

## Solution of Exercise Sheet 9

### Exercise 1 (Inter-Process Communication)

1. Describe what a critical section is.

*Processes carry out read and write operations on common data. Critical sections may not be processed by multiple processes at the same time.*

2. Describe what a race condition is.

*It is an unintended race condition of two processes, which want to modify the value of the same record.*

3. Describe why race conditions are hard to locate and fix.

*The result of a process depends on the order or timing of other events. The occurrence of the symptoms depends on different events. The symptoms may be different or disappear with each test run.*

4. Describe how to avoid race conditions.

*Race conditions can be avoided with the semaphore concept.*

### Exercise 2 (Synchronization)

1. What is the advantage of signal and wait compared with busy waiting?

*When using busy waiting, computing time of the CPU is wasted because it is again and again occupied by the waiting process. Using signal and wait causes lesser CPU workload because the waiting process is blocked and later deblocked.*

2. Which two problems can arise from blocking?

*Starvation and deadlock.*

3. What is the difference between signaling and blocking?

*Signaling specifies the execution order of the critical sections of processes.*

*Blocking secures critical sections. The execution order of the critical sections of the processes is not specified. It is just ensured that the execution of critical sections does not overlap.*

4. Which four conditions must be fulfilled at the same time as precondition that a deadlock can arise?

- |  |  |
|--|--|
| <input type="checkbox"/> Recursive function calls    | <input checked="" type="checkbox"/> Hold and wait                |
| <input checked="" type="checkbox"/> Mutual exclusion | <input type="checkbox"/> > 128 processes in <b>blocked</b> state |
| <input type="checkbox"/> Frequent function calls     | <input type="checkbox"/> Iterative programming                   |
| <input type="checkbox"/> Nested <b>for</b> loops     | <input checked="" type="checkbox"/> Circular wait                |
| <input checked="" type="checkbox"/> No preemption    | <input type="checkbox"/> Queues                                  |

5. Does a deadlock occur?

*Perform the deadlock detection with matrices.*

$$\text{Existing resource vector} = (8 \ 6 \ 7 \ 5)$$

$$\text{Current allocation matrix} = \begin{bmatrix} 2 & 1 & 0 & 0 \\ 3 & 1 & 0 & 4 \\ 0 & 2 & 1 & 1 \end{bmatrix} \quad \text{Request matrix} = \begin{bmatrix} 3 & 2 & 4 & 5 \\ 1 & 1 & 2 & 0 \\ 4 & 3 & 5 & 4 \end{bmatrix}$$

*The existing resource vector and the current allocation matrix are used to calculate available resource vector.*

$$\text{Available resource vector} = (3 \ 2 \ 6 \ 0)$$

*Only process 2 can run with this available resource vector. The following available resource vector results when process 2 has finished execution and deallocates its resources.*

$$\text{Available resource vektor} = (6 \ 3 \ 6 \ 4)$$

*Only process 3 can run with this available resource vector. The following available resource vector results when process 3 has finished execution and deallocates its resources.*

$$\text{Available resource vector} = (6 \ 5 \ 7 \ 5)$$

*Process 1 is not blocked.*

*No deadlock occurs.*

## Exercise 3 (Communication of Processes)

1. What must be considered, when inter-process communication via shared memory segments is used?

*The processes need to coordinate the accesses themselves and to ensure that their memory accesses are mutually exclusive. A receiver process, cannot read data from the shared memory, before the sender process has finished its current write operation. If access operations are not coordinated carefully, inconsistencies occur.*

2. What is the function of the shared memory table in the Linux kernel?

*Linux/UNIX operating systems contain a shared memory table, which contains information about the existing shared memory segments. This information includes: Start address in memory, size, owner (username and group) and privileges.*

3. What is the impact of a restart (reboot) of the operating system on the existing shared memory segments?

*(Only a single answer is correct!)*

- ☐ The shared memory segments are created new during boot and the contents are restored.  
☐ The shared memory segments are created new during boot, but they remain empty. This means, only the contents are lost.  
☒ The shared memory segments and their contents are lost.  
☐ Only the shared memory segments are lost. The operating system stores the contents in temporary files inside the folder `\tmp`.

4. According to which principle operate message queues?

*(Only a single answer is correct!)*

- ☐ Round Robin      ☐ LIFO      ☒ FIFO      ☐ SJF      ☐ LJF

5. How many processes can communicate with each other via a pipe?

2

6. What is the effect, when a process tries to write data into a pipe without free capacity?

*The process that tries to write into the pipe is blocked.*

7. What is the effect, when a process tries to read data from an empty pipe?

*The process that tries to read from the pipe is blocked.*

8. Which two different types of pipes exist?

*Anonymous pipes and named pipes.*

9. Which two different types of sockets exist?

*Connection-less sockets (also called: datagram sockets) and connection-oriented sockets (also called: stream sockets).*

10. Communication via pipes works...  
(Only a single answer is correct!)
- ☐ memory-based ☒ message-based
11. Communication via message queues works...  
(Only a single answer is correct!)
- ☐ memory-based ☒ message-based
12. Communication via shared memory segments works...  
(Only a single answer is correct!)
- ☒ memory-based ☐ message-based
13. Communication via sockets works...  
(Only a single answer is correct!)
- ☐ memory-based ☒ message-based
14. Which two sorts of inter-process communication operate bidirectional?
- ☒ Shared memory segments ☐ Message queues  
☐ Anonymous pipes ☐ Named pipes  
☒ Sockets
15. Name a sort of inter-process communication, which can only be used for processes, which are closely related to each other.
- ☐ Shared memory segments ☐ Message queues  
☒ Anonymous pipes ☐ Named pipes  
☐ Sockets
16. Which sort of inter-process communication allows communication over computer boundaries?
- ☐ Shared memory segments ☐ Message queues  
☐ Anonymous pipes ☐ Named pipes  
☒ Sockets
17. With which sorts of inter-process communication remains the data intact without a bound process?
- ☒ Shared memory segments ☒ Message queues  
☐ Anonymous pipes ☐ Named pipes  
☐ Sockets
18. For which sort of inter-process communication guarantees the operating system not the synchronization?
- ☒ Shared memory segments ☐ Message queues  
☐ Anonymous pipes ☐ Named pipes  
☐ Sockets

## Exercise 4 (Cooperation of Processes)

1. What is a semaphore and what is its intended purpose?

*A semaphore is a counter lock.*

2. Which two operations are used with semaphores?

*Provide the names of the operations and for each operation a short description of the functioning.*

*The access operation  $P(S)$  tries to reduce (decrement) the value of the counter variable  $S$ .*

*The access operation  $V(S)$  increments the value of the counter variable  $S$ .*

3. What is the difference between Semaphores versus blocking?

*In contrast to semaphores, can locks only be used to allow a single process entering the critical section at the same time.*

4. What is a binary semaphore?

*Binary semaphores are initialized with value 1 and ensure that 2 or more processes cannot simultaneously enter their critical sections.*

5. What is a mutex and what is its intended purpose?

*Semaphores offer the feature of counting. However, if this feature is not required, a simplified semaphore version, the mutex can be used instead. Mutexes are used to protect critical sections, which are allowed to be accessed by only a single process at any given moment.*

6. Which type of semaphores has the same functionality as the mutex?

*Binary semaphore.*

7. Which states can a mutex have?

*Mutexes can only have 2 states: „occupied“ and „not occupied“.*

8. Which Linux/UNIX command returns information about existing shared memory segments, message queues and semaphores?

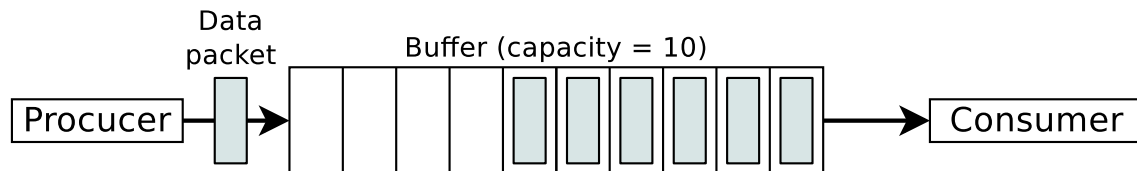
*ipcs*

9. Which Linux/UNIX command allows to erase existing shared memory segments, message queues and semaphores?

*ipcrm*

## Exercise 5 (Producer/Consumer Scenario)

A producer should send data to a consumer. A buffer with limited capacity should be used to minimize the waiting times of the consumer. Data is placed into the buffer by the producer and the consumer removes data from the buffer. Mutual exclusion is necessary in order to avoid inconsistencies. If the buffer has no more free capacity, the producer must block itself. If the buffer is empty, the consumer must block itself.



For synchronizing the two processes, create the required semaphores, assign them initial values and insert semaphore operations.

```
typedef int semaphore;           // semaphores are of type integer
semaphore filled = 0;           // counts the occupied locations in the buffer
semaphore empty  = 10;          // counts the empty locations in the buffer
semaphore mutex  = 1;           // controls access to the critical sections

void producer (void) {
    int data;

    while (TRUE) {               // infinite loop
        createDatapacket(data);  // create data packet
        P(empty);                // decrement the empty locations counter
        P(mutex);                // enter the critical section
        insertDatapacket(data);  // write data packet into the buffer
        V(mutex);                // leave the critical section
        V(filled);               // increment the occupied locations counter
    }
}

void consumer (void) {
    int data;

    while (TRUE) {               // infinite loop
        P(filled);                // decrement the occupied locations counter
        P(mutex);                // enter the critical section
        removeDatapacket(data);  // pick data packet from the buffer
        V(mutex);                // leave the critical section
        V(empty);                // increment the empty locations counter
        consumeDatapacket(data); // consume data packet
    }
}
```

## Exercise 6 (Semaphores)

In a warehouse, packages are delivered constantly by a supplier and picked up by two deliverers. The supplier and the deliverers need to pass through a gate. The gate can always be passed only by a single person. The supplier brings three packages with every shipment to the incoming goods section. One of the deliverers can pick two packages with every pickup from the outgoing goods section. The other deliverer can pick only a single package per pickup from the outgoing goods section.

```
sema gate      = 1
sema outgoing  = 1
sema empty     = 10
sema occupied  = 0
```

Supplier	Deliverer_X	Deliverer_Y
<pre>{   while (TRUE)   {     P(gate);     &lt;Pass through gate&gt;;     V(gate);      &lt;Enter incoming     goods section&gt;;      P(empty);     P(empty);     P(empty);     &lt;Unload 3 packets&gt;;     V(occupied);     V(occupied);     V(occupied);      &lt;Leave incoming     goods section&gt;;      P(gate);     &lt;Pass through gate&gt;;     V(gate);   } }</pre>	<pre>{   while (TRUE)   {     P(gate);     &lt;Pass through gate&gt;;     V(gate);      P(outgoing);     &lt;Enter outgoing     goods section&gt;;      P(occupied);     P(occupied);     &lt;Pick 2 packets&gt;;     V(empty);     V(empty);      &lt;Leave outgoing     goods section&gt;;     V(outgoing);      P(gate);     &lt;Pass through gate&gt;;     V(gate);   } }</pre>	<pre>{   while (TRUE)   {     P(gate);     &lt;Pass through gate&gt;;     V(gate);      P(outgoing);     &lt;Enter outgoing     goods section&gt;;      P(occupied);     &lt;Pick 1 packet&gt;;     V(empty);      &lt;Leave outgoing     goods section&gt;;     V(outgoing);      P(gate);     &lt;Pass through gate&gt;;     V(gate);   } }</pre>

Exactly one process **Supplier**, one process **Deliverer\_X** and one process **Deliverer\_Y** exist.

For synchronizing the three processes, create the required semaphores, assign them values and insert semaphore operations.

These conditions must be met:

- Only a single process can pass through the gate.  
*It is impossible that multiple processes pass through the gate simultaneously.*
- Only one of both existing deliverers can access the outgoing goods section.  
*It is impossible that both deliverers access the outgoing goods section simultaneously.*



- It should be possible that the supplier and one of the deliverers can simultaneously unload and pick goods.
- The capacity of the warehouse is 10 packages.
- No deadlocks are allowed.
- At the beginning, the warehouse contains no packets and the gate, as well as the incoming goods section and the outgoing goods section are free.

*Source: TU-München, Übungen zur Einführung in die Informatik III, WS01/02*

## Exercise 7 (Inter-Process Communication)

Develop a part of a real-time system, which consists of four processes:

1. **Conv.** This process reads the measured values of A/D converters (analog/digital). It checks the measured values for plausibility and converts them if this is necessary. Because we have no physical A/D converter, the process Conv must generate random numbers. These numbers must be in a certain range of values to simulate an A/D converter.
2. **Log.** This process reads the measured values from the A/D converter (Conv) and writes them into a local file.
3. **Stat.** This process reads the measured values from the A/D converter (Conv) and calculates statistical data, including the average value and the sum.
4. **Report.** This process reads the results of Stat and prints out the statistical data in the shell.

These synchronization conditions must be met:

- **Conv** must first write measured values before **Log** and **Stat** can read the measured values.
- **Stat** must first write statistical data before **Report** can read the statistical data.

Develop and implement the real-time system in C with the appropriate system calls and implement the exchange of data between the four processes once with **pipes**, **message queues** and **shared memory segments with semaphores**. This implies that you program three implementation variants of the real-time system. The source code should be clear to understand because of intensive use of comments.

## Approach

The processes `Conv`, `History`, `Stats` and `Reports` are parallel processes, which are implemented via infinite loops. Implement a framework for the start of the infinite processes with the system call `fork`. Monitor your parallel processes with appropriate commands like `top`, `ps` and `pstree` and determine the parent-child relations.

The program can be terminated with the key combination `Ctrl-C`. To realize this, you need to implement a signal handler for the signal `SIGINT`. Please make sure that when the program is terminated, all occupied resources (message queues, shared memory segments, semaphores) are released.

Develop and implement the following three variants where the exchange of data between the four processes works once with **pipes**, **message queues** and **shared memory segments with semaphores**.

Monitor the message queues, shared memory segments and semaphores with the command `ipcs`. With `ipcrm` it is possible to erase message queues, shared memory segments and semaphores if your program incorrectly missed to free these occupied resources.

## Exercise 8 (Shell Scripts, Data Compression)

1. Program a shell script, which creates a file `testdata.txt`.
  - The file should be filled with zeros.
  - The zeros provides the virtual device file `/dev/zero`.  
(Examples: `dd if=/dev/zero of=/path/to/file bs=512 count=1`)
  - The file size should be at least 128 and 512 kB maximum.
  - How large the file becomes, should be specified randomly via `RANDOM`.

```
1 #!/bin/bash
2 #
3 # Skript: testdaten_erzeugen.bat
4 #
5 # falls Ordner nicht vorhanden, Ordner erzeugen
6
7 VERZEICHNIS=/tmp/testdaten
8 DATEINAME=testdata.txt
9
10 if [ ! -d $VERZEICHNIS ] ; then
11     if mkdir $VERZEICHNIS ; then
12         echo "Ein Verzeichnis für Testdaten wurde erstellt."
13     else
14         echo "Es konnte kein Verzeichnis erstellt werden."
15     fi
```

```
16 else
17     echo "Ein Verzeichnis für Testdaten existiert schon."
18     exit 1
19 fi
20
21 if touch `echo "$VERZEICHNIS/$DATEINAME"` ; then
22     # Zufallszahl zwischen 128 und 512 erstellen
23     ZUFALLSZAHL=`awk -vmin=128 -vmax=512 'BEGIN{srand(); print
        int(min+rand()*(max-min+1))}'`
24     # Die Datei mit Nullen füllen
25     `dd if=/dev/zero of=$VERZEICHNIS/$DATEINAME bs=$ZUFALLSZAHL
        count=1K`
26     echo "Eine Datei für Testdaten wurde erstellt."
27 else
28     echo "Es konnte keine Datei erstellt werden."
29     exit 1
30 fi
```

2. Program a shell script, which reads a file name as command line argument.

- The shell script should check the file to find out if it is a file, a link or a directory.
- If it is a file, the user should have with **select** these options to choose from:

- 1) ZIP
- 2) ARJ
- 3) RAR
- 4) GZ
- 5) BZ2
- 6) All
- 7) Exit

- If the user selects a compression algorithm, the file should be compressed with this compression algorithm and the file name should be adjusted accordingly. The file size of the original file and the file size of the compressed file should be printed out both for comparison reasons. e.g.:

```
testdata.txt      <filesize>
testdata.txt.rar  <filesize>
```

- If the user selects the option (All), the script should compress the file with all compression algorithms and print out the file size of the original file and the file sizes of the compressed files for comparison reasons.

```
testdata.txt      <filesize>
testdata.txt.zip  <filesize>
testdata.txt.arj  <filesize>
testdata.txt.rar  <filesize>
testdata.txt.gz   <filesize>
```

```
testdata.txt.bz2    <filesize>

1 #!/bin/bash
2 #
3 # Skript: archivieren.bat
4 #
5 # Funktion zum komprimieren einer Datei via ZIP
6 zip_packen() {
7     if zip -r $1.zip $1 ; then
8         echo "Die Datei $1 wurde via ZIP komprimiert."
9     else
10        echo "Die Kompression der Datei $1 via ZIP ist
        fehlgeschlagen."
11    fi
12 }
13
14 # Funktion zum komprimieren einer Datei via ARJ
15 arj_packen() {
16     if arj a $1.arj $1 ; then
17         echo "Die Datei $1 wurde via ARJ komprimiert."
18     else
19         echo "Die Kompression der Datei $1 via ARJ ist
        fehlgeschlagen."
20    fi
21 }
22
23 # Funktion zum komprimieren einer Datei via RAR
24 rar_packen() {
25     if rar a $1.rar $1 ; then
26         echo "Die Datei $1 wurde via RAR komprimiert."
27     else
28         echo "Die Kompression der Datei $1 via RAR ist
        fehlgeschlagen."
29    fi
30 }
31
32 # Funktion zum komprimieren einer Datei via GZ
33 gz_packen() {
34     if gzip -c $1 > $1.gz ; then
35         echo "Die Datei $1 wurde via GZ komprimiert."
36     else
37         echo "Die Kompression der Datei $1 via GZ ist
        fehlgeschlagen."
38    fi
39 }
40
41 # Funktion zum komprimieren einer Datei via BZ2
42 bz2_packen() {
43     if bzip2 -zk $1 ; then
44         echo "Die Datei $1 wurde via BZ2 komprimiert."
45     else
46         echo "Die Kompression der Datei $1 via BZ2 ist
        fehlgeschlagen."
47    fi
48 }
49
```

```
50 # Untersuchen ob die als Kommandozeilenargument übergebene
    Datei existiert
51 if [ ! -e $1 ] ; then
52     # Die Datei existiert nicht.
53     echo "Die Datei $1 existiert nicht."
54     # Das Skript beenden.
55     exit 1
56 fi
57
58 # Untersuchen ob die Datei ein Verzeichnis ist.
59 if [ -d $1 ] ; then
60     echo "Das Kommandozeilenargument ist ein Verzeichnis."
61     exit
62 elif [ -L $1 ] ; then
63     echo "Das Kommandozeilenargument ist ein symbolischer Link."
64     exit
65 elif [ -f $1 ] ; then
66     echo "Das Kommandozeilenargument ist eine reguläre Datei."
67
68     # Auswahlmöglichkeiten ausgeben.
69     select auswahl in ZIP ARJ RAR GZ BZ2 Alle Beenden
70
71     do
72         if [ "$auswahl" = "ZIP" ] ; then
73             zip_packen $1
74             ls -lh $1|awk '{print $9,$5}'
75             ls -lh $1.zip|awk '{print $9,$5}' | column -t
76             exit
77         elif [ "$auswahl" = "ARJ" ] ; then
78             arj_packen $1
79             ls -lh $1|awk '{print $9,$5}'
80             ls -lh $1.arj|awk '{print $9,$5}' | column -t
81             exit
82         elif [ "$auswahl" = "RAR" ] ; then
83             rar_packen $1
84             ls -lh $1|awk '{print $9,$5}'
85             ls -lh $1.rar|awk '{print $9,$5}' | column -t
86             exit
87         elif [ "$auswahl" = "GZ" ] ; then
88             gz_packen $1
89             ls -lh $1|awk '{print $9,$5}'
90             ls -lh $1.gz|awk '{print $9,$5}' | column -t
91             exit
92         elif [ "$auswahl" = "BZ2" ] ; then
93             bz2_packen $1
94             ls -lh $1|awk '{print $9,$5}'
95             ls -lh $1.bz2|awk '{print $9,$5}' | column -t
96             exit
97         elif [ "$auswahl" = "Alle" ] ; then
98             zip_packen $1
99             arj_packen $1
100            rar_packen $1
101            gz_packen $1
102            bz2_packen $1
103            ls -lh $1* | awk '{print $9,$5}' | column -t
104            exit
```

```
105     else [ "$auswahl" = "Beenden" ]
106         echo "Das Skript wird beendet."
107         exit
108     fi
109 done
110 else
111     exit 1
112 fi
```

3. Test the shell script with the generated file `testdata.txt`. What is the result?

## Exercise 9 (Shell Scripts, File Browser)

Program a shell script, which implements a file browser via `select`.

- The list of files and directories in the current directory should be printed out and the individual entries should be selectable.
- If a file is selected, the file name with the extension, the number of characters, words and lines as well as an information about the file content is printed out.  
e.g.:

```
<Filename>.<Extension>
Characters: <Number>
Lines:      <Number>
Words:      <Number>
Content:    <Information>
```

*Information about the number of characters, words and lines of a file returns the command `wc`. Information about the contents of a file provides the command `file`.*

- If a directory is selected, the script should navigate into that directory and print out the files and directories in that directory.
- It should also be possible to move up the directory tree into the directory's parent directory (`cd ..`).

```
1  !/bin/bash
2  #
3  # Skript: datei_browser.bat
4  #
5  file=""
6
7  while true
8  do
9      if [ "$file" == ".." ] ; then
10         # In der Verzeichnisstruktur eine Ebene höher gehen
11         cd ..
12     elif [ -d $file ] ; then
```

```
13     cd $file                # In ein Verzeichnis wechseln
14 else
15     break
16 fi
17
18 select file in "." *      # Dateiauswahlliste ausgeben
19 do
20     break
21 done
22 done
23
24 if [ -f $file ]
25 then
26     echo $file              # Dateinamen mit Endung ausgeben
27     echo "Zeichen: "`wc -m $file | awk '{ print $1 }'`
28     echo "Zeilen:  "`wc -l $file | awk '{ print $1 }'`
29     echo "Wörter:  "`wc -w $file | awk '{ print $1 }'`
30     echo "Inhalt:  "
31     cat $file               # Inhalt der Datei ausgeben
32 fi
```