Project Description – Project Proposals

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Parameterised frames and conceptual spaces

Project Description

Sections 1-4 must not exceed 15 pages in total.

1 Starting Point

1.1 State of the art and preliminary work

This project grew out from project D01 of the Düsseldorf Collaborative Research Unit 991, whose focus of research was the theory of *frames* and their application in linguistics, philosophy and cognitive science. The project application is a revised version of the project application for the third 4-years phase of this CRC. The CRC was unfortunately not prolonged, but our project application received the grade "excellent" (see the confirming letter the application). Thus (following the advice of the CRC speaker) we submit the research project in an appropriately revised form as an individual research application.

In frame accounts, properties such as ‘red’ or ‘green’ are regarded as the values of certain attributes or property dimensions, e.g. ‘colour’. Frame accounts model complex concepts or categories as systems of attributes together with their admissible values. These values may themselves have attributes; so frames have a recursive structure. The cognitive advantage of frames, as compared to simple feature lists, is to offer economic and easily comprehensible representations of complex semantic structures. An alternative method for representing complex concepts, especially prototype concepts, is the modelling by conceptual spaces. In this project we plan to investigate the relation between conceptual spaces and frames. This comparison is especially interesting for frames that include quantitative information, either by means of quantitative attributes (e.g., *age*), or by the inclusion of additional parameters, e.g., probability distributions or typicality scores. Such frames are called *parameterised* frames.

Conceptual spaces and frames share a functional structure: both are based on attributes, i.e., functions X that assign values out of a value space Val to given objects a: $X(a) \in Val$. For example, the attribute *colour* assigns a value in the value space $Val = \{red, green, ...\}$ to a given object: *colour*(*myshirt*) = *red*. However, there are also remarkable differences. Frames, on the one hand, consist of bundles of attributes with a recursive structure, which we do not find in conceptual spaces. Conceptual spaces, on the other hand, associate value spaces with a topological or geometric structure. They come with some sort of distance measure, which need not be as fine-grained as real numbers or vector spaces, but should allow the application of topological or geometric tools, which are alien to frame representations.

What are the advantages and disadvantages of these two approaches? Are they competing accounts or are they complementary? In particular, to what extent can our frame account benefit from the elaborations of conceptual spaces? For example, how can the geometric notions of conceptual spaces be embedded in frame theory? These questions motivate the major aims of this project, that can be summarized as follows:

Aim 1 – Providing a comparison of conceptual spaces and frames, especially parameterised frames. Investigating their commonalities and differences, advantages and limitations.

The work on aim 1 is a precondition for the work on the next two aims that are intended as the innovative achievements for frame-theory:

Aim 2 – Embedding conceptual space structures in parameterised frames. Geometrical tools are fruitfully applied within parameterised frames without compromising the general frame modelling.

Aim 3 – Investigating the ontological and cognitive naturalness of frames and their attributes by applying notions from conceptual spaces theory, e.g., geometric constraints such as convexity. We conjecture that the so-explicated naturalness of concepts is strongly correlated with the ease of their learnability, and their cognitive usefulness in representing the environment and supporting cogent inferences.

In the preceding project D01 of the CRC 991, Corina Strößner, Paul Thorn and Gerhard Schurz (as PI) focused on the investigation of prototype concepts and their role in common-sense reasoning. For this purpose, they developed and investigated prototype frames. Since this project constitutes important groundwork for this project, we describe it here in some detail. Concerning the continuity of the personnel, Paul Thorn and Gerhard Schurz (as PI 1) will be part of this project. Corina Strößner has accepted a long-term position at the university of Bochum; she will only figure as an important co-operator of this project. We have a highly promising replacement for Corina Strößer, namely Lina Peine, who is completing her Master thesis on cognitive naturalness of concepts under the supervision of Professor Gottfried Vosgerau. Gottfried Vosgerau led three projects within the CRC 991, two of which focussed on the cognitive embedding of concepts in relation to motor processes (A03) and to linguistic skills (D02). It is planned that the work originally intended for Corina Strößner will be carried out by Lina Peine in the form of a PhD project, together with Gottfried Vosgerau, who figures as a second PI of this project.

Prototype frames consist not only of the general attribute value structure of frames, but carry numeric values that inform about the probability or typicality of the values and the diagnosticity of the attributes. The research in project D01 of the CRC 991 was guided by two goals:

1. Modelling prototype concepts by means of prototype frames and investigating the compositionality of prototype frames.
2. Investigating the rules of reasoning with prototypical properties and prototype frames.

Research for the first goal was carried out by Corina Strößner together with the PI, Gerhard Schurz. Strößner's core work focused on modification, which was investigated as an aspect of compositionality and as an aspect of prototype-based reasoning: How does a modified noun derive its meaning from the noun and the modifier? To what extent are typical properties inferable from categories to subcategories? To answer these questions, Strößner focused on the role of probabilistic uncertainty and knowledge constraints. In frames, knowledge constraints are known relations between a value of one attribute and the value of another attribute. For example, the knowledge that the colour of a fruit often correlates with its taste can be captured as a constraint. In a prototype frame, values are furnished with probabilities and constraints can be formulated as conditional probabilities, expressing the probability of the constrained value conditional on a constraining value. The selective modification model of Smith et al. (1988) was enriched by these knowledge constraints (Strößner et al., accepted). Beyond this theoretical work, Strößner and the PI investigated how people reason with modifiers of prototype concepts empirically, by means of experimental studies of the so-called modifier effect. The modifier effect, first reported by Connolly et al. (2007), refers to the fact that modification decreases the judged likelihood of sentences that ascribe prototypical properties. For example, people judge “Lambs are white” as more likely to be true than “Norwegian lambs are white”. The decrease in judged likelihood is smaller if the modifier is typical for the head noun, e.g., for “Fluffy lambs are white”. Our studies support the conclusion that prototypes are inherited from the unmodified to the modified noun to some degree, but, besides background knowledge, unconscious pragmatic effects are responsible for the modifier effect (Strößner & Schurz 2020). Strößner and Schurz (2020) also tested the relation between typicality and probability ratings with the result that they were almost identical. This result confirms our hypothesis that typicality can be grasped in terms of perceived probability, which is important for cognitive spaces with distance measures based on degrees of typicality.

Results of our theoretical and empirical work on modification were inter alia presented at several international conferences, such as the biannual *Cognitive Structures* conferences 2016 and 2018, the fourth *Philosophy of Language and Mind Conference* 2017 in Bochum or the 2017 meeting of the *European Society for Philosophy and Psychology* in Hertfordshire.

Paul Thorn worked on the second aim of D01 within the CRC 991, by in-depth research on rules of probabilistic prototype reasoning. His research concerned the predictive efficiency of prototype frames when they are used as a basis for default inheritance, i.e., inferences from typical properties of a category to typical properties of a subcategory. Attention is given to both the reliability and fruitfulness of inheritance inference, according to variations in environmental conditions. Thorn & Schurz (2016) used simulation studies to compare the performance of four systems of non-monotonic reasoning (O, P, Z, and QC) that admit successively stronger forms of inheritance inference. Thorn (2017, 2019) provides a formal justification for default inheritance with a preference for inheritance inferences that are based on more specific classes. Building on this work, Thorn (submitted) investigates whether and how the performance of default inheritance varies, depending on the criteria used in selecting the classes that serve as the basis for inheritance inference. Thorn’s approach, which had previously not been considered in the context of inheritance inference, is based on fitted classes with an internal similarity structure over many different attributes. Fitted classes capture the idea that prototype concepts refer to categories with an internal similarity structure. Simulation studies conducted by Thorn (submitted) show that default inheritance based on fitted classes permits more inferences and is far more reliable than inheritance inference based on unfitted classes that are defined by an atomic property. Paul Thorn's work has been presented at the European Conference for Cognitive Science, and the Meetings of the European Association for Philosophy of Science, the Canadian Philosophical Association, and Italian Society for Analytic Philosophy; follow up studies are underway.

Over four years, our CRC project had progressed in gaining new insights on representing, composing and reasoning with prototype concepts by using frames. Outside of the CRC, similar research aims were pursued with conceptual spaces. This approach is famously spelled out by Gärdenfors (2000). He proposes to represent natural properties as convex regions in spaces that are constituted by a set of integral, i.e., deeply interconnected dimensions like hue, saturation and brightness. He views conceptual spaces and prototype theory as allies and even claims that “conceptual spaces theory can be seen as combining frame theory with prototype theory” (Gärdenfors, 2011, 4). Furthermore, reasoning and categorisation with prototypes were investigated by Lieto et al. (2015, 2017), who propose a hybrid system with two systems that jointly contribute to the learning of categories. The first system is based on prototypes and conceptual spaces and stands for intuitive categorisation. The second system stands for conscious reasoning and is based on logic and ontology. Lewis & Lawry (2016) approached the long-standing problem of prototype compositionality. They used conceptual spaces to refine an older model of Hampton (1987) by defining a higher-order combination space to weight the contribution of two composing nouns, like “sports” and “games” to “sports that are also games”. Finally, Bechberger & Kühnberger (2017b,a) have worked on constraints in conceptual spaces. These investigations have a considerable overlap with our current research even though we used different tools, namely the frame approach and probability theory.

Within our own investigations, we often touched upon issues and notions from conceptual spaces theory. Strößner (2020) presents preliminary work on the possibility to use conceptual spaces within frames. Inter alia, she argues that conceptual spaces in frames could be used to give refined probabilistic representations of Barsalou’s (1992) attribute constraints, e.g., the dependencies between the power, size and price of a car. Paul Thorn’s work links prototype frames to convex regions in a general conceptual space of classes. With all these relations in mind, we want to explore the possibility to find a common framework that enables an overarching understanding of representing prototype concepts as well as other concepts.

1.2 Project-related publications

Sections 1.2.1 and 1.2.2 together must not exceed 10 publications; please number them consecutively.

1.2.1 Articles published by outlets with scientific quality assurance, book publications, and works accepted for publication but not yet published.

1. Kornmesser, S. and Schurz, G. 2019. "Analyzing Theories in the Frame Model". Erkenntnis 2019 Online first doi.org/10.1007/s10670-018-0078-5
2. Newen, A. & Vosgerau, G. accepted (in print). Situated mental representations: Why we need mental representations and how we should understand them. In Smortchkova, J., Dołęga, K. & Schlicht, T. (eds.): What are Mental Representations?, Oxford and New York: Oxford University Press, in print.
3. Schurz, G. 2012. Prototypes and their Composition from an Evolutionary Point of View. In Werning, M., Hinzen W. & Machery, E. (eds.), *The Oxford Handbook of Compositionality*, 530–553. Oxford and New York: Oxford University Press
4. Schurz, G., Hertwig, R. 2019. "Cognitive Success", Topics in Cognitive Science. 11(1), 2019, 7–36.
5. Strößner, C. 2018. The logic of ”Most” and ”Mostly”. *Axiomathes* 28(1). 107–124. doi: 10.1007/s10516017-9338-2
6. Strößner, C. & G. Schurz. 2020. The Modifier Effect: Rational Inference or Subconscious Pragmatics?", Cognitive Science 44, 2020, e12815 (doi: 10.1111/cogs.12815
7. Strößner, C., A. Schuster & G. Schurz. accepted. Modification and default inheritance. In Löbner, S., Gamerschlag, T., Kalenscher T., Schrenk, M. & Zeevat, H. (eds): Concepts, Frames and Cascades in Semantics, Cognition and Ontology. Cham: Springer.
8. Taylor, S.D., & Vosgerau, G. 2019. The explanatory role of concepts. *Erkenntnis* https://doi.org/10.1007/s10670-019-00143-0
9. Thorn, P. D. 2017. On the preference for more specific reference classes. *Synthese* 194(6). 2025–2051. doi: 10.1007/s11229-016-1035-y.

10. Thorn, P. D. & G. Schurz. 2016. Qualitative probabilistic inference under varied entropy levels. *Journal of Applied Logic* 19. 87–101. doi: 10.1016/j.jal.2016.05.004.

1.2.2 Other publications, both peer-reviewed and non-peer-reviewed

None

1.2.3 Patents

1.2.3.1 Pending

None

1.2.3.2 Issued

None

2 Objectives and work programme

2.1 Anticipated total duration of the project

Three years: 1.5./2021 - 30.4./2024

2.2 Objectives

As sketched above, there are currently two intensely researched and frequently applied methods of conceptual representation: conceptual spaces on the one hand and recursive frames on the other hand. Proponents of the two respective approaches conduct their research largely independently from each other but address very similar issues and questions. Like the frame theorists, conceptual spaces researchers have contributed to semantics (e.g., Gärdenfors, 2014), processing of natural language (e.g., Bolt et al., 2017), philosophy of science (e.g., Gärdenfors & Zenker, 2013), and metaphysics (e.g., Decock & Douven, 2015). Our research on prototype frames generated another common field of application: the formal representation of prototype concepts, their composition and associated inference patterns.

This situation – two different tools are applied to similar issues – raises the question of how frames and conceptual spaces are related: Is one of the tools more general or more precise than the other one? Do they conflict or can they complement each other? Are results obtained in one framework transferable to the other one? How can they be aggregated? Answering these questions make up the **aim 1** of the project. These answers are in turn prerequisites for the **aim 2** and **aim 3**, which are intended as the major innovations of this project. In the work on these two aims the possibilities of aggregation and unification are applied within the perspective of frame theory that is strongly represented in the research at the HHU Düsseldorf, with the purpose of extending frame theory by certain ingredients of the theory of conceptual spaces. In what follows we describe the three aims in more detail.

Aim 1 – Comparison of conceptual spaces and frames

Up until now, little comparative work on frames and conceptual spaces has been undertaken. Zenker (2014) is the only extensive contribution on this subject. He argues that conceptual spaces are superior to frames, because they can deal with quantitative measurement. The important components of frames, so Zenker claims, are recoverable in conceptual spaces. His investigation, however, concerns the specific application to history of science. Moreover, his procedure to recover frames in conceptual spaces does not acknowledge the recursivity of frames. Finally, the claim that quantitative measurement is alien to frames has been refuted (Votsis & Schurz, 2012, Kornmesser & Schurz 2019). We aim to give a more thorough comparison. As working hypothesis, we assume that neither of the two approaches will turn out to be strictly superior to the other one and that the evaluation of advantages and disadvantages should be relativised to means and applications. Our comparative investigation will also bear two challenges in mind:

Challenge 1: Differences in the representation of concepts and assumptions about the nature of concepts are interdependent. On the representational level, proponents of conceptual spaces focus on attribute value spaces with some geometrical, or at least topological, structure, while for frame theorists, value spaces in frames may also be simply sets, possessing merely a nominal scale level. Accordingly, the two representational tools – recursive frames or conceptual spaces – are often associated with different background assumptions about concepts. For example, when it comes to prototypes, researchers in conceptual spaces theory often assume that prototype concepts give rise to graded membership. Lewis & Lawry (2016) defend this view. In our frame-based work, following Schurz (2012), we deny this view: degrees of typicality do not express graded membership relations, but strength or probability of values of attributes. Thus, while comparing representational assumptions, one has to keep in mind the philosophical implications for the theory of concepts in general.

Challenge 2: Since conceptual spaces are applied in different fields and disciplines, we cannot expect that there is a homogenous understanding of what conceptual spaces are. Certainly, they are best known as representation for specific, usually perceptual, properties in domains like *colour*, *smell* and *sound*. However, the association matrices which arise from word distance studies in distributional semantics (cf. Lenci, 2018) can also be linked to conceptual spaces (McGregor et al., 2015). There they illustrate complex meaning structures along many dimensions of which one usually lacks an intuitive interpretation. Other than the specific conceptual spaces, which characterise one specific property of a category, they are intended to represent the total concept, compared to contrasting concepts. In our own work, we came across such higher-level conceptual spaces in the definition of fitted classes from centroids. We focus our investigation on domain specific spaces, because this is how they were defined by Gärdenfors (2000). As our work proceeds, we will extend our focus and consider combined conceptual spaces of several domains as well as association matrices. To a lesser extent, a plurality of approaches can also be found for recursive frames. Philosophers of science (e.g., Kornmesser, 2016; Kornmesser & Schurz, 2019) have defined and utilised frames in slightly different ways than linguists (e.g., Petersen, 2007). Our comparative work focuses on the core of the approach, i.e., the recursive attribute value structure of frames. Parameterised frames are especially important for the comparison and will receive special attention.

Aim 2 – Incorporating conceptual space structures in parameterised frames

The ordinal or quantitative structure of conceptual spaces can be a useful enrichment of the frame approach, combining the advantages from both the frame approach and the conceptual space approach. The following components from the conceptual space account will be integrated into the frame approach:

1) Assuming there is an advantage in an increased specificity, it will be useful to give more specific information about the values of attributes according to their position in conceptual spaces. For example, if one wants to represent the hair colour of a person, the specific points on the dimensions hue, saturation and brightness provide much more accuracy than the use of a natural language term, e.g., "brown''.

2) If values have an ordinal or even quantitative scale level, conceptual spaces tools can be fruitfully applied. Conceptual spaces give a natural internal structure to the values, which is not found in frames. Though Löbner (2017) showed that a comparison between different values can be realised in non-parameterised frames, a fine-grained geometrical structure would provide frames with additional power, in particular by the definition of a distance measure between values.
3) Constraints can be illustrated more efficiently and with more precision within conceptual spaces than in simple qualitative frames. Bechberger & Kühnberger (2017b,a) discuss the relation between the age and the size of a person as an interesting example. While they are correlated with each other, this correlation is itself constrained by age. Such relations can be represented geometrically, e.g., by scatterplots, where inhabitation patterns visualise the likelihood of value combinations. Such vivid and detailed representation of relations is hardly imaginable in symbolic approaches like frames.
4) Finally, prototype frames with quantitative information on typicality and diagnosticity provide a good foundation for the integration of topological and geometric notions and benefit most from them.

Aim 3 – Cognitive and ontological naturalness of concepts and ease of learnability
In the theory of cognitive spaces, certain topological and geometrical criteria for the cognitive and ontological naturalness of concepts have been developed. Based on our work on the relation between frames and conceptual spaces we will investigate these criteria within frame theory and apply them as criteria for cognitive and ontological naturalness of frames. The second step of our work for aim 3 concerns our conjecture that those concepts that are more natural are at the same time more easily learned and more efficient in representing the environment and supporting cogent inferences. For this purpose, we will relate our investigation with the so-called Binder-features. These are features with a proven neurobiological foundation (Binder et al. 2016) that are cognitively highly important and, thus, should fit with the developed criteria of naturalness and efficiency.

2.3 Work programme including proposed research methods

2.3.1 WP 1 Comparison of frames and conceptual spaces (all)

Zenker (2014) claims that frames face severe limitations in the representation of quantitatively scaled attributes. He argues that conceptual spaces extend the frames approach and are thus more general. Kornmesser & Schurz (2019) and Votsis & Schurz (2012) object that the frames approach is able to work with all kinds of attributes and measurement scales and that frames additionally allow for a recursive attribute structure. We follow up on this interesting discussion, since it raises a very general issue, which is of importance to researchers from both approaches: Which of the two frameworks, if any, is more general? Can the two frameworks be unified? What are the advantages and disadvantages of frames and of cognitive spaces, with respect to their generality and their accuracy?

It is apparent that frames and conceptual spaces share a functional structure. The functions in frames are called attributes (*at*) and have the logical form $at : D \rightarrow Val$, where D is a domain of individual objects and Val is the value space. In the commonly used graph theoretic formalisation of frames, attributes are represented as edges (Petersen, 2007). In the conceptual spaces approach, the value spaces are called dimensions and are associated with a certain amount of geometric structure, typically a distance function over *Val*.[1] Often an attribute in a frame corresponds to a collection of several (integral) dimensions; for example, conceptual spaces theory represents colour as a domain with three integral dimensions. Frequently, attributes in frames have merely classificatory (nominal) values; however, ordinal and metric scales are possible. Conceptual spaces are usually characterised by metrically measured value spaces; but ordinal and even merely classificatory values are not excluded (cf. Gärdenfors, 2000; Bolt et al., 2017). In conclusion, the difference between frames and conceptual spaces in their ability to represent differently graded concepts is only tendentious and not essential. For conceptual spaces, the metric scales are more interesting, since they give rise to distance and similarity measures. In frames, such geometric tools have rarely been investigated; quantitative information is usually not further analysed.

However, frames are not just the qualitative counterpart of conceptual spaces. While conceptual spaces typically consider one attribute or a few interconnected attributes, frames are *bundles* of attributes with a *recursive* structure: attributes can be applied to values of other attributes. In conceptual spaces, recursivity is missing. Higher order conceptual spaces, provided by Lewis & Lawry (2016), serve specific purposes, but are not equivalent to the way attributes are recursively applied to the values of other attributes in frames. A further ingredient of frames, which is rarely seen in conceptual spaces, are constraints. Limitations such as in the case of recursivity do not apply here: conceptual spaces are *prima facie* able to represent constraints very well (cf. Bechberger & Kühnberger, 2017a).

As a further step in in WP1, we investigate how conceptual space theory can benefit from the frame account. We argue that frames help to spell out the so-called *criterion C* of natural concepts, which Gärdenfors describes as follows:

A natural concept is represented as *a set of regions in a number of domains* together with an assignment of *salience weights* to the domains and *information about how the regions in different domains are correlated*. (Gärdenfors, 2000, 105)

Researchers of the conceptual spaces approach often acknowledge that the phrasing of criterion C resembles Barsalou's (1992) depiction of frames. Our working hypothesis is that frames allow one to formally represent bundling of cognitive regions belonging to different domains into one 'think' concept. Thus, frames are an important tool also within the theory of cognitive spaces. For example, if we describe the appearance of a human, we can name, inter alia, the colour of the skin, the colour of the hair, and the eye colour. In a frame, one can model the knowledge that persons have different body parts – inter alia skin, hair, and eyes – which have colours. These colours themselves are indeed best modelled in three distinct conceptual spaces. However, a representation merely in terms of conceptual spaces, in nine dimensions, e.g., hue_{skin}, hue_{hair}, hue_{eyes}, $saturation_{skin}$ etc., invariably omits some important information, namely that respective characteristics belong to different parts of the body of one person. We claim that the way that attributes are bundled and clustered in frames provides the underlying semantic outer structure of conceptual spaces that is presupposed but not explicitly modelled in conceptual space theory.

Within this work package, we will fully work out these still sketchy comparisons. A compilation of existing literature will be generated. It will describe the different results of both accounts in a common way, in order to allow their systematic comparison. The results of the work in WP1 (which will be carried out by all members of the project) will serve as an important basis and pre-requisite for the work in work packages WP2 and WP3.

[1] Proponents of conceptual spaces often use the term "dimension" to denote also attributes (e.g., Gärdenfors & Zenker, 2013). For reasons of clarity, we restrict it to a specific kind of value space.

2.3.2 WP 2 Conceptual spaces modelling within frames

Building on the results of work package WP1, we discuss how the structure of conceptual spaces, as a fine-grained approach, can be embedded into the more general frame approach. There are several formalisations of the space-like structure of conceptual spaces. Aisbett & Gibbon (2001), for example, define conceptual spaces in pointed metric spaces, i.e., sets with a comparing distance function *d* and one point of infinity, which is maximally distant from all other points. Raubal (2004) uses vectors defining his conceptual vector spaces. More recent approaches seek to combine conceptual spaces with random set theory (Lewis & Lawry, 2016) or fuzzy set theory (Bechberger & Kühnberger, 2017b). The crucial aspect of all conceptual spaces models is the inclusion of distance measures. Parameterised frames, i.e., frames with quantitative information, provide the formal foundation for modelling conceptual spaces within frames. Implementing the toolbox of conceptual spaces within parameterised frames extends the representational power of frames enormously. We will first integrate notions from conceptual spaces and then investigate the expressive power gained from this enrichment.

Working step 2.1 Foundation: Including distance and betweenness in frames
The core of conceptual spaces theory is the notion of distance and its inverse, the notion of similarity. A pair (X,d) consisting of a set X and a distance measure $d(x,y)$ for $x,y \in X$ is called a metric space. Note, however, that central notions of conceptual spaces theory are more general and presuppose only an ordered neighbourhood structure (a topology) over X.

Gärdenfors (2000, 20) presents two particularly popular measures, which both apply an importance weight w_i for the respective dimensions i: Euclidean distance

(1) $d(x,y) = \sqrt{\sum_{i=1}^{n} w_i (x_i - y_i)^2}$,

and Manhattan (city-block) distance:

(2) $d(x,y) = \sum_{i=1}^{n} w_i \, |x_i - y_i|$.

Both measures are special cases of the more general Minkowski distance:

(3) $d(x,y) = (\sum_{i=1}^{n} w_i \, |x_i - y_i|)^{1/p}$

where Manhattan distance is defined by $p = 1$ and Euclidean distance by $p = 2$. Euclidean distances are only appropriate in spaces with integral dimension, so-called domains, while Manhattan distances are used for separable dimension. The more general Minkowski distance with $1 < p < 2$ allows for graduations between these notions (cf. Hernández, 2017). There are even further ways to measure similarity, e.g., cosine similarity, but the Minkowski distances clearly dominate the discussion of conceptual spaces.[2]

Sometimes it is helpful to represent a concept in several domains at once. In order to do so, we can combine conceptual spaces to form higher dimensional spaces. Bechberger and Kühnberger (2017a, 4) propose the following distance measure for m combined domains with the respective importance weights v_j:

(4) $d(x,y) = \sum_{j=1}^{m} v_j \sqrt{\sum_{i=1}^{n} w_i \, (x_{j,i} - y_{j,i})^2}$.

The implementation of these measures into frames is a key task of this work package. We will also conduct studies generalising the work of Paul Thorn, where alternative distance measures (including importance weights) are considered, and diagnosticity is applied as a test for determining the normality of a property among a category (Thorn and Schurz, under revision). These studies will provide further tests of the robustness of Thorn's previous findings, and integrate that work with other research conducted within the project.

[2] Schwering & Raubal (2005) are a notable exception as they explicitly mention cosine similarity as an approach to conceptual spaces.

Attention will also be given to another notion of conceptual spaces, namely betweenness. In frames, we can formulate betweenness relations by using comparators in the style of Löbner (2017). We envisage formulating betweenness as a comparator attribute that takes pairs of values as arguments and yields a set of points, namely the values that are between them. For metrically scaled attributes, the betweenness relation follows straightforwardly. For non-metric ones it can be simply defined and induces an ordinal scale of the values.

Working step 2.2 Clustering of spaces, natural concepts and their role in inheritance inference

The integration of conceptual spaces also allows one to relate frames to machine learning methods like Voronoi tessellation (cf. Alpaydin, 2009). Given one has *n* salient points in a conceptual space with a similarity measure on it, Voronoi tessellation splits the space in *n* mutually disjoint and exclusive regions that map each point to the closest reference point. Thorn and Schurz (under revision) use this method to find natural concepts over a topological regions. They study the reliability of default inheritance inference of prototype concepts to subclasses (e.g., "if lambs are white, then Norwegian lambs are white") in dependency on the naturality of the subclass-forming concept "white"). In WP2 this approach will be developed further. Their method of finding most natural concepts over a topological region is based on fitted classes with an internal similarity structure over many different attributes. The similarity within the fitted classes is maximised by using *k*-means clustering, which associates each class with a tuple consisting of the mean property values of its members. The resulting so-called centroids serve as prototypes for the classes and partition the domain of objects into convex regions, corresponding to natural properties in a conceptual space in the sense of Gärdenfors (2000). Simulation studies conducted in Thorn and Schurz (under revision) support the conjecture that default inheritance based on fitted classes permits more inferences and is far more reliable than inheritance inference based on unfitted classes that are defined by an atomic property.

The results of this work address a long running debate in the field of non-monotonic reasoning, concerning the question under which conditions inheritance inference to subclasses is reliable. The major conjecture, to be investigated in this part of WP2, is that the reliability of default inheritance depends upon the *naturality* of the concepts in terms of which subclasses are defined. In the theory of cognitive spaces, three major criteria for cognitive naturality of concepts have been proposed. A first and largely uncontroversial requirement is that natural conceptual regions are *connected*. According to Gärdenfors (2000, 67), two regions X, Y of a cognitive space are connected iff the topological closures of *X* and *Y* have at least one common point. A stronger requirement is that natural concepts correspond to *star-shaped* region, or even stronger, to a *convex* region. A region is said to be star-shaped with respect to a point *p* of the region if for all points *x* and *y* the following holds: if *x* belongs to the region and *y* is between *p* and *x*, then *y* belongs to the region. A region is convex if it is star-shaped with respect to each point in the region.

The investigation of the fruitfulness of these cognitive criteria for naturality is not only important for the investigation of the reliability of default inheritance to subclasses in WP2.2, but plays also a key role for the work in WP3.

2.3.3 WP 3 Learnability and cognitive efficiency as key characteristics of natural properties and kinds

Working step 3.1 Naturality criteria for concepts based on geometric constraints
In philosophy, there is a long running debate about what makes a concept "good" or "natural", and ongoing work directed at finding an adequate characterisation of "good" or "natural" concepts. It is also noteworthy that conceptual spaces were first developed within these philosophical debates. Gärdenfors (1990) explicitly introduced topological criteria of naturalness in the context of philosophical debates on natural versus arbitrary concepts and the role of similarity in discriminating the two (Quine, 1977; Goodman, 1955, 1972). For example, consider the (in)famous Goodman-property "grue", which in one of its definitions means the same as "green before a certain future time point and blue after that time". In terms of the three cognitive naturalness criteria as defined in WP2.2, the Goodman property is neither convex, not star-shaped, and if "green" and "blue" are not regarded as immediate neighbours in the colour dimension, then it is not even connected.

Within this working step, we will evaluate the conditions on naturalness that are typically discussed in the literature on conceptual spaces. The main constraint that we consider asserts that natural properties are convex or at least star-shaped areas. In cases where a concept is characterised by a prototype, regions should also approximate the structure of a Voronoi tessellation. However, we will not follow the geometric constraints blindly. Rather we will evaluate the plausibility of the constraints by checking their results against the background of philosophical (especially metaphysical) arguments and the explanatory praxis exhibited in the cognitive sciences (Taylor & Vosgerau 2019). In particular, we will ask, to what extent do the resulting frames correspond to metaphysically plausible categories? How do the arguments presented by Gärdenfors (2000) relate to longstanding philosophical debates about the naturalness of categorisations? What philosophical arguments can support the constraint that convex regions in conceptual spaces are more natural? Is this only a requirement based on the cognitive efficiency of our mind? Or is this requirement connected with fundamental ontological feature of the world? What are the concepts like that are posited by cognitive science – do they favour cognitive or ontological features? Do properties that are natural - in the sense that they are usually lexicalised and easily learned – really correspond to convex regions? Or should one use weaker geometric constraints? Finding convincing answers to these questions is a major task of WP. 3.1.

Working step 3.2: Ease of learnability and neuroscientific features of natural concepts
Standard frame theory doesn’t entail obvious restrictions concerning which frames are learnable and useful. In the second step of WP3 we investigate our conjecture that the more natural concepts are, the more easily they can be learned and the more cognitively efficient they ae. This claim is also central to prototype theory. Rosch et al. (1976) found that there is a certain level of generality, the so-called *basic* level, at which concepts are *learned earliest* in childhood and used with most cognitive ease. Concepts on this basic level refer to categories that maximise commonalities within the category and minimise commonalities to objects outside of the category. Rosch (1978) argues that basic level categories best capture the correlational structure of the world. We will investigate to which extent those categories that are basic in the sense of Rosch fit with the criteria of natural concepts coming from the theory of cognitive spaces.

Going one step further we try to relate the developed criteria of naturalness with neurobiological findings. Many natural concepts have a rather direct neurobiological correlate. Binder et al. (2016) provide a list of features with a proven neurobiological foundation, also called Binder features. The authors also present ratings for categories, e.g., musical instrument, vehicle, and tool, indicating the strength of association of various Binder features for the categories. For example, vehicles have a high association to the Binder feature *large*.

This association is lower for musical instruments and very low for tools (Binder et al., 2016, 22).

It should be noticed that Binder features cannot be straightforwardly translated to frames or conceptual spaces. They take different places in these functional structures: *large* serves as a value (or a range of values), while *weight* is an attribute with a ratio level measurement scale. Thus, different Binder features will play very different roles in a conceptual space or in a frame. Zeevat (draft) already formulated a preliminary systematisation of Binder features in relation to frames. Within this working step, we will extend Zeevat's research first to prototype frames and second to conceptual spaces. We will thereby address, inter alia, the following questions:

a. How does the Binder feature approach generally relate to the prototype theory of concepts? Do they help to identify the same typical properties as our probabilistic account of prototypes (Schurz 2012, Strößner and Schurz 2020). How do both fit into an evolutionary based understanding of concepts, as advocated in Schurz (2012)?

b. How can a strong association of a concept and a Binder feature be represented in a prototype frame? In many cases, they clearly indicate typical values. For example, a strong connection to *large* indicates a high probability for this particular value on the size attribute. But what does a high association to *weight* mean? Does it translate to the attribute's diagnosticity?

c. How should differences in the association pattern of contrasting categories, e.g., animal and plant, (Binder et al., 2016, 21) be captured in their comparative prototype frames? How do these comparisons relate to typicality in the narrow sense?

At the end of this investigation, we will have determined a set of attributes, values, and basic frame structures that correspond to Binder features, and that are natural in the sense that they have neural correlates. Based upon this result we turn to the final question of WP2.2: do these attributes that have a neural correlate correspond to concepts that are natural in the cognitive or ontological sense? Our answer to this question will combine the findings from WP3.1 and WP3.2. At the end of this working step, we will demarcate a set of properties that are natural in the sense that they are based on domains with neural correlates *and* on values with a sensible geometric structure.

2.3.4 Timeline

	01-06	07-12	13-18	19-24	25-30	31-36
WP 1	Comparison of frames and conceptual spaces: PhD & PI2 & PI1 & Postdoc			Thesis writing PhD		Paper writing (Joint work of all)
WP 2	Research on working step 2.1 Postdoc & PI1 Paper writing			Research on working step 2.2 Postdoc & PI1 Paper writing		
WP 3	Research on working step 3.1 PhD & PI2		Paper writing on WP3.1 PhD & PI2	Research on working step 3.2 Postdoc & PI2 & PI1		Paper writing on WP3.2 Postdoc & PI2 & PI1
Events		Workshop 1: Naturalness of Concepts		Workshop 2: Uncertain inference and naturality of concepts		Symposium: Frames and Cognitive Spaces

By researchers:

- All personell will work on WP1. The PhD, Lina Peine, will especially focus on the compilation of existing literature on which the comparison of frames and cognitive spaces will be based. The results of the work in WP1 is an important pre-requisite for the work in WP2 and WP3.

Lina Peine and her supervisor Gottfried Vosgerau replace Corina Strößner, who was part of the team when the project was developed within the CRC 991. Corina Strößner now accepted a long-term position at the university of Bochum; she will only figure as an important cooperation partner for this project. Lina Peine, supervised by the second PI (PI2), Gottfried Vosgerau, will also take over major parts of the work in WP3 originally intended for Corina Strößner.

- Postdoc: Paul Thorn, together with PI1, will carry through the research in WP 2.1 and WP2.2. His results will also be applied in WP 3.1, concerning the development criteria for the naturalness of concepts. The work on the neurological foundations of concepts and on Binder features will be carried through by the postdoc in cooperation with PI2 and PI1.

Lina Peine, together with PI2, will focus on the work in WP3.1. The philosophical investigation of naturalness of concepts and their relation to geometric conceptions of concepts will be the main topic of her PhD thesis. Moreover, she will write at least one paper in co-authorship with PI2, in which the most significant results of her work will be presented.

3 Bibliography concerning the state of the art, the research objectives, and the work programme

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4 Relevance of sex, gender and/or diversity

The sex and/or gender of the researchers is not relevant to the research project.
The state of health, ethnic background or culture of the researchers is not relevant to the research project.
The research in the project is theoretical. No empirical investigations on humans or animals are involved.

5 Supplementary information on the research context

Section 5 et seq. must not exceed 10 pages.

5.1 Ethical and/or legal aspects of the project

5.1.1 General ethical aspects

There are no relevant ethical and/or legal aspects of the research project.

5.1.2 Descriptions of proposed investigations involving experiments on humans or human materials

No investigations involving experiments on humans or human materials are proposed.

5.1.3 Descriptions of proposed investigations involving experiments on animals

No investigations involving experiments on animals are proposed.

5.1.4 Descriptions of projects involving genetic resources (or associated traditional knowledge) from a foreign country

No investigations involving genetic resources (or associated traditional knowledge) from a foreign country are proposed.

5.1.5 Descriptions of investigations involving dual use research of concern, foreign trade regulations

No investigations involving dual use research of concern or foreign trade regulations are proposed.

5.2 Data handling

The research in the project is theoretical. No empirical data will be collected.
Apart from publications, the results of the theoretical research will be made public on the Internet.
The project will have its own website that will be linked to the other projects at the HHU that are working on frame theory.

5.3 Other information

Please use this section for any additional information you feel is relevant which has not been provided elsewhere.
None

6 People/collaborations/funding

6.1 Employment status information

For each applicant, state the last name, first name, and employment status (including duration of contract and funding body, if on a fixed-term contract).

Professor Dr. Gerhard Schurz, Heinrich-Heine-University Düsseldorf.
Gerhard Schurz retires 02/2022; a senior professorship will be established for him afterwards.
For the period of the project after Gerhard Schurz is retired, the HHU will provide the necessary equipment for the research of his part of the project, i.e., the work of Paul Thorn and of PI1 (see letter by the dean).

Professor Dr. Gottfried Vosgerau, Heinrich-Heine-University Düsseldorf.

6.2 First-time proposal data

Only if applicable: Last name, first name of first-time applicant
No

6.3 Composition of the project group

List only those individuals who will work on the project but will not be paid out of the project funds. State each person's name, academic title, employment status, and type of funding.

Basic staff (university employed):
Prof. Dr. Gerhard Schurz, PI1.
Prof. Dr. Gottfried Vosgerau, PI2.
Intended research staff:
Dr. Paul Thorn, Postdoc 50%.
Lina Peine, PhD 65%.
Student assistant 10 hours per week

6.4 Researchers in Germany with whom you have agreed to cooperate on this project

6.4.1 Cooperation within the HHU

During our work on prototype frames, we cooperated with several other researchers within the former CRC. We will continue these cooperations with those researches at the HHU who continue to work in frame theory within individual projects (Laura Kallmeyer, Rainer Osswald, Ingo Plag, Hana Filip, Wiebke Petersen).

Our work on conceptual naturalness will touch on several metaphysical questions. In regard to these questions we will cooperate with HHU members of the research unit Inductive Metaphysics (FOR 2495), including Markus Schrenk and David Hommen, with whom we already organised joint symposia.

List of cooperations:
- Prof. Markus Schrenk
- Prof. Christoph Kann
- Prof. Laura Kallmeyer
- Prof. Wiebke Peterson
- Dr. David Hommen
- Dr. Peter Sutton
- Prof. Henk Zeevat

6.4.12 Cooperations outside the HHU

Gerhard Schurz will continue to cooperate with Stephan Kornmesser with whom he published papers about frames.
We will also seek a close connection to research communities that base their work on conceptual spaces. We plan to cooperate with Kai-Uwe Kühnberger and Lucas Bechberger (both: University of Osnabrück), who carry out research on the integration of constraints in conceptual spaces. This is also a central topic in our work. Furthermore, conceptual spaces are also central in the work of the Emmy Noether group “From perception to belief and back again”. We will have regular cooperation with the leader of the group Peter Brössel (Ruhr

University Bochum) and in particular with the former member of our project, Dr. Corina Strößner, who is now part of the Bochum team.

List of cooperations:
- Dr. Corina Strößner, Ruhr University Bochum
- Dr. Peter Brössel, Ruhr University Bochum
- Dr. Stephan Kornmesser, Univ. of Oldenbourg
- Prof. Kai-Uwe Kühnberger, University of Osnabrück
- Lucas Bechberger, M.Sc. University of Osnabrück

6.5 Researchers abroad with whom you have agreed to cooperate on this project

We aim to cooperate with Professor Peter Gärdenfors at Lund University, Sweden, and with his cooperator Dr. Frank Zenker. Gärdenfors is the most important originator of the theory of cognitive spaces. We will also coperate with the external fellow the Emmy Noether group in Bochum, with Nina Poth (University of Edinburgh).

List of cooperations:
- Prof. Peter Gärdenfors, Lund University, Sweden
- Dr. Frank Zenker, Lund University, Sweden
- Nina Poth, M.Sc. University of Edinburgh

6.6 Researchers with whom you have collaborated scientifically within the past three years

This information will help avoid potential conflicts of interest.

PI1:
Prof. Dr. Ralph Hertwig (Max-Planck-Institute for Human Development) – Prof. Dr. Wolfgang Spohn (University of Konstanz) – Prof. Dr. Ilkka Niiniluoto (University of Helsinki) – Prof. Dr. Stephan Hartmann (Ludwig-Maximilian-University of Munich) – Prof. Igor Douven (Paris-Sorbonne University) – Prof. Erik Olssen (Lund University, Sweden) – Prof. Theo Kuipers (University of Groningen) – Prof. Markus Knauff (University of Gießen)

PI2: Prof. Albert Newen (Ruhr-University Bochum) – Prof. Raphael van Riel (University of Essen, currently Freie Universität Berlin).

6.7 Project-relevant cooperation with commercial enterprises

If applicable, please note the EU guidelines on state aid or contact your research institution in this regard.

None

6.8 Project-relevant participation in commercial enterprises

Information on connections between the project and the production branch of the enterprise

None

6.9 Scientific equipment

List larger instruments that will be available to you for the project. These may include large computer facilities if computing capacity will be needed.

None

6.10 Other submissions

List any funding proposals for this project and/or major instrumentation previously submitted to a third party.

None

[Text]

7 Requested modules/funds

Explain each item for each applicant (stating last name, first name).

7.1 Basic Module

7.1.1 Funding for Staff

We apply for one 50% postdoc position, one 65% PhD position, and 10 student assistant hours per week.

For PI1:
Postdoc 50%: Paul Thorn
Student assistant: 6 hours per week. 10.800,- Euro.

For PI2:
PhD 65%: Lina Peine
Student assistant: 4 hours per week. 7.200,- Euro.

Explanations and Job descriptions of staff:

The work in the work packages WP2 and WP3.2 requires highly experienced researchers. Paul Thorn is highly suited for this purpose. Paul Thorn has a PhD in Philosophy and Cognitive Science from the University of Arizona. He has been a member of several interdisciplinary collaborative research groups, including *Philosophy, Probability, and Modelling* (Konstanz), *the Logic of Causal and Probabilistic Reasoning in Uncertain Environments* (ESF), *New Frameworks of Rationality* (DFG), and *the Structure of Representations in Language, Cognition, and Science* (DFG). He is an author of 28 peer reviewed articles, including collaborative work with cognitive psychologists (Markus Knauff, Giessen, and Leandra Bucher, Siegen) and computer scientists (Gabriele Kern-Isberner, Dortmund). Much of Thorn's research has focused on formal and simulation-based studies of inference, especially concerning the relevance of concept and category selection to the cogency of inductive and ampliative inference. Recently he has focused on the role of similarity-based categorisations, which is especially relevant for our proposed research project.

The work in WP1 consists of an extensive comparison of frame theory and conceptual space theory with the purpose of establishing possibilities of cooperation and unification between the two approaches as a prerequisite of the work in WP2 and WP3. This work is ideally suited for a PhD. An excellent candidate for this work is Lina Peine, who will have completed her Master thesis on Gärdenfors's notion of naturalness under the supervision of Professor Gottfried Vosgerau when this project has its intended start. She is currently employed as a research assistant in Gottfried Vosgerau's team because of her excellent philosophical skills (mean grade 1,0 in her Master studies) and her interest in philosophy of mind and cognitive science. Thus, her MA thesis can both be expected to be both of a very high quality and to be an optimal preliminary work for this project.

The work of the student assistant is needed for computer programming tasks in work packages 2. Moreover, the student assistant will help in preparing and carrying out the workshops.

7.1.2 Direct Project Costs

7.1.2.1 Equipment up to € 10,000, Software and Consumables
None

7.1.2.2 Travel Expenses

We plan to present the results of our research at both national and international workshops and conferences. The following list provides an idea of the kind of conferences we are planning to attend and of the related expenses:
Calculation of travel costs: 3 conferences a year, one of them abroad, including: Society for the Metaphysics of Science (USA/EU), British Society for the Philosophy of Science (UK), European Philosophy of Science Association (EU), GAP Kongress; CogSci (Congitive Science Society conference), DGPhil Kongress; GWP Kongress.
Costs of a European conference: 200 travel and 250 accommodation = 450€.
Minimal costs of an overseas conference (USA): 600 travel, 300 accommodation = 900€.
This makes 1.800 € per year for each project member (2 PIs plus 1 postdoc and 1 PhD).
<u>Applied sum: 21.600 €</u> (10.800 for each PI).

7.1.2.3 Visiting Researchers (excluding Mercator Fellows)
None

7.1.2.4 Expenses for Laboratory Animals
None

7.1.2.5 Other Costs
None

7.1.2.6 Project-related Publication Expenses
None

7.1.3 Instrumentation

7.1.3.1 Equipment exceeding € 10,000
None

7.1.3.2 Major Instrumentation exceeding € 50,000
None

7.2 Module Temporary Position for Principal Investigator
Not applicable

7.3 Module Replacement Funding
Not applicable

7.4 Module Temporary Clinician Substitute
Not applicable

7.5 Module Mercator Fellows

Not applicable

7.6 Module Workshop Funding

We aim to initiate a closer connection between the research communities that base their work on conceptual space or frames, respectively. For this reason, we will organise highly interdisciplinary workshops each year, where researchers with a different background – frames or concept spaces – can exchange ideas on how to approach topics central to both formats of conceptual representation. We envisage covering the following topics:

− Workshop 1: Criteria of naturalness of concepts in philosophy and cognitive science
− Workshop 2: Uncertain inference and naturality of concepts, with a focus on the reliability of inheritance inference
− Workshop 3: Establishing bridges: Frames and cognitive spaces

The first two workshop will focus on particular topics, which are approached from different angles by conceptual spaces researchers and by frame-theorists. The third workshop is devoted to relationships and possible bridges between frame theory and theory of cognitive spaces viewed from a broader angle.

These meetings will benefit from the still on-going frame-related research in Düsseldorf and will attract many conceptual spaces research groups in the academic neighbourhood, for example the Emmy Noether group in Bochum „From perception to belief and back again“ (Brössel) and the Osnabrück research group (Kühnberger, Bechberger), with whom we will cooperate. The purpose of these workshops is also to lay down foundation for future collaborations between conceptual spaces theorists and scholars from frame theory.

We will invite researchers from more distant places in Germany and Europe (about 4 per Workshop) and overseas (about 1 per workshop). We calculate 4 x 500€ accommodation costs and 2000€ travel costs for our speakers per workshop, which makes 4.000,- per workshop. Applied sum: 12.000 € (6.000 for each PI).

7.7 Module Public Relations Funding

Not applicable