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Investigating the Flow Direction in Business Process Models: An Eye Tracking Study

Bachelor thesis at Ulm University

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Abstract

There exist a plethora of different process modelling languages for the graphical documentation of business processes. In this context, the Business Process Model and Notation (BPMN) 2.0 is one of the most well-known modelling languages and has become the de-facto standard in industry. Guidelines in BPMN 2.0 exist that describe to keep a modelling and reading direction from left-to-right or top-to-bottom. However, there exist no work so far providing empirical evidence about the influence of different reading direction during the reading and comprehension of process models. For this reason, the thesis at hand addresses this issue in an empirical study in order to investigate the influence of different reading directions. In particular, an eye tracking study involving 28 participants was conducted. In this study, four reading directions (i.e., left-to-right, right-to-left, top-to-bottom, bottom-to-top) were presented to the participants and their influence on process model comprehension was evaluated. The results of the eye tracking study show that performance in process model comprehension was similar in all four reading directions and, hence, no significant differences were found. Moreover, the results demonstrate that process model readers adapt well to less common reading directions in business process models.

Acknowledgment

My sincere thanks go to my reviewer Prof. Dr. Manfred Reichert.
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Also I want to thank all the participants and assistants from the Institute of Databases and Information Systems. My special thanks go to my friends Niklas, Steffen, Felix, Eric, Maximilian, Adrian, Michael and Hannah for their help and advice. I also want to thank Matthias Fink who gave his best advice and help.

Contents

1

Introduction

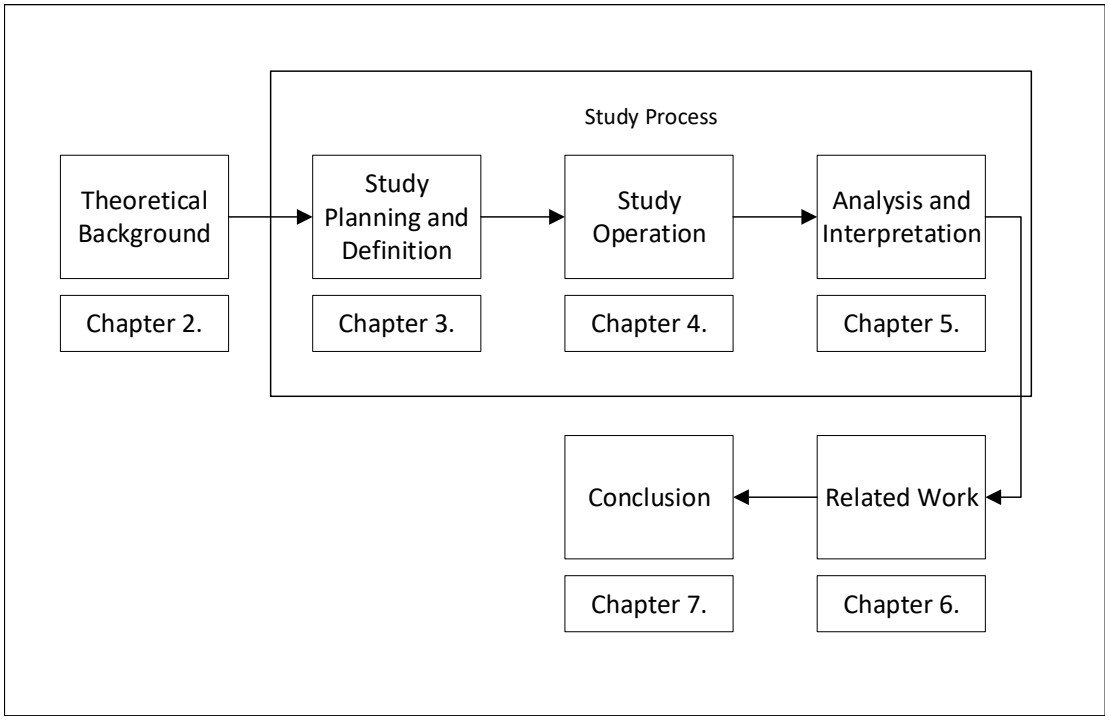

Figure 1.1: Chapter Overview

Through increasing globalization and competitive pressure, organizations are forced to optimize their structures and processes. For this business process modelling is used. Business processes describe which tasks need to be performed to reach business goals. During recent years, a lot of research was made in business process modelling [1, 2, 3, 4], through which our understanding of working with process models have improved. Despite this research, there still are many open questions [5]. This also leads to misunderstandings between process modelling experts and stakeholders, because most

stakeholders have neither experience with process modelling nor deeper knowledge of process modelling languages. For this reason, it is important to identify the factors that lead to a better comprehension of process models.
Some factors which lead to better comprehension of process models were found through research. These research demonstrates, that there are a lot of possibilities to improve the understanding of process models, for example the usage of swim lanes in Business Process Model and Notation, which decreases the required mental effort [6]. Recently, there has been a lot more research in this direction, since creating easily understandable process models is desired and there seems to be a lot of room for further improvement.
This thesis focuses on the comprehension of business process models through experimental research. Through a study, it tries to find whether there is an optimal flow direction for modelling business processes. To investigate this, the eye movements of participants were monitored and their approaches to comprehending process models with different flow directions were assessed.

The further structure of this thesis is as follows: Chapter 2 introduces Business Process Model and Notation and fundamental knowledge for the study. Chapter 3 presents the hypothesis, planning and definition. The study operation, which also includes preparation, execution and data validation is presented in Chapter 4. Results of the obtained data is analysed and described in Chapter 5. In Chapter 6 the work which is related to this thesis is discussed. Finally, Chapter 7 summarizes the study and its results.
The whole structure of this thesis is illustrated in Figure 1.1.

2

Theoretical Background

In this chapter, the theoretical background and basic knowledge for BPMN 2.0 is given in Section 2.1 and after this in Section 2.2 it is explained why Eye Tracking is useful for conducting a study.

2.1 Theoretical Background

First, process models describe a process; there are different process modelling languages, one of these is Business Process Model and Notation (BPMN) and another is Event-driven process chain (EPC). All these different modelling languages have their way to visualize processes.

BPMN today is a standard for business process modelling and was published in 2006 by the Object Management Group [7]. The latest version of BPMN is BPMN 2.0 which was released in 2011 [8]. One important purpose of Business Process Management (BPM) is to visualize business processes of an organization [9]. The visualizations enable process managers or analysts to identify properties of a process, for example bottlenecks. A business process is a set of procedures and activities which are executed in a predefined order, to realize an organizational structure or policy goal, most commonly in an organizational structure. BPMN was designed for modelling business processes and the goal of BPMN is to provide a notation that is understandable by all business users. Thus, BPMN closes the gap between process design and process implementation.

In Figure 2.1 are the basic elements displayed, these are Events, Activities, Gateways and Sequence Flows. There are even more elements than these few, but the more

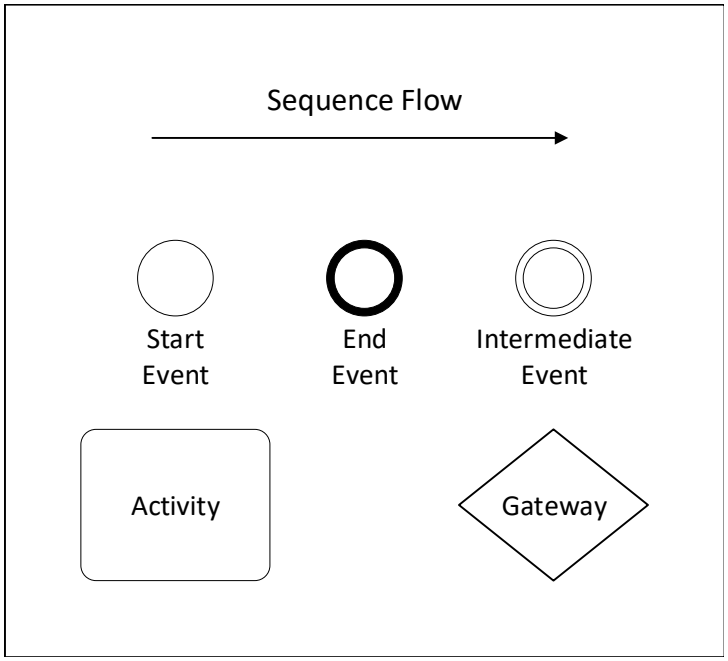

Figure 2.1: The Basic Elements of BPMN

complex elements are not needed for understanding of the process models in this thesis. In this thesis only collaboration diagrams are explained, the other two types from BPMN 2.0 are conversation and choreography diagrams. In the specification given by the Object Management Group in [8] these elements are explained as followed:

- Event: There are many different kinds of events. The most important events are the Start and End events. The Start event occurs on the start of a Business Process Model and declares the begin of this process. The End event indicates where the process ends. Beside the Start and End events there are the Intermediate events and they occur between the Start and End event. These Intermediate events affect the flow of the Process.
- Activity: Activities are used to represent work that is performed by humans or machines in the process.
- Gateways: A Gateway is used to split and join the sequence flow of a process. There are Exclusive-Gateways, AND-Gateways, OR-Gateways and Event-Based-Gateways. Normally they are used to visualize decisions or parallels.

- Sequence Flow: The Sequence Flow shows the order of how Activities are performed in the process.

One simple process model with these basic elements can be seen in Figure 2.2. This process model has a start and end event, after the start event activity A follows which is succeeded by activity B, after that there is a XOR Gateway, the XOR needs conditions. In this process model, after activity C can be seen that there is an AND Gateway which has two paths and these two paths activate the activities F and G. The process ends with H and after that the end event.

With these few elements, all later shown process models are modelled and can be understood.

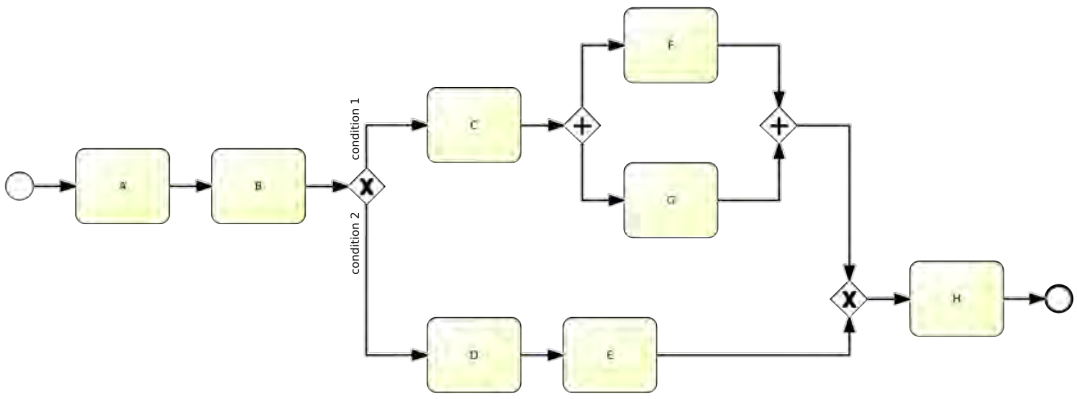

Figure 2.2: A simple process model, modelled with the basic elements.

For a more detailed explanation of BPMN the specification of OMG [8] can be useful. In this specification, it is said that most of the process models are easier to understand if the direction of the Sequence Flows is either left to right or top to bottom. Today process modelling gets more important, because of the digitalization of the whole business world. BPM is an enabler for digitalization because it is used to show the company's how they can handle the digitalization best and get an advantage out of it. For this reason, it is

important to develop understandable process models, in a way that they are precise but still easily understood, which is why research in BPM is very important. A way to improve comprehension of process models was the definition of the seven process modelling guidelines, which help to develop better process models [10]. There also exists some work about process modelling quality frameworks. One of these is the SEQUAL framework [11].

Moreover, there are papers which discuss layout algorithms for BPMN, these offer useful information about the modelling direction, one of these papers is [12]. In these papers, the start of a process model is on the left-hand side and the end to the right-hand side. For example, [13] said that the process flow should be from left to right because of the western handwriting. Less common for BPMN is to model the diagram from top to bottom. The Sequence Flow arrows can be used as hints for the reading direction [14]. A study about how humans inspect BPMN models [15] found three ways of how BPMN process models are inspected. This may help to find a flow direction for process models that fits best. The cultural influence of the direction of written language was researched and it was proven that it has influence on the understanding of sequence diagrams [14]. In the different literature, it isn't stated exactly why left to right or top to bottom are the best reading directions.

2.2 Eye Tracking

In this Section, it will be explained why Eye Tracking is useful for a study. Firstly, an Eye Tracker collects additional data, which wouldn't be accessible by using just a questionnaire. The following information can be gained by using an Eye Tracker:

- Time of the tasks
- Eye Movement of participants
- Fixations with Time

One of the visualized data of the Eye Tracker can be seen in Figure 2.3, this is one visualized eye movement path with fixations of a participant. With this data, the software

of the Eye Tracker can generate even more useful data, can be used for analysis, for example, a focus map can be created, which shows the points on the screen, most participants looked. All this data can be used alongside the normal way of collecting data for a study, which only means a clearer look at what the study focus.

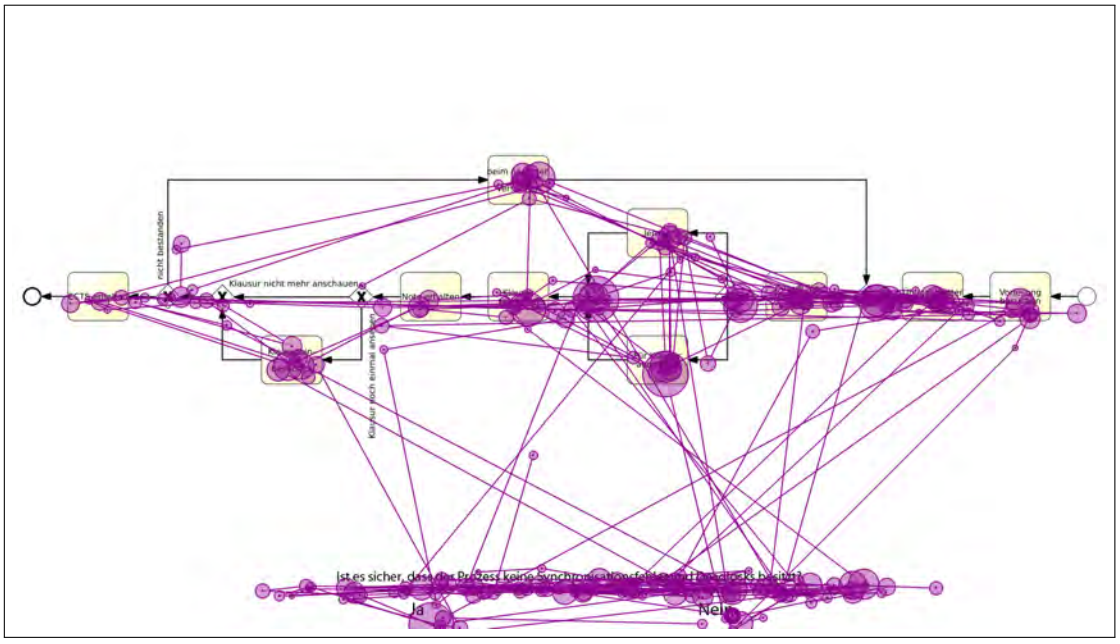

Figure 2.3: A process model with fixations and eye movement of a participant

3

Study Planning and Definition

In this chapter, the first steps of the study are explained, how the important components like the process models and the questions were developed. It also explains which tools were used for the creation and analysis of the study in Section 3.4. The Section 3.3 Participants explains who participated in the study. The structure of this chapter can be seen in Figure 3.1.

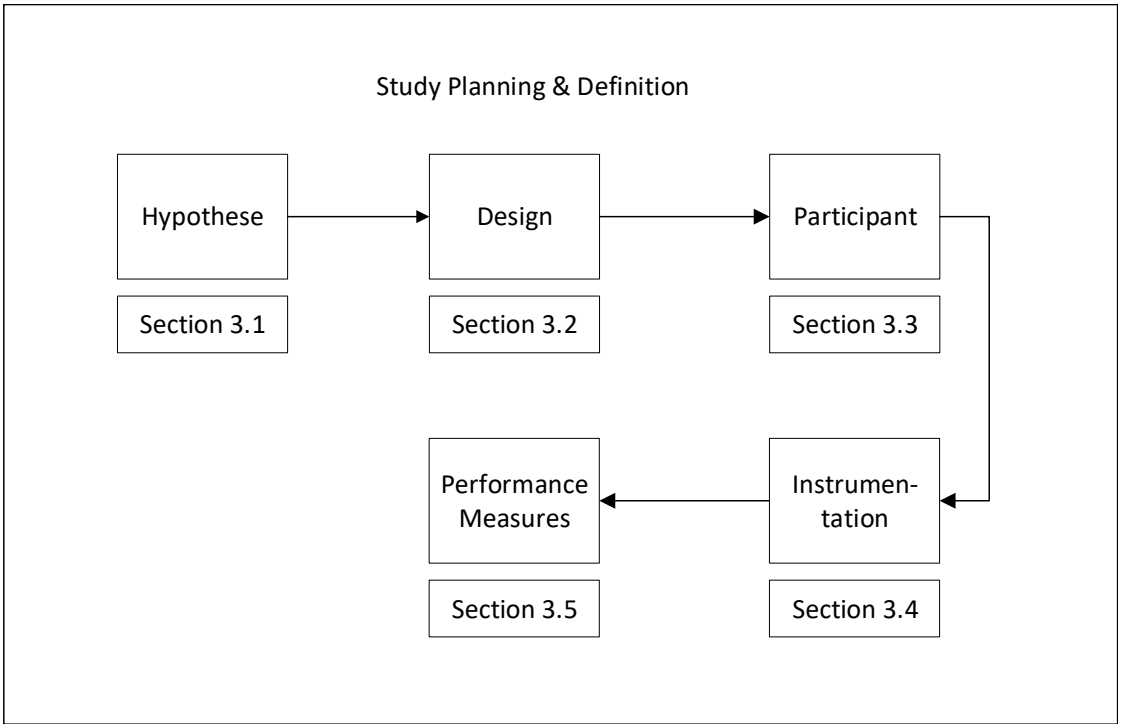

Figure 3.1: Study Planning and Definition

3.1 Hypotheses

After the theoretical background in Chapter 2, we will now define the hypothesis of the study. From Chapter 2 we assume that the flow direction of diagrams are influenced by written language and other conventions [8, 14]. The specification of BPMN 2.0 recommends to model from left-to-right. Hence, the first question is whether there exists any difference between flow directions; maybe there is an optimal flow direction for understanding a process model, or the most common flow directions left to right and top to bottom are the optimal directions to model a process.

In this context we formulate now the hypotheses, of which we have two types of hypotheses: *null hypothesis* and *alternative hypothesis*

Null Hypothesis H_N states there is no difference or no association in the study setting. The experiment tries to disprove the null hypothesis, because it is initially assumed to be true.
Alternative Hypothesis H_A is the opposite of the null hypothesis, it states that the research question and obtained study results have an association. The alternative hypothesis is what should be shown with the research.

So the hypotheses for the study are:

- H_N: The flow direction has no influence in process model comprehension.
- H_{A0}: There are differences between the flow directions in process model comprehension.
- H_{A1}: The best flow directions in process model comprehension are left to right and top to bottom.

3.2 Study Design

At first, we needed to clarify what should be tested and after that, we could start with the design of the study. So, the first steps were to think about how the structure of the

study should look like and how we can get the right information to confirm or disprove the hypotheses. After this, the first process models and the questions which could be used were developed. These process models can be found in A.3 and they describe simple processes which appear in the life of a student. The questions can be found in A.4. The questions were designed as Yes/No questions because this makes it easier for the later analyse of the study. After the design of the process models and the questions, these were paired that they can be used for the study. One of these process models with the question is presented in Figure 3.2.

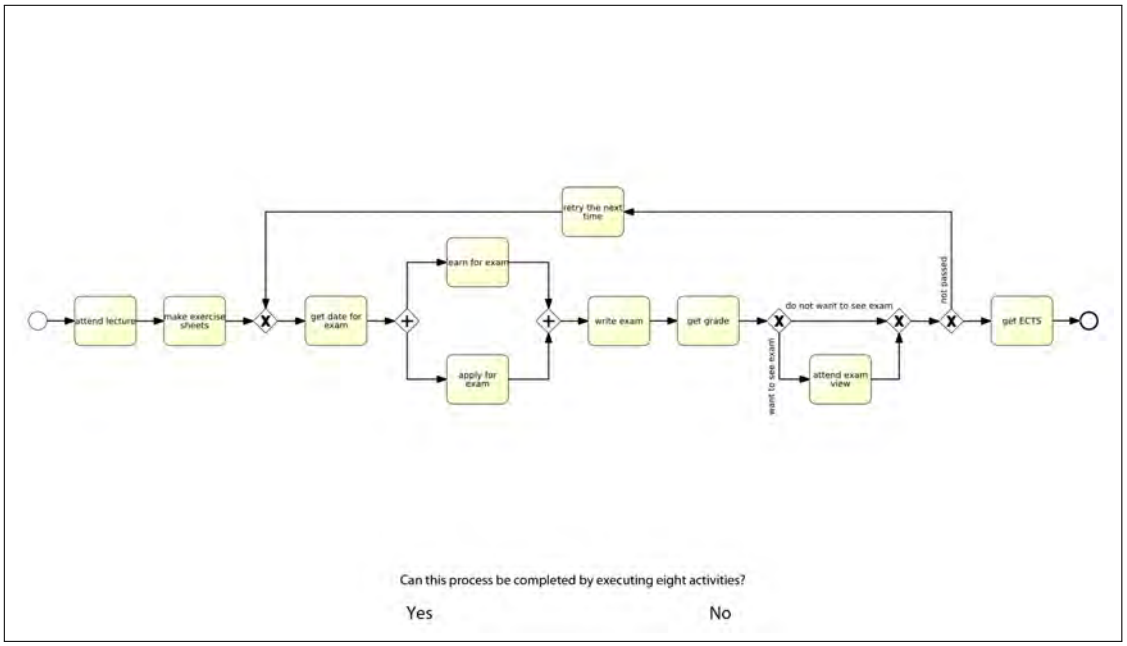

Figure 3.2: Process Model 1 with the first question

Then after the process models were finished for the study, the questionnaire was developed. For the questionnaire, we took as an example the set of modelling questions from Mendling and Strembeck [10]. The first part of the questionnaire was a demographic survey about gender, age, knowledge of BPMN, education level etc. This is presented in Figures (A.1, A.2, A.3). Part two of the questionnaire was gathering information about the knowledge the participants had, these questions can be seen in A.2. The whole study was tested by four test persons, which went through the whole study. That means they had to answer the questionnaire and the questions in the Eye Tracker. The result of

this test study was used to correct little misunderstandings of the questions and showed problems of the study that occurred but could be solved because of the testing. Some of the main problems of the study were technical difficulties with the Eye Tracker and the setup of the eye tracking room. This study was designed this way, because at every step in development problems could be solved by testing and analysing. It was also chosen because the questionnaire was used in other study before and the knowledge questions of it had as a template the questions from [10]. The process models were as simple as in [12].

3.3 Participants

In this study, only students participated. These students participated also in the lecture Business Process Intelligence, because of this, they had a fundamental understanding of BPMN. This can be seen in table A.4, based on the Sum of the Evaluated Score. The maximum that could be reached was 10 Points and the lowest score was 3 which means the participants had a fundamental knowledge of BPMN. The questions of this Evaluation can be found in A.2.

3.4 Instrumentation

For the creation of the process models, we used Signavio Process Manager [16] and to create the process models with the questions, Adobe Photoshop was used. The questionnaires were designed with Google Forms [17] and the data from the questionnaire and the Eye Tracker were collected in Microsoft Excel. For tracking and recording of the eye movement, the SMI iView X Hi-Speed System was used, with a sampling rate of 240 Hz. The Eye Tracker was placed in front of a monitor that presented the process model. The monitor had a resolution of 1920x1080 and 23 inches. The data from the Eye Tracker was analysed, visualised and exported with BeGaze 3.7. The whole data collected in an excel document and evaluated with IBM SPSS Statistics 25 [18].

3.5 Performance Measures

This Section explains the performance measures of the study. These are split into two types, the types are *factors* and *performance measures*.

Factors are variables, which could be manipulated during the study.
Performance Measures depend on the value of the *factors*, these changes if the *factors* change. They are used for the evaluation of the study.

The *factors* are:

- **Flow Direction** : This is the variable, later called version which describes which flow direction was used in the study, it is needed for evaluating because of this all the same directions could be compared with the others.
- **Questionnaire Score**: It shows the score that was reached and could be used to interpret the knowledge level of the participant.

The *performance measures* are:

- **Test Score**: Is the score that was scored during the eye tracking task. This score could be used to measure the comprehension of the process models.
- **Time**: Is required to measure the comprehension of a process model.
- **Scan Path Length**: Used to compare the lengths in the different flow directions and is a measurement for comprehending process models.
- **Number of Fixations**: Is used to see the comprehension of the process models and critical points for reading a process model.

The factor Flow Direction is essential for the study, to test through the four flow directions and know which of them was chosen. The performance measures are required to see how good the comprehension of the different process models look like.

4

Study Operation

Chapter 4 deals with the study operation, which means how the study was prepared can be seen in Section 4.1, how it was executed can be seen in Section 4.2 and in Section 4.3 it is explained how the collected data was examined. Figure 4.1 summarizes Chapter 4.

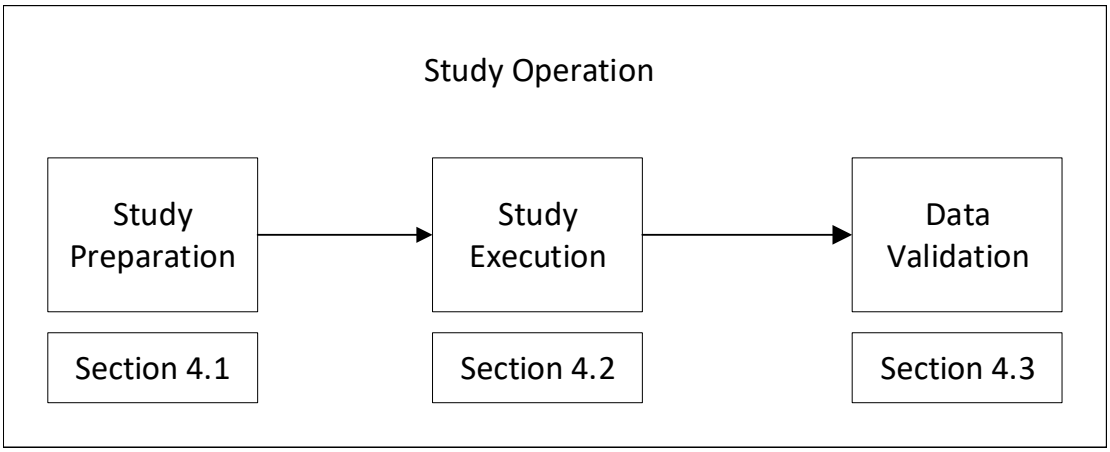

Figure 4.1: Study Operation

4.1 Study Preparation

The study was prepared after the design of the study was finished as described in 3.2. For this all process models were checked if they are correct, if not they had to be corrected. A first test with the whole eye tracking setup was made to see if everything works right. After this, employees of the Institute of Databases and Information Systems helped to correct little problems with the setup and get the right configurations. Next, a

pilot study took place. In this pilot study four people participated, these participants had to go through the whole study testing, which showed some problems with the questions of the process models. The problems were resolved and after this the study was ready to start.

4.2 Study Execution

The study took place in the Eye Tracking Room of the Institute of Databases and Information Systems at Ulm University. In this room, only one person could participate in the study. Therefore, several appointments were offered over a period of three weeks. Each study needed about 30 minutes and followed the following procedure (see Figure 4.2):

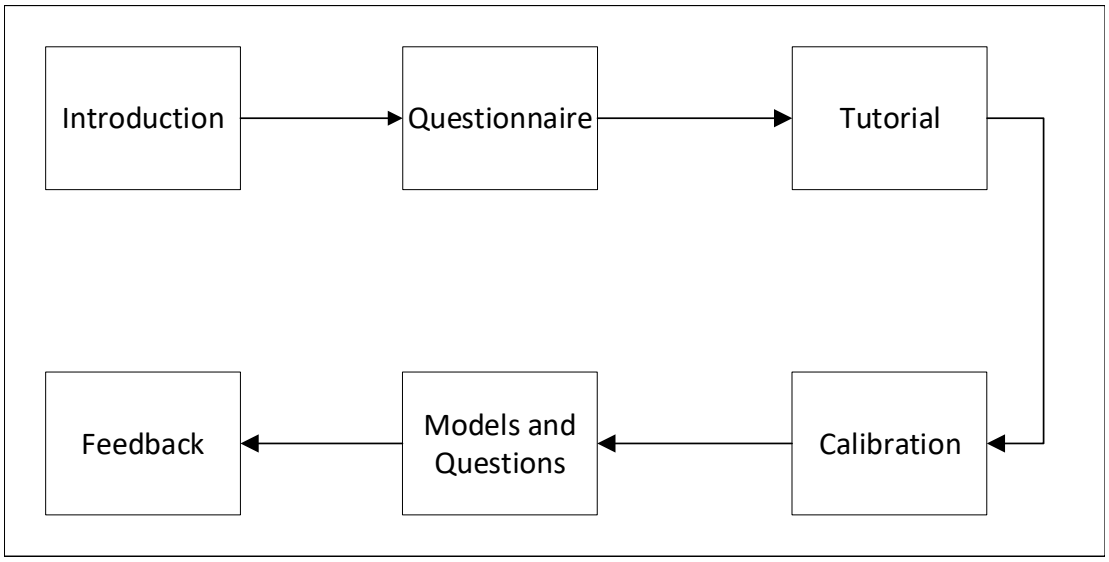

Figure 4.2: Study Execution

At the beginning of the study, an introduction was given to the participant. Afterwards, they were requested to fill out the questionnaire. Then the participant had to work with the Eye Tracker and make a short tutorial, these process model can be seen in Figure A.4. After the first experience with the Eye Tracker, the calibration took place, after that, a flow direction was chosen which can be seen in Figure 4.3 and the correct process

models for this direction were displayed with the questions. The participants had to answer these questions with a button for yes and one for no. After finishing this task the participant could leave feedback and were asked if they found something that is not normal on the process models. All results were saved in Google Forms [17] and a Text File. Later these results were stored in an Excel Document for Validation.

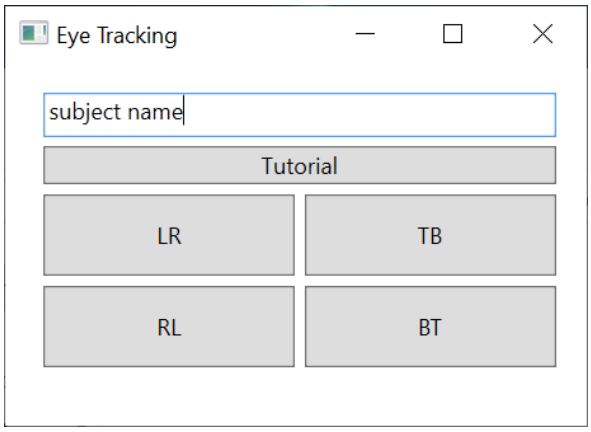

Figure 4.3: Window for choosing a flow direction

4.3 Data Validation

After performing the study, data was collected from 28 participants. 15 of these participants were female and 13 were male. This can be seen in table A.4, in this table the age and evaluation score of the participants is presented. For 10 participants the data of the Eye Tracker was removed, for one additional person only a part of the collected Eye Tracker data had to be removed. The data from these participants were removed due to the following reasons:

- The resulting Scan Path was incomplete.
- The resulting Scan Path was distorted because of a failure in the calibration or difficulties with the Eye Tracker.
- The data was not generated because of the participants wearing glasses.

After removing, data of 28 participants and 17 Eye Tracking surveillances was used for data analysis (cf. Section 5). The Eye Tracking data after removing came from 6 females and 11 males.

5

Study Analysis and Interpretation

Chapter 5 deals with statistical analysis and interpretation, this is the last part of the study. Section 5.1 shows the obtained raw data from the study. In Section 5.2 the Validation of the Hypothesis is tested. The last Section 5.4 discuss what else can be done and what the study didn't test. Figure 5.1 shows the structure of Section 5.

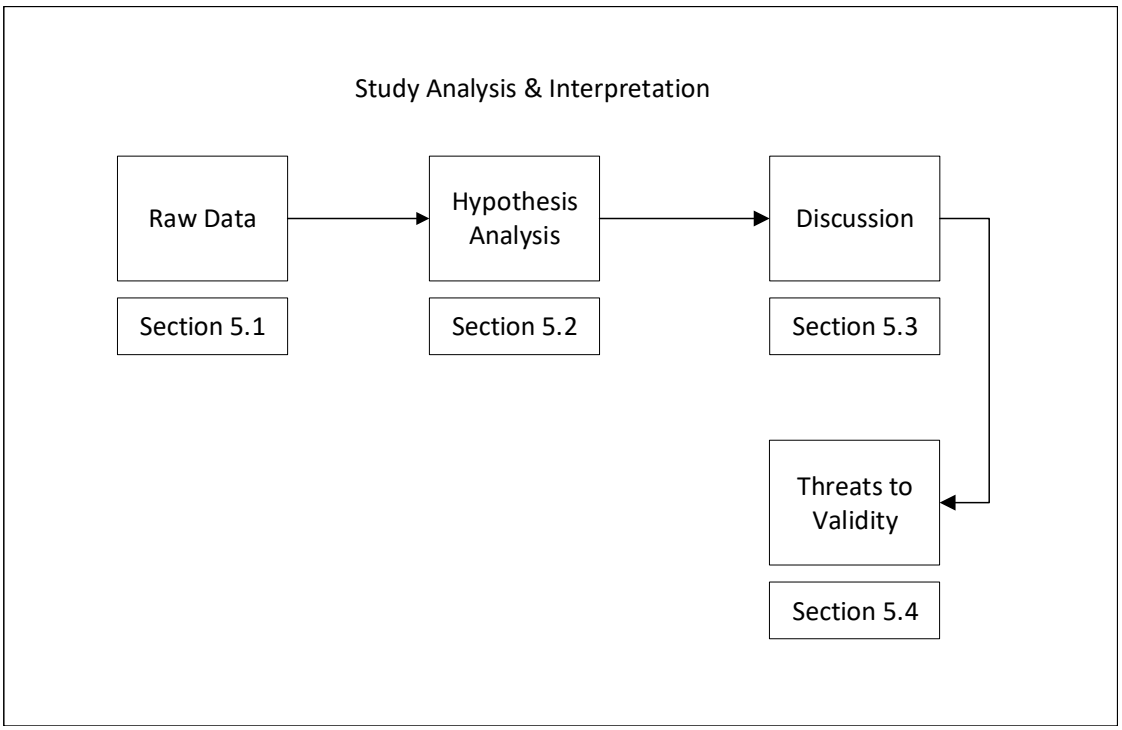

Figure 5.1: Study Analysis and Interpretation

5.1 Raw Data Analysis

The collected data is visualized in descriptive statistics as tables to provide good comprehension. Descriptive statistics give no assessment about the validity of the results. These different tables below show each a descriptive statistic of one measure of the study.

First, Table 5.1 describes what is meant by Version in the different descriptive statistics. Also, the numbers in the first column of each descriptive table means which of the three process models were used. Each table shows the process model which was used, version, mean, the standard deviation and the amount of the results which weren't removed during the data validation.

Version	Reading Direction
0	Left-Right
1	Top-Bottom
2	Right-Left
3	Bottom-Top

Table 5.1: Description of the Version numbers

Table 5.2 contains the results of the score the participants had reached during the questionnaire. The highest score that could be reached was 5 Points. In this table, it can also be seen that process model 3 had the best scores of the three process models. Out of this statistic table, a slight difference can be seen, the score in total for process model 2 is the lowest and process model 3 had the highest score. In this table it also can be seen that the data of every 28 participants could be used for analysis, every process model and flow direction had the same number of participants. The highest mean score is 5 which can be seen in process model 3 version 0 and 2.

Table 5.3 contains the time in milliseconds the participants needed to finish the tasks according to the different process models. Hence, there can be seen that the process model 3 needed less time than the others. The number of data which could be used was from all 28 participants, the table also shows that every process model and flow direction had 7 participants each. The lowest standard deviation can be seen by time 2 and version 0. The lowest mean time was in process model 3 version 0.

	Version	Mean	Std. Deviation	N
Score_1	0	3,71	0,756	7
	1	3,57	0,976	7
	2	3,57	1,272	7
	3	4,29	0,756	7
	Total	3,79	0,957	28
Score_2	0	2,71	1,113	7
	1	3,57	1,134	7
	2	3,29	0,951	7
	3	3,14	0,900	7
	Total	3,18	1,020	28
Score_3	0	5,00	0,000	7
	1	4,71	0,488	7
	2	5,00	0,000	7
	3	4,71	0,488	7
	Total	4,86	0,356	28

Table 5.2: Descriptive Statistics for Test Score

	Version	Mean	Std. Deviation	N
Time_1	0	92717,14	12763,172	7
	1	99525,71	42835,853	7
	2	96402,86	29764,297	7
	3	100484,29	25606,757	7
	Total	97282,50	28215,354	28
Time_2	0	87590,00	3649,731	7
	1	87490,00	21787,687	7
	2	91004,29	26027,507	7
	3	82574,29	24275,648	7
	Total	87164,64	19982,658	28
Time_3	0	49307,14	9040,508	7
	1	79274,29	20461,178	7
	2	56608,57	18196,329	7
	3	66882,86	19971,743	7
	Total	63018,21	20129,315	28

Table 5.3: Descriptive Statistics for Time(ms)

Table 5.4 contains the number of fixations that the participants needed to finish the different tasks in the process models. Also, it can be seen that there is an extreme disparity between process model 3 and the other two process models. This is because the mean of process model 3 version 1 is very high, which is because one participant had

much more fixations there. But between process model 1 and process model 2, there is not much disparity. In this table it also can be seen that data from some participants couldn't be used, only from 18 participants in whole the data could be used. Every version had a different amount of data from participants, the lowest is version 2. The lowest standard deviation is 22,546 in process model 3 version 0.

	Version	Mean	Std. Deviation	N
Fixation_1	0	339,75	45,879	4
	1	389,80	140,582	5
	2	246,00	31,321	3
	3	395,50	120,971	6
	Total	356,61	111,914	18
Fixation_2	0	306,00	37,921	4
	1	319,80	80,182	5
	2	241,67	30,665	3
	3	318,33	106,367	6
	Total	303,22	77,696	18
Fixation_3	0	182,50	22,546	4
	1	20421,20	45058,369	5
	2	141,33	39,501	3
	3	251,33	77,783	6
	Total	5820,44	23759,783	18

Table 5.4: Descriptive Statistics for Fixation

Table 5.5 contains the descriptive statistic of the scan paths from the process models. There can be seen that between the process models don't exist much difference because the mean numbers aren't that different. The only difference is that the scan path total of process model 3 is lower than the other. The data of the participants that could be used were 17 data sets. In version 2 there only 3 participants data could be used. The lowest standard deviation is 3863,062 in process model 2 version 2.

	Version	Mean	Std. Deviation	N
ScanPath_1	0	70843,75	12892,525	4
	1	60860,00	18437,873	4
	2	56327,67	9381,951	3
	3	70699,83	18239,105	6
	Total	65882,18	15752,711	17
ScanPath_2	0	61581,50	9528,936	4
	1	57577,75	16570,876	4
	2	58188,33	3863,062	3
	3	54768,50	13969,445	6
	Total	57636,06	11764,058	17
ScanPath_3	0	43497,75	6229,173	4
	1	53340,00	12760,663	4
	2	35545,00	7061,570	3
	3	49063,50	13563,657	6
	Total	46374,53	11850,372	17

Table 5.5: Descriptive Statistics for Scan Path

5.2 Hypothesis Analysis

In this Section, the hypothesis will be compared with the results of the study. This will show if the hypotheses are correct or if the results show a different behaviour. To analyse the raw data of the study IBM SPSS Statistics 25 [18] was used and the results of this analyse can be seen in the tables of this Section. In these tables the significance can be seen, a result is significant if the significant level is lower than 0.05, if it is higher it means that the result isn't significant. Furthermore, ME is the abbreviation of Main Effect and IE is the abbreviation of Interaction Effect.

First, table 5.6 shows as ME 1 the statistical analysis of the score. ME 2 is the version with the score of the test of within-subject effect. IE shows the interaction between score and version.

	df	F	Sig.
ME 1	F(1,977; 47,447);	33,314;	0,000
ME 2	F(5,931; 47,477);	0,227	0,877;
IE	F(3; 24)	1,392	0,238;

Table 5.6: Effects of Score and Version

Table 5.7 looks like table 5.6 but ME 1 is Time, ME 2 is the test of within-subject effect, IE also shows the interaction of the time and the version.

	df	F	Sig.
ME 1	F(1,720; 41,281);	33,098;	0,000
ME 2	F(5,160; 41,281);	0,486;	0,695
IE	F(3; 24);	1,562;	0,191

Table 5.7: Effects of Time and Version

Table 5.8 and table 5.9 are like table 5.6 and table 5.7, but regarding other variables. Table 5.8 has ME 1 as the fixations and the IE is between fixations and version. In table 5.9 ME 1 is the measurement of the scan paths and because of this, the IE is between scan paths and version.

	df	F	Sig.
ME 1	F(1,000; 14,000);	0,707;	0,414
ME 2	F(3,000; 14,000);	0,850;	0,490
IE	F(3; 14);	0,847;	0,491

Table 5.8: Effects of Fixations and Version

	df	F	Sig.
ME 1	F(1,512; 19,659);	24,304;	0,000
ME 2	F(4,537; 19,659);	0,390;	0,762
IE	F(3; 13);	2,254;	0,094

Table 5.9: Effects of Scan Path and Version

Table 5.11 and 5.10 are different because these two shows the interaction with the flow. Flow means the usual used reading direction for process models, like in the Alternative Hypothesis H_{A1} described.

	df	F	Sig.
ME 1	F(1,966; 51,109);	31,021;	0,000
ME 2	F(1,966; 51,109)	0,356;	0,556
IE	F(1; 26);	0,237;	0,786

Table 5.10: Effects of Score and Flow

Out of all these analysed tables, the hypotheses H_{A0} and H_{A1} are rejected. The tables 5.6, 5.7, 5.8 and 5.9 can be used to reject Hypothesis H_{A0}. The data of the analysis

	df	F	Sig.
ME 1	F(1,793; 46,616);	30,170;	0,000
ME 2	F(1,793; 46,616)	0,002;	0,964
IE	F(1; 26)	0,147;	0,841

Table 5.11: Effects of Time and Flow

shows the different flow direction labelled as version in the tables compared with different other measurements that were collected while the study. Through table 5.10 can be seen that ME 1 is significant but ME 2 is not significant, even the interaction between both isn't significant which means that the score gained while the study wasn't influenced by the flow direction.
Table 5.11 shows that ME 1 is significant and ME 2 is not significant, through the IE can be seen that the interaction between the time and the flow isn't significant, which means that the flow direction of a process model does not influence the time that the participants needed to finish the study.
In table 5.8 can be also seen that ME 1, ME 2 and IE aren't significant, which means that the fixations aren't influenced by the flow direction.
With table 5.9 it can be proved that the flow direction of a process model does not influence the understanding of the process models because ME 1 is significant, but IE isn't significant which means the flow direction does not influence the scan path.

Because of these results, it can be said that the flow direction of process models have no influence of the readability and understanding of the process model, which means that H_{A0} is rejected.

Now to the analysis of the Hypothesis H_{A1}, in table 5.10 it can be seen that ME 1 is significant, but ME 2 isn't significant, so IE is not significant which also means that the standard flow directions have no influence on the score.
In table 5.11 it also can be seen that the standard flow directions do not influence the time that was needed for the study, this can be seen by IE which isn't significant. This means that H_{A1} can be rejected and the "normal" flow directions aren't better than the others. This all means that the Null Hypothesis H_N is true and the flow direction don't influence the comprehension of process models.

5.3 Threats to Validity

This Section discusses the threats to validity, which means the risk factors. First, the process models aren't so complex that they can be compared to process models in the business world. Which means that the result maybe isn't applicable to companies, because their process models may be more complex, their process models maybe even can't be presented on one display, that they need more displays or must scroll through the process model.
The study also has a problem in terms of generalization, as in the study only students participated, and students aren't experts in the modelling of business processes. But students can be compared to experts to a certain degree, because students could be considered experts on a theoretical level with less practical experience. An even bigger limitation is that there were only 28 participants and only from 17 of them the eye tracking data could be used, which means the study may give another result if more participants are used. Furthermore, the cultural background of the written language of the participants wasn't considered, which could lead to other results. Maybe there is a optimal flow direction for people who have not a western cultural background of written language.

5.4 Discussion

The study of this thesis aimed at finding an answer to which flow direction is optimal for process model comprehension. The hypothesis was that the use of different flow directions influence the comprehension of process models, it was also claimed that the typical flow directions (left-to-right, top-to-bottom) might ease comprehension, because of the written language [14] and the guidelines for BPMN [8].
Analysis of the study revealed interesting results. The Alternative Hypotheses stated that the flow direction influences process model comprehension and that the optimal two flow directions are left-to-right and top-to-bottom. These two hypotheses were both rejected through the results of the study, because the analysis of the data leads to no significant disparity in the comprehension of process models with different flow directions. Through

this, the Null Hypothesis was approved, which stated that there exist no differences in understanding process models based on differing flow directions. These results are unexpected, which mind be explained by the fact that when the participants are confronted with process models and are asked to answer comprehension questions, they might be especially cautious and inclined to pay more attention to the process models than they usually would when working with such models. Furthermore, the process models were quiet simple which reduces the required cognitive effort and leads to better overall performance. This can be seen in the statistical results from process model 3 by comparing it with the results of the other process models. The results for process model 3 were much better due to its less complex structure. Moreover, another explanation for the result is that BPMN heavily relies on sequence flows, modelled with arrows, these help understanding the flow of a structure [14]. The threats to validity shouldn't be ignored either. These are explained in Section 5.3.

For these reasons further work on this topic could deliver clearer results. Thus study should be repeated in a similar fashion with a larger group participants. If the study would be repeated in the future, it should also test whether the results are different if the participants are not limited to students and whether cultural differences concerning the common direction of the written language influence the result. Such a study should then also include additional, more complex process models, which are closer to those actually used in businesses and leave more room for error.

This study delivered the same conclusion as another study of flow direction in business process modelling [12]. In practice this means that the flow direction of process models is largely irrelevant and can thus be varied at will to fit the preferences of those who work with them. As this study comes to the same conclusion as [12], it solidifies this conclusion and therefore gives a baseline for subsequent research. Such research could try to further solidify this conclusion or find other ways to improve the understanding of business process models.

6

Related Work

This thesis investigates the impact of different flow directions in BPMN. By now, there is not that much works which investigate the impact of flow directions in BPMN. To be true there is only one other work that investigates the same topic as this thesis, namely the work of [12]. This work was a study which tested the comprehension accuracy, comprehension efficiency and the influence on the perceived ease of use of process models. They also used simple process models for testing and designed them with the four flow directions. At the end of their testing, they came to the same result as the study of this thesis, which means they found that there is no superior flow direction.
Furthermore, a study of [14] examined if the cultural background of written language direction would influence the learning of sequences and classification of dinosaurs from normal-order and reversed-order diagrams. In this work, they took 9. grade students from two schools. Through their testing, they gained the result that the participants learned more from the normal-order sequence diagram than from the reversed-order sequence diagram. This may be also be applied to BPMN, goes against what this thesis has shown, which might be because BPMN uses Sequence Flows with arrow, as [14] also stated that understanding and learning could be influenced by arrows.
By now, there are some papers about process model comprehension and whether a model with a good comprehensive design is better readable. For example, in the paper [3] they discuss the lessons learned during eye tracking experiments on process model comprehension. They grouped these lessons into nine categories, which are familiarity with scenarios, understanding of process models, modelling of process models, structure & layout, process modelling languages, basic modelling elements, modelling constructs, individuals and measurement methods. In these nine categories, it is explained which

factors influence the comprehension of process models. For example, in the category familiarity with scenarios, it is explained that the cognitive load might become lower if the process shows a scenario which is familiar to the person. In [6] they found that swim lanes in BPMN models help to understand the process model better. This is because of the cognitive effort that is needed in understanding a process models. Another work that discusses the comprehension of process models is [2]; they found out that the visual cognition has an influence on the comprehension of process models.
Through research with experts [19] found out that these experts only explore a part of an entire process model if asked comprehension questions. It was also tested by [20], if a process model is easier to understand for non-experts than a textual description of the process. The result was that process models aren't better for non-experts but do influence experts in understanding processes. They researched these so-called Relevant Regions and if they could improve process model comprehension. Another interesting work about the understandability of business process models in BPMN is [21]. They researched modularity of process models and the comprehension of these modularized models. The result of their study was that for business practitioners the process model with not collapsed sub-processes are the most understandable. Through all this information about the comprehension of process models and the results from this thesis, better understandable process models can be developed.

7

Conclusion

In this thesis results from a flow direction study on business process models that used eye tracking were presented. The Null Hypothesis which stated that, the comprehension of process models isn't influenced from different flow directions, was approved and the two defined Alternative Hypotheses were rejected. This was concluded through the analysis of data gathered via a questionnaire, tracked eye movements and results from questions asked during the eye tracking process. These findings support the results of another study, which investigated the flow direction of process models [12].
But this study didn't find any negative effects of the left-to-right flow direction or any other flow direction, which means, that there is no need to change the recommended flow direction in BPMN from left-to-right to another direction. This is an important result for the application of business process models and also provides opportunities for subsequent research.
However, a follow-up study with a larger and broader sample is needed to provide more definitive evidence. Cultural differences concerning the common direction of the written language might also be an interesting factor to be considered in such a follow-up.

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A

Appendix

A.1 Evaluation Table

Version	Reading Direction
0	Left-Right
1	Top-Bottom
2	Right-Left
3	Bottom-Top

Table A.1: Description of the Version numbers

Age number	Age
0	under 25
1	25-35

Table A.2: Description of the Age numbers

Gender number	Gender
0	male
1	female
2	diverse
3	prefer not to say

Table A.3: Description of the Gender numbers

ID	Version	Age	Gender	Sum_Eval_Score
0A2K7A0B9	2	0	1	9
0A5t4e5S14	2	1	1	6
0F5G3N1S9	3	1	0	6
0L4n4a0R8	0	0	1	5
0M4L4O0K8	0	0	0	7
0V3r6a3E12	1	0	1	6
1F6n2c0L9	0	1	0	8
1J3r6a0B10	3	0	1	8
1T5y9u0O47	3	1	1	8
2C2r6a1S11	2	0	1	8
2D7R2L0W11	2	1	0	6
2P3E5P0S10	2	0	0	9
2P4y4r0W10	1	0	0	8
2S5h4n0S11	1	1	0	7
3M6k3x0L12	0	1	0	8
4S3r5h1M13	3	0	1	9
5C6e2a0O13	1	1	1	5
5S4R4N1M14	0	0	0	4
6M6S2S0B14	3	1	0	6
6R5r3a0K14	3	1	1	8
7M8R1K0R16	1	1	0	8
7S4n5n0B16	1	0	0	5
7S7n2r0O16	1	1	1	3
8i5s4a2n19	0	1	1	4
8L8y0a0M16	2	1	1	7
9A5y3a1S18	2	1	1	8
9c7r1n1d18	0	1	1	8
9J7r2s0H18	3	1	0	6

Table A.4: Evaluated Questionnaire

A.2 Questionnaire

- After exclusive choices, at most one alternative path is executed (yes/no).
- Exclusive choices can be used to model repetition (yes/no).
- Synchronization means that two activities are executed at the same time (yes/no).
- An inclusive OR can activate concurrent paths (yes/no).
- If two activities are concurrent, they have to be executed at the same time (yes/no).
- If an activity is modelled to be part of a loop, it has to be executed at least once (yes/no).
- Having an AND-split at the exit of a loop can lead to non-termination (yes/no).
- A deadlock is the result of an inappropriate combination of splits and joins (yes/no).
- Processes without loops cannot deadlock (yes/no).
- A OR Gateway can be modelled with a AND- and XOR-Gateway (yes/no).

Persönlicher Code

Um die erhobenen Daten zu anonymisieren, verwenden wir für den weiteren Verlauf der Studie einen Code. Erstellen Sie diesen Code nach dem folgenden Muster:

1. Zweite Ziffer des Tags Ihres Geburtsdatums
2. Erster Buchstabe Ihres Vornamens
3. Zweite Ziffer Ihres Alters
4. Letzter Buchstabe Ihres Familiennamens
5. Letzte Ziffer Ihres Geburtsjahres
6. Letzter Buchstabe des Vornamens
7. Erste Ziffer des Monats Ihres Geburtsdatums
8. Erster Buchstabe des Familiennamens
9. Berechnen Sie die Prüfsumme aller Ziffern

* Erforderlich

Beispiel:

Name:	John Public
Alter:	29
Geburtstag:	19.05.1988

1.	Zweite Ziffer des Tags Ihres Geburtsdatums:	19	→ 9
2.	Erster Buchstabe Ihres Vornamens:	John	→ J
3.	Zweite Ziffer Ihres Alters:	29	→ 9
4.	Letzter Buchstabe Ihres Familiennamens:	Public	→ c
5.	Letzte Ziffer Ihres Geburtsjahrs:	1988	→ 8
6.	Letzter Buchstabe des Vornamens:	John	→ n
7.	Erste Ziffer des Monats Ihres Geburtsdatums:	05	→ 0
8.	Erster Buchstabe des Familiennamens:	Public	→ P
9.	Berechnen Sie die Prüfsumme aller Ziffern:	9+9+8+0	→ 26

Der in diesem Beispiel generierte Code lautet **9J9c8n0P26**.

1. **Ihr persönlicher Code** *

Demographischer Fragebogen

2. **Geschlecht** *
   Markieren Sie nur ein Oval.
   - ◯ weiblich
   - ◯ männlich
   - ◯ divers
   - ◯ keine Angabe

Figure A.1: Demographic Survey - Part1

3. **Alter** *
Markieren Sie nur ein Oval.

- ◯ jünger als 25
- ◯ 25 - 35
- ◯ 36 - 45
- ◯ 46 - 55
- ◯ älter als 55

4. **höchster Bildungsabschluss** *
Markieren Sie nur ein Oval.

- ◯ Ohne Abschluss
- ◯ Hauptschulabschluss oder Volkshochschulabschluss
- ◯ Realschulabschluss (Mittlere Reife)
- ◯ Fachhochschulreife
- ◯ Hochschulreife (Abitur)
- ◯ Fachhochschulabschluss
- ◯ Bachelor Hochschulabschluss
- ◯ Master Hochschulabschluss
- ◯ Sonstiges: _____

5. **Wie hoch ist Ihre aktuelle Anzahl an Ausbildungsjahren (inkl. Grundschule)**

_____

6. **Welche berufliche Ausbildung trifft am ehesten auf Sie zu?** *
Markieren Sie nur ein Oval.

- ◯ Auszubildende(r)/Student
- ◯ Abgeschlossene Berufsausbildung
- ◯ Abgeschlossene Ausbildung an einer Meister- oder Technikerschule
- ◯ Akademiker(in)
- ◯ Sonstiges: _____

7. **Falls Sie studieren (oder studiert haben), geben Sie bitte Ihren Studiengang mit Semesterzahl oder den erreichten Abschluss an:**

_____

8. **Haben Sie bereits Erfahrung mit Prozessmodellen bzw. Prozessmodellierung** *
Markieren Sie nur ein Oval.

- ◯ ja
- ◯ Nein

Figure A.2: Demographic Survey - Part2

9. **Bitte kreuzen Sie an, welche Notation zur Prozessmodellierung haben Sie während Ihrer Ausbildung/Studium als erstes gelernt**
   Markieren Sie nur ein Oval.

   - ◯ BPMN
   - ◯ Deklarativ
   - ◯ eGantt
   - ◯ EPK
   - ◯ Flow Chart
   - ◯ IDEF 3
   - ◯ Petri Netz
   - ◯ UML Aktivitätdiagramm
   - ◯ Sonstiges: _____

10. **Mit welcher der in der vorherigen Frage angegebenen Notationen zur Prozessmodellierung haben Sie bisher die meiste Zeit verbracht?**

    _____

11. **Wie häufig begegnen Sie Prozessmodellen in der Praxis**
    Markieren Sie nur ein Oval.

    - ◯ nie
    - ◯ seltener als einmal im Monat
    - ◯ häufiger als einmal im Monat
    - ◯ Täglich

12. **Wann haben Sie zum ersten Mal mit Prozessmodellen gearbeitet?**
    Markieren Sie nur ein Oval.

    - ◯ vor weniger als einem Monat
    - ◯ vor weniger als einem Jahr
    - ◯ vor weniger als drei Jahren
    - ◯ vor mehr als drei Jahren

Wissensfragen

Bitte beantworten Sie die folgenden Wissensfragen mit ja oder nein

13. **Nach einem XOR-Gateway wird höchstens einer der alternativen Pfade ausgeführt?** *
    Markieren Sie nur ein Oval.

    - ◯ ja
    - ◯ Nein

14. **XOR-Gateways können genutzt werden, um Schleifen zu modellieren?** *
    Markieren Sie nur ein Oval.

    - ◯ ja
    - ◯ Nein

Figure A.3: Demographic Survey - Part3

A.3 Process Models

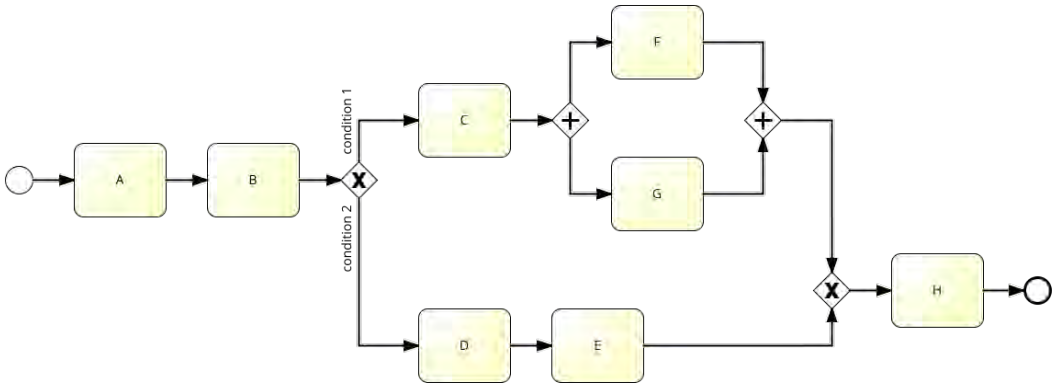

Figure A.4: The Process Model to start with

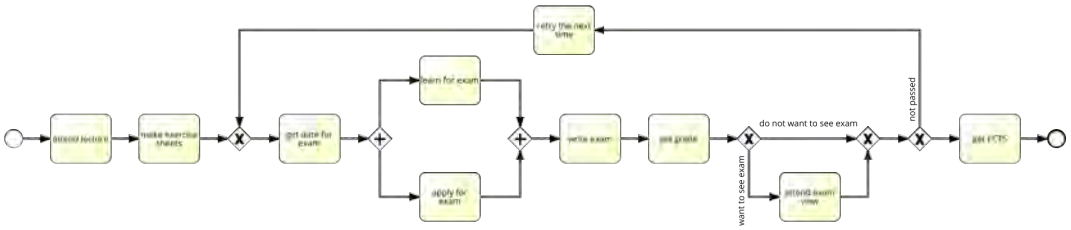

Figure A.5: Process Model 1 Left-Right

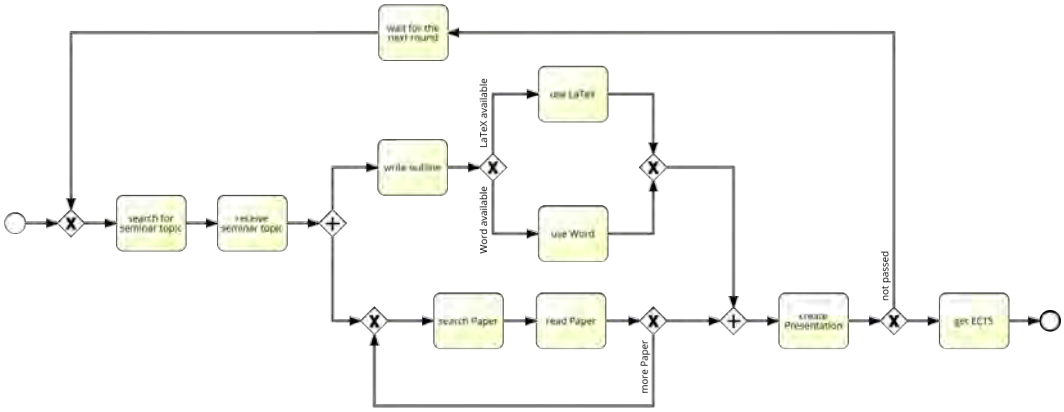

Figure A.6: Process Model 2 Left-Right

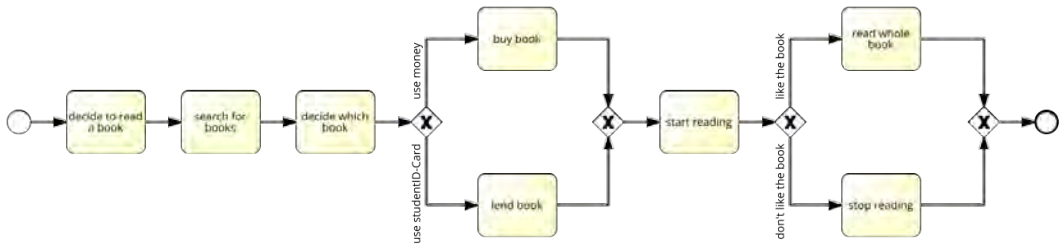

Figure A.7: Process Model 3 Left-Right

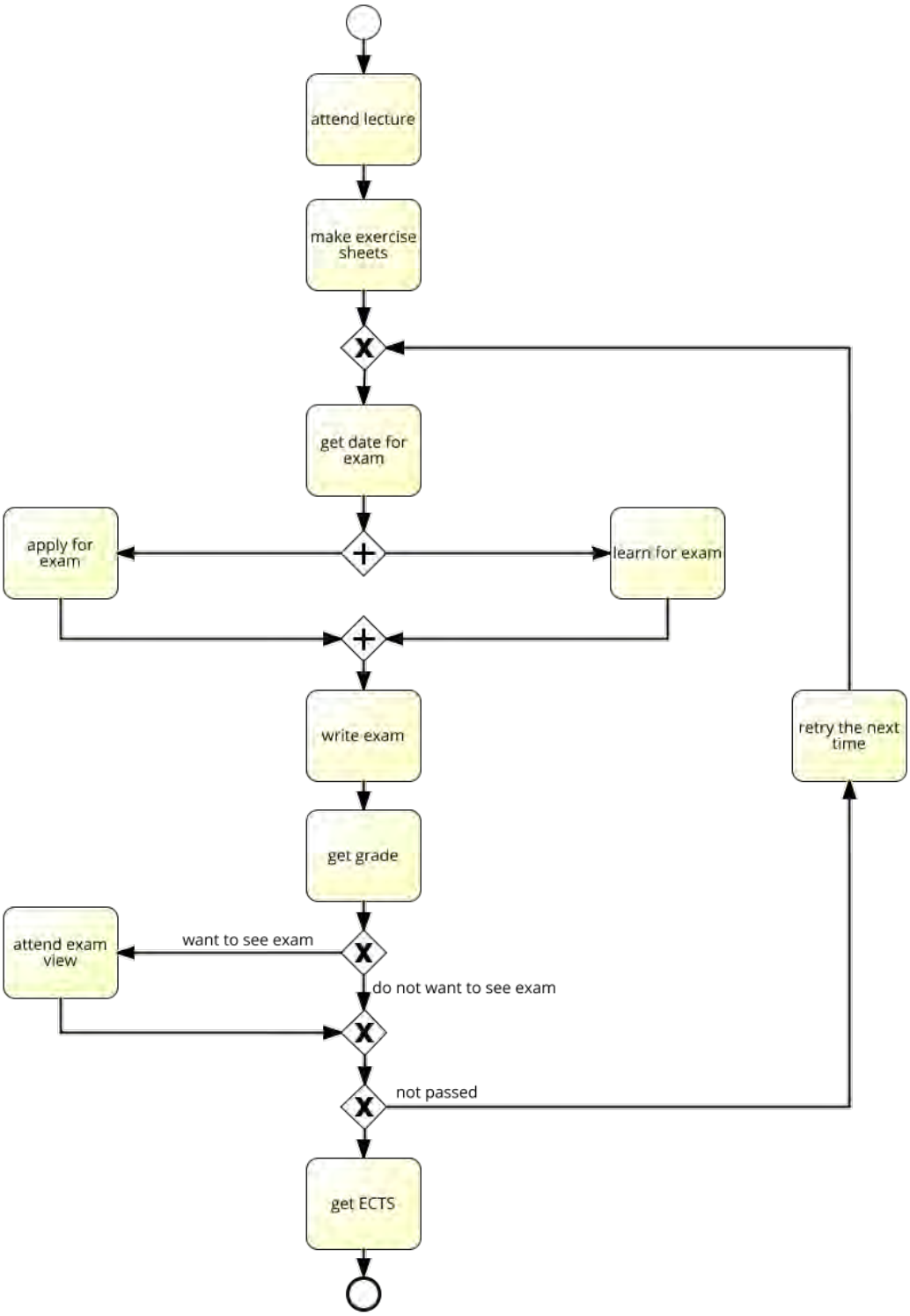

Figure A.8: Process Model 1 Top-Bottom

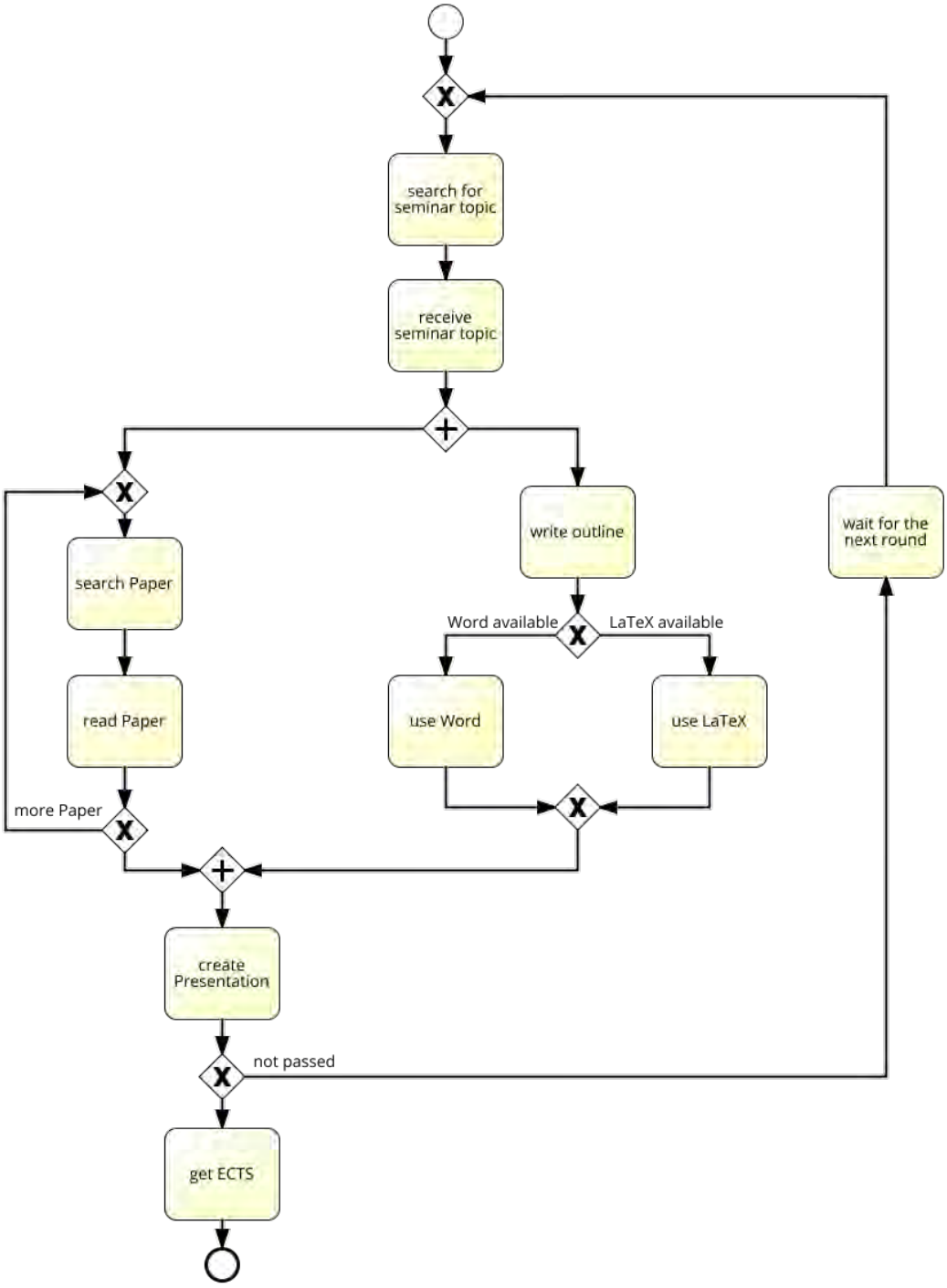

Figure A.9: Process Model 2 Top-Bottom

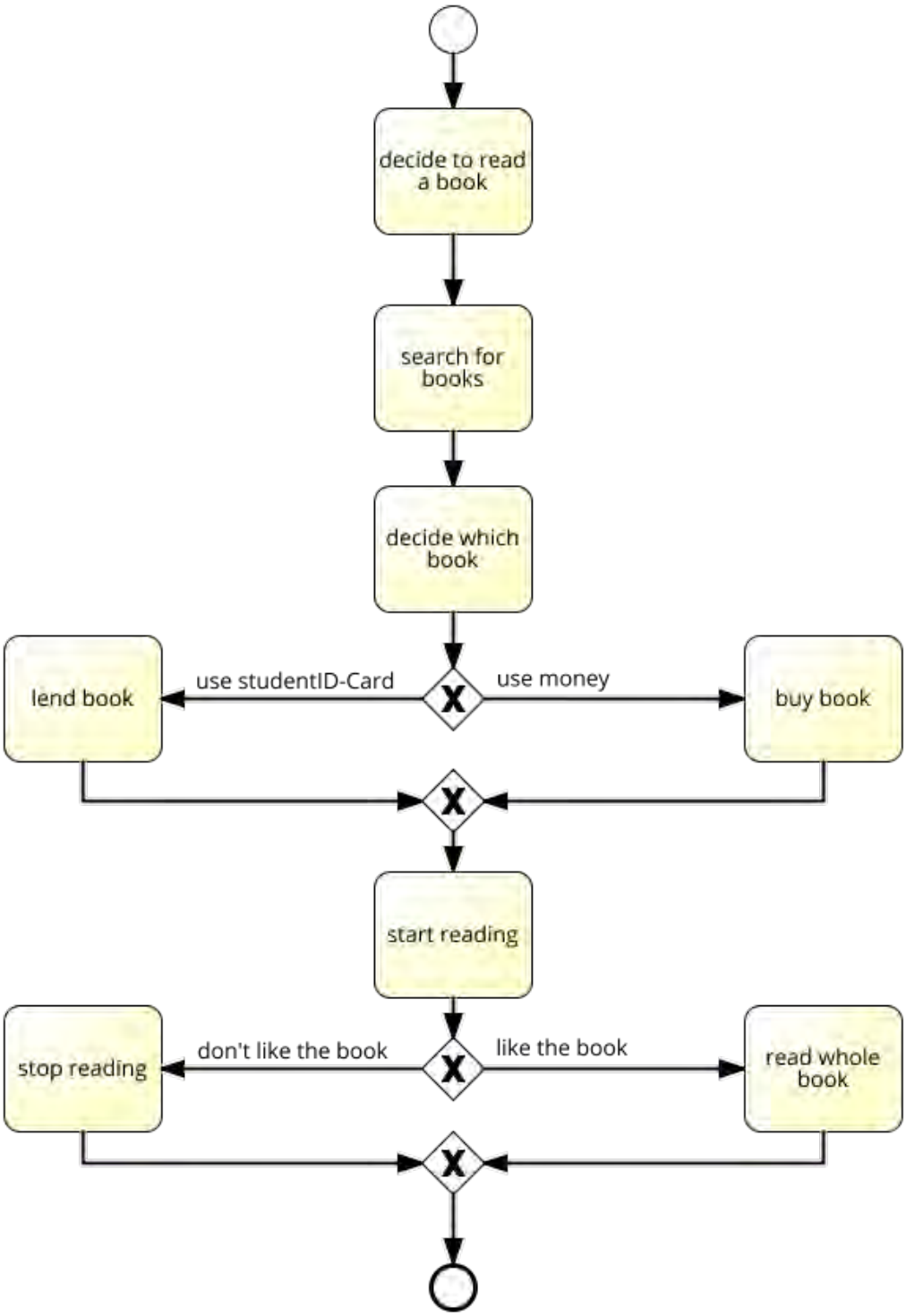

Figure A.10: Process Model 3 Top-Bottom

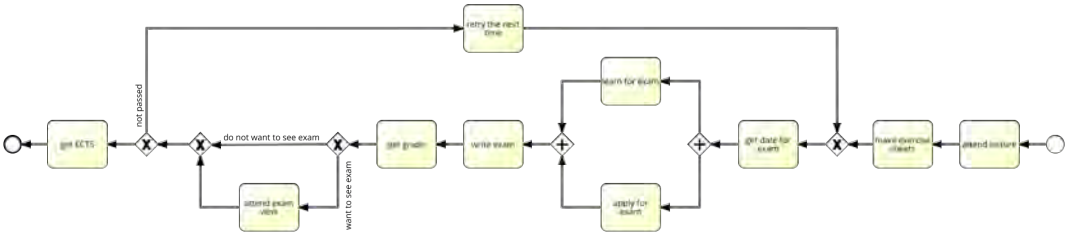

Figure A.11: Process Model 1 Right-Left

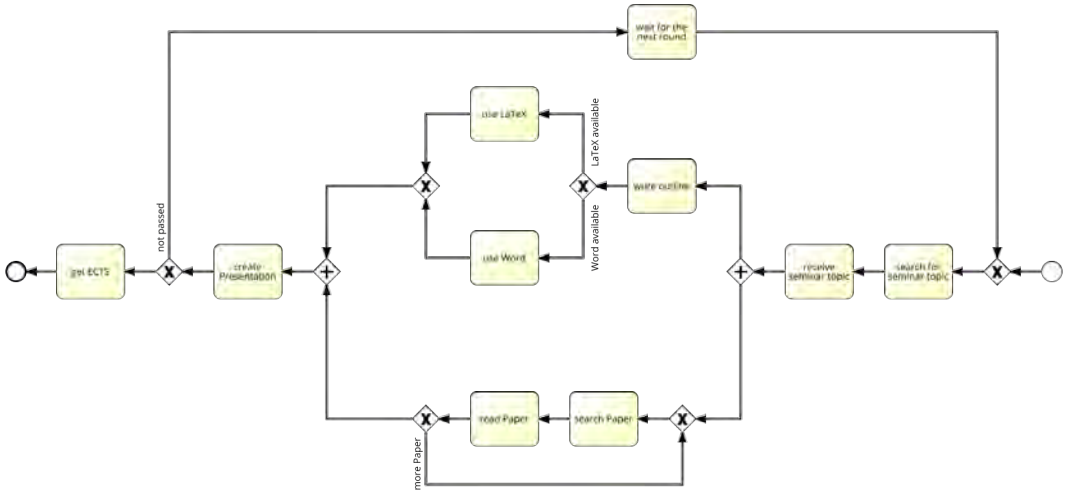

Figure A.12: Process Model 2 Right-Left

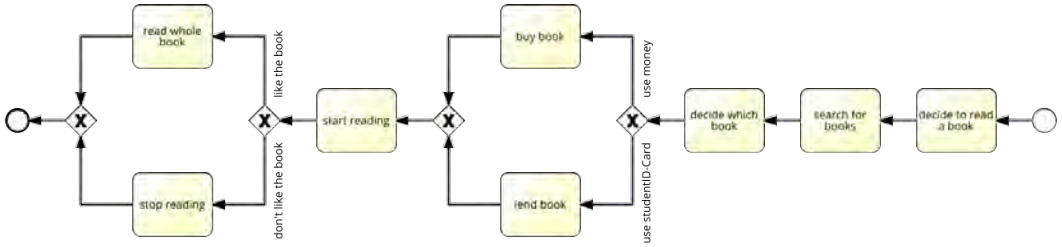

Figure A.13: Process Model 3 Right-Left

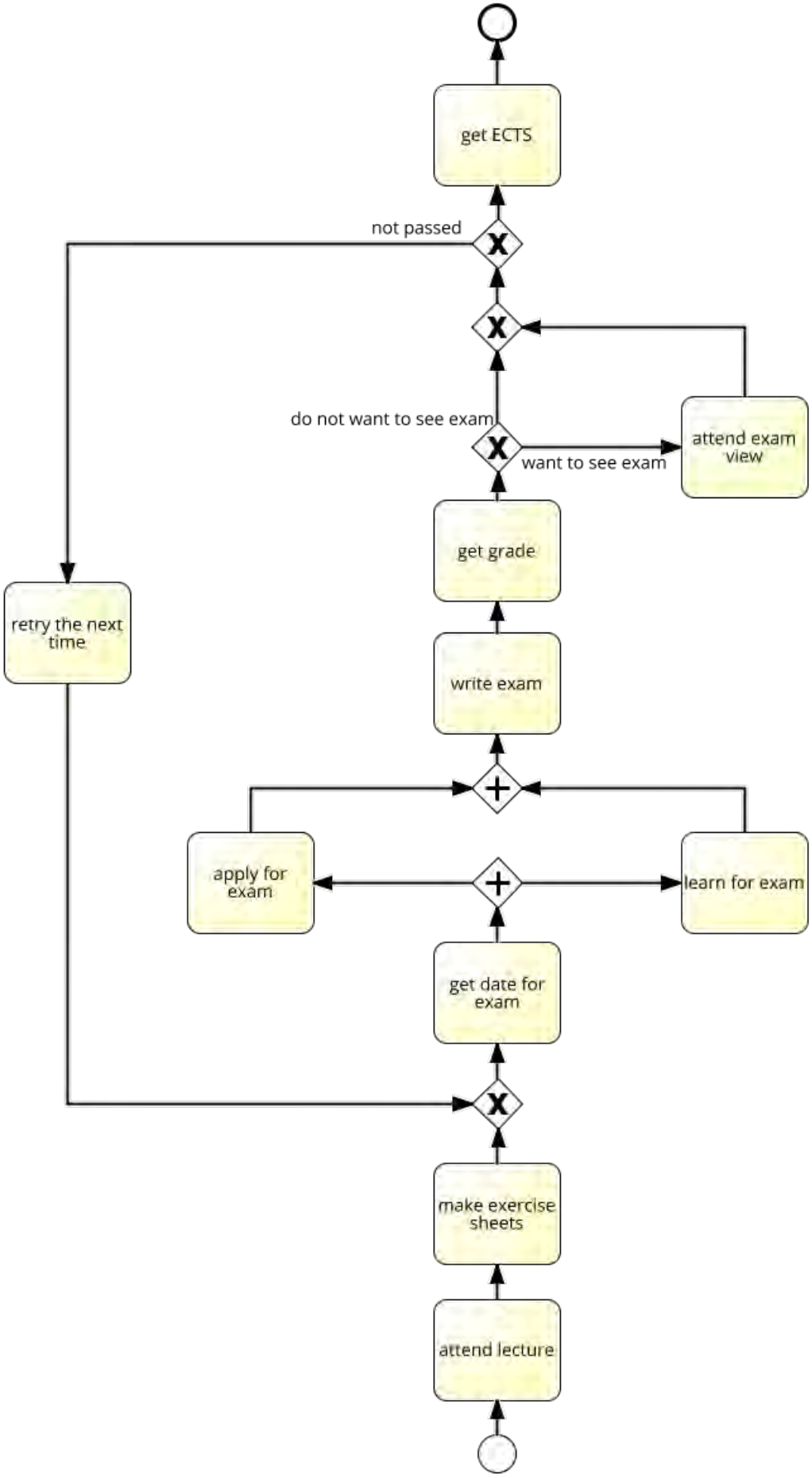

Figure A.14: Process Model 1 Bottom-Top

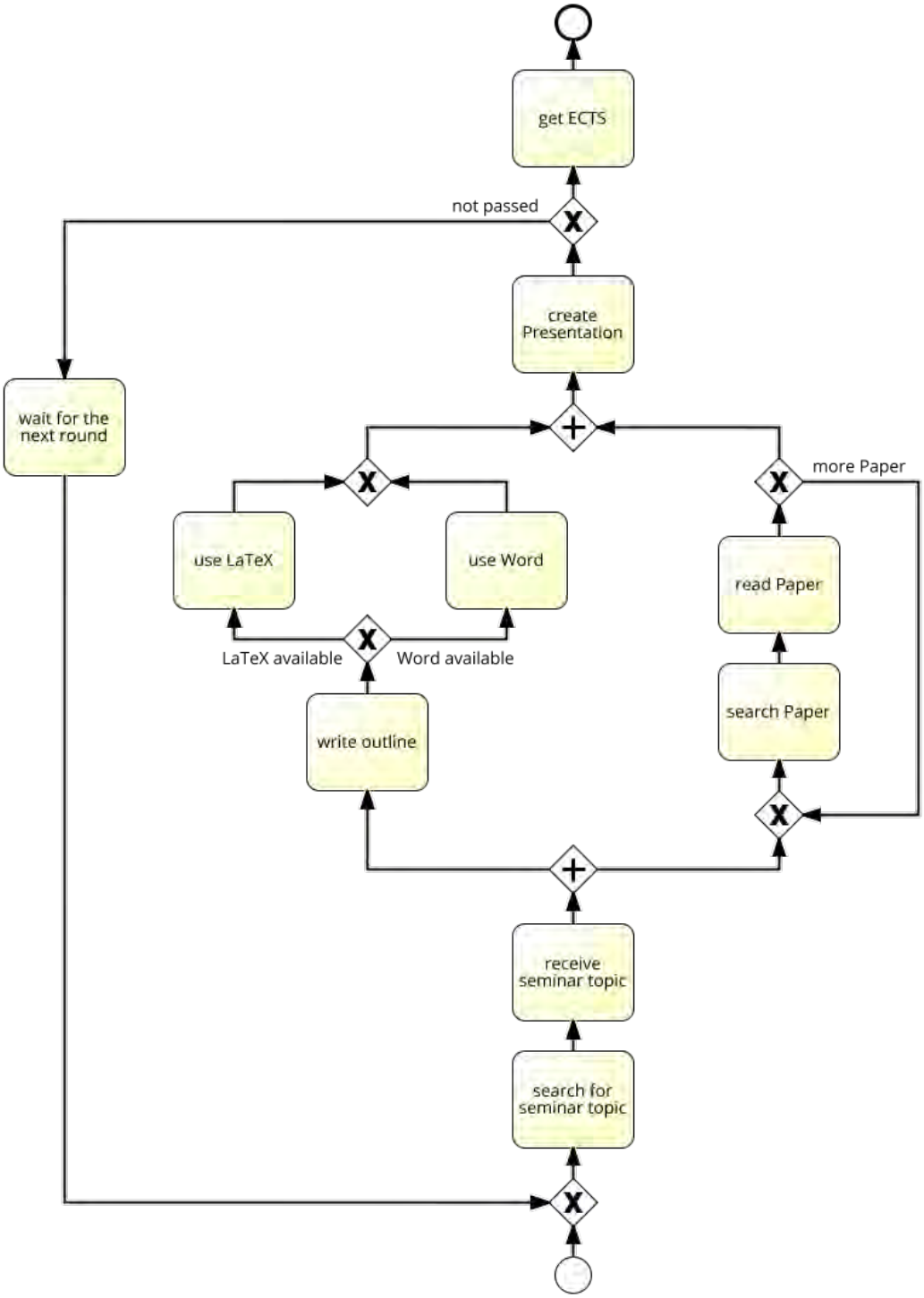

Figure A.15: Process Model 2 Bottom-Top

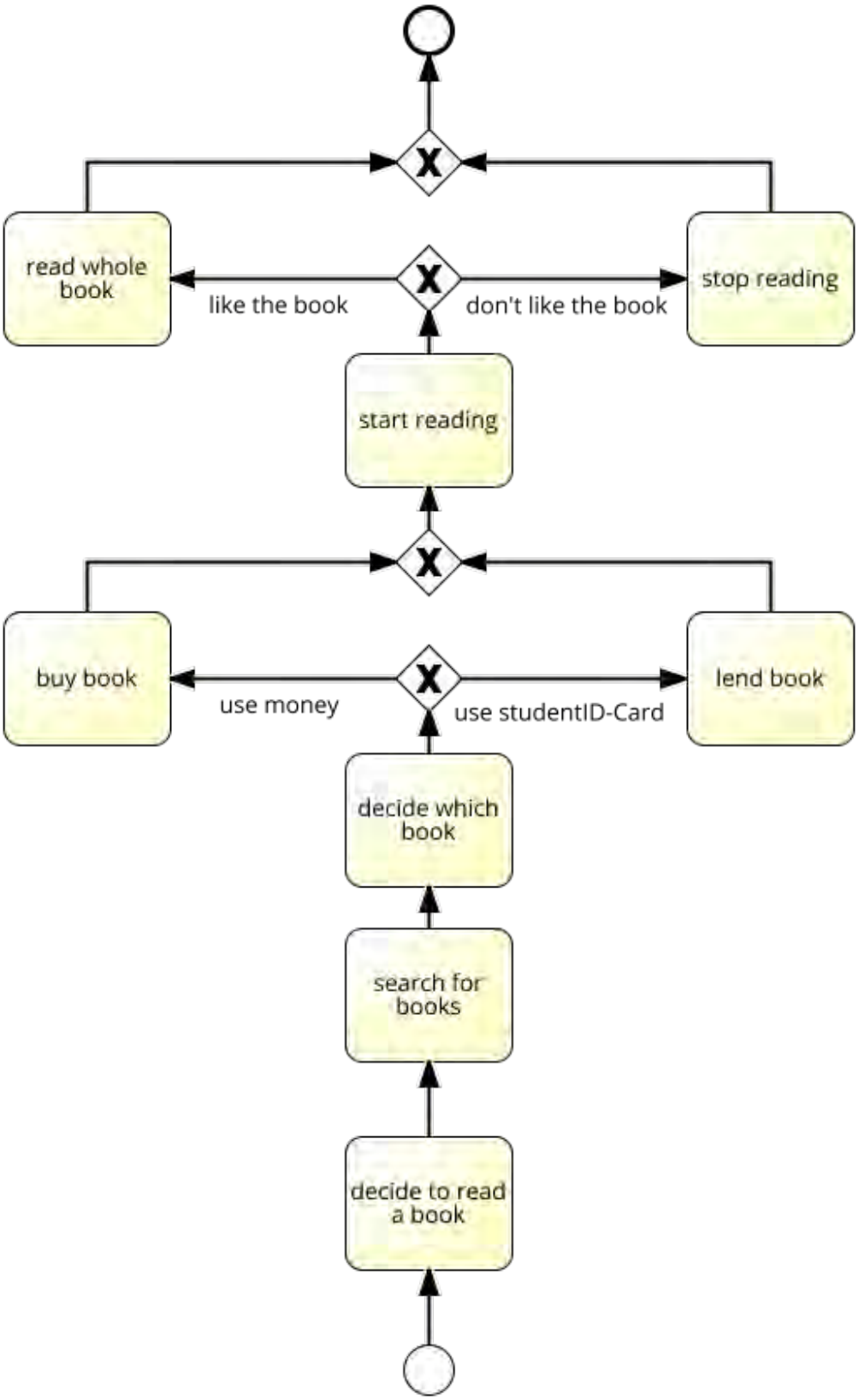

Figure A.16: Process Model 3 Bottom-Top

A.4 Question Design

A.4.1 StartModel

1. Is F always executed, when C has been executed? (yes/no)
2. Can this process be completed by executing less than five activities? (yes/no)
3. Is it possible to execute C as well as D after B? (yes/no)

A.4.2 PM1

1. Can this process be completed by executing eight activities? (yes/no)
2. When ***retry the next time*** is executed, is it possible that ***attend exam view*** has been executed before? (yes/no)
3. Is it possible to execute ***attend lecture***, when ***apply for exam*** has been executed? (yes/no)
4. If ***write exam*** is executed, has ***learn for exam*** or ***apply for exam*** been executed? (yes/no)
5. Is it guaranteed that the process has neither deadlocks nor lack of synchronization? (yes/no)

A.4.3 PM2

1. Can this process be completed by executing less than six activities? (yes/no)
2. When ***use LaTeX*** is executed, is it possible that ***wait for the next round*** has been executed before? (yes/no)
3. Is it possible to execute ***use Word***, when ***use LaTeX*** has been executed? (yes/no)
4. If ***search for seminar topic*** is executed for the first time, is it possible that ***wait for the next round*** has been executed? (yes/no)
5. Is it guaranteed that the process has no lack of synchronization? (yes/no)

A.4.4 PM3

1. Can this process be completed by executing less than six activities? (yes/no)
2. When ***lend book*** is executed, is it possible that ***buy book*** has been executed before? (yes/no)
3. Is it possible to execute ***buy book***, when ***start reading*** has been executed? (yes/no)
4. If ***start reading*** is executed, has ***buy book*** or ***lend book*** been executed? (yes/no)
5. Is it guaranteed that the process has no deadlocks? (yes/no)

List of Figures

List of Tables

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Honesty disclaimer

I hereby affirm that I wrote this thesis independently and that I did not use any other sources or tools than the ones specified.

Ulm, ...

Kai Kretschmann