Concurrent Systems

Nebenläufige Systeme

VIII. Monitor

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November 27, 2014
Agenda

Preface

Fundamentals
    Mutual Exclusion
    Condition Variable
    Signalling Semantics

Implementation
    Data Structures
    Use Case
    Operations

Summary
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Summary
discussion on **abstract concepts** as to “a shared variable and the set of meaningful operations on it” [7, p. 121]:

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  - associates a set of procedures with a shared variable
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  - i  check that only these procedures are carried out on that variable  
  - ii ensure that the respective operations exclude each other in time


Subject Matter

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- one or more special variables that do “not have any stored value accessible to the program” [12, p. 550]
- used to indicate and control a particular wait mode
- for the respective process inside the monitor
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in functional terms, get to know “monitor” as fundamental means of synchronisation independent of linguistic features
- explanation of various styles: Hansen, Hoare, Concurrent Pascal, Mesa
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- in functional terms, get to know “monitor” as fundamental means of synchronisation independent of linguistic features
  - explanation of various styles: Hansen, Hoare, Concurrent Pascal, Mesa
  - according to this, schematic representation of implementation variants
  - demonstrate basic functions of a fictitious (language) run-time system
for all advantages, semaphores are to be approached with caution:
- too low level, programmers must keep track of all calls to $P$ and $V$
- although different, used for both uni- and multilateral synchronisation
Motivation

Semaphore Considered Harmful

for all advantages, semaphores are to be approached with caution:
- too low level, programmers must keep track of all calls to $P$ and $V$
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out of it, various design and languages concepts originated:
- secretary idea for structuring control of sharing [5, p. 135–136]
- critical region mutual exclusive use of a shared variable [6]
- event variable a shared variable associated with an event queue [6]
- path expressions synchronisation rules within type definitions [2]
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- synchronisation rules within type definitions [2]
- **class-like** synchronised data type [7, 12, 14]
- inspired by SIMULA 67 [4, 3]
- first implemented in Concurrent Pascal [9]
- comes in a characteristic of many kinds [1, 10]
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■ first implemented in Concurrent Pascal [9]
■ comes in a characteristic of many kinds [1, 10]

however, the concept is beyond a programming-language construct
■ it is fundamental for system programming and system-level operation

Hint (Monitor [7, p. 121])

*The purpose of a monitor is to control the scheduling of resources among individual processes according to a certain policy.*
Outline

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  Mutual Exclusion
  Condition Variable
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Summary
key aspect is to facilitate solely indirect access to shared variables by means of **monitor procedures**
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- by definition, these procedures have to execute by mutual exclusion
  - on behalf of the calling process, the procedure prologue applies for exclusive occupation of the monitor \( \leadsto \) lockout simultaneous processes
  - on behalf of the occupying process, at return the procedure epilogue releases the monitor again \( \leadsto \) proceed locked processes, if any
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usually, a compiler is in charge of ejecting the procedure pro- and epilogue

- only infinite loops or hardware failures may prevent epilogue execution
- only constructs beyond the **frame of reference** may force abnormality\(^1\)

\(^1\)Thinking of a multi-language system.
Class Concept Expanded by Coordination

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- in logical respect, deadlocks due to programmed absence of unblocking of critical sections are impossible

- accordingly, instructions for synchronisation are cross-cutting concern of the monitor and no longer of the whole non-sequential program

- particularly, instructions to protect critical sections are not made explicit

- given that foreign-language synchronisation primitives cannot be used

---

1 Thinking of a multi-language system.
multilateral (blocking) synchronisation is implicit basis of a monitor, but *unilateral synchronisation* needs to be made explicit
multilateral (blocking) synchronisation is implicit basis of a monitor, but \textbf{unilateral synchronisation} needs to be made explicit

Hansen proposed to attach a shared variable to an \textit{event} \cite[p. 577]{6}

- with \textit{cause} and \textit{await} as intrinsic functions for event signalling
Intentional Process Delay

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- proposed a non-attached *condition variable* [12, p. 550]
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    - but signalling is non-effective (void) if no process would be waiting on it.
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- In this spirit, the **signalling convention** makes the wide difference and affects structuring of monitor-based non-sequential programs [13].
Signalling Conventions

- explicit signal operation assumed
Signalling Conventions

cf. [13]

explicit signal operation assumed, \textbf{signal-and-}\(\phi\), with \(\phi\) indicating the behaviour of the signalling process as follows:

\begin{itemize}
  \item \textbf{wait} \hspace{1cm}
    \begin{itemize}
      \item join monitor \textbf{entrance queue} and leave the monitor
      \item resume all signalled processes (one at a time)
      \item re-enter the monitor, compete against all processes
    \end{itemize}
  \end{itemize}

\vspace{1cm}
in case of absence of a signal primitive, signalling may still happen:

\begin{itemize}
  \item automatic
    \begin{itemize}
      \item leave the monitor and re-evaluate waiting conditions
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Signalling Conventions

- explicit signal operation assumed, **signal-and-φ**, with φ indicating the behaviour of the signalling process as follows:

  **urgent wait**
  - join **preferential queue** and leave the monitor
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  - re-enter the monitor, enjoy priority over entrant processes
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explicit signal operation assumed, \textbf{signal-and-}φ, with φ indicating the behaviour of the signalling process as follows:

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explicit signal operation assumed, **signal-and-\(\phi\)**, with \(\phi\) indicating the behaviour of the signalling process as follows:

- **continue**
  - carry on holding the monitor, keep inside the procedure
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in case of absence of a signal primitive, signalling may still happen:

- \textbf{automatic}  
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a main issue is the \textbf{control transfer} between signaller and signallee

\textbf{Waiting inside a monitor}

Without leaving the monitor, another process is unable to signal.
Atomicity of Control Transfer

- consequence for the **ownership structure** of monitor and signaller:
  - change
    - signal and wait, urgent wait, or return
  - keep
    - signal and continue or automatic signalling
Atomicity of Control Transfer

- consequence for the ownership structure of monitor and signaller:
  - change  ■ signal and wait, urgent wait, or return
  - keep    ■ signal and continue or automatic signalling
- with an indivisible change in ownership a signallee has guarantee on
  the still effective invalidation of its waiting condition

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- **wait**
  - only for one out of possibly many signalled processes
  - if applicable, the order of process resumption is undefined
  - a resumed signallees may change the condition for the others
  - makes re-evaluation of the waiting condition necessary

\[
\text{while (!condition), wait: tolerant to false signalisation}
\]
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- with an **indivisible change** in ownership a signallee has guarantee on the still effective invalidation of its waiting condition:

  **urgent wait**  ■ exactly for the single signalled process
  ■ by definition, the process to be resumed is predetermined
  ■ no other process can re-establish the waiting condition
  ■ makes re-evaluation of the waiting condition unnecessary
  
  \[
  \text{if (!condition), wait: intolerant to false signalisation}
  \]

  **return**  ■ *ditto*
Atomicity of Control Transfer

- consequence for the **ownership structure** of monitor and signaller:
  - **change** signal and wait, urgent wait, or return
  - **keep** signal and continue or automatic signalling
- with an **indivisible change** in ownership a signallee has guarantee on the still effective invalidation of its waiting condition:
  - **wait** only for one out of possibly many signalled processes
    - if applicable, the order of process resumption is undefined
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    - makes re-evaluation of the waiting condition necessary
  - **urgent wait** exactly for the single signalled process
    - by definition, the process to be resumed is predetermined
    - no other process can re-establish the waiting condition
    - makes re-evaluation of the waiting condition unnecessary
  - **return** ditto
- keeping ownership by the signaller means fewer context switches and, thus, less background noise but higher (signal) allocation latency
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Summary
typedef struct monitor {
    semaphore_t mutex; /* initial {1} */
#ifdef __FAME_MONITOR_SIGNAL_URGENT_WAIT__
    lineup_t urgent; /* urgent waiting signallers */
#endif
} monitor_t;

typedef struct condition {
    monitor_t *guard; /* enclosing monitor */
    lineup_t event; /* signal-waiting processes */
} condition_t;
typedef struct monitor {
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typedef struct condition {
    monitor_t *guard; /* enclosing monitor */
    lineup_t event; /* signal-awaiting processes */
} condition_t;

data type used for keeping track of waiting processes (cf. p. 18):

typedef struct lineup {
    int count; /* number of waiting processes */
    event_t crowd; /* wait-for event */
} lineup_t;
Monitor Procedures

Functional Interface

```c
extern void lockout(monitor_t*);  /* enter monitor */
extern void proceed(monitor_t*);   /* leave monitor */
extern void watch(condition_t*);   /* wait on signal */
extern void spark(condition_t*);   /* signal condition */
```

consider these operations an additional **run-time system** element for a compiler of a “concurrent C-like” programming language

- calls to `lockout` and `proceed` will be automatically generated as part of the pro- and epilogue of the respective monitor procedure
- similarly, calls to `watch` and `spark` will be generated for the corresponding applications of condition variables
- in addition, instances of type `monitor` and `condition` will be automatically ejected, too, by the code generation process of such a compiler
Monitor Procedures

Functional Interface

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Consider these operations an additional run-time system element for a compiler of a “concurrent C-like” programming language:

- Calls to lockout and proceed will be automatically generated as part of the pro- and epilogue of the respective monitor procedure.
- Similarly, calls to watch and spark will be generated for the corresponding applications of condition variables.
- In addition, instances of type monitor and condition will be automatically ejected, too, by the code generation process of such a compiler.
- Further improvements [12, p. 551] are imaginable to also better reflect the different signalling semantics.
a bounded buffer is controlled by a pair of condition variables:

```
#include "monitor.h"

#define BUF_SIZE 80

typedef struct buffer {
    condition_t space;  /* control of reusables */
    condition_t data;   /* control of consumables */
    char store[BUF_SIZE]; /* reusable resource */
    unsigned in, out;   /* store housekeeping */
    unsigned count;     /* wait/signal condition */
} buffer_t;
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instantiation of the necessary monitor and condition variables:

static monitor_t storehouse = {1};  /* monitor is free */
static buffer_t buffer = {
    &storehouse}, {&storehouse}       /* actual buffer */
};
```
handmade monitor procedure to put one item into the buffer:

```c
void put(char item) {
    lockout(&storehouse);  /* procedure prologue */
    {
        while (buffer.count == BUF_SIZE)
            watch(&buffer.space);

        buffer.store[buffer.in] = item;
        buffer.in = (buffer.in + 1) % BUF_SIZE;
        buffer.count += 1;

        spark(&buffer.data);
    }
    proceed(&storehouse);  /* procedure epilogue */
}
```

2–3  ■ monitor **entrance**, usually to be generated by a compiler
4–11 ■ **body** of monitor procedure, to be programmed by a human
12–13 ■ monitor **exit**, usually to be generated by a compiler
handmade monitor procedure to get one item out of the buffer:

```c
char get() {
    char item;

    lockout(&storehouse); /* procedure prologue */
    {
        while (buffer.count == 0) watch(&buffer.data);

        item = buffer.store[buffer.out];
        buffer.out = (buffer.out + 1) % BUF_SIZE;
        buffer.count -= 1;

        spark(&buffer.space);
    }
    proceed(&storehouse); /* procedure epilogue */

    return item;
}
```

- monitor entrance and exit and body of monitor procedure as before
a classic monitor implementation on **event queue** basis is considered:

```c
typedef struct event { } event_t;

extern void catch(event_t *);    /* expect event */
extern int coast();                /* wait for event */
extern int await(event_t *);      /* catch & coast */
extern int cause(event_t *);      /* signal event */
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a classic monitor implementation on \textbf{event queue} basis is considered:

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\textit{catch} makes the process unsusceptible against \textbf{lost wakeup}:

\begin{enumerate}
  \item non-effective in case of cooperative scheduling, otherwise
  \item inhibits preemption or dispatching (SMP), resp., or
  \item notifies event sensibility to potential signalers (\textit{cause})
\end{enumerate}

\textit{cause} ensures that a process in running state is detectable by \textit{cause}
Event Queue

Classical Technique for Monitor Implementation

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**catch** makes the process unsusceptible against **lost wakeup**:
- i. non-effective in case of cooperative scheduling, otherwise
- ii. inhibits preemption or dispatching (SMP), resp., or
- iii. notifies event sensibility to potential signalers (**cause**)

**coast**
- ■ if the process was not yet detected by **cause**, blocks on the event
- ■ otherwise, clears the catch state and keeps the process running
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extern int coast();              /* wait for event */
extern int await(event_t*);      /* catch & coast */
extern int cause(event_t*);      /* signal event */
```

- **catch** makes the process unsusceptible against *lost wakeup*:
  1. non-effective in case of cooperative scheduling, otherwise
  2. inhibits preemption or dispatching (SMP), resp., or
  3. notifies event sensibility to potential signalers (*cause*)

- **coast** ensures that a process in running state is detectable by *cause*
  - if the process was not yet detected by *cause*, blocks on the event
  - otherwise, clears the catch state and keeps the process running

- **await** blocks the process on the specified event (i.e., signalled by *cause*)
a classic monitor implementation on event queue basis is considered:

typedef struct event { } event_t;

extern void catch(event_t*); /* expect event */
extern int coast(); /* wait for event */
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extern int cause(event_t*); /* signal event */

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- **await** blocks the process on the specified event (i.e., signalled by **cause**)
- **cause** unblocks processes (tentatively) waiting on the specified event

Based on this abstraction, **waitlist operations** can be composed next.
Waitlist Operations I

Control of Blocking

```c
inline void brace(lineup_t *this) {
    this->count++;  /* one more delaying */
    catch(&this->crowd);  /* ready to block/continue */
}

inline void shift(lineup_t *this) {
    coast();  /* conditionally block */
    this->count--;  /* one less delaying */
}

inline void defer(lineup_t *this) {
    this->count++;  /* one more delaying */
    await(&this->crowd);  /* unconditionally block */
    this->count--;  /* one less delaying */
}

inline int level(lineup_t *this) {
    return this->count;  /* number delayed procs. */
}
```
inline int avail(lineup_t *this) {
    if (this->count > 0) /* any delayed? */
        cause(&this->crowd); /* yes, unblock */
    return this->count;
}

inline int evoke(lineup_t *this) {
    int count = this->count; /* save state */
    if (count > 0) /* any delayed? */
        admit(elect(&this->crowd)); /* yes, seize CPU */
    return count;
}
inline int avail(lineup_t *this) {
    if (this->count > 0) /* any delayed? */
        cause(&this->crowd); /* yes, unblock */
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- note that evoke forces a process switch within a still locked monitor
- as the case may be, the resuming process then unlocks the monitor
- consequently, the monitor should not be protected by a mutex object
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        admit(elect(&this->crowd)); /* yes, seize CPU */
    return count;
}

- note that `evoke` forces a process switch within a still locked monitor
- as the case may be, the resuming process then unlocks the monitor
- consequently, the monitor should not be protected by a `mutex` object
- therefor, a cut-through to basic `process management` is appropriate:
  - `elect` selects the next process, if any, from the specified waitlist
  - `admit` books the current process (signaller) “ready to run” and
    makes the elected process (signallee) available to the processor
Signalling Semantics

- as has been foreshadowed by a **configuration option** (cf. p. 12):
  - signal and continue
  - signal and return
  - signal and wait
  - signal and urgent wait
- Mesa-style [14]
- Hansen-style as to Concurrent Pascal [8, 9]
- Hansen-style as originally proposed [7]
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- as indicated by the data type (cf. p. 12), the designs presented next are typical for an approach using **event queues**
  - note that signalling is non-effective if no process is waiting on it (cf. p. 8)
  - this excludes the use of semaphores, as *V* leaves a signal trace
    - *V* always has an effect: at least it increases the semaphore value
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- lightweight and efficient monitor operation benefits from **cross-layer optimisation** in constructive means
  - from language- to system-level run-time system to operating system
void lockout(monitor_t *this) { P(&this->mutex); }

void proceed(monitor_t *this) { V(&this->mutex); }

void watch(condition_t *this) {
    brace(&this->event); /* prepare to release */
    proceed(&this->guard); /* release monitor */
    shift(&this->event); /* release processor */
}

void spark(condition_t *this) {
    avail(&this->event); /* try signal process */
}
Signal and Continue

```c
void lockout(monitor_t *this) { P(&this->mutex); }
void proceed(monitor_t *this) { V(&this->mutex); }
void watch(condition_t *this) {
    brace(&this->event); /* prepare to release */
    proceed(&this->guard); /* release monitor */
    shift(&this->event); /* release processor */
}
void spark(condition_t *this) {
    avail(&this->event); /* try signal process */
}
```

as `watch` needs to release the monitor before releasing the processor, a potential **race condition** must be prevented:

- `brace` notifies upcoming blocking of the current process to the system
- this is to assure the current process of progress guarantee as soon as the monitor was released and another process is enabled to `spark` a signal
void lockout(monitor_t *this) { P(&this->mutex); }

void proceed(monitor_t *this) { V(&this->mutex); }

void watch(condition_t *this) {
    brace(&this->event); /* prepare to release */
    proceed(this->guard); /* release monitor */
    shift(&this->event); /* release processor */
}

void spark(condition_t *this) {
    if (!avail(&this->event)) /* no watcher waiting? */
        proceed(this->guard); /* release monitor */
}

Signal and Return
Signal and Return

```c
void lockout(monitor_t *this) { P(&this->mutex); }

void proceed(monitor_t *this) { V(&this->mutex); }

void watch(condition_t *this) {
    brace(&this->event); /* prepare to release */
    proceed(this->guard); /* release monitor */
    shift(&this->event); /* release processor */
}

void spark(condition_t *this) {
    if (!avail(&this->event)) /* no watcher waiting? */
        proceed(this->guard); /* release monitor */
}
```

- calling `spark` must be the **final action** within a monitor procedure
- similar to the `continue` statement of Concurrent Pascal [9, p. 205]
void lockout(monitor_t *this) { P(&this->mutex); }
void proceed(monitor_t *this) { V(&this->mutex); }
void watch(condition_t *this) {
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- calling `spark` must be the **final action** within a monitor procedure
- similar to the `continue` statement of Concurrent Pascal [9, p. 205]
- otherwise, the signaller could proceed inside an unlocked monitor if no signallee was detected
void lockout(monitor_t *this) { P(&this->mutex); }

void proceed(monitor_t *this) { V(&this->mutex); }

void watch(condition_t *this) {
    brace(&this->event); /* prepare to release */
    proceed(this->guard); /* release monitor */
    shift(&this->event); /* release processor */
}

void spark(condition_t *this) {
    if (evoke(&this->event)) /* signalleee done! */
        lockout(this->guard); /* re-enter monitor */
}
void lockout(monitor_t *this) { P(&this->mutex); }

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    if (evoke(&this->event))    /* signallee done! */
        lockout(this->guard);    /* re-enter monitor */
}

as the case may be, the signaller blocks on a condition variable:

12 in case of a pending signalle, the signaller interrupts execution
13 a process switch inside the looked monitor takes place (cf. p. 19)
13 in the further course, another process unlocks/releases the monitor
13 accordingly, the signaller must make sure to relock the monitor
void lockout(monitor_t *this) { P(&this->mutex); }

void proceed(monitor_t *this) {
  if (!avail(&this->urgent)) /* no urgent waiting */
    V(&this->mutex); /* release monitor */
}
void lockout(monitor_t *this) { P(&this->mutex); }

void proceed(monitor_t *this) {
    if (!avail(&this->urgent)) /* no urgent waiting */
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In contrast to the solutions discussed before, **exit** from the monitor needs to check two waitlists for pending processes:

1. the re-entrance waitlist (**urgent**), but only in case of urgent processes
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by definition, urgent processes interrupted own operation in favour of processes pending for **event** handling

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indicator of urgent waiting processes is a counter by means of which the number of process blockings is registered
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}

void spark(condition_t *this) {
    if (avail(&this->event))    // watcher waiting?
        defer(&this->guard->urgent); // urgent wait
}
Signal and Urgent Wait II

Condition Handling

```c
void watch(condition_t *this) {
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as the case may be, `spark` makes the current process urgent waiting
- a **preferential queue** (Ger. *Vorzugswarteschlange*) is used to this end
- `defer` results in a process switch from line 9 to line 4, back and forth
- from `spark` to `shift`, out of `watch`, and back to `spark` at monitor exit
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as the case may be, *spark* makes the current process urgent waiting

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urgent waiting processes keep *proceed* off from unlocking the monitor

- when the monitor owner returns or blocks, an urgent process resumes
- as a consequence, the monitor should not be protected by a *mutex*

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ready ↔ running
running → blocked
blocked → ready

- wait (←), scheduler (↔)
- urgent wait
- all, iff effective signalling (i.e., waiting signallee)
Process States and State Transitions

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  - wait (←), scheduler (↔)
- **running → blocked**
  - urgent wait
- **blocked → ready**
  - all, iff *effective signalling* (i.e., waiting signallee)
- **running ↔ pending**
  - all (→), signallee released monitor (←)
- **pending → blocked**
  - all, no overlap of signaller and signallee
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- **ready** ↔ **running**
- **running** ↔ **blocked**
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- **running** ↔ **pending**
- **pending** → **blocked**

- **ready** ↔ **running**: wait (←), scheduler (↔)
- **running** ↔ **blocked**: urgent wait (→), wait (←, iff full preemptive)
- **blocked** → **ready**: all, iff effective signalling (i.e., waiting signallees)
- **running** ↔ **pending**: all (→), signallees released monitor (←)
- **pending** → **blocked**: all, no overlap of signaller and signallees
Résumé

- in linguistic terms, a monitor is a language notation for a critical region and one or more associated shared variables
  - a shared class [7, p. 226–232], inspired by SIMULA 67 [3]
  - linked with event queues [6] or condition variables [12], resp.
  - differentiated by several signalling semantics and conventions [13]
- in operating-system terms, a monitor is a means of control of the scheduling of resources among interacting processes
  - mutual-exclusive use of non-preemptable reusable resources
  - coordinated use of consumable resources according to a causal chain
- in system-programming terms, a monitor can be readily implemented by a binary semaphore and event queues
  - note that a mutex is to be rejected for the signal and wait variants

Hansen

In practice, monitors would, of course, be implemented by uninterruptible operations in assembly language. [11, p. 31]
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[1] **Buhr, P. A.; Fortier, M.**:
Monitor Classification.

[2] **Campbell, R. H.; Habermann, A. N.**:
The Specification of Process Synchronization by Path Expressions.


SIMULA—An ALGOL-Based Simulation Language.
In: *Communications of the ACM* 9 (1966), Sept., Nr. 9, S. 671–678

[5] **Dijkstra, E. W.**:
Hierarchical Ordering of Sequential Processes.
   In: *Communications of the ACM* 15 (1972), Jul., Nr. 7, S. 574–578

   ISBN 0–13–637843–9


[14] **Lampson, B. W. ; Redell, D. D.**:
Experiences with Processes and Monitors in Mesa.

[15] **Schmidt, D. C.**:
Strategized Locking, Thread-safe Interface, and Scoped Locking: Patterns and Idioms for Simplifying Multi-threaded C++ Components.
In: *C++ Report* 11 (1999), Sept., Nr. 9, S. 1–9

[16] **Schröder-Preikschat, W.**:
*The Logical Design of Parallel Operating Systems.*

[17] **Schröder-Preikschat, W.**:
Processes.
In: *Lehrstuhl Informatik 4* (Hrsg.): *Concurrent Systems.*
FAU Erlangen-Nürnberg, 2014 (Lecture Slides), Kapitel 3
handmade monitor procedures are prone to absence of unblocking the monitor before return: `proceed` is missing or will never be executed.

- object constructors/destructors find a remedy [16, p. 220, Sec. 6.1.4]

```cpp
class atomic {
    static monitor_t sluice;

public:
    atomic() { lockout(&sluice); };
    ~atomic() { proceed(&sluice); };
};
```

- exit from the scope of an `atomic` instance implicitly performs `proceed`:

```cpp
int64_t inc64(int64_t *i) {
    atomic inc; return *i + 1;
}
```

- a technique that is also known as the `scoped locking` pattern [15]