

**Esolution**

Place student sticker here

**Note:**

- During the attendance check a sticker containing a unique code will be put on this exam.
- This code contains a unique number that associates this exam with your registration number.
- This number is printed both next to the code and to the signature field in the attendance check list.

## Basics of TUMexam

**Exam:** IN0000 / Endterm  
**Examiner:** Prof. Dr.-Ing. Georg Carle

**Date:** Friday 1<sup>st</sup> February, 2019  
**Time:** 13:00 – 14:00

	P 1	P 2	P 3	P 4	P 5	P 6
I						

### Working instructions

- This exam consists of **16 pages** with a total of **6 problems**.  
Please make sure now that you received a complete copy of the exam.
- The total amount of achievable credits in this exam is 76 credits.
- Detaching pages from the exam is prohibited.
- Allowed resources:
  - one **non-programmable pocket calculator**
  - one **analog dictionary** English ↔ native language
- Subproblems marked by \* can be solved without results of previous subproblems.
- **Answers are only accepted if the solution approach is documented.** Give a reason for each answer unless explicitly stated otherwise in the respective subproblem.
- Do not write with red or green colors nor use pencils.
- Physically turn off all electronic devices, put them into your bag and close the bag.

Left room from \_\_\_\_\_ to \_\_\_\_\_ / Early submission at \_\_\_\_\_

## Problem 1 Configuration (25 credits)

The general configuration for an exam is made in the file `conf/examconf.tex`. Various exam-specific parameters which are described in the following have to be set there.

0	<input type="checkbox"/>	a) Specify the title of your exam. That commonly refers to the lecture to which the exam belongs.
1	<input type="checkbox"/>	<div><code>\title{Basics of TUMexam}</code></div>
0	<input type="checkbox"/>	b) Specify the type of your exam, e. g. Endterm, Retake, Modulprüfung.
1	<input type="checkbox"/>	<div><code>\type{Endterm}</code></div>
0	<input type="checkbox"/>	c) Set your module number, normally a code consisting of two letters and four to five digits.
1	<input type="checkbox"/>	<div><code>\module{IN0000}</code></div>
0	<input type="checkbox"/>	d) Specify the date of your exam (day, month, year).
1	<input type="checkbox"/>	<div><code>\date{1}{2}{2016}</code></div>
0	<input type="checkbox"/>	e) Specify the begin and end times of your exam.
1	<input type="checkbox"/>	<div><code>\starttime{13:00}</code> <code>\stoptime{14:00}</code></div>
0	<input type="checkbox"/>	f) Choose the language (english or german).
1	<input type="checkbox"/>	<div><code>\lang{english}</code></div>
0	<input type="checkbox"/>	g) Set your organization with the corresponding acronym as defined in <code>tumcommon/tumlang.sty</code> .
1	<input type="checkbox"/>	<div><code>\organization{NET}</code></div>
0	<input type="checkbox"/>	h) Set the examiner (you can use <code>\chairhead</code> if that is the examiner).
1	<input type="checkbox"/>	<div><code>\examiner{\chairhead}</code></div>

i) State if you want to have one or two correction passes

☐ \singlepasstrue (one correction pass)

☒ \singlepassfalse (two correction passes)

j) State if you want to give half credits.

☒ \halfcredittrue

☐ \halfcreditsfalse

k) Registration stickers vs. registration boxes:



1							
2							
3							
4							
5							
6							
7							
8							
9							
0	<input checked="" type="checkbox"/>						

Registration number

☐ \registrationstickerfalse (no stickers but boxes)

☒ \registrationstickertrue (stickers)

Everyone who has used TUMexam once knows about the manual task of preparing the attendee lists with registration stickers. Of course, TUMexam also supports registration boxes as alternative. However, we urge you to use the registration stickers whenever possible. The reasons are:

1. It seems to be a tough task for our students to correctly mark their registration number in the box.
2. If 5% of your students do not get their registration number correctly marked, and you have 1000 participants, do the math of manually fixing registration numbers.
3. Of course, that is only a hassle, provided that students follow requests and write their registration number as digits in the headline of the box (and if they do, given that you can read it ...).
4. However, most important, a student might accidentally hit the registration number of another student that is registered to the exam but does not show up. That case cannot be detected and the exam is assigned to the wrong student!

Registration stickers are virtually fail-proof. So it is up to you whether you want peace of mind at cost of some time or you rather want the quickest way of creating attendee lists and accept the possibility of undetectable errors.

l) If you want to create your problem sheet separate from the answer sheet, then you may need this option. Separate answer sheets may ease your decision regarding the online exam review as the problems are not made available to students after the exam, only their answers. Please contact us for details.

☒ \externalproblemsfalse

☐ \externalproblemstrue

m) State if you want an additional cover sheet. We discourage the use as it increases the print times due to the additional envelope per exam.

☒ \coversheetfalse

☐ \coversheettrue

n) Specify how your exam should be printed and stapled.

☒ \booklet (a booklet)

☐ \onestaple (one staple at the top left corner)

☐ \nostaple (only useful if there is only one sheet)

o) Specify if you want serif font or the TUM corporate design font Helvetica.

☐ \seriftrue

☒ \seriffalse

p) Specify if you want arabic numbering of subproblems.

☒ \subproblemarabicfalse

☐ \subproblemarabictrue

q) Do not show the amount of credits per problem.

☒ \noproblemcreditsfalse

☐ \noproblemcreditstrue

r) Remove the problem heading. This option is useful only if your exam consists of a single problem with multiple subproblems, e. g. quizzes and surveys.

☒ \noproblemfalse

☐ \noproblemtrue

s) Remove the title section from the first page. This option is useful for very compact exams, quizzes, or surveys.

☐ \notitletrue

☒ \notitlefalse

t) The title page of an exam has a rectangular corrector box per problem and per correction pass. It is meant solely as a signature field for correctors to indicate whether or not and by whom a specific problem has been corrected. If you do not want those boxes for some reason, e. g. you have so many problems that the boxes do not fit into a single line, you may remove them using this option.

☐ \nocorrectorboxtrue

☒ \nocorrectorboxfalse

u) Enable if you want to print single-sided exams. This may be usefull if in combination with the `\onestaple` option. The backsides will still have pagecodes, which is important for scanning as we cannot prevent students from writing something on the backsides. Do **not** use this option together with `\coversheettrue`.

☐ `\singlesidetrue`

☒ `\singlesidefalse`

Some texts can be modified as follows.

v) Allowed tools

The allowed tools can be modified in `conf/toolsallowed.tex`.

0  
1

w) Announcement of tools

In `conf/toolsannouncement.tex` you can state where you announced the allowed tools.

0  
1

x) Notes on the exam title page

Additional notes on the exam title page can be configured in `conf/examnotes.tex`.

0  
1

y) Notes on the binder

Additional notes on the binder can be configured in `conf/bindernotes.tex`.

0  
1

## Problem 2 Building (10 credits)

The template depends on an up to date version of texlive-full and GNU make to build everything you need for your exam. Please note that using an IDE for  $\text{\LaTeX}$  documents such as TeXstudio is not explicitly supported, but possible for the most part if you correctly setup the directories from which class and style files are loaded.

The first part of make commands is used during exam creation, i. e., before building the final exam copies, attendee lists, seatplans, and protocols.

**Hint:** For answers to the following questions, build a solution with correction notes of this exam using `make correction`.

- 0 ☐  
1 ☐
- a) How is the exam itself built?
- ```
make or make exam
```
- 0 ☐  
1 ☐
- b) How is the solution built?
- ```
make solution
```
- 0 ☐  
1 ☐
- c) How is the annotated solution containing all correction notes built?
- ```
make correction
```
- 0 ☐  
1 ☐
- d) How is an example exam with page codes as it is printed built?
- ```
make example
```
- 0 ☐  
1 ☐
- e) How is a side by side version of the exam and the annotated solution built?
- ```
make hud
```
- 0 ☐  
1 ☐
- f) How are all of the above documents built?
- ```
make all
```

The second part of make commands is used to create the documents for printing.

g) How are all of the individual exams built?

**Hint:** EXAMCOUNT is set to the number of copies required.

```
make EXAMCOUNT=10 examids
```

0  
1

h) How are all of protocol, attendeeelist, etc. built?

```
make print
```

0  
1

i) How is all the remaining metadata that is needed for scanning built?

```
make scan
```

0  
1

j) How can we speed up the building of exams?

Specify the number of threads to use, e.g. `make -j 16`. Note that our Makefile also builds external TikZ figures in the subfolder "figures" in parallel.

0  
1

### Problem 3 Some background on how TUMexam works (14 credits)

In the following we discuss some more background regarding the TUMexam L<sup>A</sup>T<sub>E</sub>X template. This understanding will prevent you from some pitfalls that users sometimes encounter.

a)\* The instruction box below contains a page code which is typeset three times on every page of a printable exam copy. Which information is contained in such a code?



IN-BT-1-20200101-E0001-01

<department>--<instance>--<exam\_id>--<date>--<ERID>--<page>

- department: short name of your department, e. g. IN for Informatics; defined by by \organization
- instance: short name of your instance, chosen when creating an instance and also part of the URL of your instance
- exam\_id: integer value representing the exam (primary key in database)
- date: date of your exam in the format yyyyymmdd
- erid: ERID (Exam Relative Identifier) representing a specific exam copy, unique to each printed copy
- page: page number within an ERID

b)\* Is it necessary that all page codes can be read.

No.

A single page code is sufficient such that a scanned page can be associated with an exam. However, TUMexam aligns scanned pages (deskews the scan) to perfectly detect cross boxes. This step is vital and works best if one of the codes at the bottom and the code at the top of a page is detected. Depending on which codes are detected, alignment may be suboptimal.

c)\* What happens if an ERID is printed twice?

We end up with duplicate page codes, which cannot be processed.

The only possible recovery is to remove all page codes from one exam and note an unused ERID on each page by hand. This results in error pages during processing for which we can manually enter valid, unique page codes.



d)\* Can additional pages, e. g. scratch paper, be added to an exam?

Yes, but it is not recommended: we can note the ERID to which the paper belongs and a sequential page number on each *side* (front and back). Those pages will be reported as error pages during processing and can then be added to the correct ERID.

<input type="checkbox"/>	0
<input type="checkbox"/>	1
<input type="checkbox"/>	2

e)\* The first page of a printable exam copy (one with page codes) contains a box named "Exam empty" in the footline, all other pages have a box named "Page empty". What are these boxes used for?

Marking one of those boxes declares the whole exam or the respective page as being empty, i. e., credit boxes are set to zero without needing to cross all boxes.  
Be carefull when using the "Page empty" box as it may happen that you accidentally set the credits for a subproblem to zero if the solution for that subproblem is not on the same page as the credit box, e. g. subproblems of the form "mark somehting in Figure ..." with the figure being on a different page.

<input type="checkbox"/>	0
<input type="checkbox"/>	1
<input type="checkbox"/>	2

## Problem 4 Creating problems (10 credits)

This section describes how the problems of an exam are created. It is advisable to not only read this document, but also have a look at the source code of the sample problems.

**Hint:** Problems that can be solved without solving previous subproblems first are marked by \*. (It is up to you whether or not you want to tell that your students, but if you do, please do it carefully.)

0  
1

a)\* First, we need to declare a problem.

```
\problem{The problem title}
```

0  
1

b) Then, we need to declare the subproblems.

```
\subproblem{1} or \subproblem*{1}
```

There are different environments to create solutionboxes.

0  
1

c) How can we define a normal solutionbox of 3 cm in height?

```
\begin{solutionbox}[3cm]
This is the solution.
\end{solutionbox}
```

0  
1

d) How can we annotate the solution with correction notes?

```
\credit
\hcredit
\correction{ }
```

0  
1

e) How can we define a solutionbox with instructions?

```
\begin{instructionbox}
This is instructiontext, e.\g. a table preprint
\solution{
This is the solution.
}
\end{instructionbox}
```

f) How can we define a solutionbox with gridlines?

0  
1

[illegible]

g) How can we define a solutionbox with grid and instructions?

0  
1

```
\begin{gridinstructionbox}
This is instructiontext, e.\g. a table preprint
\solution{
This is the solution.
}
\end{gridinstructionbox}
```

#### h) How can we define a multiple choice question?

Mark correct answers with a cross





*To undo a cross, completely fill out the answer option*



*To re-mark an option, use a human-readable marking*



 \subproblem[strict\_multiple\_choice]{1}

 \subproblem[binary\_multiple\_choice]{1}

□ \subproblem{1}

Please contact us if you want to use multiple choice questions as there are some details to be clarified regarding how MC questions should be evaluated by TUMexam.

- 0 ☐ i)\* TUMexam allows to pass a seed value for pgfmath's pseudo random number generator via jobnames. If  
 1 ☐ no jobname is supplied or the jobname is not an integer, we use the magic number 42 for initialization. That  
 allows for deterministic sample solutions but randomized problems for students.

1,2,3,4  
 2,3,4,1  
 3,4,1,2  
 4,1,3,2  
 1,3,2,4  
 2,4,3,1  
  
 3,1,2,4

- 0 ☐ j)\* „Ich bitte Sie, das neue Corporate Design konsequent umzusetzen. Sehen Sie darin eine Loyalitätspflicht  
 1 ☐ der Hochschulmitglieder, damit sich der Hinweis auf die Rechtsverbindlichkeit erübrigen kann.“<sup>1</sup>

For that reason, TUMexam is based on Helvetica, and we do our best to convince you of Helvetica—even in math mode:

mathnormal

abcdefghijklmnopqrstuvwxyz  
 ABCDEFGHIJKLMNOPQRSTUVWXYZ  
 1234567890

αβγδεζηθκλμνξπρστυφχψω

ΔΘΛΠΦΨΩ

mathbit

**abcdefghijklmnopqrstuvwxyz**  
**ABCDEFGHIJKLMNOPQRSTUVWXYZ**  
**01234567890**

αβγδεζηθκλμνξπρστυφχψω

ΔΘΛΠΦΨΩ

mathcal

*ABCDEFGHIJKLMNOPQRSTUVWXYZ*

symbols

$$\sum_{n=1}^N \frac{N(N-1)}{2}, \quad \frac{1}{2\pi} \int_{-\infty}^{\infty} f(x) e^{-j\omega t} dt$$

addons

$\Pr [X = x \mid Y = y], \text{Var} [x], E [X]$

If you plan to disobey this request, you may use computer modern instead by setting `\seriftrue` in `examconf.tex`.

<sup>1</sup>Wolfgang A. Herrmann, Corporate Design Handbuch 2016

## Problem 5 Single stream point-to-point MIMO on multiple carriers (4 credits)

We consider the communication scenario in Figure 5.1 where multiple data streams  $s_k$  are transmitted on  $K$  subcarriers, one stream per carrier. The signals  $s_k$  are mutually independent and Gaussian distributed with zero mean and unit variance, i. e.,  $s_k \sim \mathcal{N}_{\mathbb{C}}(0, 1)$ . The transmitter and receiver have  $N$  and  $M$  antennas, respectively. The signal  $s_k$  denotes the data stream transmitted on carrier  $k$  which is precoded with  $\mathbf{p}_k \in \mathbb{C}^N$

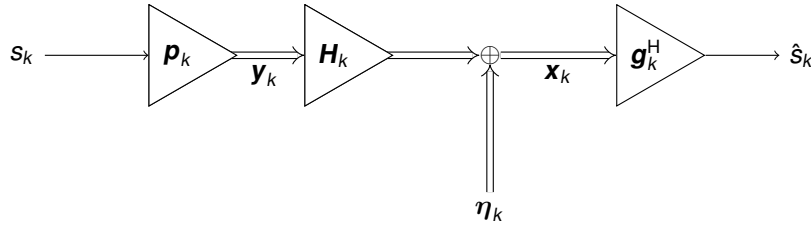


Figure 5.1: Single-stream point-to-point MIMO

and transmitted via the channel  $\mathbf{H}_k \in \mathbb{C}^{M \times N}$ .

The received signal  $\mathbf{x}_k \in \mathbb{C}^M$  is perturbed with Gaussian noise  $\eta_k \sim \mathcal{N}_{\mathbb{C}}(\mathbf{0}_M, \mathbf{C}_k)$  with noise covariance  $\mathbf{C}_k \in \mathbb{C}^{M \times M}$ . Filtering with the receive filter  $\mathbf{g}_k \in \mathbb{C}^M$  yields the received signal  $\hat{s}_k$ . The sum transmit power across all carriers is bounded by

$$\sum_{k=1}^K \mathbb{E} [\|\mathbf{y}_k\|_2^2] \leq E_{\text{Tx}}. \quad (1)$$

In the first part of this problem we will consider above system without equalizer.

a)\* Give an expression for  $\mathbf{x}_k$  as a function of  $s_k$  and  $\eta_k$ .

0  
1

$$\mathbf{x}_k = \mathbf{H}_k \mathbf{p}_k s_k + \eta_k$$

b)\* Rewrite the power constraint (1) as a function of  $\mathbf{p}_k$ .

0  
1

$$\sum_{k=1}^K \mathbb{E} [\|\mathbf{y}_k\|_2^2] = \sum_{k=1}^K \mathbb{E} [s_k^* s_k \mathbf{p}_k^H \mathbf{p}_k] = \sum_{k=1}^K \mathbf{p}_k^H \mathbf{p}_k \leq E_{\text{Tx}}$$

c) Calculate the covariance matrix  $\mathbf{C}_{\mathbf{x}_k}$  of the received signal  $\mathbf{x}_k$ .

0  
1  
2

$$\mathbf{C}_{\mathbf{x}_k} = \mathbb{E} [\mathbf{x}_k \mathbf{x}_k^H] = \mathbf{H}_k \mathbf{p}_k \mathbf{p}_k^H \mathbf{H}_k^H + \mathbf{C}_k$$

## Problem 6 Finite extension fields (13 credits)

Given the finite field  $\mathbb{F}_p$ , we consider finite extension fields

$$F_q[x] = \left\{ \sum_{i=0}^{n-1} a_i x^i \mid a_i \in \mathbb{F}_p \right\}. \quad (2)$$

0 ☐ 1 ☐ a)\* State the conditions on  $p$ ,  $q$ , and  $n$  such that a finite extension field  $F_q[x]$  exists.

If  $p \in \mathbb{N}$  is prime,  $F_q[x]$  exists for any  $q = p^n$  with  $n \in \mathbb{N}$ .

0 ☐ 1 ☐ b)\* What is a *generator* of  $\mathbb{F}_p$ ?

Some  $g \in \mathbb{F}_p$  is called *generator* if  $\bigcup \{g^i : i = 0, 1, \dots, n-1\} = \mathbb{F}_p \setminus \{0\}$ .

We now consider the finite extension field  $F_{16}[x]$  built upon  $\mathbb{F}_2 = \{0, 1\}$ .

0 ☐ 1 ☐ 2 ☐ c)\* State two reasons why this extensions field is of particular interest with respect to network coding.

- The probability of two random vector  $\mathbf{x}, \mathbf{y} \in F_q^N[x]$  is low for  $N \geq 4$ .
- The field allows for very efficient implementations.
- Symbols are represented by a nibble, i. e., two symbols make up an octet.

0 ☐ 1 ☐ 2 ☐ d)\* List all elements of  $F_{16}[x]$ .

$F_8[x] = \{0, 1,$   
 $x, x + 1,$   
 $x^2, x^2 + 1, x^2 + x, x^2 + x + 1$   
 $x^3, x^3 + 1, x^3 + x, x^3 + x + 1, x^3 + x^2, x^3 + x^2 + 1, x^3 + x^2 + x, x^3 + x^2 + x + 1\}$

e)\* Explain why a reduction polynomial  $r(x)$  is needed for the multiplicative group of  $F_q[x]$ .

Multiplication of  $c = a \cdot b$  of  $a, b \in F_q[x]$  may result in  $c \notin F_q[x]$ .  
Therefore, multiplication is defined as

$$c = a \cdot b \bmod r \quad \forall a, b \in F_q[x].$$

0
1
2

f) State the conditions a polynomial  $r(x)$  has to fulfill to be a suitable reduction polynomial.

- $r \nmid a \cdot b \quad \forall a, b \in F_q[x]$
- $\deg(r) = n + 1$  for  $q = 2^n$

0
1
2

g) Find a reduction polynomial  $r(x) \neq x^4 + 1$  for  $F_q[x]$ .

$$x^4 + 1$$

**[Rechenweg fehlt (← this is a \fixme, not a comment for correctors)]**

0
1
2
3

Additional space for solutions—clearly mark the (sub)problem your answers are related to and strike out invalid solutions.

A large grid of graph paper, consisting of 30 columns and 40 rows of small squares. A diagonal watermark with the text "Sample Solution" in a light blue, sans-serif font is overlaid across the grid, running from the bottom-left towards the top-right.