A Comparison of German Semantic Verb Classifications

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Abstract

Various approaches towards a semantic classification of German verbs exist, but even though all refer to classification criteria concerning verb meaning, they differ substantially. To address the questions of why there are so many classifications, why and how they differ, and whether any of them is 'optimal', this paper performs a manual study of four German semantic verb classifications: We compare *GermaNet, FrameNet/SALSA*, the verb classes of *Ballmer and Brennenstuhl* and those of *Schulte im Walde*, with respect to their motivation, class organisation and sense and feature distinctions, focusing on the *manner of motion* domain.

1 Introduction

Both in theoretical and computational linguistics we find various approaches to a semantic classification of verbs. Even though all classifications refer to the same objects of interest and to similar classification criteria concerning verb meaning, they differ substantially. Obviously, the background of the authors, their goals and their strategies direct the development of the verb classes. But even when two approaches classify verbs in a common language and according to a common framework, the results may still disagree. For example, Schulte im Walde (2003) defines semantic classes for German verbs by similar criteria as FrameNet (Baker *et al.*, 1998); however, while Schulte im Walde classifies the *manner of motion (MOM)* verbs *eilen* and *hasten* (both meaning: 'to rush, to hurry') into a MOM subclass *rush*, FrameNet does not distinguish speed of motion into a separate class and groups these verbs with other *self motion* verbs. Both classes and assignments are plausible, but focus on different properties of the verbs – one concentrating on the rush, the other on an agent as mover. It seems that such differences are not fundamental flaws in the resources, but rather inherent in the task of semantic classification. This paper explores this intuition, by addressing the questions of why there are so many such classifications, why and how they differ, and whether any of them is 'optimal'. While in the long run it would be desirable to automate the comparison using empirical criteria, this paper presents the first step of the analysis in the form of a manual study of a limited domain of the classifications.

Our interest in this study originates from a computational perspective: (a) the acquisition and (b) the use of verb classes in computational learning tasks. With respect to (a) the *acquisition of verb classes*, a manual definition of large-scale classifications is expensive, so work such as Schulte im Walde (2003) addresses an automatic acquisition. But the decision about which criteria are relevant for a verb classification influences both the experiment setup (with regard to feature selection) and the choice of a manually constructed gold standard for evaluation. The question is, whether there is <u>the</u> correct classification to be used as gold standard? How do we decide on valid criteria for a classification, noticing that existing classifications differ substantially? With respect to (b) *the use of verb classes*, lexical classifications are used as a basis in a wide range of NLP tasks, to refine properties that received insufficient empirical evidence, or for generalisation. For example, in the computation of selectional preferences, classifications are used to generalise from seen co-occurrences, e.g. in the nominal case from *schoolboy/rush* and *doctor/rush* to *person/rush*, and in the verbal case from *cycle/into town* and *walk/into town* to *move/into town*. But any individual lexical resource has its problems, like holes in coverage or variations in granularity. So it is an interesting question whether a combination of resources can achieve better generalisation properties.

The paper compares four manually constructed semantic classifications of German verbs. We describe the resources with respect to (1) the motivations and goals of their work, (2) their overall structure, i.e. the organisation of the classes and the relations linking the classes and (3) the general decision criteria applied in verb sense distinction and grouping verbs into classes. The four resources to be compared are the process-based classification by Ballmer and Brennenstuhl (1986) (henceforth **BB**), the psycholinguistic semantic taxonomy GermaNet (**GN**), cf. Hamp and Feldweg (1997); Kunze (2000), the FrameNet classes (**FN**), cf. Baker *et al.* (1998); Erk *et al.* (2003), and the semantic classes by Schulte im Walde (2003) (**SIW**). BB and SIW are original classifications of German verbs, whereas GN and FN both use the existing English resources as starting point for the German pendants.

For comparing the classifications, the resources are characterised along dimensions (1)-(3), underlined by a case study on the domain of *manner of motion* verbs.

2 Description of Four Verb Classifications

In this section we give a short description of the four resources, describing the motivations and goals of their construction, their overall structure, and the general decision criteria applied in verb sense distinction and grouping verbs into classes.

2.1 Ballmer/Brennenstuhl: A Process-based Classification

Ballmer and Brennenstuhl (1986) classify 8,000 common, non-prefixed German verbs according to their meaning. Their goal is to build a complete thesaurus of German verbs. Verbs are grouped into classes, which are formed by paraphrasing based on a set of 10 elementary verbs; if verbs agree in central parts of their paraphrases, they are grouped together, such as *sich distanzieren* and *sich entfernen* (both meaning 'distance oneself'), *wegfahren* 'drive away' and *verschwinden* 'disappear' in a common class paraphrased as *moving oneself away from a place*; or *karren* 'cart', *schiffen* 'ship', *löffeln* 'spoon', *schaufeln* 'shovel' (among others) in a common class paraphrased as *somebody transporting something from a place, using an instrument/vehicle*.

The verb classes are then organised into *process models*. For example, the process model *Fortbewegung* 'moving ahead' contains the verb classes for resting, wanting to move, raising, starting to move, moving ahead, moving in circle, moving as passenger, accompanying, getting lost, arriving, stopping, etc. Each verb class designates a phase of the process model, i.e. an initial situation, a transition from initial to end situation, an end situation, precondition, result, or consequence. The classes that belong to the same process model are related to each other by semantic relations such as temporal ordering, causativity or implication.

2.2 WordNet/GermaNet

WordNet is a lexical semantic taxonomy developed at the University of Princeton (Miller *et al.*, 1990; Fellbaum, 1998). The lexical database is inspired by psycholinguistic research on human lexical memory. The resource organises English nouns, verbs, adjectives and adverbs into classes of synonyms (*synsets*), which are connected by lexical and conceptual relations such as hyponymy, hypernymy, meronymy, etc. The hypernym-hyponym relation imposes a multi-level hierarchical structure on the taxonomy. Words with several senses are assigned to multiple classes. The decision on synonymy is mainly based on substitution tests in prototypical contexts.

The idea of WordNet has been transfered to other languages than English. The University of Tübingen is developing the German version of WordNet, *GermaNet* (Hamp and Feldweg, 1997; Kunze, 2000). An example verb in GermaNet is *eilen* 'rush', which is assigned to a common synset with the verbs *sputen, beeilen* 'hurry' and *pressieren* 'be under pressure'. The hypernym synsets of the verb class are (bottom-up) *spezielle Geschwindigkeit* (special speed), *spezielle Bewegart* (special kind of moving), *fortbewegen* (move ahead), *bewegen* (move), and *lokalisieren* (localise).

2.3 FrameNet/SALSA

FrameNet (Baker *et al.*, 1998) is based on Fillmore's frame semantics (Fillmore, 1982) and thus describes *frames*, the background and situational knowledge needed for understanding a word or expression. Each frame provides its set of semantic roles, the participants and properties of the prototypical situation. For example, the *motion* frame is introduced as following: *Some entity (Theme) starts out in one place (Source) and ends up in some other place (Goal), having covered some space between the two (Path).* To construct frames, FrameNet uses semantic properties both of the target words to be classified and of their semantic roles (Ellsworth *et al.*, 2004). The criteria for sense distinction also lead to a consistent separation of causative, inchoative and static uses into different frames.

The frames of FrameNet are linked by three different kinds of frame-to-frame relations: *Inheritance* is an is-a relation between a parent frame and a child frame that includes full inheritance of semantic roles. *Subframe* is used for linking a scenario frame to its subevents; they may be temporally ordered (in which case scenarios are like BB's processes). *Using* expresses a weaker relation of presupposition, not requiring a full mapping of all semantic roles, as well as deep conceptual relatedness.

The Berkeley FrameNet project is building a dictionary which links frames to the words and expressions that introduce them, illustrating them with example sentences from the British National Corpus. Frames may be introduced by verbs as well as nouns, adjectives, prepositions, adverbs, and multi-word expressions.The SALSA project (Erk *et al.*, 2003) is annotating the German TIGER corpus (Brants *et al.*, 2002) with frames and frame-semantic roles. Its aim is to construct a large, semantically annotated corpus resource as a reliable basis for the large-scale acquisition of word-semantic information. In the course of the annotation, the project builds a German FrameNet, linking the (English) frames to German target expressions.

2.4 Schulte im Walde: Automatic Class Acquisition

The semantic classification of Schulte im Walde (2003) contains 168 partly ambiguous German verbs. The purpose of the classification is to evaluate the reliability and performance of clustering experiments, which seek to automatically acquire semantic verb classes. The basis of class creation is subjective conceptual knowledge, monolingual and bilingual dictionary entries and corpus search. Verbs are assigned to classes according to their similarity of lexical and conceptual meaning, and each verb class is assigned a semantic class label. Some classes are arranged into a common larger group that again bears a label, yielding a flat hierarchy of only two levels. For example, the coarse label *manner of motion* is sub-divided into the finer labels *locomotion, rotation, rush, vehicle, flotation*. The class description is closely related to FrameNet: Each verb class is given a conceptual scene description which captures the common meaning components of the verbs. Annotated corpus examples illustrate the combinations of verb meaning and conceptual constructions, to capture the variants of verb senses.

Representing the gold standard for a statistical task, the choice of verbs is based on empirically relevant demands: The classes include both high and low frequency verbs, in order to exercise the clustering technology in both data-rich and data-poor situations: the corpus frequencies of the verbs range from 8 to 71,604. The classification was checked to ensure the lack of bias, so that there are no majorities of high frequent verbs, low frequent verbs, strongly ambiguous verbs, verbs from specific semantic areas, etc. Any bias in the classification could influence the evaluation of clustering methods.

3 Case Study: *Manner of Motion* Verbs

In this section we compare our four resources with respect to their classifications of MOM verbs. We first comment on the placement of the *manner of motion* classes in the overall classification structure, and then discuss and exemplify the central criteria for sense distinction and class assignment.

Overall structure of the motion domain. In BB, there are five motion-related processes, one describing non-agent, inchoative motion *(Bewegungs-*

modell: Eigenveränderungen von Individuen/Objekten im Raum) 'self change of individuals/objects in space', one for motion in place with an agent *(Aktivbewegung)* 'active motion', one for agent motion with change of place *(Fortbewegung)* 'forward motion', one for transport *(Transport)*, and one for movement with control over a vehicle *(Fremdbewegung)* 'external motion'. The processes all include non-movement as beginning and end state, and preparation and finishing of the movement, such as getting the orientation in agentive models, and packaging and de-packaging in the transport model.

In GN, all motion and position verbs are below *lokalisieren* 'localise'; in fact, *bewegen* 'move' and *Position einnehmen* (gloss: 'something is or is being localised in space') are the only hyponyms of (this sense of) *lokalisieren*, so GN also establishes a close relation between position and motion. Even more, the hyponyms of *Position einnehmen* are position verbs in different stages (partly similar to BB processes) of getting into vs. being in a position. In addition, further down in the is-a hierarchy of *Position einnehmen* are verbs where an agent causes motion, such as *tragen* 'carry', *werfen* 'throw', *bringen* 'bring', *lehnen* 'lean', which again would be motion verbs in BB. But unlike in BB, the position verbs are not part of the motion verbs. The motion verbs themselves subsume the specific verb synsets *regen, rühren* 'move slightly' and *rühren* 'stir', but also the coarse categories *bewegen auf Stelle* 'move in place', two senses of *fortbewegen* ('moving away from source' and 'moving ahead with direction'), and *transportieren* 'transport'. Inchoative vs. causative motion is therefore not a criterion on high-level GN, but change of place and means for movement. Criteria such as specific kinds of movement and agentivity are distinguished further down in the hierarchy.

As the FrameNet hierarchy is still being constructed, we can only draw conclusions from the links that are actually present. FN motion-related classes are not organised in a single contiguous inheritance hierarchy but all point to the central *motion* class via the *using* relation. Motion is unspecified with respect to the type of mover; only its child frame *self motion*, which also inherits from *intentionally act*, requires an animate mover. A further area of motion frames contains *cause motion*, *carrying* and *sending*, which all inherit from or use *intentionally affect*. A "process" of motion (in BB's terms) is described in the scenario frame *motion scenario* with the subsituations *departing, motion,* and *arriving*.

In SIW, we find 18 motion verbs in five motion subclasses: *locomotion* contains agentive verbs of forward movement, *rotation* refers to verbs expressing the specific kind of movement, not distinguishing agentive vs. inchoative characteristics, *rush* relates to the specific hurry in motion, *flotation* to the inchoative floating of objects, and *vehicle* to motion with a vehicle, subsuming both agentive and participating roles. Verbs denoting the start or the end of a motion "process" (in BB's terms), such as *existence* verbs, *aspect* verbs, or *position* verbs, are assigned to a separate top-level class, not related to motion. Some agentive transport verbs are subsumed under *transfer of possession*.

Manually extracting main criteria. Table 1 summarises the main criteria that each resource uses for the classification. Criteria were extracted manually as follows: For the more coarse-grained FN and SIW, each class distinction was considered as a major aspect. For the fine-grained GN and BB, criteria were included in the table if they were interior nodes in the hierarchy with a substantial amount of subclasses (GN) or formed the basis of more than one class (BB). For grouping of classes into criteria, class name, class members (verbs), definitions and glosses were used as indicators.

Main criteria in the classification. The type of mover, group (1) in Table 1, plays a major role in all classifications. All but GN distinguish animate and inanimate movers. In BB there are even separate process models for agent and non-agent movements (with the lower-level structure of the two models partially parallel). For the verbs distinguished by agent/non-agent in BB, GN uses the group/single mover distinction instead. FN, like GN, distinguishes the movement of groups and single movers, but it has the agent/non-agent distinction as well in the most general class *motion* and its subclass *self motion*. Interestingly, a special case of the group/single mover distinction, the motion of fluids, is considered relevant in 3 of the 4 resources.

Group (2) in Table 1 lists common prominent criteria of the classifications. For the source/goal/path criteria, FN has the classes *arriving, departing, escaping* and *path shape*. GN has a high-level synset *Pfad spezifiziert* 'path specified' with subclasses for the deictic verbs *kommen* 'come' and *gehen* 'go', and directional (vertical such as *hochbewegen* 'rise' and *runterbewegen* 'sink', and others such as *ankommen* 'arrive' and *entfernen* 'move away') vs. non-directional movement (such as *flanieren* 'stroll' and *vagabundieren* 'vagabund'). BB contains many classes profiling source, path

[1] Motion of fluid and motion in fluid together.
[2] Separation of operating and riding a vehicle.
[3] Only rotation.
[4] Wide category including various kinds of object manipulation.
[5] Only sending and putting.

Criteria	**GN**	**BB**	**SIW**	**FN**
(1) Type of mover				
Animate vs. inanimate mover		BB	SIW	FN
Group vs. individual mover	GN			FN
Motion of fluid	GN		SIW[1]	FN
(2) Common prominent criteria				
Source/goal/path	GN	BB	SIW	FN
Noise during motion	GN	BB		FN
Speed	GN	BB	SIW	
Vehicle	GN[2]	BB[2]	SIW	FN[2]
(3) Movement in place				
Moving in place	GN	BB	(SIW)[3]	FN
Body movement	GN	BB		FN
Iterative movement	GN	BB	SIW	
(4) Accompaniment and transport				
Accompaniment/chase		BB		FN
Cause motion	GN	BB[4]	(SIW)[5]	FN
(5) Idiosyncratic criteria				
Propel	GN			
Travel (long journey)				FN
Movement by gravity				FN
Uncontrolled/erroneous movement		BB		
Preparation of movement		BB		
Reason for movement		BB		
Non-movement		BB		

Table 1: Main criteria in structuring the MOM domain.

or goal, such as *aufbrechen* 'leave', *Richtung ändern* 'change direction', *wegbewegen in verschiedene Richtungen* 'moving away in different directions', *sich an einen Ort bewegen* 'move to some place'. In SIW, the *locomotion* verbs do refer to source, path and goal, but are not contrasted with their non-directional pendants. Noise during motion (*crackle*, *rumble*) is profiled in GN and FN and occurs in one class in BB. Speed of motion is important in all classifications but FN, which lists these verbs simply in *self motion* (*rennen* 'run', *kriechen* 'creep'). The existence of a vehicle is an important criterion in all classifications. Interestingly, most classifications have separate classes for the profiled agent as driver and as passenger.

The criteria in group (3) describe movement in place. While BB emphasises the distinction of movement with and without change of place and especially the distinction of iterative and non-iterative movement, FN has few such classes and not yet integrated. GN has a separate hierarchy for *body verbs*, which joins the movement part of the hierarchy for verbs describing both motion in place and body movement. SIW lists only *rotation*.

The criterion of caused motion in group (4) is important in all resources. In BB the verbs describing caused motion are in a separate process model. In the GN hierarchy they appear below *transportieren* 'transport', in SIW as *transfer of possession* and *bring into position* verbs. In FN the distinction between causatives and inchoatives permeates the whole classification, leading to classes like *motion* vs. *cause motion*, *moving in place* vs. *cause to move in place* and *posture* vs. *change of posture*. In contrast, the criterion of two agents moving, one either accompanying or following the other, is used only in the FN and BB classifications.

The idiosyncratic criteria in group (5) appear in only one classification. The ones for BB reflect the process-centred structure of the resource (with criteria such as *preparation for movement* and *non-movement*), and also show that this very fine-grained resource uses criteria that are much more specific than those used elsewhere. The list of BB idiosyncratic criteria is a sample and far from complete. The FN idiosyncratic criteria are listed in full. They are in the frame *travel* (e.g. *reisen* 'travel', *touren* 'tour', *pendeln* 'commute'), which in GN and BB are classified just as individual movement with an agent mover, and in the frame *motion by gravity* (e.g. *fallen* 'fall'). The GN idiosyncratic criterion describes a force propelling an object; it is the main subclass of the transportation synset, ancestor of a large number of transportation, accompaniment and object manipulation classes.

A detailed inspection of some verbs. As final part of the comparison, Table 2 presents a choice of example verbs and their assignment to verb classes. The choice underlines the agreement vs. idiosyncrasies in the classifications, as described above.

4 Discussion and Conclusions

In the beginning of this paper, we asked why there are so many semantic verb classifications, why and how they differ, and whether there is any kind of 'optimal' classification. Our main motivation arises from computational learning tasks addressing the acquisition and the use of verb classes.

anschauen 'look at' – In FN *perception active*; in GN hyponym of perception verb *sehen* 'see'. In BB idiosyncratic classification into active motion model *Aktivbewegung* in subclass *bemustern* 'judge'.
ausdehnen 'expand' – BB lists *ausdehnen* in the non-agent movement model as well as in the agent movement model. In FN, *expand* is in a frame describing an item changing its physical size. In GN, *ausdehnen* is below spatial *erstrecken, spannen* 'spanning', causative change (of plans) *verschieben* 'postpone' and the change of state verbs *vergrößern* 'enlarge' (inchoative) and *verformen* 'deform' (both causative and inchoative). So FN and GN mainly refer to change of state, but not to motion.
einatmen 'breathe in' – In BB an agent moving in place. In GN, SIW not related to motion. In FN frame *breathing*, which uses *fluidic motion.*
einpacken 'pack' – In BB preparation of *transport* process. In GN, SIW, FN not related to motion.
fahren 'drive, ride' – In FN three classes, distinguishing riding a vehicle (*ride*), driving a vehicle (*drive*) and transportation (*drive*). The SALSA annotation found the driver/passenger distinction problematic – the only language-specific problem to occur so far in the annotation of German data with English frames, since German *fahren* does not differentiate between the focal participant being driver or passenger. However the same distinction is made in GN and BB, two resources developed on German data. In SIW simple *locomotion* verb.
fallen 'fall' – In BB either just *motion* or *erroneous motion.* In GN *motion with path* specified as vertical. FN has separate class for *motion by gravity.*
sitzen 'sit' – In FN *posture* describing stable body posture of agent. In SALSA, a frame was constructed: *being situated* describing the (geographic) position of an object. In GN *position* verb under *rest.* In BB *rest phase* in motion models. In SIW position verb *be in position.*
wimmeln 'swarm' – In FN *mass motion*; in GN similar class *group motion.* In BB active motion model *Aktivbewegung* in subclass *oszillieren im Kollektiv* 'oscillate in collective', which refers both to group motion (as in FN and GN) and also to the kind of movement.

Table 2: A detailed inspection of some verbs.

For the *manner of motion* domain of the four resources we have studied, we find a small set of central sense distinctions that appear in all or almost all resources, and there are idiosyncratic criteria that are used by few or only one resource. The agreement in the central criteria for meaning is even more surprising as the four resources differ in their overall structure (GN has a hierarchical structure, BB is scenario-centred, FN and SIW have both), in the extent of their MOM domains, and in their classification of individual verbs. Interestingly, the criteria in Table 1 are mostly independent of each other and describe different dimensions of meaning in the MOM domain. MOM verbs may instantiate one or more of these dimensions; for example *hurry* comprises both a *speed* and an *animate mover* aspect – and may be categorised according to either one of the criteria, or even according to both.

Our study also confirms that while each resource has its strengths, they also have weaknesses. In GN, it is striking that motion classes high in the hierarchy, like *movement* and *change of place*, tend to have "heavy" as well as "lightweight" children, i.e. on the one hand children that are themselves high-level concepts, on the other hand very specialised leaf concepts. BB make strongly idiosyncratic decisions, such as grouping some verbs from the cognition, communication and perception domains with MOM verbs, e.g. *anschreien* 'yell at', *angucken* 'look at', *achten auf* 'pay attention to'. All these verbs have some source-path-goal image to them and seem to have been grouped on the basis of that motion image. FN is still evolving and has large gaps in its coverage. Unsurprisingly, SIW suffers from the same coverage problem, however it was constructed as a gold standard for automatic semantic classification, not as a comprehensive resource.

Concluding, while classifications often disagree, this is not a question of right or wrong but rather results from them focusing on different meaning criteria. It therefore seems both promising and advisable to combine several lexical resources: Combining resources is *promising* because, judging from the MOM domain, they seem to agree in central categories, so their combination should strengthen central meaning aspects while weakening marginal ones. Combining resources is *advisable* because each individual resource has weaknesses that may lead to mis-generalisations.

Finally, combining classification knowledge can enhance the evaluation of automatically induced verb classes: A resulting cluster in a cluster analysis is judged 'wrong' as compared to a gold standard, if the gold standard does not capture the criteria underlying that specific cluster. For example, a plausible, automatically induced, cluster contains the verbs *ermorden* 'assassinate', *erschießen* 'shoot', *töten* 'kill', as well as *festnehmen*, *verhaften* (both 'arrest'), *befragen* 'interrogate' and *entlassen* 'release'; it therefore refers to the different stages of a process involving a person who kills someone, the killer's arrest, interrogation and release from prison. In SIW, whose classification is closely related to the FrameNet framework, this kind of cluster is judged 'wrong', although it corresponds to BB's definition of process classes. A combined set of verb classes could provide a more comprehensive gold standard for such cases.

References

Collin Baker, Charles Fillmore, and John Lowe. The Berkeley FrameNet Project. In *Proceedings of the 17th International Conference on Computational Linguistics and the 36th Annual Meeting of the Association for Computational Linguistics*, Montreal, Canada, 1998.

Thomas T. Ballmer and Waltraud Brennenstuhl. *Deutsche Verben*. Gunter Narr Verlag, Tübingen, 1986.

Sabine Brants, Stefanie Dipper, Silvia Hansen, Wolfgang Lezius, and George Smith. The TIGER Treebank. In *Proceedings of the Workshop on Treebanks and Linguistic Theories*, Sozopol, Bulgaria, 2002.

Michael Ellsworth, Katrin Erk, Paul Kingsbury, and Sebastian Padó. PropBank, SALSA, and FrameNet: How Design Determines Product. In *Proceedings of the LREC 2004 Workshop on Building Lexical Resources from Semantically Annotated Corpora*, Lisbon, Portugal, 2004.

Katrin Erk, Andrea Kowalski, and Manfred Pinkal. A Corpus Resource for Lexical Semantics. In *Proceedings of the 5th International Workshop on Computational Semantics*, Tilburg, The Netherlands, 2003.

Christiane Fellbaum, editor. *WordNet – An Electronic Lexical Database*. Language, Speech, and Communication. MIT Press, 1998.

Charles Fillmore. Frame Semantics. *Linguistics in the Morning Calm*, 1982.

Birgit Hamp and Helmut Feldweg. GermaNet – a Lexical-Semantic Net for German. In *Proceedings of the ACL Workshop on Automatic Information Extraction and Building Lexical Semantic Resources for NLP Applications*, Madrid, Spain, 1997.

Claudia Kunze. Extension and Use of GermaNet, a Lexical-Semantic Database. In *Proceedings of the 2nd International Conference on Language Resources and Evaluation*, pages 999–1002, Athens, Greece, 2000.

George A. Miller, Richard Beckwith, Christiane Fellbaum, Derek Gross, and Katherine J. Miller. Introduction to Wordnet: An On-line Lexical Database. *International Journal of Lexicography*, 3(4):235–244, 1990.

Sabine Schulte im Walde. *Experiments on the Automatic Induction of German Semantic Verb Classes*. PhD thesis, Institut für Maschinelle Sprachverarbeitung, Universität Stuttgart, 2003.