UNIVERSITÄT ZU LÜBECK
INSTITUT FÜR
THEORETISCHE INFORMATIK

Inference of Causal Models based on Large Language Models' Domain Knowledge

TODO

Masterarbeit

verfasst am
Institut für Theoretische Informatik

im Rahmen des Studiengangs
Entrepreneurship in digitalen Technologien
der Universität zu Lübeck

vorgelegt von
Djorde Holst

ausgegeben und betreut von
Prof. Dr. Maciej Liśkiewicz

mit Unterstützung von
TODO

Lübeck, den 18. Juni 2025

Eidesstattliche Erklärung

Ich erkläre hiermit an Eides statt, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

Djorde Holst

Zusammenfassung

Es ist nicht leicht, eine Abschlussarbeit so zu schreiben, dass sie nicht nur inhaltlich gut ist, sondern es auch eine Freude ist, sie zu lesen. Diese Freude ist aber wichtig: Wenn die Person, die die Arbeit benoten soll, wenig Gefallen am Lesen der Arbeit findet, so wird sie auch wenig Gefallen an einer guten Note finden. Glücklicherweise gibt es einige Kniffe, gut lesbare Arbeiten zu schreiben. Am wichtigsten ist zweifelsohne, dass die Arbeit in gutem Deutsch oder Englisch verfasst wurde mit klarem Satzbau und gutem Sprachrhythmus, dass keine Rechtschreib- oder Grammatikfehlern im Text auftauchen und dass die Argumente der Autorin oder des Autors klar, logisch, verständlich und gut veranschaulicht dargestellt werden. Daneben sind aber auch gut lesbare Schriftbilder und ein angenehmes Layout hilfreich. Die Nutzung dieser LaTeX-Vorlage hilft der Schreiberin oder dem Schreiber dabei zumindest bei Letzterem: Sie umfasst gute, sofort nutzbare Designs und sie kümmert sich um viele typographische Details.

Abstract

Read QA again. It is not easy to write a thesis that does not only advance science, but that is also a pleasure to read. While the scientific contribution of a thesis is undoubtedly of greater importance, the impact of *writing well* should not be underestimated: If the person who grades a thesis finds no pleasure in the reading, that person are also unlikely to find pleasure in giving outstanding grades. A well-written text uses good German or English phrasing with a clear and correct sentence structure and language rhythm, there are no spelling mistakes and the author's arguments are presented in a clear, logical and understandable manner using well-chosen examples and explanations. In addition, a nice-to-read font and a pleasing layout are also helpful. The LaTeX class presented in this document helps with the latter: It contains a number of ready-to-use designs and takes care of many small typographical chores.

Acknowledgements

This is the place where you can thank people and institutions, do not try to do this on the title page. The only exception is in case you wrote your thesis while working or staying at a company or abroad. Then you should use the Weitere␣Unterstützung key to provide a text (in German) that acknowledges the company or foreign institute. For instance, you could use texts like »Die Arbeit ist im Rahmen einer Tätigkeit bei der Firma Muster GmbH entstanden« or »Die Arbeit ist im Rahmen eines Forschungsaufenthalts beim Institut für Dieses und Jenes an der Universität Entenhausen entstanden«. Do not name and thank individual persons from the company or foreign institute on the title page, do that here.

Contents

1 DELETE THIS LATER 1

1.1 Test Kram 3

1.2 Creating Graphics 3

2 Introduction 11

3 Background 12

3.1 Large Language Models(LLMs) 12

3.2 Causality 12

4 Previous Work 16

4.1 Causal Order: The Key to Leveraging Imperfect Experts in Causal Inference 16

5 Methodology 19

5.1 19

6 Results and Discussion 20

6.1 20

7 Conclusion 21

7.1 21

Bibliography 22

A Technical Appendix 23

A.1 Experimental Parameters 23

A.2 USB-Stick mit dem Projekt TODO 23

List of Figures

Figure 1.2 The logo of the University of Lübeck. It consists of the university's seal together with the text "Universität zu Lübeck". The corporate design manual of the university requires this logo to be put at the upper left corner of title pages of university publications. 4

Figure 1.3 The logo of the University of Lübeck, but now with a "paper-like background". Note how, compared to Figure 1.10, a much stronger impression is created that this figure depicts something printed. 6

Figure 1.4 An example visualization created with Ti*k*Z, see the template source for the code details. In the graphic, a number of predefined styles are used (like `node` or `small␣block`), each of which can be passed an optional color. These styles are setup automatically to produce visually pleasing shapes that go well with the overall layout and fonts. 7

Figure 1.5 The same visualization as in Figure 1.4, but with the `thesis␣box␣shapes` option set. As can be seen, this option causes the predefined shapes to be filled. It is a matter of taste whether one prefers this over the `outline` style from Figure 1.4. 8

Figure 1.6 Once more, the same visualization as in Figure 1.4, but now with `thesis␣flat␣shapes` option set. This option creates more "flat" shapes (without a border). Once more it is a matter of taste what one prefers. 9

Figure 1.10 The logo of the University of Lübeck. It consists… 10

List of Tables

Table 1.9 Sounds made by different kinds of animals… 10

1

DELETE THIS LATER

Writing a bachelor's or master's thesis is not easy.[1] You must *research* the thesis's topic scientifically – and you must do this well. You must *describe* your research and the results – and you must use not just any words, but those that are used in the scientific community. Finally, you must *write* everything *down* – by creating an electronic document that is a pleasure to read.

It is the last item where this text may help: It is, first, a *template* that you, dear student, can copy and then modify when writing your thesis. Of course, you still have to write the text, but the template will take care of numerous technical details for you. As a teaser, have a look at Listing 1.1 on the following page, which shows the code for the "hello world of theses"[2] and which already produces a PDF file with five pages of so-called front matter (like the title page, the abstract or the table of contents) and already four pages of actual content – not bad for a single page of code.

This template document is a LaTeX document that uses the UZL-THESIS document class. This means that in order to work with it, you need to use Donald Knuth's TeX text processing system (Löschen, 1986), Leslie Lamport's LaTeX extension of TeX (Lamport, 1994) and my (that is, Till Tantau's) UZL-THESIS document class. In particular, you will need to learn LaTeX if you have not already done so (definitely a good idea anyway).

Some students may wonder at this point whether this text applies to them at all since they do not intend to (or perhaps even may not) use LaTeX for their thesis. However, while these readers can safely skip the technical details of how the UZL-THESIS class is used, I would like to urge them (and, of course, everyone else) to read Chapter **??**, starting on page ??: In this chapter, I explain my views on "how to write a good thesis" and try to give as many practical hints as possible that anyone attempting to write a thesis will hopefully find useful – independently of which text processing tool they use.

The "hints" given in Chapter ?? address many of the problems that I see students struggle with when they write their thesis. Of course, I cannot give a magic recipe for creating a scientific breakthrough. But I *can* give you hints on how to put a breakthrough

[1] Neither is writing a PhD thesis, but this document does *not* concern them. It is intended *only* as a template for bachelor's and master's theses written at the University of Lübeck. When you write a PhD thesis, you are invited to find your own style.

[2] In computer science, a "Hello World" program is a minimal program in a given programming language that just prints these two words.

Listing 1.1: Minimal LaTeX manuscript that generates a bachelor's thesis using the UZL-THESIS class. The manuscript has to be processed twice using lualatex, followed by a run of bibtex, followed by a run of lualatex once more.

```
\documentclass[english, version-2020-11]{uzl-thesis}

\UzLStyle{computer modern oldschool design}

\UzLThesisSetup{
  Bachelorarbeit,
  Verfasst = {am}{Institut für tolle Forschung},
  Titel auf Deutsch = {Hallo Welt},
  Titel auf Englisch = {Hello World},
  Autor = {Max Mustermann},
  Betreuerin = {Prof. Dr. Petra Wichtig-Wichtig},
  Studiengang = {Irgendwas mit Tieren},
  Datum = {1. Juli 2020},
  Abstract = {It is about saying ``hello'' to the world.},
  Zusammenfassung = {Es geht darum, der Welt »Hallo« zu sagen.},
  Numerische Bibliographie
}

\begin{document}
  \chapter{Introduction}
  \section{Contributions of this Thesis}
  This thesis says ``Hello World!'', see also \cite{Kernighan1974}.
  \section{Related Work}
  There are many hello world programs.
  \section{Structure of this Thesis}
  In Chapter~\vref{chapter-main}, we say hello.

  \chapter{Main Chapter}
  \label{chapter-main}
  Hello World!

  \chapter{Conclusion}
  Saying hello world is quite easy.

  \begin{bibtex-entries}
    @TechReport{Kernighan1974,
      author = {Brian Kernighan},
      title = {Programming in C - A Tutorial},
      institution = {Bell Laboratories},
      year = {1974}
    }
  \end{bibtex-entries}
\end{document}
```

into words that other people understand and will like to read – and, hopefully, will like to reward with good grades.

Please be aware that the views expressed in Chapter ?? are *my* views and some of them may not be shared by other professors and, more importantly for you, they may not be shared by your adviser – who happens to be the person who will grade your thesis. This means that you better *always listen to your adviser* and do what she or he asks you to do.[3] The excuse "but Professor Tantau writes that…" may be flattering to me, but it will not get you high grades.

So, *always listen to your adviser.* You will read this again later on. Repeatedly.

…

This thesis[4] consists of two main chapters: Chapter **??** describes how the UZL-THESIS LaTeX class is used on a technical level. This chapter starts with the technical details of how you setup the TeX work-flow in conjunction with the class (where to install it and which programs to use), but the bulk of the chapter is taken up by the different aspects of using that class – like how bibliographies are created or how math text should be written. The explanations only try to highlight what is important and different when using the UZL-THESIS class; they are not intended as a complete introduction to LaTeX. In Chapter ??, I then list the many small and big things you should consider and take care of when writing a thesis. I will explain how long the different parts should be, I will sketch why the abstract, the introduction and the conclusion all summarize the main part of the thesis, but still all three need to be written, I will explain why you should write "we will show that" and not "I will show that" but "I believe that" and not "we believe that" and I will give recommendations on many other topics. But of course, whatever you read in the following, remember that you must *always listen to your adviser!*

1.1 Test Kram

With the thesis class, you add figures and tables using the standard `figure` and `table` environments. You should always add a caption to a figure and the caption should be below it, while the caption of a table should be above it. You should always label the figure and you *must* reference all figures at least once in the text. See Question **??** on page ?? for some hints on what to write in captions.

1.2 Creating Graphics

External Graphics

Graphics (like plots, images, drawings or other data visualizations) can be added to a LaTeX document in two ways: First, you can include an *external graphic* like a PDF file or

[3] If your adviser thinks the thesis should be typeset using a typewriter font with double line spacing and all headlines should be in pink, then I may (very) strongly disagree with that, but you do not have that luxury and you just typeset everything in double line spacing pink typewriter.

[4] Actually, "this text" would be more appropriate since this is obviously not a real thesis. But this is what you would write in a real thesis at this point.

a JPG file. Second, you can use "describe your graphic using LaTeX commands". We discuss external graphics next, internal ones later on.

You include external graphics using the includegraphicscommand, which is a standard LaTeX command. There is no need to include any packages for this, it is available automatically. For instance, you could say:

```
The university slogan \includegraphics{uzl-thesis-logo-slogan.pdf} in a
    sentence.
```

to get: "The university slogan IM FOCUS DAS LEBEN in a sentence."

As can be seen, the effect of the includegraphics command is to directly include the graphic at the very position in the line where the command is used. Indeed, from TeX's point of view, an external graphic is indistinguishable from a black rectangle of the same size as the graphic.

You will rarely wish to put a graphic in the middle of a sentence (although there are applications). Instead, you will usually place it inside a |figure| environment: Recall that it is the job of the environment to creating "floating" text with a caption – and it is then the job of includegraphics to replace the "text" by a picture. Here is an example of how you will usually do this:

```
\begin{figure}[htpb]
  \centering
  \includegraphics{uzl-thesis-logo-uzl.pdf}
  \caption{The logo of the University of Lübeck. It consists...}
  \label{fig-logo}
\end{figure}
```

The result is Figure 1.10 on page 10.

Figure 1.2: The logo of the University of Lübeck. It consists of the university's seal together with the text "Universität zu Lübeck". The corporate design manual of the university requires this logo to be put at the upper left corner of title pages of university publications.

The includegraphicscommand takes many options, the most important of which are likely |height| and |width|. These allow you to scale the graphic to a given height or width. *Avoid these options whenever possible.* The reason is that most graphics have a natural size (such as the logo) in which the text and fonts in the graphic are at the correct sizes. Any scaling will cause the graphic to become too large or too small. *Scaling is evil* and you will

find more comments on this in Question **??** on page ??. All professors I know find scaled-down graphics with unintelligible text *among the most irritating things a student could possibly do.*

This means that when you *create* graphics with another program, make *sure* that any text in the external graphic has the same size as normal text in the thesis and that *no* scaling is needed.

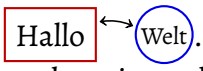
Inline Graphics via TikZ

The alternative to external graphics are *internal* graphics. They are created using special LaTeX commands such as the following:

```
\tikz \draw [->] (0,0) -- (1cm, 2mm);
```

which yields  when used in a paragraph. A more complex example would be

```
\tikz [baseline, anchor=base] {
  \node [block = emph]                                (h) {Hello};
  \node [small node = emph blue, right = 5mm of h] (w) {Welt};
  \draw (h) edge[bend left=15, <->] (w);
}
```

which yields  .

The TikZ package is used for these inline graphics and it is loaded automatically – so *if* you are going to create inline graphics, use TikZ. If you wish to learn TikZ, please read the tutorials from the manual (Tantau, 2019, Part I).

The thesis class sets up some styles for TikZ that you can either explicitly use or that are generally set up. For instance, the default arrow tip is setup according to the chosen design as well as the standard line width. You usually do not need to worry about these automatic settings.

Predefined TikZ Styles

There are several styles that are predefined and that you are "invited" to use:

base shape This is a style on which the styles described next are based. It is to be used with the |node| command and will, for instance, fill the node with white color and will draw a thick border around it. The color that is used for the border can be passed as an argument, but see below for which colors you should use. Here is a simple example how this style is used:

```
\tikz \node [base shape, ellipse] {Hello};
```

yields  .

The default color used for shapes is defined by the design (either black or the color |Ozeangruen|, which is the university's corporate design color, depending on the design).

small shape This style can be used in addition to |base shape| and will change the font to a smaller size and will reduce the inner seperation:

```
\tikz \node [base shape, small shape, ellipse] {Hello};
```

yields Hello.

block A rectangular node: |Hello| yields Hello.

small block A smaller version: Saying |Hello| will now give Hello.

node A circular node, especially in a graph: |n| yields n.

small node Small version: |n| yields n.

tiny node A small, unnamed circular node: |o| yields o.

paper This is a special style that installs a "paper-like background" as fill color. I recommend using this style as a background for all cases where you wish to create the impression of showing an "original text" from another paper, that is, where you wish to show that the text or graphic "looks like this in the original". Consider for instance,

```
\begin{figure}[htpb]
  \centering
  \tikz \node [paper] {\includegraphics{uzl-thesis-logo-uzl.pdf}};
  \caption{The logo of the University of Lübeck, but now...}
  \label{fig-logo-paper}
\end{figure}
```

which yields Figure 1.3.

Figure 1.3: The logo of the University of Lübeck, but now with a "paper-like background". Note how, compared to Figure 1.10, a much stronger impression is created that this figure depicts something printed.

An example of how many of these styles can be used is shown in Figure 1.4 on the next page.

Predefined Colors

The thesis class defines a number of colors that you should use in graphics. You should *not* use colors like |red| or |green|: Pure green is a very light color and text in this color

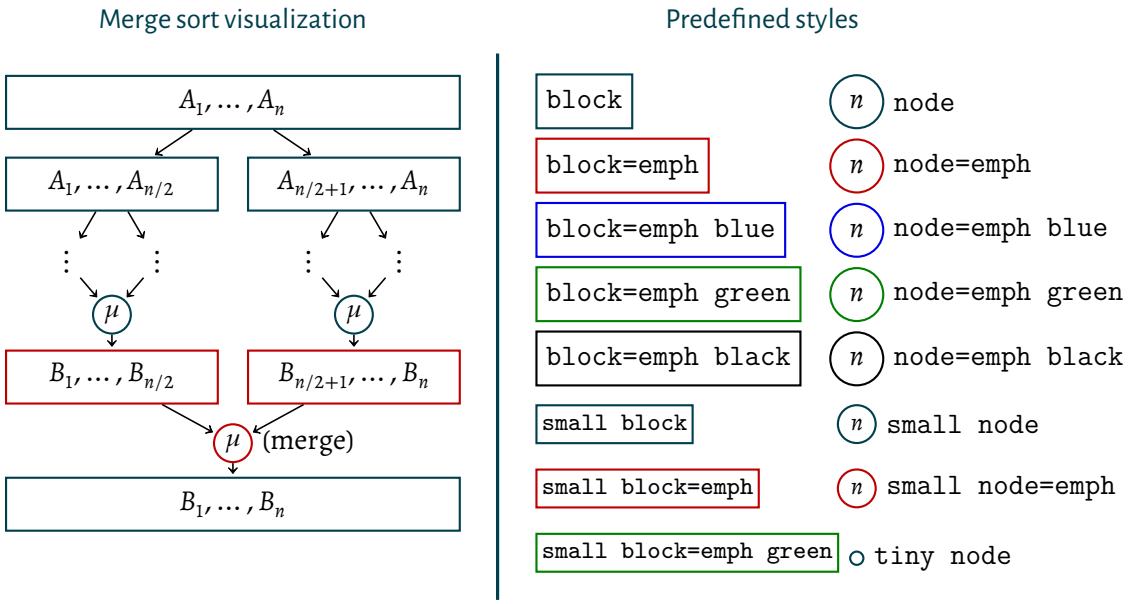


Figure 1.4: An example visualization created with TikZ, see the template source for the code details. In the graphic, a number of predefined styles are used (like `node` or `small␣block`), each of which can be passed an optional color. These styles are setup automatically to produce visually pleasing shapes that go well with the overall layout and fonts.

is hard to read on paper and impossible to read in an electronic document. Instead of pure green, a rather dark version of green must be used. In contrast, pure blue is already rather dark and only needs to be darkened very slightly. The following colors have been setup to provide a uniform contrast against a white background:

emph A red color. Used in an outline and filled
emph red This is the same as |emph|.
emph green Used in an outline and filled
emph blue Used in an outline and filled
emph black This is just black: Used in an outline and filled

Looking for more colors? Think carefully whether you really need more: It is hard to remember too many colors as a reader. It may be better to use a different style (like thicker lines) for purposes of further differentiation.

Designs for TikZ Graphics

In addition to the designs for the whole thesis, see Section **??**, there are also three designs for graphics. Each of them redefines |base shape|, resulting in a different "look":

thesis outline shapes This TikZ style defines |base shape| and all styles built on top of it (like |block| and |node|) to a white background and simple thick line around the shape. For instance:

```
\tikzset{thesis outline shapes} % generally set the design
\tikz \node [block] {Hello};
```

yields Hello. See Figure 1.4 on the preceding page for a larger example.

thesis box shapes This style defines |base shape| similarly to the outline style, but fills the shapes with a light background:

```
\tikzset{thesis box shapes} % generally set the design
\tikz \node [block] {Hello};
```

yields Hello. See Figure 1.5 for an example.

thesis flat shapes This style redefines |base shape| differently: The shapes are only filled and no border is drawn. This creates a stylish "flat" look:

```
\tikzset{thesis flat shapes} % generally set the design
\tikz \node [block] {Hello};
```

yields Hello. See Figure 1.6 on the following page for a larger example.

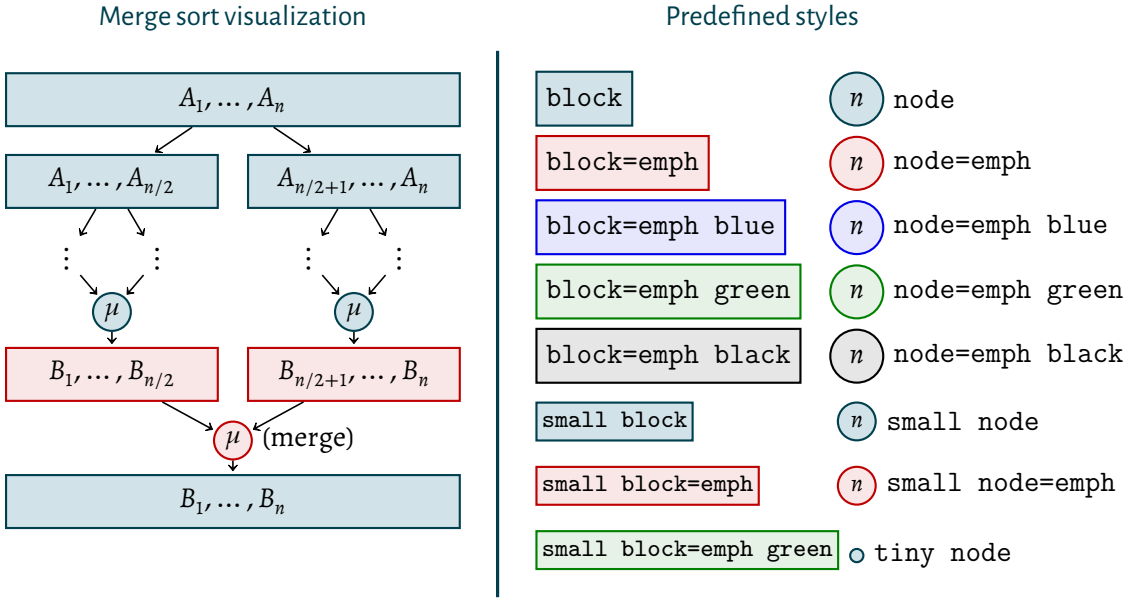


Figure 1.5: The same visualization as in Figure 1.4, but with the thesis box shapes option set. As can be seen, this option causes the predefined shapes to be filled. It is a matter of taste whether one prefers this over the outline style from Figure 1.4.

```
print "Please enter a number below 10."
input n
if n > 9 then
print "Too high!"
```

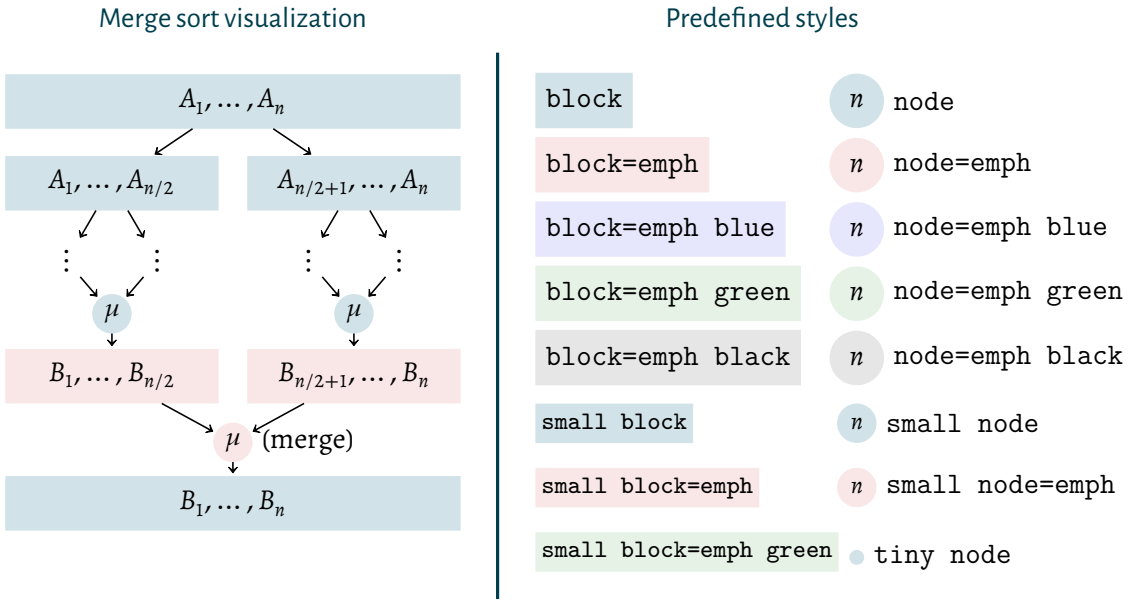


Figure 1.6: Once more, the same visualization as in Figure 1.4, but now with thesis␣flat␣ shapes option set. This option creates more "flat" shapes (without a border). Once more it is a matter of taste what one prefers.

Listing 1.7: The first Javacript code here.

```
Name.prototype = {
  methodName: function(params){
    var doubleQuoteString = "some␣text";
    var singleQuoteString = 'some␣more␣text';
    // this is a comment
    if(this.confirmed != null && typeof(this.confirmed) == Boolean &&
        this.confirmed == true){
      document.createElement('h3');
      $('#system').append("This␣looks␣great");
      return false;
    } else {
      throw new Error;
    }
  }
}
```

Listing 1.8: The first C program from the tutorial in (Kernighan, 1974).

```
main( ) {
printf("hello,␣world");
}
```

else
print “Thank␣you!”

Conjecture 1.1 (Goldbach). *Every even integer $n \geq 4$ is the sum of two primes.*

Lemma 1.2. *Every $n \in \{4, 6, 8, 10\}$ is the sum of two primes.*

Proof. We have $4 = 2 + 2$, $6 = 3 + 3$, $8 = 5 + 3$ and $10 = 5 + 5$. □

Javascript im Text: `var␣i` weiterer Text `var i`.

Table 1.9: Sounds made by different kinds of animals…

Animal	Sound
Cat	Meow
Dog	Wuff or bark

Figure 1.10: The logo of the University of Lübeck. It consists…

The TEX system (Vashishtha et al., 2024) is due to Vashishtha et al.
The TEX system (Long, Schuster, and Piché, 2024) is due to Long, Schuster, and Piché.
The TEX system (Kıcıman et al., 2024) is due to Kıcıman et al.

Wie in 1.7 beschrieben. Oder auch in 1.7 on the previous page.
(P)⟶(C)

2

Introduction

3

Background

Recession > Lay offs > Less money to spend > Recession

3.1 Large Language Models(LLMs)

(Long, Schuster, and Piché, 2024)

3.2 Causality

Causality describes a cause-and-effect relationship. One such relationship is the well-known fact that smoking causes lung cancer. Thus, we can say there is a causal relationship between smoking and lung cancer. (Long, Schuster, and Piché, 2024)

Causal Diagrams

Causal diagrams, also referred to as causal graphs, are a way to visualize causality. To do so, I will use directed acyclic graphs (DAGs). A DAG is made out of nodes and edges. The nodes represent the variables, both measured and unmeasured. To display the node, it is common to use the corresponding variable name. Since a DAG is directed, the edges are arrows that connect parent nodes with child nodes (Parent → Child). In our case, the parent node represents an action or cause, the child represents the outcome, and the arrow represents a direct causal relationship. Accordingly, a missing edge indicates a missing direct causal relationship between two nodes.

Furthermore, these edges can be weighted. In our case, this weight would most likely represent the probability of P causing C (Wrong? Do we even have weighted graphs? TODO).

Since a DAG is also acrylic, these edges are not allowed to draw cycles or loops. We need this limitation because a variable can not be the cause of itself.

Additionally, for the DAG to be causal, it must include all common causes of any pair of variables. (TODO leave in?)

Overall, it represents causal pathways. This means every variable is the effect of all its ancestors and the cause of all its descendants.

A known to be correct causal DAG is named a ground truth DAG.

(Long, Schuster, and Piché, 2024)

Causation vs. Correlation

We might be tempted to think that a strong correlation in our data also means that there is a cause-and-effect relationship. But does the crowing rooster make the sun rise? No, it does not. Strongly correlated variables do not necessarily have a cause-and-effect relationship. Especially when we look at observational data, correlations are unlikely to hint at a causal relationship. This is because, most of the time, a human has already predicted an outcome and engaged in behavior that leads to a more desirable one. This is also why there can be casual relationships between variables that have no observable correlation. Someone intervened, but it was not measured.

TODO Maybe the sailor example if there is time. Maybe in Confounding for masking This intervening individual would be a confounding factor. IS IT THOUGH? TODO (**mixtape**) chapter 1 Intoduction

Covariates

Invariance means the causal relationship between X-> Y is still there even if we intervene on other paths. Invariant means unchanged. The Markov blanket is used to train models from observational data. It leads to the optimal prediction of Y in this specific training model. The Markov Blanket is the minimum set of variables to condition on to block all paths from variables outside the set. This result leads to the optimal prediction of Y in the SAME DISTRIBUTION. The same distribution means there is no additional intervention or something similar. In other words, the graph has to stay the same. Suppose we want to predict Y in another distribution because we added an intervention node to the original training distribution. In that case, we only use the parents of Y for the conditioning set for optimal prediction. This is because if we intervene on any other node than the parents, we could be masking causal association or worse. This is called the optimal robust prediction.

Confounders

TODO

A confounding factor influences both the cause and the effect variable. By influencing both variables, a confounding factor can lead to three things:

1. A false assumption of cause and effect. For example, by being the actual cause of both. So both variables might rise and fall concurrently, giving the impression of being in a causal relationship.
2. The confounder could be the real cause. By not accounting for it one could identify the wrong cause. This wrong cause would most likely be associated with the confounder.

3. Choosing the wrong direction. TODO
cite Chat GPT lul can't do that, can you?

Colliders

Causal Inference

Causal Inference is about inferring the causal effect of a specific treatment (T) or action on an outcome (Y). Let us assume that the treatment is taking a pill. We either let a person (i) take the pill ($\text{do}(T = 1)$) or we do not ($\text{do}(T = 0)$). This leads to two possible outcomes:

the outcome where person i did take the pill ($Y_i|_{\text{do}(T=1)} \triangleq Y_i(1)$)
and the outcome where person i did not ($Y_i|_{\text{do}(T=0)} \triangleq Y_i(0)$).

Now, we can measure the effect, also known as the individual treatment effect (ITE), through $Y_i(1) - Y_i(0)$. Assuming that $Y_i(x)$ can be 0 or 1, we could get three different ITEs: 1, 0, and -1. 1 and -1 would mean that the treatment had an effect while 0 would mean it did not.

However, it is not as simple as it looks. We need to know $Y_i(1)$ and $Y_i(0)$, but we can only choose one path per person. The only way to get the other outcome is to estimate it. This estimated outcome is known as a counterfactual, while the outcome of the chosen path is known as a factual. There are methods to estimate those counterfactuals. (TODO) I'll explain some of them in cite ..., ..., and .... But for now, we assume we know how to get them.

If we have more records of our pill treatment, we can compute all their measured effects and take the average treatment effect (ATE). This average is also known as the expected value ($\mathbb{E}$) of $Y_i(1) - Y_i(0)$ or $\mathbb{E}[Y_i(1) - Y_i(0)]$. This is the same as taking the average of $Y_i(1)$ and $Y_i(0)$ and then subtracting them ($\mathbb{E}[Y_i(1)] - \mathbb{E}[Y_i(0)]$). We know that because of the linearity of expectation.

(**causal_course**) 2.3

Identifiability

2.5

Ignorabilty and Exchangability

2.4

Counterfactuals

Intervention and Randomized Experiments

Judea Pearl's Framework

Evaluation Methods

Dtop Structural Hemming Distance

Challenges and Open Questions

Causal Order

Do this or just on previous work?
(Vashishtha et al., 2024)

4

Previous Work

Can large language models build causal graphs?
Causal Reasoning and Large Language Models: Opening a New Frontier for Causality
"Causal Order: The Key to Leveraging Imperfect Experts in Causal Inference"

4.1 Causal Order: The Key to Leveraging Imperfect Experts in Causal Inference

- Pairwise prompts are not able to distinguish between direct and indirect edges.

-A causal Graph is not a great output for domain knowledge because edges indicate a DIRECT CAUSAL RELATIONSHIP. So, the incorporation of potential mediators between two variables is necessary. - To alleviate that problem, they introduce causal order (- Causal order describes a sequence or permutation of nodes (π) wherein all nodes before a given node X_i cannot be its descendants and all nodes after it cannot be its ancestors. This means the only POSSIBLE ancestors are in front of the given node and all POSSIBLE descendants are behind it. But not every node in front of/behind it has to be its ancestor/descendant.) TODO this is only true for $D_{top} = 0$ isn't it? - Formal Definition for causal order? - Causal order only determines an ancestor-descendant relationship. So to draw an edge between two variables we do not need a DIRECT CAUSAL RELATIONSHIP.

- Formal Def. for Dtop? - They use the topological divergence metric D_{top} as quality measurement. - In this paper D_{top} is calculated by counting the not recoverable edge in the merged final DAG. Not recoverable edges face in the opposite direction than they do in the ground truth DAG. (- D_{top} is a better measurement than SHD because D_{top} is a measurement for causal order while SHD is a measurement for graph equality. D_{top} can be 0 for a changed sequence or permutations of the same order. But a changed graph will lead to SHD > 0.) Is this true? TODO

- Most other papers use graphs as outputs for the domain knowledge, which are "final" and not adaptable. This is problematic because we often want to process them further. So the DAG being "final" leads to errors in further processing. - Causal order is not final, it can adapt missing variables later on - Given only a subset of variables, an optimal

perfect expert will always predict a correct causal order for the whole set, but a causal graph could be incorrect.

- But inferring causal order from LLMs/imperfect experts through pairwise prompting leads to many cycles - To get more accurate graphs with significantly fewer cycles, they also introduce a triplet-based prompting strategy - Fewer cycles because a pair occurs more than once, at least for graphs with more than 3 nodes. This can lead to conflicting edges. The final relationship (A->B, B->A, or no edge) is voted for by a majority vote. - ZITAT: For practical usage, we use the variance in votes for each pair to motivate a final edge removal step that ensures that no cycles are present in the final output. - Using the estimated causal order for downstream discovery and effect inference leads to fewer errors

Getting causal order from imperfect Experts

There are different ways to get the causal order from an imperfect Expert such as an LLM. Using just a single prompt for all nodes would likely lead to information overload, which can lead to suboptimal results. To avoid this, we could use two nodes, the smallest possible set for inferring causal order, for every prompt and infer causal order by going through all possible TODO pairs (or tuples?) one at a time and then aggregating the outputs. But this leads to many cycles in the final graph (leading to $D_{top} > 0$). To reduce these cycles, they propose a triplet-based query strategy, which even has a better performance than the pairwise strategy.

The algorithm

Include Algorithm graphic

Compute all possible triplets from the given node set.

Then ask the expert, in our case the LLM, to generate the causal DAG. In this paper, the prompt also included the context, the request to give the reasoning behind the edges, node descriptions, and examples for the wanted input and output structure. (TODO did we use the prompt? we could just make a cite)

Count the number of appearances of the three orientations (A $\rightarrow$ B, B $\rightarrow$ A, or no connection) for each pair of nodes. If one of the three orientations appears in more than 50% of the triplets it can be in, it will be picked for the final causal graph. If it is equal to or lower than 50% for all orientations, the expert will be asked to pick one through reasoning.

Merge the computed orientations for every pair to get the final DAG from which we can extract the causal order.

This causal order might only be true for the graph we produced. It does not have to be true for the ground truth DAG of the problem. This is what leads do $D_{top} \neq 0$.

This order can now be used as a prior for causal discovery algorithms and effect inference.

In this paper, they used PC and CaMML.

- TODO I don't get it. Is this even important? ZITAT: While the causal order is a simpler structure than the full graph, it is useful by itself, aiding downstream tasks like effect inference and graph discovery. For example, correct causal order is sufficient for identifying a valid backdoor set for any pair of treatment and outcome variables. Moreover, a causal order-based metric, topological divergence (Dtop), correlates better with the effect estimation accuracy than commonly used graph metrics such as structural hamming dis-

tance (SHD). Specifically, Dtop = 0 if and only if the causal order provides a valid backdoor adjustment set. In contrast, there exist predicted graphs where the identified backdoor set is accurate (and topological divergence is zero), but their SHD can be arbitrarily high. In addition to effect inference, causal order can also be used to improve the accuracy of graph discovery algorithms. To this end, we provide simple algorithms for using causal order to improve existing causal discovery algorithms.

(Vashishtha et al., 2024)

5

Methodology

Given the variables: 1.

Go through the following steps 1 by 1 and justify/(give your reasoning for) each. 1. Build all possible (n! / 3!(n−3)!) with n=4 triplets.

5.1

6

Results and Discussion

Nur graphisch oder auch rechnerisch?

Soll ich was am prompting verändern?

Neue Datensätze testen? weil vermutlich schlechtere ergebnisse

Deepseek? CoT-Model oder nicht?

Mit 4 statt 3? Hypotese schnellere laufzeit aber schlechtere ergbnisse.

6.1

7

Conclusion

7.1

Compile with Lualatex > Bibtex > Lualatex x2
Shitft Option 7 for backslash
option q for «
shitt option q for »
.
.
Strg+f suche nach casual und ersetzte durch causal TODO
STRG+F suche nach descendant und descendent und entscheide dich für eine schreibweise
Bei CHatGPT hochladen NACHDEM du lernen aus deinen prompt rausgenommen hast und nach rechtschreibung (US englisch), richtigkeit und scientific style fragen.
Plagiatscheck?
.
!!
If something changes in the Bib:
Delete the <Name>-bibtex-entries.bib
Run LuaLatex, then Bibtex, then Lualatex again twice
!!
Glossary? TODO

Bibliography

Kernighan, B. (1974). *Programming in C – A Tutorial*. Tech. rep. Bell Laboratories.

Kıcıman, E., Ness, R., Sharma, A., and Tan, C. (2024). *Causal Reasoning and Large Language Models: Opening a New Frontier for Causality*. arXiv: 2305.00050v3 [cs.AI]. URL: https://arxiv.org/abs/2305.00050v3 (visited on 01/22/2025).

Lamport, L. (1994). LaTeX: A Document Preparation System. Second edition. Addison-Wesley.

Long, S., Schuster, T., and Piché, A. (2024). *Can large language models build causal graphs?* arXiv: 2303.05279v2 [cs.CL]. URL: https://arxiv.org/abs/2303.05279v2 (visited on 01/22/2025).

Löschen, H. (1986). The TeXbook. Addison-Wesley.

Tantau, T. (2019). *The TikZ and PGF Packages: Manual for version 3.1.3*. URL: https://github.com/pgf-tikz/pgf.

Vashishtha, A., Reddy, A.G., Kumar, A., Bachu, S., Balasubramanian, V.N., and Sharma, A. (2024). Causal Order: The Key to Leveraging Imperfect Experts in Causal Inference. In Causality and Large Models @NeurIPS 2024, URL: https://openreview.net/forum?id=3fzCBL6ar7 (visited on 01/22/2025).

A

Technical Appendix

A.1 Experimental Parameters

A.2 USB-Stick mit dem Projekt TODO