Chapter 9
Why Chocolate Eggs Can Taste Old but Not Oval: A Frame-Theoretic Analysis of Inferential Evidentials

Wiebke Petersen and Thomas Gamerschlag

Abstract So-called *phenomenon-based perception verbs* such as 'sound, taste (of)', and 'look (like)' allow for a use in inferential evidential constructions of the type 'The chocolate egg tastes old'. In this paper, we propose a frame-theoretic analysis of this use in which we pursue the question how well-formed inferential uses can be discriminated from awkward uses such as #'The chocolate egg tastes oval'. We argue that object knowledge plays a central role in this respect and that this knowledge is ideally captured in frame representations in which object properties are easily translated into attributes such as TASTE, SMELL, AGE, and FORM. We represent the more general knowledge of the range and domain of the attributes in a type signature. In principle, an inference is recognized as admissible if the values of one attribute can be inferred from the values of another attribute. In the analysis, this kind of inferability is modeled as an inference structure defined on the type signature. The definitions of type signatures and inference structures enable us to establish two constraints which are sufficient to discriminate the admissible and inadmissible uses of phenomenon-based perception verbs in simple subject-verb-adjective constructions.

Keywords Inferential evidential • Phenomenon-based perception verbs • Frame-theoretic analysis • Type signature

9.1 Introduction

As recently pointed out by Gisborne (2010) and Whitt (2009, 2010), perception verbs play an important role as a lexical means to express evidentiality. In languages like English and German especially, the evidential use of verbs of this

W. Petersen (✉) • T. Gamerschlag
Department of Linguistics and Information Science, Heinrich Heine University Düsseldorf, Universitätsstraße 1, Düsseldorf 40225, Germany
e-mail: petersen@phil.uni-duesseldorf.de; gamer@phil.uni-duesseldorf.de

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type compensates for the lack of the elaborate grammatical system of evidential markers which is attested for other languages in the typological literature (among others Chafe and Nichols 1986, Willett 1988, de Haan 1999, Aikhenvald 2004). For example, the perception verb 'taste (of)' can be used to express inferential evidentiality as in (1). Here, the inference that the chocolate egg is old is based on the way it tastes. More precisely, the proposition made up of the predicative complement and the subject referent is inferred from the sensory evidence which is explicated by the perception verb.

(1) The chocolate egg tastes old.

The evidential use of 'taste' in (1) can be differentiated from the nonevidential use of the verb in (2), which is called the "attributary use" by Gisborne (2010). In this use, the quality expressed by the secondary predicate is not inferred but rather perceived directly in the way indicated by the perception verb. With respect to the example in (2), this means that the fact that the chocolate egg is bitter is perceived directly through its taste.

(2) The chocolate egg tastes bitter.

The attributary use can be considered more basic since the predicative complement simply highlights a quality specific to the sense modality indicated by the verb. By contrast, the evidential use in (1) is characterized by some kind of mismatch between the predicative complement and the verb, since 'old' does not refer to a gustatory quality of the chocolate. As a consequence, awkward combinations such as the one in (3) cannot be ruled out as inferential evidentials by a mismatch between the sense modality referred to by the verb and the quality expressed by the predicative complement. Rather, (3) is excluded because the form of the chocolate egg cannot be inferred from its taste.

(3) # The chocolate egg tastes oval.

The knowledge of admissible and nonadmissible inferentials such as (2) and (3) is part of the speaker's object knowledge.[1] For instance, we know that chocolate has a taste and that there is some correlation between the taste of chocolate and its age. By contrast, we know that there is no such relation between the taste of a chocolate egg and its form. One might think of a situation in which a blindfolded person has to guess at the form of food put into his/her mouth, but then s/he would rather say that something *feels* oval.

[1]The admissibility and awkwardness of the examples (1)–(3) can neither be explained by pure linguistic nor by pure world knowledge. In our view, the strict separation between world and lexical knowledge has to be abandoned in order to account for evidential uses of perception verbs.

In Gamerschlag and Petersen (2012), we argue that this kind of object knowledge is best captured in frame representations understood as recursive attribute-value structures in the sense of Barsalou (1992). Properties such as taste, age, and form can be translated directly into the corresponding attributes TASTE, AGE, and FORM in the frame of an object such as a chocolate egg. Furthermore, we have argued that different object types such as different types of chocolate eggs can be represented in a type hierarchy whose elements differ with respect to the values of the attributes. We have proposed a general constraint which conceptually well-formed evidential constructions need to satisfy. It requires the attribute encoded by the perception verb to exhibit covariation with the attribute for which the predicative complement specifies a value. For instance, the attribute encoded by the verb 'taste' in the evidential construction 'The chocolate egg tastes old' is TASTE while the predicative complement 'old' refers to the value of the attribute AGE. The example is well-formed since the values of TASTE and AGE covary for different instances of chocolate eggs, i.e., the taste of an old chocolate egg is different from the taste of a new one. By contrast, the construction 'The chocolate egg tastes oval' is awkward because the attributes TASTE and FORM do not show covariation in the frame of a chocolate egg. Since chocolate eggs are conceptualized by their specific egg-form, they do not vary in their form. However, even the more general concept 'chocolate piece' does not exhibit covariation between the values of the attributes TASTE and FORM: an oval and a square piece of chocolate may have an identical taste.

Although our former approach in Gamerschlag and Petersen (2012) can be considered adequate to capture the cognitive process of experiential learning and deducing which underlies conceptually well-formed inferential evidentials of the type in focus, it is problematic with respect to untypical instances of objects. The approach depends on the key assumption that the type hierarchy can be learned from the experience of individual instances and thus that for every instance there exists an adequate type in the type hierarchy. Hence, in a realistic type hierarchy of chocolate eggs there will also be untypical instances such as a new chocolate egg with the taste of an old one and vice versa. As a consequence, covariation of TASTE and AGE only holds if one disregards the untypical instances and narrows the view to the typical instances. However, it is a nontrivial problem to capture the notion of typical and untypical instances in a formal approach. One option would be to introduce weighted type hierarchies in which the types are weighted by their typicality. But this would raise new problems like how to compute the weights and how to interpret them. In the present paper we will propose a different approach, in which admissible inferences are directly built into the type hierarchy. Thus, we extend the type hierarchies by explicit knowledge about admissible inferences. From a cognitive point of view, this knowledge can be induced from experience. Before coming to the details of our new analysis in Sect. 9.4, we will first introduce the frame model in the next section and then present some more data on inferential evidentials in Sect. 9.3.

9.2 Frame Model

In our frame model we follow Barsalou's claim that frames understood as recursive attribute-value structures "provide the fundamental representation of knowledge in human cognition" (Barsalou 1992, p. 21). A *concept frame* consists of a set of attribute-value pairs with each attribute specifying a property by which the described concept is characterized. For the attributes, we demand that they assign unique values to concepts and are thus functional relations. Frames are recursive in the sense that the value of an attribute is not necessarily atomic, but may be a frame itself. Formally, frames can be represented as connected directed graphs with labeled nodes (vertices) and arcs (edges): the arcs are labeled with attributes and the nodes with types. The latter restrict both the domain and the range of the attributes which are connected to the labeled nodes. Furthermore, one of the nodes in a frame is identified as the *central node* of the frame. The central node is the node which determines what the frame is about.

A graph drawing of an example frame is given in Fig. 9.1 (adapted from an example in Petersen et al. 2008). The central node, which is marked by a double border, represents the concept of a car with a 4-cylinder diesel engine.[2] As the central node is typed with *car*, this concept is modeled by a frame of type *car*. Furthermore, three attributes apply to the central node, namely COLOR, ENGINE and MILEAGE. These attributes specify the dimensions according to which the concept is further characterized. Values assigned to attributes are frames themselves and determine the concrete realization of the property given by the attribute. The values may differ with respect to specificity and structural complexity. For instance, in Fig. 9.1 the value of the attribute ENGINE is a complex frame with three additional attributes, whereas atomic values, which are not further specified by additional attributes, are assigned to the two attributes COLOR and MILEAGE. While the value

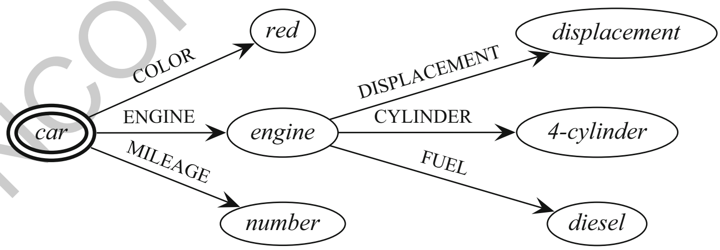


Fig. 9.1 An exemplary *car* frame in graph representation

[2]Note that in our framework the central node does not necessarily need to be the root of the graph (as it is in the example). Hence, it needs to be explicitly marked. For instance, in frames of functional concepts like 'mother of' or 'taste of' the central node is usually not a root node of the frame graph. For a discussion of frames with central nodes which are not roots see Petersen and Osswald (this volume).

of COLOR is rather specific, namely *red*, the value *number* of MILEAGE is not, since it comprises the whole range of the function MILEAGE. It is the recursive structure of frames and the possibility of choosing more or less specific types as labels for their nodes that makes them flexible enough to represent concepts of any desired grade of detail.

Note that our frames are closely related to feature structures as defined by Carpenter (1992). However, they differ from this kind of structure in that the central node need not be the root node of the graph (cf. Footnote 2). Frames, therefore, can be regarded as generalized feature structures. Hereby our definition gains the necessary flexibility to model the relationality of concepts like 'spouse' or 'sister' that bear an inherent relation (cf. Petersen and Osswald this volume). However, for the present paper, relational concepts and their properties are not relevant.

Formally, a concept frame is defined as follows (cf. Petersen 2007, p. 5):

Definition 9.1. Given a set TYPE of types and a finite set ATTR of attributes. A *frame* is a tuple $F = (Q, \bar{q}, \delta, \theta)$
where:

- Q is a finite set of nodes,
- $\bar{q} \in Q$ is the central node,
- $\delta : \text{ATTR} \times Q \to Q$ is the partial *transition function*,
- $\theta : Q \to \text{TYPE}$ is the total *node typing function*;

such that the underlying graph (Q, E) with edge set $E = \{\{q_1, q_2\} \mid \exists a \in \text{ATTR} : \delta(a, q_1) = q_2\}$ is connected.

The underlying directed graph of a frame is the graph $(Q, \mathbf{E})$ with edge set $\mathbf{E} = \{(q_1, q_2) \mid \exists a \in \text{ATTR} : \delta(a, q_1) = q_2\}$.

If $\theta(\bar{q}) = t$, we say that the frame is of type t. If $\theta(q) = t$ is true for a frame, we call this node a *t-node*. And if $\delta(a, q_1) = q_2$ is true for a frame, we say that the frame has an *a-arc* from q_1 to q_2.

So far, the frame representation as described above does not impose formal restrictions on either the type of the node an attribute may be attached to or on the type of its value. This can lead to undesirable frames in which attributes connect nodes with inappropriate type labels not fitting the domain and the range of the attribute (e.g., an attribute FUEL connecting a node of type *book* to a node of type *number*). In order to restrict the set of admissible frames, we assume a *type signature* which conveys two kinds of information: first, it defines the set of types and imposes an order on it. Second, it states appropriateness conditions for the types which specify the domain and range of attributes (cf. Carpenter 1992).

An example type signature is given in Fig. 9.2 (taken from Petersen et al. 2008). Here, subtypes, i.e., more specific types, are written below their supertypes (e.g., *apple* is a subtype of *fruit*, which is itself a subtype of *physical object*). The hierarchy of types is enriched with appropriateness conditions (ACs). For instance, 'SHAPE:*shape*' is an AC for the type *physical object*. ACs fulfill two tasks: first, they restrict the attribute domains by declaring the set of adequate attributes for frames of

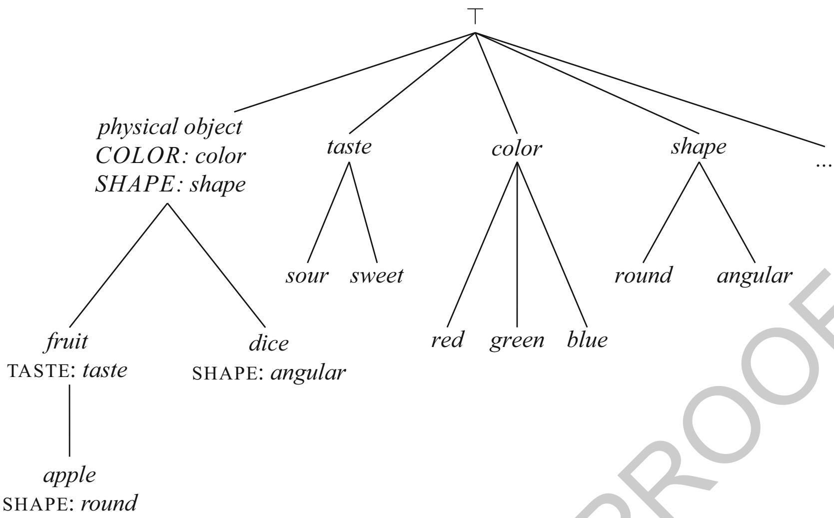


Fig. 9.2 Example type signature

a certain type (e.g., the attributes SHAPE and COLOR but not TASTE may be attached to nodes of the type *physical object*). Second, they restrict the attribute ranges by requiring all values of an attribute to be at least of a certain type (e.g., the values of TASTE may be of type *taste*, *sour* or *sweet*, but not of type *red*). Subtypes inherit all ACs of their supertypes and may tighten them up. For example, in the type signature in Fig. 9.2 the type *fruit* inherits the ACs 'COLOR:*color*' and 'SHAPE:*shape*' from *physical object*, adds the AC 'TASTE:*taste*' and passes all three ACs on to its subtype *apple*. The latter tightens the inherited AC 'SHAPE:*shape*' up to 'SHAPE:*round*'.

Both the example type signature in Fig. 9.2 as well as the example frame in Fig. 9.1 exhibit some kind of redundancy: strings which occur as attribute labels occur as type labels as well (e.g., the AC 'TASTE:*taste*' at the type *fruit* in Fig. 9.2 or the labels 'engine' and 'displacement' in Fig. 9.1). Such redundancies are typical in typed attribute-value representations like feature structures and frames. In contrast to grammar formalisms like *Head-driven Phrase Structure Grammar*, HPSG, (Pollard and Sag 1987, 1994) which use frames as a technical device, we assume that frames are cognitive structures (Löbner this volume). In order to capture the ontological status of attributes we follow the arguments given by Guarino (1992), who points out that attribute concepts like COLOR which bear an inherent relationality always carry two interpretations: they can be interpreted *denotationally* as the set of all colors and *relationally* as the function assigning to each object its color. Thus in terms of frames, there is a systematic relationship between the attribute COLOR and the type *color*; the former corresponds to the relational and the latter to the denotational interpretation of 'color'. The attribute COLOR denotes the color-assigning function and the type *color* the value range of this function.

In our type system, there exists for each attribute a unique type corresponding to the value range of the attribute. As the correspondence between these types and the attributes is one-to-one, we can identify the attributes by their range types and postulate that the attribute set is a subset of the type set (for details, see Petersen 2007). If we refer to such a label in its role of an attribute resp. function, we will simply call it *attribute* and use small capitals for its label and when we refer to it in its role of a type we will call it an *attribute type*. In our example type signature in Fig. 9.2 we can find three attribute types, namely *shape*, *color* and *taste*. Note that the subtypes of an attribute type need not be attribute types themselves. Furthermore, we assume that for each attribute ATTR the type signature contains an introductory type with the AC 'ATTR:*attr*', which states the relation between the label 'attr' used as an attribute and as a type, namely that the type denoting the value range of ATTR is *attr*.[3]

Formally, we define a type signature based on the definition of a type hierarchy (Petersen 2007, p. 13f.):

Definition 9.2. A *type hierarchy* (TYPE, $\sqsupseteq$) is a finite partially ordered set which forms a join semilattice, i.e., for any two types there exists a least upper bound. A type t_1 is a *subtype* of a type t_2 if $t_1 \sqsupseteq t_2$.

Given a type hierarchy (TYPE, $\sqsupseteq$) and a set of attributes ATTR $\subseteq$ TYPE, an *appropriateness specification* on (TYPE, $\sqsupseteq$) is a partial function Approp : ATTR $\times$ TYPE $\rightarrow$ TYPE such that for each $a \in$ ATTR the following holds:

(i) *Attribute introduction:* There is a type Intro$(a) \in$ TYPE with:

- Approp$(a, \text{Intro}(a)) = a$ and
- For every $t \in$ TYPE : if Approp(a,t) is defined, then Intro$(a) \sqsubseteq t$.

(ii) *Specification closure:* If Approp(a,s) is defined and $s \sqsubseteq t$, then Approp(a,t) is defined and Approp$(a,s) \sqsubseteq$ Approp(a,t).

(iii) *Attribute consistency:* If Approp$(a,s) = t$, then $a \sqsubseteq t$.

A *type signature* is a tuple (TYPE, $\sqsupseteq$, ATTR, Approp), where (TYPE, $\sqsupseteq$) is a type hierarchy, ATTR $\subseteq$ TYPE is a set of attributes, and Approp : ATTR $\times$ TYPE $\rightarrow$ TYPE is an appropriateness specification.

The first two conditions on an appropriateness specification are standard in the theory of type signatures (Carpenter 1992), except that we tighten up the attribute introduction condition. We claim that the introductory type of an attribute 'a' carries the appropriateness condition 'a:a'. By the attribute-consistency condition, we ensure that Guarino's consistency postulate holds (Guarino 1992).

Type signatures may be considered an ontology covering the background or world knowledge. According to Definition 9.3 below, a frame is considered to be

[3] Note that in the AC 'ATTR:*attr*' the expressions ATTR and *attr* do not refer to two distinct objects carrying identical labels, rather the two expressions are identical and denote the same object (attr $\in$ ATTR $\subseteq$ TYPE). Only to improve readability we use typography as a marker to distinguish between the attribute role and the type role of an attribute.

well-typed with respect to a type signature if all attributes of the frame are licensed by the type signature and if additionally the attribute values are consistent with the appropriateness specification.

Definition 9.3. Given a type signature (TYPE, $\sqsupseteq$, ATTR, Approp), a frame $F = (Q, \bar{q}, \delta, \theta)$ is *well-typed* with respect to the type signature, if and only if for each $q \in Q$ the following holds: if $\delta(a, q)$ is defined, then Approp$(a, \theta(q))$ is also defined and Approp$(a, \theta(q)) \sqsubseteq \theta(\delta(a, q))$.

The definition of the appropriateness specification guarantees that every arc in a well-typed frame points to a node that is typed by a subtype of the type corresponding to the attribute labeling the arc. In the remaining, we claim that all frames are well-typed.

For our frame-based analysis of inferential uses of PBVs in expressions like 'The chocolate egg tastes old' we need to solve the problem of deducing the implicit attribute AGE from its value *old* specified by the adjective 'old'. To this end, we introduce the notion of a *minimal upper attribute* of a type (cf. Petersen 2007). Since Definition 9.2 claims that the attribute set is a subset of the set of types, technically, types may be subtypes of attributes:

Definition 9.4. An attribute a is called a *minimal upper attribute (mua)* of a type t, if it is a supertype of t ($a \sqsubseteq t$) and if there is no other attribute a' with $a \sqsubseteq a' \sqsubseteq t$. A minimal upper attribute of a type t is denoted by mua(t).

The example type signature in Fig. 9.2 shows several instances of minimal upper attributes. For example, TASTE equals mua(*sour*) and COLOR equals mua(*red*). Note that, although no such instance occurs in the example type signature, a type may have more than one minimal upper attribute (cf. Petersen et al. 2008).

9.3 Inferential Evidentials and Phenomenon-Based Perception Verbs

Before presenting our analysis, we will first have a closer look at the type of perception verbs that show up in inferential evidentials. Characteristically, these verbs belong to a subclass of perception verbs which realize the stimulus as subject, whereas the experiencer usually remains unrealized. Since perception verbs of this type demote the experiencer and focus on the perceived phenomenon, they are called *phenomenon-based perception verbs* in the typological study by Viberg (1984). Alternative terms of reference for this subclass are *stimulus subject perception verbs* (Levin 1993), *object-oriented perception verbs* (Whitt 2009, 2010), and SOUND-*class verbs* (Gisborne 2010). In the following, we will use Viberg's term *phenomenon-based perception verbs* (henceforth: PBVs). As illustrated in (4) there is a PBV for each of the five sense modalities in English which isolates a specific sensory attribute of the subject referent 'chocolate egg' and allows for the specification of a value by means of an adjective. For instance, 'soft' in (4c) specifies a value of the attribute TOUCH while 'bitter' in (4d) denotes the value of the attribute TASTE. The attributes encoded by the PBVs in (4) can be translated directly into attributes in frame representations, as will be shown in the next chapter.

(4) The chocolate egg ...

a. looks oblong. (SIGHT)
b. sounds hollow. (SOUND)
c. feels soft. (TOUCH)
d. tastes bitter. (TASTE)
e. smells sweet. (SMELL)

The examples given in (4) are instances of the attributary use of PBVs. In addition, all of the PBVs can show up in inferential evidentials. Since they select a predicative argument, they involve an embedded proposition which consists of the subject referent and the embedded predicate. This property makes verbs of this subtype particularly suitable for the use in inferential evidentials and sets them apart from other types of perception verbs such as 'hear' and 'listen (to)' which realize the experiencer as subject.

The sentences in (5) illustrate the evidential use of PBVs, in which a mismatch between the attribute encoded by the verb and the value explicated by the adjective leads to the inference of a suitable attribute. In (5a) 'happy' cannot be interpreted as the value of SIGHT. Instead, it is a specific state of a person's MOOD which is inferred from the way s/he looks. Likewise, 'solid' in (5b) does not specify a SOUND-quality but rather the SOLIDITY of the wall. In (5c) 'expensive' characterizes the PRICE of the seats, which is deduced from their TOUCH. The adjective 'French' in (5d) refers to the ORIGIN of the wine, something one can guess from its TASTE. Finally, in (5e) the smell emitted by the carpet serves as an indicator to judge its AGE.

(5) a. Peter looks happy. (SIGHT → MOOD: *happy*)
b. The wall sounds solid. (SOUND → SOLIDITY: *solid*)
c. The car seats feel expensive. (TOUCH → PRICE: *expensive*)
d. This wine tastes French. (TASTE → ORIGIN: *French*)
e. The carpet smells new. (SMELL → AGE: *new*)

The inferences in the above examples are implicatures since they can be negated without yielding a contradiction. As can be seen in (6), the sentence in (5d) can be combined with the negation of the inference.

(6) The wine tastes French, but actually it's not French, but Italian.

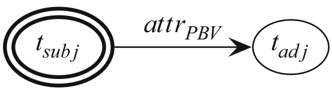
Before we come to our analysis, it is important to note that languages differ significantly with respect to the repertory of PBVs and the flexibility of inferential evidentials based on these verbs. As shown in Gamerschlag and Petersen (2012), French only has the PBVs *sonner* 'sound' and *sentir* 'smell (of)', which are highly limited with respect to the predicative complements they can take. Moreover, the inferential use of these verbs is virtually absent. By contrast, German has a repertory of PBVs which is similar to English and is at least as flexible in the inferential use. The following analysis is designed to capture the conceptual base of inferential evidentials in languages like English and German, whereas we will not address language-specific restrictions.

9.4 A Frame-Based Analysis of the Attributary and Evidential Use of PBVs

The aim of this section is to give a frame-based analysis of the different uses of PBVs that is rigid enough to model the conditions which determine the acceptability of these uses. We will examine the attributary use and the inferential use separately and formulate constraints that rule out awkward sentences such as 'The chocolate egg smells oval' or 'The sound tastes sweet'. As a premise of this analysis, we assume a fixed type signature (TYPE, $\sqsupseteq$, ATTR, Approp).

9.4.1 Attributary Use: Judging Well-Typed Instances by Object Knowledge (Direct Perception)

If a PBV is used noninferentially, as in 'The chocolate egg tastes bitter', its predicative complement expresses a quality of the subject referent that is perceived directly via the sense modality specified by the verb. From a frame-theoretic perspective, PBVs specify attributes. Hence, a noninferential use of a PBV is given if, first, the attribute specified by the verb is admissible in the frame of the subject referent and, second, if the adjective corresponds to a type that fits into the range of the attribute. To be more precise, we claim that the lexicon provides a lexical frame F_{subj} of type t_{subj} for the subject referent, a type t_{adj} for the adjective and an attribute $attr_{pbv}$ for the PBV. Moreover, the frame



consisting of these components is required to be well-typed:

(C1) WELL-TYPEDNESS CONSTRAINT: The frame $((q_1, q_2), q_1, \delta, \theta)$ with

- $\theta(q_1) = t_{subj}$,
- $\theta(q_2) = t_{adj}$,
- $\delta(attr_{\text{PBV}}, q_1) = q_2$

is well-typed with respect to the type signature (TYPE, $\sqsupseteq$, ATTR, Approp).

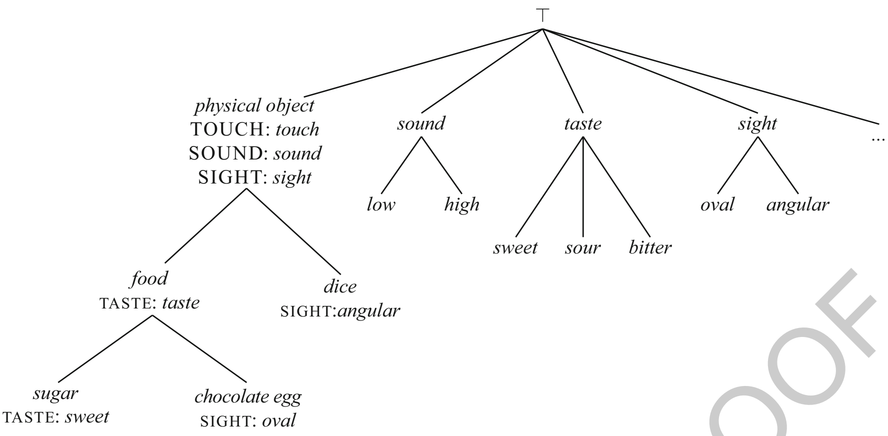


Fig. 9.3 Section of the type signature covering the background world knowledge

Fig. 9.4 Frame of a bitter-tasting chocolate egg

This constraint can be seen as a specific variant of a more general principle which captures the selectional restrictions of a verb (or of heads in general) by means of a constraint that requires the arguments to mirror (some of) the attributes encoded by the verb. Even more generally, a universal well-typedness constraint demands all concept frames to be well-typed. Constraint C1 is merely a specific instance of this universal constraint.

Three simple examples shall help to illustrate the constraint. Figure 9.3 shows a simplified section of the underlying type signature. It covers some world knowledge, like the fact that food usually has a taste, while for example sounds do not. Note that the actual type signature covering the full world knowledge of a speaker would be much more complex. An example that does not violate constraint C1 is (2), repeated as (7) below:

(7) The chocolate egg tastes bitter.

Since a chocolate egg is a kind of food and TASTE is an appropriate attribute for objects of type *food* and *bitter* is an admissible value for the attribute TASTE, it follows that the frame for example (7) in Fig. 9.4 is well-typed and that (7) does not violate constraint C1.

There are two possible ways to violate constraint C1: first, the attribute expressed by the verb may not be appropriate for the frame of the subject referent. Second, the adjective may not specify a possible value or a possible value set of the attribute expressed by the verb. An example of the first type of violation is:

(8) #The sound tastes bitter.

Here, TASTE is not an appropriate attribute in a *sound* frame since in the type signature in Fig. 9.3 *sound* is not specified as a subtype of the type *physical object*, which is the introductory type of TASTE and thus the least specific type for which TASTE is an appropriate attribute. Hence, the frame for (8) in Fig. 9.5 is not well-typed and (8) is ruled out by constraint C1.[4]

Fig. 9.5 Non-well-typed frame of a bitter-tasting sound violating constraint C1

The example in (3), repeated as (9), illustrates the second type of constraint violation:

(9) # The chocolate egg tastes oval.

The attribute TASTE is appropriate for a frame of type *chocolate egg*, since *chocolate egg* is a subtype of the type *physical object*. But, according to the type signature in Fig. 9.3, the values of TASTE must be of type *taste* or of one of the subtypes of *taste*. Since *oval* is not a subtype of *taste*, the frame for (9) in Fig. 9.6 is not well-typed and constraint C1 is violated by (9).

However, not all PBV-based constructions violating constraint C1 are unacceptable. In the next subsection, we will give a frame-based analysis of constructions with inferential uses of PBVs that exhibit the same type of mismatch as the example in (9), but are acceptable.

9.4.2 *Inferential Use: Deducing Attributes and Types Through Knowledge of Admissible Inferences*

A mismatch between the attribute encoded by the verb and the value type encoded by the adjective as in (9) does not necessarily result in an awkward construction. Instances of inferential uses like the introductory example repeated in (10) are acceptable although, in principle, they exhibit the same kind of mismatch.

(10) The chocolate egg tastes old.

[4]Note that it is not principally impossible to declare properties of abstract entities like sounds. Clearly, expressions like ‘a loud sound’, in which the adjective specifies the value range of the attribute VOLUME encoded in ‘sound’, are unproblematic. Even synesthetic metaphors like ‘a loud color’ are acceptable. For a frame-based analysis of these expressions see the discussion in Petersen et al. (2008).

Fig. 9.6 Non-well-typed frame of an oval-tasting chocolate egg violating constraint C1

Although *old* is not a subtype of *taste*, a chocolate egg may taste old. This is because old chocolate usually has a special taste which results from chemical processes which take place over time. However, language users do not need to have any chemical knowledge to accept or produce (10), it is sufficient if they have experienced enough chocolate-tasting events with old and new (resp. fresh) chocolate in order to learn that the age of chocolate influences its taste and that thus usually the approximate age of a piece of chocolate is deducible from its taste. We will refer to this type of knowledge as *knowledge of admissible inferences*.

In our analysis, we will capture the knowledge of admissible inferences by defining an inference structure on the type signature. Such an inference structure states for each type which attributes can be inferred from others. It can thus be seen as a relation which assigns pairs of attributes to types. Two conditions must hold for an attribute pair which is related to a type by an inference structure: first, both the inferred attribute and the one from which it is inferred must be appropriate for frames of the type in focus. Second, we claim that subtypes inherit the inference properties of their supertypes. The first condition excludes undesirable inferences as for example TASTE $\rightarrow$ AGE for objects of type *movie* (a movie has an age, but no taste) or TASTE $\rightarrow$ COCOA CONTENT for objects of type *apple* (an apple has a taste, but no cocoa content). The second condition ensures that the knowledge of admissible inferences is not lost when specifying a concept in greater detail: in the type signature all information is monotonically transferred downwards from types to their subtypes. Hence, if an inference relation TASTE $\rightarrow$ AGE is true for chocolate in general, it is true for chocolate eggs as well. Formally, inference structures are defined as follows.

Definition 9.5 (preliminary version). INF $\subseteq$ TYPE $\times$ ATTR $\times$ ATTR is an *inference structure* on a type signature (TYPE, $\sqsupseteq$, ATTR, Approp) if the following holds:

(i) Compatibility: if $(t, a_1, a_2) \in$ INF then both Approp(a_1, t) and Approp(a_2, t) are defined.
(ii) Specificity closure: if $(t_1, a_1, a_2) \in$ INF and $t_1 \sqsubseteq t_2$ then $(t_2, a_1, a_2) \in$ INF.

Elements of INF are called *inference relations*. If $(t, a_1, a_2) \in$ INF we say that attribute a_2 is inferable from attribute a_1 in frames of type t.

So far, the definition of inference structures only captures the knowledge of which implicit attribute is, in principle, inferable from an explicitly mentioned one. For example, the information (*chocolate egg*, TASTE, AGE) $\in$ INF expresses that for

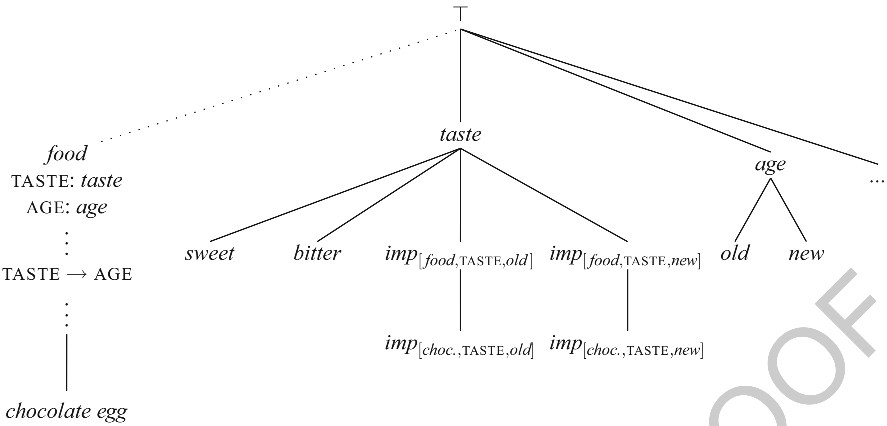


Fig. 9.7 Example type signature with inference structure and implicit value types

chocolate eggs the attribute AGE, which is implicit in expression (10), is inferable from the attribute TASTE, which is explicitly expressed by the verb in (10). However, the common knowledge of admissible inferences is more complex and quite fine-grained. It involves some knowledge of the implicit value of the attribute expressed by the PBV: the taste of an old-tasting chocolate egg is totally different from the taste of old-tasting whisky or old-tasting cheese. Hence, the type of the subject referent heavily influences the implicit value of the attribute expressed by the PBV. Furthermore, the implicit value also depends on the PBV used: for instance, old-tasting and old-looking are two different properties of an object. Finally, the implicit value depends on the adjective used: e.g., old-tasting and fresh or new-tasting is not the same. In consequence, the *implicit value type* of the attribute expressed by the PBV depends on three pieces of information: the type of the subject referent, the attribute expressed by the PBV and the type specified by the adjective. The following extension of Definition 9.5 captures the knowledge of implicit value types:

Definition 9.5 (continued). If INF $\subseteq$ TYPE $\times$ ATTR $\times$ ATTR is an inference structure on a type signature (TYPE, $\sqsupseteq$, ATTR, Approp) then the following holds:

(iii) Existence of implicit value type: if $(t, a_1, a_2) \in$ INF then there exists for each Approp$(a_2, t) \sqsubset t_i$ an implicit value type $imp_{[t,a_1,t_i]} \in$ TYPE with Approp$(a_1, t) \sqsubseteq imp_{[t,a_2,t_i]}$.

Figure 9.7 shows a section of an example type signature with inference structure and implicit value types. Note that due to space limitations, most types and ACs stated in the type signature in Fig. 9.7 are left out. However, in what follows we will assume that our type signature is complete and includes all the inference relations and ACs mentioned so far. In Fig. 9.7 the inference relation (*food*, TASTE, AGE) $\in$

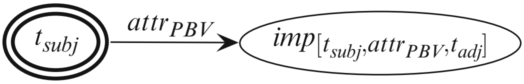
INF is specified as TASTE → AGE for the type *food*.[5] The inference relation (*chocolate egg*, TASTE, AGE) ∈ INF is inherited from type *food* and thus not explicitly stated in the type signature. Due to the third condition of Definition 9.5, the fact that (*chocolate egg*, TASTE, AGE) ∈ INF and that *taste* ⊏ *old* implies the existence of the implicit value type $imp_{[chocolate\ egg, \text{TASTE}, old]}$. Altogether, the single inference relation (*food*, TASTE, AGE) ∈ INF implies the existence of four implicit value types: $imp_{[food, \text{TASTE}, old]}$, $imp_{[food, \text{TASTE}, new]}$, $imp_{[chocolate\ egg, \text{TASTE}, old]}$, and $imp_{[chocolate\ egg, \text{TASTE}, new]}$.

Furthermore, since the unification of two frames fails whenever the types are not unifiable, we have to assume additional types, for the conjunction of implicit value types with other types (e.g., a chocolate egg can at the same time taste old and bitter). It turns out that inference relations may increase the number of types in realistic type signatures dramatically and type signatures with inference structures can become quite complex. The question arises whether all types are needed and whether the assumption of such an extensive type signature is cognitively realistic. However, from a cognitive perspective, the huge amount of additional types is not problematic, as these types result from a productive process. Thus they do not need to be learned or memorized, they can be produced whenever necessary from the inference relations.

The problem as to whether all productively generated types are needed or whether they lead to overgeneralization needs more attention. First, we would like to point out that although expressions like 'The chocolate tastes semi-aged' sound awkward to the average chocolate consumer, this is not necessarily the case for chocolate experts. Additionally, for other types of food like 'cheese' it is common to assign them the property 'tastes semi-aged'. Furthermore, the argument that our definition of inference structures produces for non-chocolate experts the superfluous type $imp_{[chocolate, \text{TASTE}, semi\text{-}aged]}$ would only hold, if for objects of type *chocolate* the value type *semi-aged* would lie in the range of the attribute AGE (cf. Definition 9.5, condition (iii)). Thus, the expression 'The chocolate tastes semi-aged' can only be accepted by somebody who also accepts the expression 'The chocolate is semi-aged'. Second, even if some superfluous types are likely to be produced, one could modify our analysis by assuming weighted types and a continuous adaption of the type signature in the process of language learning. Many awkward expressions produced by young children can be explained by overgeneralizations, resulting from a not yet finally fine-tuned type signature. To sum up, our assumption is that the types are first productively generated and then in a later stage speakers learn by experience which types give raise to less used expressions and consequently weaken their weights or remove them.

[5] It is not clear whether (*food*, TASTE, AGE) is a realistic inference relation as the value range of TASTE for objects of type *food* is so diverse that there is probably no general correspondence between the age of food and its taste. However, some of our informants accepted the sentence 'The food tastes old' and in order to exemplify the inheritance of inference relations we included this relation into our example type signature.

Given a type signature with an inference structure, an inferential construction such as ‘The chocolate egg tastes old’ is admissible if the frame



built from the type of the subject referent, the attribute specified by the PBV and the implicit value type, is well-typed with respect to the type signature. These conditions are formalized as follows.

(C2) Inference Constraint: There exists a minimal upper attribute $\text{mua}(t_{adj})$ of t_{adj} such that $(t_{subj}, attr_{\text{PBV}}, \text{mua}(t_{adj})) \in \text{INF}$ and the inferred frame $(\{q_1, q_2\}, q_1, \delta, \theta)$ with

- $\theta(q_1) = t_{subj}$
- $\theta(q_2) = imp_{[t_{subj}, attr_{\text{PBV}}, t_{adj}]}$
- $\delta(attr_{\text{PBV}}, q_1) = q_2$

is well-typed with respect to the type signature (TYPE, $\sqsupseteq$, ATTR, Approp).

The frame inferred from ‘The chocolate egg tastes old’ is depicted in Fig. 9.8a. Since it is well-typed with respect to the type signature with the inference structure in Fig. 9.7, the example ‘The chocolate egg tastes old’ is admissible. Instead of using the technical type labels of implicit value types from Definition 9.5, one could alternatively use more descriptive type labels like *old chocolate taste* in Fig. 9.8b.

Example (9) which violates constraint C2 is repeated in (11):

(11) # The chocolate egg tastes oval.

In (11), the minimal upper attribute of type *oval* is SIGHT. Although SIGHT is an appropriate attribute for a frame of type *chocolate egg* and *oval* an appropriate value for SIGHT, (11) violates constraint C2 because TASTE → SIGHT is not an inference relation of type *chocolate egg* ((*chocolate egg*, TASTE, SIGHT) $\notin$ INF). That is, for chocolate eggs it is usually not possible to detect their optical appearance from their taste. By consequence, (11) is ruled out as an inferential evidential.

The fact that the inferences in the inferential uses of PBVs are implicatures, which can be negated, is compatible with the frame analysis. Consider the example in (12):

(12) The chocolate egg tastes old, but actually it is not old, but pretty new.

Logically, (12) states a conjunction of the propositions ‘The chocolate egg tastes old’ and ‘The chocolate egg is not old’. The conjunction is admissible although the adjective ‘old’ and *its negation* cannot hold of an object at the same time. The reason for this is that in (12) ‘old’ does not determine the value of the attribute AGE, but of the attribute TASTE. Hence, the value of AGE can be specified by the

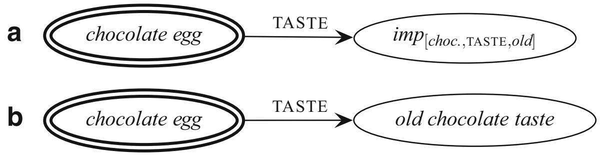


Fig. 9.8 Two variants of a frame of an old-tasting chocolate egg (above with technical type label, below with informal type label)

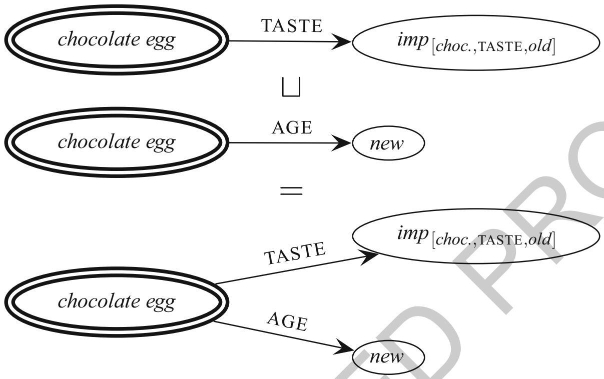


Fig. 9.9 Frame of an old-tasting chocolate egg which is not old but new

Fig. 9.10 Contradictory frames for old and new chocolate eggs

adjective 'new'. In terms of frames, both conjuncts in (12) can be translated into a frame, one for the old-tasting chocolate egg and one for the new chocolate egg. Figure 9.9 demonstrates that these two frames can be unified, resulting in a frame of an old-tasting chocolate egg that is not old but new.

An example of a nonadmissible conjunction is given in (13):

(13) # The chocolate egg is old, but it is new.

Conjunctions lead to contradictions if the frames of the conjuncts cannot be unified. For example, (13) is not admissible, since the two frames in Fig. 9.10 cannot be unified. The unification fails because both frames specify a value for the attribute AGE and both values are incompatible with each other with respect to the type signature and therefore cannot be unified. This follows from Definition 9.1, which states that attributes are partial functions and thus cannot simultaneously assign two distinct values to the same node.

9.5 Results

We have shown that the analysis of both the attributary use and the inferential use of phenomenon-based perception verbs requires explicit reference to object dimensions.[6] Consequently, a frame-theoretic approach which captures object dimensions as frame attributes is ideally suited for the analysis of both uses. For both uses, we have formulated a separate constraint that has to hold. By relating both constraints to each other, the following hypothesis on PBV uses sums up the results of the preceding sections:

Hypothesis on PBV uses: An expression:

(E) subject ∘ PBV ∘ adjective

is admissible if and only if (E) satisfies one of the constraints C1 and C2:

– If (E) satisfies C1 then (E) is an instance of an attributary use of a PBV.
– If (E) satisfies C2 then (E) is an instance of an inferential use of a PBV.

Both constraints C1 and C2 are based on well-typedness conditions of frames that are specific to PBV constructions. Thus, both constraints can be seen as special instances of a universal well-typedness constraint that claims that constructions are admissible if and only if they result in well-typed frames.

Moreover, we have shown that our approach can model the fact that the knowledge of admissible inferences exhibits varying degrees of abstraction. For example, the generalization that there is a relation between the taste and the age of food is captured by the inference relation $(\textit{food}, \text{TASTE}, \text{AGE}) \in \text{INF}$. The applicability of this generalization to more specific instances of food results from the principle that subtypes inherit all the properties of their supertypes. Furthermore, specific value co-occurrences of the attributes in an inference relation can be built directly into the type signature as implicit value types.

In our frame-theoretic analysis of inferential evidentials, we have focused on the identification of admissible PBV-uses and demonstrated that it is well-suited to account for the fact that the inferences are implicatures which can be negated. However, we have not discussed the process of inferencing as a result of which admissible inferences are established. We consider the integration of this process into the frame account as a future task which has to be tackled in order to arrive at a full-fledged frame model of inferencing. On the formal side, this also involves a truth-conditional interpretation of frames.

[6]From a cognitive perspective, abstract object properties such as taste and age can be conceived as object ‘dimensions’. A dimension can be defined as a set of mutually exclusive properties of which an individual has exactly one at each point of time (cf. Löbner 1979). Thus, stative verbs encoding specific object dimensions can also be referred to as ‘stative dimensional verbs’ (cf. Gamerschlag et al. 2013 for a frame analysis of posture verbs such as ‘stand’ and ‘sit’, which constitute another type of dimensional verbs.

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