critical sections controlled by processes in a **run-to-completion style** can be handled straightforwardly.

**Definition (Run to Completion (Process))**

A potentially preemptive process free from self-induced wait states as to the possible non-availability of reusable or consumable resources.
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- Processes interacting with an **internal process** due to **resource sharing**.

Both styles of execution concern the period of a critical section, only but at large, a process may be classified run to completion and stopover.
critical sections controlled by processes waiting on events caused by external processes can be handled straightforwardly
- as the external process, in order to making progress, does not depend on any internal process or state of any critical section
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Run-to-Stopover for Peer Processes

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  - thus, interaction between external and internal processes is **non-critical**
- unlike **internal processes**, provided that they have to interact with their peers using **shared resources** inside a critical section

---

3 Have peripherals (i.e., I/O devices) in mind to understand external processes. Production of input data using a keyboard, mouse, network card, disk, or sensor, for example, is not caused by an OS-controlled **producer-process instance**.
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- as a consequence, **precautions** must be taken for interacting internal processes—similar to signalling inside monitors [15, p. 9]
  - without clearing the guarded section, a **stopover process** may deadlock

---

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Overlapping Pattern

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i. requesters of any guarded section may overlap each other

ii. self-overlapping of a sequencer is impossible

iii. only sequencers of different guarded sections may overlap each other
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  - furthermore, synchronisation then happens to be even **wait-free** [5]
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**Hint (Wait Freedom)**

*Any process can complete any operation in a finite number of steps, regardless of the execution speeds of the other processes.* [7, p. 124]
typedef struct guard {
    bool busy;                /* state: initial false */
    queue_t load;             /* pending passage requests */
    indicator_t *hint;        /* sequencer blocked-on event */
} guard_t;
typedef struct guard {
    bool busy; /* state: initial false */
    queue_t load; /* pending passage requests */
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} guard_t;

locking (\textit{clasp}) and unlocking (\textit{loose}) of a guarded section:

\begin{verbatim}
inline bool clasp(guard_t *this) {
    return this->busy || TAS(&this->busy);
}

inline void loose(guard_t *this) {
    this->busy = false;
}
\end{verbatim}

- \textit{clasp} is a \textbf{test-and-test-and-set} (TATAS) to mitigate \textbf{bus lock bursts}
- note that the TAS-part should be mapped to CAS or LL/SC, resp.
  - the former or a CISC- and the latter for a RISC-type of processor
inline bool vouch(guard_t *this, order_t *work) {
    bool busy = clasp(this);
    if (busy)
        chart(&this->load, &work->next);
    return busy == false;
}

inline order_t *clear(guard_t *this) {
    order_t *next;
    if ((next = (order_t *)fetch(&this->load)) == 0)
        loose(this);
    return next;
}
inline bool vouch(guard_t *this, order_t *work) {
    bool busy = clasp(this);
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clearing, as shown here, is prone to the **lost update** problem:

10  ■ the process just leaving the critical section finds no pending passage request and will lose the guarded section next

11  ■ but before the guarded sections is loosened, a simultaneous process comes in and attempts claiming it

■ another passing request is generated—and may get lost forever
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using an **indicator** for the “art of waiting” (p. 42) of the sequencer

```c
inline bool phase(guard_t *this, indicator_t *hint) {
    enroll(hint); /* expect external event */
    loose(this);  /* leave guarded section */
    repose(hint); /* receive external event */
    return clasp(this); /* retry to enter... */
}
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```

2. the sequencer indicates interest in receiving an external signal,
3. leaves the guarded section—but pending requests still may exist,
4. will block (if signal is pending) or continue (if signal occurred),
5. and, finally, reapplies for passing through the guarded section
   - further action is context-dependent and better up to the **phase** caller
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if **reaplication** fails, the current process is no longer sequencer
- during the waiting period, another process entered the guarded section
- thus, the current process must leave the guarded section or synchronise
Watch for External Processes

using an **indicator** for the “art of waiting” (p. 42) of the sequencer

```cpp
inline bool phase(guard_t *this, indicator_t *hint) {
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5. and, finally, reapplyes for passing through the guarded section
   - further action is context-dependent and better up to the **phase** caller

- if **reapplication** fails, the current process is no longer sequencer
- during the waiting period, another process entered the guarded section
- thus, the current process must leave the guarded section or synchronise
- as requests may be and remain still pending, waiting on respective internal processes is problematic ~ **trailing conditional wait**
inline void trail(guard_t *this, indicator_t *hint) {
    enroll(this->hint = hint);
}

inline order_t *clear(guard_t *this) {
    order_t *next;
    if ((next = (order_t *) fetch(&this->load)) == 0) {
        indicator_t *hint;
        if ((hint = this->hint)) this->hint = 0;
        loose(this);
        if (hint) repose(hint); /* block or continue */
    }
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**deadlock hazard** due to potential of a **lost update** (cf. p. 26):

7–10 **hazard zone** of missing meanwhile arriving passage requests

9 fetch and reset wait indicator, as an indivisible “guarded” operation

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**Trailing Conditional Wait**

**Watch for Ex-/Internal Processes**

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    if ((next = (order_t *)fetch(&this->load)) == 0) {
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        if ((hint = this->hint)) this->hint = 0;
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    }
    return next;
}
```

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---

Private Study

- prevent lost update & deadlock hazard

---

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CS (WS 2014, LEC 10)  
Process Events – Implementation
typedef struct order {
  chain_t next;  /* passage-request chaining */
  item_t post;   /* argument placeholder */
} order_t;
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layout of an **argument vector** for passage-request parameters:

typedef union item {
    long (*lump)[];  /* argument vector (N > 1) */
    long sole;  /* single argument (N = 1) */
} item_t;

- depending on the number of parameters, the structure describes a multi- or uni-element argument vector
- in the multi-element case, the argument vector is placed adjacent to its item or order, resp., instance (cf. p. 43)
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- in the multi-element case, the argument vector is placed adjacent to its item or order, resp., instance (cf. p. 43)
- in addition, this vector also serves as placeholder for a future value
fore editing of passage-request parameters, optional:

1
order_t * task = order (2);
/* two parameters */

2
(* task -> post . lump )[0] = (long) index ;

3
(* task -> post . lump )[1] = value ;

entry protocol, agreement on the sequencer process:

4
extern guard_t gate ;

5
if ( vouch (& gate , task ))
do
/* enter section */

midsection (i.e., actual critical section)

6
extern indicator_t hint = { 0 };
/* initial : block */

7
trail (& gate , & hint );
/* block in clear */

8
/* alternatively or combined , depending on what suits */

9
if (! phase (& gate , & hint ))
break;
/* block in-place */

exit protocol, processing of pending passage requests:

10
while (( task = clear (& gate )));
/* leave section */
fore editing of passage-request parameters, optional:

```c
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besides logical synchronisation in the **midsection**, any other programming statements are doable as well—like in conventional critical sections
Outline

Preface

Hardware Events
   Fundamentals
   Sequencing
   Implementation

Process Events
   Fundamentals
   Sequencing
   Implementation

Summary
Résumé

- guarding of critical sections at operating-system as well as instruction set architecture level and in a non-blocking manner
  - processes are never delayed at entrance of an already occupied critical section, however their requests to pass through
  - not unlike procedure chaining, but also supporting in-line functions at both levels, overlappings as to simultaneous processes result in a multiple-enqueue/single-dequeue model of request handling
  - the sequencer will be the only process being in charge of dequeuing that is, the continuation of a requester (lev. 3) or the guardian (lev. 2)
  - whereby this continuation is commander-in-chief of a critical section when a requester process requires a direct result from the sequencer process, interaction in a consumer/producer-style takes place
  - in such a case, the respective request is associated with a future object it carries the promise of the sequencer to deliver a result to the requester a future-specific signalling semaphore then indicates result availability besides supporting conventional critical sections, this approach eases design of non-blocking synchronised non-sequential programs

© wosch  CS (WS 2014, LEC 10)  Summary
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- besides supporting conventional critical sections, this approach eases design of non-blocking synchronised non-sequential programs

\(^4\)Operating-system machine or instruction set architecture level, respectively.
Résumé

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  - not unlike procedure chaining, but also supporting in-line functions at both levels, overlappings as to simultaneous processes result in a multiple-enqueue/single-dequeue model of request handling
  - the sequencer will be the only process being in charge of dequeuing that is, the continuation of a requester (lev. 3) or the guardian (lev. 2)\(^4\)
  - whereby this continuation is commander-in-chief of a critical section when a requester process requires a direct result from the sequencer process, interaction in a consumer/producer-style takes place
    - in such a case, the respective request is associated with a future object it carries the promise of the sequencer to deliver a result to the requester
    - a future-specific signalling semaphore then indicates result availability

- besides supporting conventional critical sections, this approach eases design of non-blocking synchronised non-sequential programs

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\(^4\)Operating-system machine or instruction set architecture level, respectively.
Résumé

- guarding of critical sections at operating-system as well as instruction set architecture level and in a non-blocking manner
  - processes are never delayed at entrance of an already occupied critical section, however their requests to pass through
  - not unlike procedure chaining, but also supporting in-line functions at both levels, overlappings as to simultaneous processes result in a multiple-enqueue/single-dequeue model of request handling
  - the sequencer will be the only process being in charge of dequeuing
  - that is, the continuation of a requester (lev. 3) or the guardian (lev. 2)
  - whereby this continuation is commander-in-chief of a critical section when a requester process requires a direct result from the sequencer process, interaction in a consumer/producer-style takes place
    - in such a case, the respective request is associated with a future object
    - it carries the promise of the sequencer to deliver a result to the requester
    - a future-specific signalling semaphore then indicates result availability
- besides supporting conventional critical sections, this approach eases design of non-blocking synchronised non-sequential programs

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4 Operating-system machine or instruction set architecture level, respectively.
[1] Baker, T. P.:
Stack-Based Scheduling of Realtime Processes.

The Incremental Garbage Collection of Processes.
In: Low, J. (Hrsg.): Proceedings of the 1977 ACM Symposium on Artificial Intelligence and Programming Languages.

[3] Clark, D. D.:
The Structuring of Systems Using Upcalls.
In: Baskett, F. (Hrsg.); Birrell, A. (Hrsg.); Cheriton, D. (Hrsg.):
Proceedings of the Tenth ACM Symposium on Operating System Principles (SOSP ’85).

Guarded Commands, Nondeterminacy and Formal Derivation of Programs.
In: Communications of the ACM 18 (1975), Aug., Nr. 8, S. 453–457
[5] **Drescher, G. ; Schröder-Preikschat, W.**:
*Guarded Sections: Structuring Aid for Wait-Free Synchronisation.*
2015. – Scheduled for publication

[6] **Friedman, D. P. ; Wise, D. S.**:
The Impact of Applicative Programming on Multiprocessing.
In: *Proceedings of the International Conference on Parallel Processing (ICPP 1976).*

[7] **Herlihy, M.**:
Wait-Free Synchronization.
In: *ACM Transactions on Programming Languages and Systems 11* (1991), Jan.,
Nr. 1, S. 124–149

[8] **Hibbard, P.**:
Parallel Processing Facilities.
A Language Implementation Design for a Multiprocessor Computer System. 

[10] Leffler, S. J.; McKusick, M. K.; Karels, M. J.; Quarterman, J. S.: 
The Design and Implementation of the 4.3 BSD UNIX Operating System. 
Addison-Wesley, 1989. – 
ISBN 0–201–06196–1

Promises: Linguistic Support for Efficient Asynchronous Procedure Calls in Distributed Systems. 
New York, NY, USA: ACM, 1988. – 


In: Lehrstuhl Informatik 4 (Hrsg.): Concurrent Systems. FAU Erlangen-Nürnberg, 2014 (Lecture Slides), Kapitel 8
Guardian Insulating and Invoking

_joint:
  pushl %ecx  # save volatile register
  movl $0, %ecx # pass IRQ number
_jointN:       # come here for IRQ number N > 0
  pushl %edx  # save another volatile register
  pushl %eax  # ditto
  call _guardian # fastcall to guardian
  popl %eax   # restore volatile register
  popl %edx   # ditto
  popl %ecx   # ditto
  iret        # resume interrupted process

each IRQ entry in the CPU exception vector is associated with a joint

_joint42:
  pushl %ecx  # save volatile register
  movl $42, %ecx # pass IRQ number
  jmp _jointN  # switch to common joint section...
**Simple Interrupt Handler**

- **first-level interrupt handler (FLIH), at CPU/OS priority (p. 11, l. 7)**

```c
remit_t *prelude(/*optional*/ usher_t *tube) {
    static remit_t task = {{}, postlude};
    /* Come here for device pre-processing &
    * device-related IRQ acknowledgement. */
    deter(tube, &task); /* force postlude to queue */
    return 0;          /* don’t request shortcut */
}
```

- without l.5, **postlude shortcut (p. 11, l. 20)** goes with `return &task`

- **second-level interrupt handler (SLIH), at OS priority (p. 11, l. 7/13)**

```c
void postlude(/*optional*/ order_t *todo) {
    /* Come here for device post-processing &
    * any asynchronous system interaction. */
    V((semaphore_t *)todo->post.sole);
}
```

- **system interaction means: to *vouch* for guarded sections (cf. p. 30)**
Interrupt-Handler Guard

a **doorman** (Ger. *Pförtner*) for guarded sections at the low level of handling asynchronous program interrupts, a **specialised guard**:

```c
typedef guard_t usher_t;

inline void deter(usher_t *tube, remit_t *task) {
    chart(&tube->load, &task->data.next);
}

inline remit_t *untie(usher_t *tube) {
    return (remit_t *)fetch(&tube->load);
}

inline void flush(usher_t *tube) {
    remit_t *next;
    do if ((next = untie(tube))) remit(next);
    while (next != 0);
}
```

- with queue synchronisation style: `#define __FAME_SYNC_ITS__`
  - resulting in “{chart,fetch}_ms_lfs” or “_wfs”, resp.
Job Definition and Start

- a SLIH or an interrupt-handler postlude, resp., is a **passage request** (cf. p. 29) attended by a procedure address
  - that is to say, a request object with implicit processing method

```c
typedef struct remit {
    order_t data;  /* parameter set */
    void (*code)(order_t *);  /* procedure address */
} remit_t;

inline void remit(remit_t *this) {
    (*this->code)(&this->data);  /* run that job */
}
```

- at process-event level, this structure specifies different **parameterised critical sections** associated with the same guarded section
  - it allows for **procedure chaining** similar to that of Synthesis [12, p. 10]
straightforward is the use of a **signalling semaphore**:\(^5\):

```c
typedef semaphore_t indicator_t;
inline void enroll(indicator_t *hint) { }
inline void repose(indicator_t *hint) { P(hint); }
inline void arouse(indicator_t *hint) { V(hint); }
```

- note that a semaphore has **memory semantics** with regard to signals
- thus, awaiting a signal by means of \(P\) once a sequencer process released
  the guarded section is free of the lost-wakeup problem
- a \(V\) saves the signalling event in the semaphore, causing \(P\) to continue

another option is falling back on the **event queue** [15, p. 17]:
- just if one wants to implement \(P\) and \(V\) as a guarded section, for example

```c
typedef event_t indicator_t;
inline void enroll(indicator_t *hint) { catch(hint); }
inline void repose(indicator_t *hint) { coast(); }
inline void arouse(indicator_t *hint) { cause(hint); }
```

\(^5\)A **binary semaphore** used in a producer/consumer style of interaction.
inline order_t *order(unsigned long n) {
    order_t *item;
    if (n < 2)
        item = (order_t *) malloc(sizeof(order_t));
    else {
        item = (order_t *) malloc(sizeof(order_t) + n * sizeof(long));
        if (item)
            item->post.lump = (void *) ((long)item + sizeof(*item));
    }
    return item;
}

inline void ditch(order_t *item) {
    free(item);
}

in order to decrease latency and lower overhead, specialisation towards
the use of an order pool is recommended
void alert(void *index, long value) {
    extern guard_t gate;    /* guard instance */
    order_t *task = order(2); /* order of 2 parameters */

    (*task->post.lump)[0] = (long)index;
    (*task->post.lump)[1] = value; /* request filled */

    if (vouch(&gate, task)) do {    /* try to pass */
        extern semaphore_t sign;    /* to await clearance */

        backup(&task->post); /* buffer and display data */
        printf("order %p with [%p, %lu]\n", task,
               (*task->post.lump)[0], (*task->post.lump)[1]);

        ditch(task); /* delete current request */
        if (!phase(&gate, &sign)) break; /* clearance? */
    } while ((task = clear(&gate))); /* next request? */
}

- for **trailing conditional wait**, line 16 reads: trail(&gate, &sign);
a future object is the promise—of a guarded section, here—to deliver a result at some later point in time:

```
typedef enum status {  
PENDING, KEPT, BROKEN  
} status_t;
```

```
typedef struct promise {  
  status_t bond; /* processing state */  
  item_t item; /* future-value placeholder */  
} promise_t;
```

whereby the promise is a result placeholder, on the one hand, and keeps track of the status of result delivery, on the other hand.
```c
inline status_t probe(future_t *this) {
    return this->data.bond;
}

inline void trust(future_t *this) { enroll(&this->gate); }

inline item_t *exact(future_t *this) {
    repose(&this->gate);
    return probe(this) == KEPT ? &this->data.item : 0;
}

inline void bring(future_t *this, status_t bond) {
    this->data.bond = bond;
    arouse(&this->gate);
}

inline void prove(future_t *this, item_t *item) {
    this->data.item = *item;
    bring(this, KEPT);
}

inline void abort(future_t *this) { bring(this, BROKEN); }
```