

ABSTRACTION OF CONVENTIONAL DEFINITIONS: ANNOTATED DEMONSTRATIONS

In this section, we present a series of demonstrations of our system abstracting definitions from the combination of its prior knowledge and the new portions of network built to represent its understanding of story fragments that contain new words.

7.1. THE “BRACHET” DEMONSTRATION

The examples in this chapter are taken from Malory's *Le morte Darthur* [Malory 1972]. In these examples, Lumiansky's translation of Malory appears in boldface. A simpler English translation, such as could be parsed by the grammar we intend to use in future versions of this work, appears in italics (in place of the SNePSUL version the system was actually given). Comments glossing the system output are prefixed by a semi-colon. Much of the information from the story was input using the SNePSUL command "add", which causes forward-chaining inference (so that the system can notice logical consequences of the input). Many of these inferences (especially those found by *reduction*: eliminating an arc and the node at its head from a proposition) are irrelevant to the story, and so have been deleted for clarity. Unedited transcripts of these runs appear in the appendix.⁷

At the beginning of this run, the KB contained the following facts and rules:

If x is a mammal, then it bears young. If x bears young, then it is a mammal. Mammals are animals. Quadrupeds are vertebrates. Vertebrates are animals. Harts are deer. Halls are buildings. Hounds are dogs. Dogs are mammals. Dogs are quadrupeds. Dogs are carnivores. Dogs are predators. Dogs are animals. Rex is a dog. Rex belongs to a person. Cats are mammals. Cats are animals. Cats are quadrupeds. Cats are predators. Presumably, cats purr. Presumably, cats hunt. Frisky is a cat. Frisky sleeps in an armchair. Predators are carnivores. Presumably, carnivores eat meat. Presumably, predators hunt. Pyewacket is a cat. Evelyn owns Pyewacket. Evelyn is a person. Pyewacket bears kittens. Deer are mammals. Deer are quadrupeds. Deer are herbivores. Carnivores are animals. Predators are carnivores. “Herbivore” and “carnivore” are antonyms. “Predator” and “herbivore” are antonyms. Mammals are animals. Mammals are vertebrates. Quadrupeds are vertebrates. Animals are physical objects. The Round Table is a table. King Arthur is a king. The Round Table is King Arthur's table. Excalibur is a sword. Excalibur is King Arthur's sword. Merlin is a wizard. Wizards are persons. King Ban is a king. King Bors is a king. King Lot is a king. Sir Galahad is a knight. Sir Gawain is a knight. Sir Tristram is a knight. Sideboards are furniture. Tables are furniture. Chairs are furniture. Horses are quadrupeds. Horses are herbivores. Ungulates are herbivores. Horses are animals. Knights

⁷In the interest of conserving space and resources, the appendices to this work are being maintained on-line. They are available via ftp from [ftp.cs.buffalo.edu](ftp://ftp.cs.buffalo.edu) in the directory `/ftp/users/ehrllich`. **Appendix One—Program Code** is stored in the file `appendix.one` and runs 3,165 lines in ascii format. **Appendix Two—Transcripts of Program Runs** is stored in file `appendix.two` and runs 33,931 lines in ascii format. Compressed versions are also available in the same directory. Either appendix may also be obtained by Internet communication with the author at ehrllich@cs.buffalo.edu.

are persons. “Person” is a basic-level category. “Dog” is a basic-level category. “Cat” is a basic-level category. “Horse” is a basic-level category. “Deer” is a basic-level category. “Chair” is a basic-level category. “Table” is a basic-level category. White is a colour. Black is a colour. Small is a size. “Small” and “little” are synonyms. Large is a size. “Large” and “big” are synonyms. Good is a value. Bad is a value. If something is a hound, then presumably its function is to hunt. If x is a horse, then presumably there is a person, y , such that the function of x is to be ridden by y . If a rider rides an animal that belongs to some class, then that class is a subclass of equine. If an animal belonging to some class bays, then it is a hound, and the class to which it belongs is a subclass of hound. If something bites, then it’s an animal. If something sleeps, then it’s an animal. If something ambles, then it’s an animal. If something is an animal and a member of another class, then that class is a subclass of animal.⁸ If something is presumed to be an animal and a member of another class, then presumably that class is a subclass of animal.⁸ If something is a mammal and a member of another (non-superordinate) class, then that class is a subclass of mammal. If someone belongs to a subclass of person then that someone is a person. If something belongs to a subclass of a basic category, then it’s a member of that category. If a person can carry an object, then that object is small. If a person wants something, then it is valuable. If someone says they want something, then they do. If something has colour and belongs to some class, then then that class is a subclass of physical object. If something has size and belongs to some class, then then that class is a subclass of physical object. If a member of some class has a property, then it is possible for other members of that class to have that property. If an animal acts, then the act performed is an action. If a person acts, then the act performed is an action. Spears are weapons. If something is a weapon, then its function is to damage. Kings are persons. Squires are persons. Yeomen are persons. If something is a carnivore, then it eats meat. If something is an herbivore, then it eats plants and does not eat meat. If something is a mammal, presumably it bears.⁹ If something bears, then it is a mammal. If something is a predator, then presumably it hunts. If an agent leaps onto an object at time x , then there is a time y when the leaper is on the object, and y is after x . If an agent leaps to a goal at time x , then there is a time y when the leaper is at the goal, and y is after x . If an agent leaps from an object at time x , then there is a time y when the leaper is on the object, and y is before x . If x is an elder, then x has the property “old”, and presumably x is a person. If x chases y , then x runs behind y . Dwarfs are persons. Pavilions are tents.

**Right so as they sat, there came a white hart running into the hall
with a white brachet next to him, and thirty couples of black hounds
came running after them with a great cry. [p. 66]**

A hart runs into King Arthur’s hall.

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;M233: In the story, B17 is a hart.
(M233! (KN_CAT story)
  (OBJECT1 B17)
  (OBJECT2 (M1 (LEX hart)))
  (REL ISA))
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;M344: In the story, B17 runs into B18.
(M344! (ACT (M194 (LEX run)))
  (AGENT B17)
  (INTO B18)
  (KN_CAT story))
```

⁸This rule sounds a little odd. In general, it is not the case that x being an element of two sets, A and B , implies that one is a subset of the other. Rather, x being an element of A and B implies that there is an intersection of the two sets. However, once again “animal” is a special case.

⁹This rule should really say that if x is a mammal, then presumably there is a y such that x bears y , and y is young, and x and y are of the same species.

;M347: In the story, B18 is a hall.
(M347! (CLASS (M4 (LEX hall)))
 (KN_CAT story)
 (MEMBER B18))

;M350: In the story, the hall (B18) is a hall of its possessor, King Arthur (B3).
(M350! (KN_CAT story)
 (OBJECT B18)
 (POSSESSOR B3)
 (REL (M4 (LEX hall))))

A white brachet is next to the hart.

;M352: In the story, B19 is a brachet.
(M352! (KN_CAT story)
 (OBJECT1 B19)
 (OBJECT2 (M351 (LEX brachet)))
 (REL ISA))

;M355: In the story, the brachet (B19) is next to the hart (B17).
(M355! (KN_CAT story)
 (OBJECT1 B19)
 (OBJECT2 B17)
 (REL (M354 (LEX next to))))

;M356: In the story, the brachet has the property "white".
(M356! (KN_CAT story)
 (OBJECT1 B19)
 (PROPERTY (M97 (LEX white))))

;M358: Brachets are a subclass of physical object
; (deduced since only physical objects have colour).
(M358! (SUBCLASS (M351 (LEX brachet)))
 (SUPERCLASS (M38 (LEX phys obj))))

Define the noun "brachet"
--> (defn_noun 'brachet)

;A **brachet** is a physical object that may be white.
((CLASS INCLUSION= (phys obj) STRUCTURE= NIL FUNCTION= NIL
ACTIONS= (NIL) OWNERSHIP= NIL POSSIBLE PROPERTIES= ((white))
SYNONYMS= NIL)

At this first mention of a brachet, little information is available, so all the system can say is that brachets are physical objects that may be white. The only other datum is that the brachet is next to a hart. Being next to something else is a very accidental property, and cannot be considered salient to a conventional definition, even at this early stage. >From here on, the SNePS node representations will be

omitted to save space.

A group of black hounds ran behind the hart.

;M364: In the story, (the members of) the group B20 are hounds.

;M365: In the story, the hounds (B20) have the property “black”.

;M366: In the story, the hounds run.

;M368: In the story, the hounds (B20) are behind the hart (B17).

In Malory’s text, the black hounds are described as running behind “them”, i.e., the hart and the brachet (a fact which S used to deduce that the brachet was an animal running next to the hart— see response S₁ of the “brachet” protocol). Our translation has the hounds running behind the hart, but even if we added a proposition to the effect that they are running behind the brachet (also), our system would not be able to deduce yet that a brachet is an animal. Perhaps if our system were connected to a grammar capable of pronoun resolution, we could give it the knowledge that plural pronouns (such as “them”) usually apply to either animate entities or inanimate objects, but not both at once. Then, since the hart is animate, the parse of the sentence could force the conclusion that the brachet also is.

Then the hart went running about the Round Table; as he went by the sideboard, the white brachet bit him in the buttock [. . .] [p. 66]

The hart runs next to the Round Table.

;M370: In the story, the hart is next to the Round Table.

The brachet bites the hart’s buttock.

;M371: In the story, the brachet (B19) bites B21.

;M360: Brachets (M351) are a subclass of animals (M18)

; (deduced because B19, a brachet, bit — an act

; only performed by animals).

;M373: The brachet, B19, is an animal

; (deduced for the same reasons as M360).

;M382: In the story, B21 is a buttock of its possessor the hart (B17).

;M383: In the story, B21 is a buttock.

Define the noun “brachet”

;A brachet is an animal that can bite and may be white.

Now we can declare brachets to be animals, because we've read of one biting. At this point S decided that brachets were sharp toothed animals (response S_2), whereas R thought they might be animals, but was not yet ready to believe it a certainty (response R_4). Note that biting is reported as a possible action of brachets. We do not have any general information about whether brachets, as a class, bite, but it is at least possible for them to do so, since we have learned of one that did. If the system had in its KB rules about the general behaviour of brachets, the actions of a specific brachet would not figure in the definition. We ignore individuals in favour of generalized rules, because we wish to abstract the most salient information for our definitions. Should the system have knowledge of the activities of many individuals, and report them all when asked for a definition of the class to which the members belong, our definitions would quickly become cluttered with less-than-salient information. (We assume that, if the system knew about the actions of a great many brachets, it would also have information about the behaviour of brachets in general.) However, at this stage, we know of only one individual and nothing about brachets as a class, save what we can infer from that individual.

Therewith the knight arose, took up the brachet, went forth out of the hall, took his horse and rode away with the brachet. [p. 66]

A knight arises.

;M396: In the story, B22 is a knight.
;M398: B22 is a person (deduced because knights are persons).
;M401: In the story, the knight (B22) arises.

The knight picks up the brachet.

;M405: In the story, the knight (B22) picks up the brachet (B19).

The knight mounts his horse.

;M409: In the story, the knight (B22) mounts B23.
;M412: In the story, B23 is a horse.

The knight rides his horse.

;M417: In the story, the knight (B22) rides the horse (B23).

The knight carries the brachet.

;M420: In the story, the knight (B22) carries the brachet (B19).

;M424: The brachet (B19) has the property “small”
; (deduced since it is carried by the knight).

Define the noun “brachet”

;A **brachet** is an animal that can bite, and may be small or white.

The system has now added “small” to its list of the possible properties of brachets because of its previous belief about the size of the things that a person can carry. In this, it parallels R’s reasoning (response R₄). If we did not know that brachets were animals and could bite, but had only the stative properties and the knowledge that brachets are physical objects, the system would now report that brachets can be picked up and carried by a person. However, since we do know that brachets are animals that can bite, we do not look for the occurrence of “brachet” as the object of an action.

S noticed (response S₃) that the brachet preyed on the deer, but did not attack the man who picked it up, and reasoned that this behaviour might imply that it was a domestic animal such as a dog. We made no attempt to give our system the background knowledge that would have allowed such a deduction.

**Right so a lady came in on a white palfrey and cried aloud to King Arthur,
‘Sire, suffer me not to have this spite for the brachet is mine that the
knight led away.’ [p66]**

A lady says that the knight is taking the brachet.

;M434: In the story, B24 is a lady.
;M438: In the story, the lady (B24) says that the knight (B22)
; takes the brachet (B19)

The lady says that the brachet is hers.

;M441: In the story, the lady (B24) says that the brachet (B19)
; is a brachet of its possessor (B24).

The lady says that she wants the brachet.

;M443: In the story, the lady (B24) says that she (B24)
; wants the brachet (B19).
(OBJECT (M442!)))
;M442: The lady (B24) wants the brachet (B19)
; (deduced because she said that she wanted it).

;M446: The brachet (B19) has the property “valuable”
; (deduced because the lady wants it).

Define the noun “brachet”

;A **brachet** is an animal that can bite and may be small or white or valuable.

Our system follows R’s reasoning that, since the lady wants the brachet, the brachet is of value (response R₄). Again, we made no attempt to build S’s ideas on pet ownership in mediaeval society into the KB. (See response S₄). Note that the ownership slot in the definition is still empty. Our system believes that people are telling the truth when they say that they want something, but it has no parallel belief about claims to ownership.

‘Then,’ said Merlin, ‘call sir Gawain, for he must bring back the white hart. Also, sir, ye must call Sir Tor, for he must bring back the brachet and the knight, or else slay him. [. . .]’ [p67]

Merlin says that Sir Gawain must bring the hart to King Arthur’s hall.

;M459: In the story, Merlin (B5) says that Sir Gawain (B8) must bring
; the hart (B17) to Arthur’s hall (B18).

Merlin says that Sir Tor must bring the brachet to the hall.

;M460: In the story, Merlin (B5) says that B25 must bring
; the brachet (B19) to Arthur’s hall (B18).
;M466: In the story, B25 has the proper name “Sir Tor”.
;M467: In the story world, Sir Tor (B25) is a knight.

Merlin says that Sir Tor must either bring the knight to Arthur’s hall or else slay him.

;M472: In the story, Merlin (B5) says that exactly one of the following
; must be: Sir Tor (B25) brings the knight (B22) to King Arthur’s
; hall (B18), or, Sir Tor slays the knight.

Define the noun “brachet”

;A **brachet** is an animal that can bite and may be small or white or valuable.

Neither human reader found this passage (number 5 in the protocol) very informative regarding the definition of “brachet”, nor did our system.

‘Sir,’ said the elder ‘there came a white hart this way this day and many hounds chased him, and a white brachet was always next to him.’
[p67]

An elder says that a white hart comes to a place.

;M475-M479: In the story, an elder (B26) says that a hart (B27)
;that has the property “white” comes to a place (B28)

The elder says that a group of hounds chased the hart.

;M481-482: In the story, the elder (B26) says that hounds (B29) chase the hart (B27).

The elder says that a white brachet is next to the hart.

;M484-M486: In the story, the elder says that a white brachet (B30) is next to the hart (B27).

;M487-M489: In the story world, the brachet the elder saw (B30),
;the hart the elder saw (B27) and the hounds the elder saw (B29)
;are the same as the brachet (B19) the hart (B17) and the hounds (B20).

Define the noun “brachet”

;A **brachet** is an animal that can bite and may be small or white or valuable.

At this point (passage 6), R was starting to be convinced that brachets were animals, while S was hypothesizing that they were a breed of hound. Our definition falls somewhere between the two, with the belief in the animacy of brachets established, but no hypothesis about what type of animals they are. Our system found nothing new in passage 6

When Sir Tor was ready, he mounted upon his horse’s back, and rode after the knight with the brachet. [71]

Sir Tor mounts his horse.

;M490-M493: In the story, Sir Tor (B25) mounts his horse (B31).

Sir Tor rides his horse in the direction of the knight who took the brachet.

;M494-M497: In the story, Sir Tor (B25) rides his horse (B31)
; in the direction of B22, a knight with the brachet (B19).

‘Ye shall say [you are sent] by the knight who went in quest of the knight with the brachet.’ [71]

;M504: In the story, Sir Tor (B25) says that B32 shall say that
; they (B32) are sent by M500: the questor-for the knight (B22)
; and the brachet (B32).
;M506: In the story world, Sir Tor (B25) and the questor-for
; knight and brachet (M500) are the same.

Define the noun "brachet"

;A **brachet** is an animal that can bite and may be small or white or valuable.

These passages (numbers 7 and 8) produced no change in the definition for the human readers or for Cassie.

'I know you ride after the knight with the white brachet, and I shall bring you where he is,' said the dwarf. [72]

*A dwarf says the he knows that Sir Tor seeks the knight.
The dwarf says that he will bring Sir Tor to the knight.*

;M511: In the story, B33 says that B33 knows that Sir Tor (B25)
; seeks the knight (B22).
;M514: In the story, the dwarf (B33) says that he (B33) brings
; Sir Tor (B25) to B34.
;M516: In the story, B34 is the place where the knight (B22) is.
;M517: In the story-world, B34 is the place where the brachet (B19) is.
;M518: In the story, B33 is a dwarf.

Then he went to the other pavilion and found a lady lying sleeping therein; and there was the white brachet which bayed at him fast. [p. 72]

Sir Tor goes to a pavilion.

;M520: In the story, Sir Tor (B25) goes to B35.
;M522: In the story, B35 is a pavilion.

The lady is sleeping in the pavilion

;M523: In the story, the lady (B24) sleeps at place B35.
; (This should probably be accompanied by a proposition
; to the effect that B24 is *in* B35, but it makes
; no difference to definition of "brachet")

Sir Tor finds the lady at the pavilion.

;M535: In the story, Sir Tor (B25) finds the lady (B24) at the
; pavilion (B35).

Sir Tor finds the brachet at the pavilion.

;M537: In the story, Sir Tor (B25) finds (M534) the brachet (B19)
; at the pavilion (B35).

The brachet bays in the direction of Sir Tor.

;M538: In the story, the brachet (B19) bays in the direction of
; Sir Tor (B25).

;M541: Brachets are a subclass of hound (deduced since this
; brachet bays, and since anything that bays is a hound).

Define the noun “brachet”

;A **brachet** is a dog whose function is to hunt. Brachets can bay and bite.

At this point, both human readers associated the activity of baying with dogs. Our system had the prior beliefs that baying is something done by hounds and that hounds are dogs. It therefore concludes that a brachet is a hound and thus a dog. Often, in the process of developing a definition, we move down a taxonomic hierarchy toward greater specificity because we often begin with superordinate categories, but “hound” represents a subordinate category, and we seek a basic-level category for our definition whenever possible. Cassie still believes that brachets are hounds, even if that belief isn’t included in the definition, so “brachet” can inherit the hunting function that is attributed to hounds, but not to dogs in general. If the KB happened to contain structural information on hounds at the time this story was read, that, too, would be inherited.

Note that the assorted properties of the individual brachet (its size, colour, and value) are no longer reported as part of the definition (though, again, the information is still in the KB). Function and structure— especially as they distinguish a noun from its superclasses— are conventionally salient information for the production of dictionary-style definitions [Miller & Johnson-Laird 1976, Elshout-Mohr & van Daalen-Kapteijns 1987]. If no information about such aspects of meaning is available, then it is appropriate to report whatever properties we know, but once we can fill in the more salient information, we do not wish to clutter our definitions with less salient data derived from idiosyncratic experience with the term.

As soon as Sir Tor spied the white brachet, he took it by force and

gave it to the dwarf. [p. 72]

Sir Tor spies the brachet

;M546: In the story, Sir Tor (B25) spies the brachet (B19).

Sir Tor takes the brachet

;M548: In the story, Sir Tor (B25) takes the brachet (B19).

Sir Tor gives the brachet to the dwarf.

;M551: In the story, Sir Tor (B25) gives the brachet (B19) to the dwarf (B33).

With the noise, the lady came out of the pavilion with all her damosels. [p. 72]

A noise causes the lady to come from the pavilion.

;M553: In the story, the lady (B24) comes from the pavilion (B35).

;M559: In the story, a noise (B37) causes the lady (B24) to come from
; the pavilion (B35).

The noise causes a group of damosels to come from the pavilion.

;M556: In the story, B36 comes from the pavilion (B35).

;M561: In the story, the noise (B37) causes B36 to come from the
; pavilion (B35).

;M563: In the story, (the members of) B36 are damosels.

;M564: In the story world, the damosels (B36) are persons.

;M565: In the story world, the noise (B37) is the same as
; the brachet (B19) baying.

‘What! Will ye take my brachet from me?’ said the lady. [p. 72]

The lady asks Sir Tor if he is taking the brachet from her

;M568: In the story, the lady (B24) asks Sir Tor (B25) if he (B25)

; is taking the brachet (B19) from her (B24).

;M572: In the story world, the lady (B24) has the property “angry”.

;M574: In the story world, Sir Tor (B25) taking the brachet (B19) from

; the lady (B24) is the cause of the lady (B24) being angry.

‘Yes,’ said Sir Tor, ‘this brachet I have sought from King Arthur’s court hither.’ [p. 72]

Sir Tor says to the lady that he is taking the brachet from her.

;M575: In the story, Sir Tor (B25) says (M148) to the lady (B24) that

; he (B25) is taking the brachet (B19) from her (B24).

Sir Tor says that he sought the brachet from King Arthur’s hall to

here.

;M577: In the story, Sir Tor (B25) says (M148) that he (B25) seeks
; the brachet (B19) from King Arthur's hall (B24) to the
; pavilion (B35).

Define the noun "brachet"

;A **brachet** is a dog whose function is to hunt. Brachets can bay and bite.

S had no comment on this part of passage **10**. R viewed it as confirmation that the brachet was small. It resulted in no change to our definition. We did not have Cassie read the remaining seven passages from the "brachet" protocol, because they contained no new structural or functional information about brachets. There were additional actions mentioned (tracking, running and licking) that would be included in the definition had we input the remaining passages, but there was no general information about the probable actions of brachets as a class.

Our system has settled on a definition that is very close to that at which the human readers arrived. It did so a little more quickly than R and somewhat less quickly than S. One fact noticed by both human readers, that a brachet several times appeared to be leading a pack of hounds, could not be taken into account because we have no slot for such information in our definitions. Our system is also somewhat handicapped by the lack of a sophisticated grammar. In the future, we plan to input the stories in English (even if it is a somewhat simpler English than Malory's) and let the grammar build the SNePS representations of the input sentences. For now, we build those representations directly. This should make little difference to the KB, but it does deprive it of some clues in the text itself. As mentioned above, the use of the plural pronoun "them" gave one reader an early clue that the brachet was an animal. The phrase "other hounds" (passage **13**) was immediately noticed by both readers, although it occurred sufficiently late in the text that it served more to confirm the definition than to provide new information. Our system could only benefit by the ability to notice such clues during the parsing process, although in the present case it did not need them. (For further discussion of grammar, parsing, and syntactic clues, see section 8.)

7.2. THE “TOMATO” DEMONSTRATION

As we have seen in the “brachet” and “hackney” demonstrations, our system does not include stative properties of individuals once structural or functional information is available. Since the examples taken from Malory did not include cases where the system had information about the general stative properties to be expected of objects in a class as well as their structural and functional properties, we present the following toy example. At the beginning of this run, the system had no KB present. The run consisted of building a toy KB about tomatoes and then asking for a definition of “tomato”.

Begin tomato demonstration.

;M3: It is a fact of life that tomatoes are fruits.
;M5: It is a fact of life that tomatoes are vegetables.
;M7: It is a fact of life that “tomato” is synonymous with “love-apple”
;M10: It is a life-rule.1 that, presumably tomatoes are red
;M12: It is a life-rule.1 that, presumably tomatoes are round
;M14: It is a life-rule.1 that tomatoes have seeds.
;M16: It is a life-rule.1 that tomatoes have pulp.
;M18: It is a life-rule.1 that tomatoes have skins.
;M20: It is a fact of life that “tomato” represents a basic-level category.
;M24: It is a life-rule.1 that, for all V1, if V1 is a tomato, then
; presumably there is a P12 that is a person who eats V1, and
; the function of V1 is to be eaten by P12.
;M25: It is a life-rule.1 that, for all V1, V2, and V3, if V2 is a
; V3 of its possessor V1, then V2 is a V3.

Define the noun “tomato”

;A **tomato** belongs to the classes “fruit” and “vegetable”.
;Tomatoes have pulp, seed, and skin. The function of a tomato is
;to be eaten. Tomatoes are red and round. Tomatoes are like love-apples.

End of tomato demonstration.

Because the stative properties of roundness and redness are properties that may be expected of tomatoes in general, rather than observed properties of individual tomatoes, they are reported even though both structural and functional information are present. (The human-centered notion of the function of a tomato given here seems to be typical of many dictionaries. >From the tomato’s “point of view”, its function is to make more tomato plants.)

7.3. THE “DRESS” DEMONSTRATIONS

Because the protocols (section 3.4) on which this section is based involved two different types of learning (R added a new sense to the definition of “dress”; S developed a definition of the nonsense word “varl”), we will examine two program runs. The first uses the nonsense word, and so requires no revision of belief. The second run demonstrates additive revision (as outlined in section 6.3.3). At the beginning of each of these runs, the KB contained the following information:

Herbivores are mammals. Mammals are animals. King Arthur is a king. Excalibur is King Arthur’s sword. Merlin is a wizard. Wizards are persons. King Ban is a king. King Bors is a king. Sir Galahad is a knight. Sir Gawain is a knight. Horses are quadrupeds. Horses are animals. Knights are persons. “Person” is a basic-level category. “Horse” is a basic-level category. If x slays y at some time, y is thereafter dead. If x is dead at time y , it can perform no actions at that time or at any subsequent time. If x is a horse, dog, or deer, it is an animal. If x is a horse, its presumed function is to be ridden. If x belongs to a category y which is a subclass of person, x is a person. If an animal acts, the act performed is an action. If a person acts, the act performed is an action. Spears are weapons. If x is a weapon, its function is damage. If w x s y to z , then x is bitransitive. If w x s y , then x is transitive. If w x s w , then x is reflexive. Kings are persons. If one is hurt, one is presumably not dead. A battle is an abstract object. Shields are armour. Spears are weapons. If w performs some act x on an object y while preparing for z and y is associated with z , then w prepares y for z . Shields, spears, swords, harness, and armour are associated with battle and combat. Battle and combat are associated. If an agent performs one act, and then performs another act, presumably the purpose of the first action was the second action. If an agent rides toward an opponent, then the riding is part of fighting. If an agent performs one act, and then performs another act, and the second act is part of a third, then presumably the third act was the purpose of the first, and presumably the first enabled the third. If x dresses y , then there is a z such that y wears z , and z is clothing. Shields, swords, spears, harness and armour do not wear clothing. If x is armed at time y , then there is a z such that x carries z at time y , and z is a weapon.

7.3.1. First “Dress” Demonstration — the “Varl” Demo.

The following run has been edited in the same fashion as those in earlier sections of this chapter.

An unedited transcript appears in the appendix.

Begin varl demo

Therewith two of them varled their spears and Sir Ulfyus and Sir Brastias varled their spears; they ran together with great force. Claudas’ knights broke their spears, but King Arthur’s two knights’ held and bore the other knights out of their saddles to the earth; [p. 15]

Two of King Claudas’s knights varled their spears.

;M107: “Varl” is a transitive verb (deduced).

;M124: Varling is an action (deduced).
;M165: In the story, B9 is a spear.
;M114: B9 is associated with combat (deduced).
;M114: B9 is associated with battle (deduced).
;M168: It is not the case that the spear (B9) wears its clothing (M166) (deduced).

It should be noted that it is extremely unlikely that a human would hold beliefs such as M168! or the rule that allowed it to be deduced. A belief such as M168! might come into being if someone asked “Does that spear over there wear clothing?”, but we could not finish reading a single sentence if we had to explicitly conceptualize all the things that were *not* true of each word as we read it. Instead, we rely on positive information. We know what types of things do wear clothing (people, dolls, some people’s pets). Our negative response to the above question depends on our belief that we have reasonably complete knowledge about what wears clothing. If we read or hear something that implies that a spear wears clothing, we experience cognitive dissonance. Cassie, however, has no belief that her knowledge about anything is complete. If we wish her not to accept the notion of a clothed spear as readily as that of a clothed person, we must first let her know that spears do not wear clothing. (We could write a rule that said *only* people and dolls wear clothing instead of saying explicitly that spears do not, but then we’d have to tell her that spears are not people or dolls.)

;M169: The spear (B9) is a weapon (deduced).

Sir Ulfyus varled his spear.
Sir Brastias varled his spear.
One of the knights rode his horse toward Sir Brastias.

;M201: In the story, the knight (B8) rode B18 toward Sir Brastias (B16) at time B19.
;M207: Riding is an action (deduced).
;M208: “Ride” is transitive (deduced).
;M209: In the story, B18 is a horse of the knight B8.
;M210: In the story world, Sir Brastias (B16) is an opponent of B8.
;M112: B8 riding is part of B8 fighting (deduced).

The other knight rode his horse toward Sir Ulfyus.
Sir Ulfyus rode his horse toward the second knight.

;M184: Sir Ulfyus riding is part of Sir Ulfyus fighting (deduced).

Sir Brastias rode his horse toward the first knight.

;M231: Sir Brastias (B16) riding (M52) is part of Sir Brastias fighting (deduced).
;M243: Presumably, the purpose of M104 is M102 (deduced).
;M104: The knight (B8) varled at time B10.
;M102: The knight (B8) rode at time B19.
;M245: Presumably, the purpose of M177 is M216 (deduced).
;M177: Sir Ulfyus varled at time B10
;M216: Sir Ulfyus rode at time B19
;M247: Presumably, the purpose of M234 is M233 (deduced).
;M234: Sir Brastias varled at time B10
;M233: Sir Brastias rode at time B19
;M250: Presumably, the purpose of M104 is M208 (deduced).
; (B8 varled at time B10 for the purpose of (B8) fighting at
; time B19).
;M252: Presumably, M104 enabled M208 (deduced).
; (B8 varling at time B10 enabled (B8) fighting at time B19).
;M255: Presumably, the purpose of M177 is M253 (deduced).
; (Sir Ulfyus (B14) varled at time B10 for the purpose of (B14)
; fighting at time B19).
;M257: Presumably, M177 enabled M253 (deduced).
; (Sir Ulfyus varling at time B10 enabled him (B14) fighting at
; time B19).
;M260: Presumably, the purpose of M234 is M258 (deduced).
; (Sir Brastias (B16) varled at time B10 for the purpose of (B16)
; fighting at time B19).
;M262: Presumably, M234 enabled M258 (deduced).
; (Sir Brastias varling at time B10 enabled him (B16) fighting at
; time B19).

Define the verb “varl”

;A person can **varl** a spear, which enables him to fight.

The first knight broke his spear.

The second knight broke his spear.

Neither Sir Ulfyus’s spear nor Sir Brastias’s spear was broken.

Sir Ulfyus unhorsed the second knight.

;M301: “Unhorse” is a transitive verb.

Sir Brastias unhorsed the first knight.

Define the verb “varl”

; A person can **varl** a spear, which enables him to fight.

**Then they varled their shields and began to couch their spears,
many good knights.** [p. 16]

Knights varled their shields.

The knights couched their spears.

;M319: “Couch” is a transitive verb (deduced).

Define the verb “varl”

; A person can **varl** a shield or spear, which enables him to fight.

[Merlin said] ‘**When it is daylight, varl your battle right before the Northern host and the strong passage-way, so that they may see all your host.**’ [p. 19]

Merlin said that King Arthur should varl his battle in the pass so that the enemy could see his host.

Define the verb “varl”

; A person can **varl** a shield, spear or battle, which enables
; him to fight.

Therefore King Ban and King Bors made ready and varled their shields and harness. They were so courageous that many knights shook and trembled with eagerness. [p. 21]

*King Ban and King Bors made ready.
King Ban varled a shield and harness.
King Bors varled a shield and harness.
They were courageous.*

Define the verb “varl”

; A person can **varl** a spear, a shield, harness, or battle,
; which enables him to fight.

At this point the definition has reached the stage at which it will remain for the rest of this demonstration; we have therefore omit the rest of the run.

S theorized that to varl something is to prepare it for battle. Our system reports that varling enables one to fight. The concepts of battle preparation and fight enablement were each hypothesized at the first passage and remained through subsequent passages. The only change that subsequent passages made to the system’s definition was the addition of possible categories for the object of the verb. S commented on the immediacy of varling before battle, and suggested that it implied a quick preparation. The definition reported here is silent on such temporal issues, in part because there is no slot for such information in the definitional framework, but also because the only temporal relations of which the system is aware are “before”, “after”, and “at the same time”. Our system currently has no capacity to

distinguish between “shortly before” and “long before” or between “briefly” and “for a long time”. (But see Almeida [1987, 1995] for discussion of more complex temporal representation in SNePS.) We do represent the directionality (such as R noticed) when someone is said to varl (or dress) toward someone or something, but again, our current definitional frame for verbs does not include a slot for direction or orientation.

7.3.2. Second “Dress” Demonstration — Belief Revision

All the preceding demonstrations were run using the current release of SNePS. In order to automate the selection of a belief to be revised when a contradiction is encountered, the following demonstration was run using SNePSwD [Cravo & Martins 1993]

Before beginning the passages from Malory, we give the system an example of the common use of the term “dress” and ask for a definition.

;M101: It is a fact of life that King Arthur dressed himself.

Define the verb “dress”

(P72 (ACT (M94 (LEX wear)))
(AGENT V28)
(OBJECT (P71 (A1 V28) (SKF clothes-of))))

(P73 (OBJECT1 (P71))
(OBJECT2 (M95 (LEX clothing)))
(REL ISA))

;A person can **dress** itself, which results in (it) wearing clothing.

(A (person) CAN DRESS ITSELF
RESULT= (P72 P73)
ENABLED BY= NIL)

It may be noted that the results of an action are reported as a list of pattern nodes. As described in section 5.2, we look for explicit (CAUSE EFFECT) case frames when reporting results, but we also look for rules whose antecedent is that the target action occurred, and report the results of that rule as

the results of such an action. These pattern nodes do not really translate into English outside the context of the rules in which they occur, since the rule provides the binding for the variables.

Literally, P72 and P73 together say only that something wears its clothing. Ali's [1993] system, ANALOG (a descendant of SNePS), uses structured variable nodes that would allow us to characterize V28 as "that which is dressed", so we give the English gloss of P72 and P73 as "that which is dressed wears its clothing." In its current form, however, ANALOG lacks certain SNePS facilities (such as belief revision) that we need for this work.

Begin dress demonstration.

Therewith two of them dressed their spears and Sir Ulfyus and Sir Brastias dressed their spears; they ran together with great force. Claudas' knights broke their spears, but King Arthur's two knights' held and bore the other knights out of their saddles to the earth; [p. 15]

Two of King Claudas's knights dressed their spears.

;M132: "Dress" is a transitive verb (deduced).
;M135: In the story, B8 dressed B9 at time B10.
;M141: B9 wears M140 (the clothes of B9) (deduced).
;M142: M140 is (a) clothing (deduced).
;M144: "Wear" is a transitive verb (deduced).

Rank your beliefs in order of certainty

What wears clothing?

The requested deduction results in the system noticing a contradiction among the logical implications of its beliefs. B9 is a spear, and spears do not wear clothing, so M160! must hold (i.e., B9 does not wear clothing). But the knight dressed B9, and that which is dressed wears clothing, so M141! must hold (i.e., B9 wears clothing). This perceived contradiction invokes SNeBR. In the interaction below, the symbol "=><=" is the SNeBR prompt. User responses appear in boldface.

A contradiction was detected within context DEFAULT-DEFAULTCT.
The contradiction involves the newly derived wff:
(M160! (MIN 0) (MAX 0)
 (ARG (M141! (ACT (M94 (LEX (wear)))) (AGENT (B9))
 (OBJECT (M140 (A1 (B9)) (SKF (clothes-of)))))))

and the previously existing wff:
(M141! (ACT (M94 (LEX (wear)))) (AGENT (B9))
(OBJECT (M140 (A1 (B9)) (SKF (clothes-of)))))

You have the following options:

1. [C]ontinue anyway, knowing that a contradiction is derivable;
2. [R]e-start the exact same run in a different context which is not inconsistent;
3. [D]rop the run altogether.

(please type c, r or d)

=><= **r**

Do you want any suggestions ?

=><= **y**

To remove the contradiction from the current context, keeping the hypothesis you just added, you have the following alternatives:

Alternative 1:

Remove: (M96!)

Do you want to examine some hypotheses?

=><= **n**

Do you want to follow this suggestion?

=><= **y**

Several previous assertions led to the deduction of the contradictory beliefs:

M135: In the story, the knight (B8) dresses the spear (B9) at time B10.

M155: In the story, B9 is a spear.

M96: It is a life-rule.1 that if x dresses y then y wears z (the clothes of y) and z is clothing.

M97: It is a life-rule.1 that if x is a shield, sword, spear, harness, or armour, then x doesn't wear clothing.

but those at the same, lowest-present, level of certainty were the rules that spears do not wear clothes, and that that which is dressed does wear clothes. Of those two rules, the latter involves a verb in the antecedent, so our version of SNeBR offers it as the suggested culprit in need of revision. We accept the suggestion.

The contradiction above was observed to occur in what SNeBR calls "the default context" (in which we were working). SNeBR now reports that it sees the same contradiction as part of what it calls "the global context" [Shapiro & Martins 1990, Cravo & Martins 1993], but since SNeBR is already in

the process of correcting the situation, we do not tell it to restart the run again, but simply to continue.

A contradiction was detected within context %%globalcontext%%.

The contradiction involves the newly derived wff:

(M141! (ACT (M94 (LEX (wear)))) (AGENT (B9))
(OBJECT (M140 (A1 (B9)) (SKF (clothes-of)))))

and the previously existing wff:

(M160! (MIN 0) (MAX 0)
(ARG (M141! (ACT (M94 (LEX (wear)))) (AGENT (B9))
(OBJECT (M140 (A1 (B9)) (SKF (clothes-of)))))

You have the following options:

1. [C]ontinue anyway, knowing that a contradiction is derivable;
2. [R]e-start the exact same run in a different context which is not inconsistent;
3. [D]rop the run altogether.

(please type c, r or d)

=><= c

Removed:

(M96 (FORALL V26 V28) (ANT (P70 (ACT (M93 (LEX (dress)))) (AGENT V26)
(OBJECT V28))) (CQ (P72 (ACT (M94 (LEX (wear)))) (AGENT V28) (OBJECT
(P71 (A1 V28) (SKF (clothes-of))))) (P73 (OBJECT1 (P71 (A1 V28) (SKF
(clothes-of)) (OBJECT2 (M95 (LEX (clothing)))) (REL (ISA))))
(KN_CAT (life-rule.1)))

Added:

(M161 (FORALL V26 V28) (ANT (P70 (ACT (M93 (LEX (dress)))) (AGENT V26)
(OBJECT V28))) (CQ (P109 (MIN 1) (MAX 1) (ARG (P72 (ACT (M94 (LEX
(wear)))) (AGENT V28) (OBJECT (P71 (A1 V28) (SKF (clothes-of)))))
(SOMETHING))) (P73 (OBJECT1 (P71 (A1 V28) (SKF (clothes-of)))))
(OBJECT2 (M95 (LEX (clothing)))) (REL (ISA)))) (KN_CAT (life-rule.1)))

(M160!)

;We tell the system to describe and assert the new rule it has built

;to replace the culprit rule it discarded.

* (describe M161!)

;M161: It is a life-rule.1 that if V26 dresses V28, then P73 and P109

;both hold.

(M161! (FORALL V26 V28)
(ANT (P70 (ACT (M93 (LEX dress))))
(AGENT V26)
(OBJECT V28)))
(CQ

;P109: Either V28 wears P71 (the clothes-of V28) or else "SOMETHING".

(P109 (MIN 1)
(MAX 1)
(ARG

(P72 (ACT (M94 (LEX wear)))
(AGENT V28)
(OBJECT (P71 (A1 V28)
(SKF clothes-of)))
SOMETHING))
;P73: P71 is clothing.
(P73 (OBJECT1 (P71))
(OBJECT2 (M95 (LEX clothing)))
(REL ISA)))
(KN_CAT life-rule.1))

(M161!)

The automation of SNeBR is not as complete as it might be. At present, when we expect a contradiction to arise, we explicitly tell the system to rank its beliefs in order of certainty, so that it will be able to choose a culprit from the conflict set. It would be preferable if, when SNeBR was invoked by a contradiction, it automatically ranked its beliefs before presenting its suggestion(s) for deletion. (That is, the ranking function, would be called by the program rather than a human user.) In such a case, we would not need explicitly to ask the system to deduce the consequences of an assertion such as “B9 is a spear”. Instead, we could add that proposition in the mode that causes forward-chaining inference. Then the system would notice the contradiction without being told to deduce anything, rank its beliefs, and suggest which to delete, all without human interference.

It would also improve the automation of SNeBR if the revision of the discarded rule were automatically asserted in the current context. At present, the system automatically builds the revised rule, and reports it as being added (e.g., Removed: M96, Added: M161) but it is not actually believed until explicitly asserted by a human user (using the “!” operator).

We now continue with the story:

Sir Ulfyus dressed his spear.

;M180: In the story, B14 dressed B15 at time B10.
;M162: Either B12 wears (its) clothing or else “SOMETHING” (deduced).
;M176: It is not the case that M96 holds (deduced).
;M96: If V26 dresses V28, then V28 wears P71 (the clothes of V28) and P71 is clothing.
;M187: Either B15 wears (its) clothing or else “SOMETHING” (deduced).

;M196: In the story, B14 is named Sir Ulfyus.
;M197: In the story world, Sir Ulfyus (B14) is a knight.
;M198: In the story, B15 is a spear.
;M199: In the story, B15 is a spear of Sir Ulfyus (B14).
;M200: In the story world, Sir Ulfyus (B14) is a knight of King Arthur (B1).
Sir Brastias dressed his spear.

;M201: In the story, B16 dressed B17 at time B10.
;M203: In the story, B16 is named Sir Brastias.
;M204: In the story world, Sir Brastias (B16) is a knight.
;M205: In the story world, Sir Brastias (B16) is a knight of King Arthur (B1).
;M206: In the story, B17 is a spear.
;M207: In the story, B17 is a spear of Sir Brastias (B16).

One of the knights rode his horse toward Sir Brastias.

;M208: In the story, the knight B8 rode B18 toward Sir Brastias (B16) at time B19.
;M215: “Ride” is transitive.
;M216: In the story, B18 is a horse of the knight B8.
;M217: In the story world, Sir Brastias (B16) is an opponent of
; the knight B8.

*The other knight rode his horse toward Sir Ulfyus.
Sir Ulfyus rode his horse toward the second knight.
Sir Brastias rode his horse toward the first knight.
The first knight broke his spear.
The second knight broke his spear.
Neither Sir Ulfyus’s spear nor Sir Brastias’s spear was broken.
Sir Ulfyus unhorsed the second knight.
Sir Brastias unhorsed the first knight.*

Define the verb “dress”

; A person can **dress** a spear or a person, with the result
; that either the object dressed wears its clothes (or something),
; or the person is enabled to fight.

End of dress demonstration.

The remaining passages from the protocols were not input as part of this run. As may be seen in the “varl” demonstration, their only effect on the definition is to add to the list of the categories of things that can be dressed.

The form of the above definition is not entirely satisfactory, as the two senses of the term are not clearly distinguished. “Person” and “spear” appear in the same list of possible direct objects, and a single list of results contains both the wearing of clothing and the enabling of fighting. From this definition alone, it is not clear which result pertains to dressing which object (though Cassie still knows

that spears do not wear clothes).

7.4. THE “SMITE” DEMONSTRATIONS

In this section we shall examine the revision of a less entrenched understanding of a word’s meaning. At the beginning of the first run, Cassie had the following beliefs:

There is a king named King Arthur. There is a sword named Excalibur. Excalibur is King Arthur’s sword. Horses are animals. Knights are persons. “Person” is a basic-level category. “Horse” is a basic-level category. If something is dead at time x , it can perform no actions at that time or at any subsequent time. If someone belongs to a subclass of person, that someone is a person. If a person acts, the act performed is an action. If an agent acts on an object, and there is an indirect object of the action, then the action is bitransitive. If an agent acts on an object, then the action is transitive. If an agent acts on itself, then the action is reflexive. Kings are persons. If one is hurt at some time, then one is not dead at that time. There is a king named King Lot. If x smites y at time z , then x hits y at time z , and y is dead at time z , and the hitting caused the death. Dukes are persons. “Before” and “after” are transitive relations. If something is *not* dead at a given time, then it was not dead at any prior time.

Begin smite demonstration.

With that, King Arthur turned with his knights and smote behind and before; and ever King Arthur was in the foremost press till his horse was slain underneath him. Therewith King Lot smote down King Arthur. With that, his four knights rescued him and set him on horseback; then he drew his sword Excalibur, and it was so bright in his enemies eyes that it gave light like thirty torches. [p. 13]

King Arthur turned himself and his horse.

King Arthur smote before and behind.

King Arthur’s horse was slain.

King Lot smote down King Arthur.

Define the verb “smite”

; A person can **smite** a person. If x smites y at time z ,
; then x hits y at time z , and y is dead at time z ,
; and the hitting caused the death.

What property did King Arthur have at time B7?

;M69: King Arthur was dead at time B7 (deduced).

Since we gave Cassie the initial misconception that smiting implies killing by hitting, she now believes that Arthur is dead because Lot smote him. R had immediate doubts about this because of a prior understanding that Mordred—not Lot—killed Arthur. We did not tell Cassie about that, so, for the moment she notices nothing amiss. Neither does she notice anything incongruous in the story, below, when Arthur is rescued and set on another horse, since she had no beliefs about whether a dead person could be rescued.

*King Arthur's knights rescued him.
The knights set King Arthur on a(nother) horse.
King Arthur drew Excalibur.
When did King Arthur draw?*

Now Cassie does notice a contradiction. She deduced before that Arthur died when Lot smote him. Now the story says he drew his sword *after* being smitten. But drawing a sword is an action, and one can perform no actions after dying. Of the various beliefs that lead to this contradiction, the belief about what it means to smite is the least entrenched, so it is selected as the belief to revise. Because it has KN_CAT ‘‘life-rule.2’’, revision will be ‘‘subtractive’’ (see section 5.3.2).

A contradiction was detected within context DEFAULT-DEFAULTCT.
The contradiction involves the newly derived wff:
(M121! (MIN 0) (MAX 0)
(ARG (M101! (ACT (M99 (LEX (draw)))) (AGENT (B1)) (TIME (B12))))
(M116 (ACT (M99 (LEX (draw)))) (AGENT (B1)) (TIME (B7))))))
and the previously existing wff:
(M101! (ACT (M99 (LEX (draw)))) (AGENT (B1)) (TIME (B12)))
Do you want any suggestions ?
=><= **y**

To remove the contradiction from the current context, keeping the hypothesis you just added, you have the following alternatives:

Alternative 1:
Remove: (M39!)

Do you want to follow this suggestion?
=><= **y**

Removed: (M39!) Added: (M124)

SNeBR reports as added only the last belief built. Actually, two rules have been built to replace rule M39, though neither is yet asserted in the current context. We manually assert and describe both the replacement rules our system has created:

* (describe M123!)

```
;M123: It is questionable that if V18 smites V19 at time V20, then
;   V18 hits V19 at time V20 and possibly V19 is dead at time V20.
(M123! (FORALL V18 V19 V20)
 (ANT
  (P23 (ACT (M37 (LEX smite))) (AGENT V18) (OBJECT V19) (TIME V20)))
 (CQ (P24 (ACT (M38 (LEX hit))) (AGENT V18) (OBJECT V19) (TIME V20))
  (P83 (MODE (M122 (LEX qpossibly)))
   (OBJECT (P25 (OBJECT V19) (PROPERTY (M19 (LEX dead))) (TIME V20))))))
 (KN_CAT questionable))
```

* (describe M124!)

```
;M124: It is a life-rule.2 that if V18 smites V19 at time V20, and V19
;   is dead at time V20, then the hitting is the cause of the death.
(M124! (FORALL V18 V19 V20)
 (&ANT
  (P23 (ACT (M37 (LEX smite))) (AGENT V18) (OBJECT V19) (TIME V20))
  (P25 (OBJECT V19) (PROPERTY (M19 (LEX dead))) (TIME V20)))
 (CQ
  (P26
   (CAUSE (P24 (ACT (M38 (LEX hit))) (AGENT V18) (OBJECT V19)
    (TIME V20)))
   (EFFECT (P25))))
 (KN_CAT life-rule.2))
```

Print the list of all terms whose meaning you consider questionable.

```
;(smite)
(M37)
```

Define the verb "smite"

```
; A person can smite a person. If x smites y at time z,
; then x hits y at time z and possibly y is dead at time z.
```

[Information about the identities of Claudas, Brastias and Ulfyus is identical to that in the dress demonstrations omitted here.]

[Sir Ulfyus & Sir Brastias, traveling as messengers are spied upon and waylaid by 8 knights of King Claudas.] **[Two of] Claudas' knights broke their spears, but King Arthur's two knights' held and bore the other two knights out of their saddles to the earth; so they left them lying there**

and rode their ways. The other six knights rode ahead to a passage to meet with them again. Sir Ulfyus and Sir Brastias smote another two down and passed on their ways, and the same then occurred a third time. At the fourth passage they met two for two, and both King Claudas' knights were laid onto the earth. So there was no one of the eight knights who was not sorely hurt or bruised. [p. 15]

[The passage with the first pair of Claudas's knights is in the dress demonstration.]

Two of King Claudas's knight rode toward a passage.

Sir Ulfyus rode ahead.

Sir Brastias rode ahead.

Sir Ulfyus smote down one of King Claudas's two knights.

;M154: In the story, Ulfyus (B14) smote down the knight B16 at time B21.

;M159: Sir Ulfyus (B14) hit B16 at time B21 (deduced).

;M161: Possibly, the knight B16 is dead at time B21 (deduced).

;M165: "Hit" is transitive (deduced).

;M61: "Smite" is transitive (previously deduced when forming definition,
; but noticed again here.)

;M166: In the story world, B21 is after B20.

Sir Brastias smote down the other knight.

;M172: Brastias (B15) hit (M38) the knight B19 at time B21 (deduced).

;M174: Possibly, the knight B19 is dead at time B21 (deduced).

:[Passage with third pair of knights omitted from story.]

Sir Ulfyus and Sir Brastias rode ahead.

Sir Ulfyus fought and unhorsed another of Claudas's knights.

Sir Brastias fought and unhorsed the last of Claudas's knights.

*Sir Ulfyus and Sir Brastias laid King Claudas's last two knights
on the ground.*

All of King Claudas's knights were hurt and bruised.

;M195: In the story, the knight B16 was hurt at time B26.

;M198: It is not the case that B16 was dead at time B26 (deduced).

;M199: In the story world, B26 is after B24.

;M201: In the story, the knight B16 was bruised at time B26.

;M202: In the story, the knight B19 was hurt at time B26.

;M205: It is not the case that B19 was dead at time B26 (deduced).

;M206: In the story, the knight B19 was bruised at time B26.

;M207: In the story, the knight B23 was hurt at time B26.

;M208: In the story, the knight B23 was bruised at time B26.

;M209: In the story, the knight B25 was hurt at time B26.

;M210: In the story, the knight B25 was bruised at time B26.

R perceived no contradiction between the above passage and the original definition of smiting as killing (R_2). In this run, however, Cassie did not believe that one could be simultaneously hurt and dead. Even without that belief, however, she would not return to believing something she has already withdrawn because of a contradiction.

The information that the knights B16 and B19 were hurt was added in forward-chaining mode to allow Cassie to notice that that they were still alive at time B26 (and therefore could not have died earlier at time B21. Of course, B23 and B25 are not dead, either, but the information on their suffering was simply asserted, so Cassie doesn't notice whether they're dead or not). Cassie has now heard of two cases in a row (King Arthur, and the knights B15 and B16) where a smitee has survived being smitten, with no intervening cases of death by smiting. Therefore, when the verification function checks to see whether the possible consequents of questionable rules hold true, it finds that the possible death consequence of being smitten does not apply, and that consequence is eliminated from the rule, and the KN_CAT is upgraded to "life-rule.2". Barring further contradictions, the rule has stabilized, although the definition could still be updated by adding more possible categories for the subject and object of "smite" or by deducing something about the conditions that enable smiting. The definition reported now is approximately the same as that R was considering after the next passage (R_3).

```
;See whether the possible consequents of any questionable rules
;have been shown to be either true or false.
--> (snebr::verify)
```

```
;Print all terms whose meaning is understood to be questionable.
--> (print snebr::mdoubt)
```

```
;No such terms found.
NIL
```

```
;Describe the questionable rule originally created after the detection
;of the contradiction.
* (describe M123)
```

```
;No response, which means that the rule M123 no longer exists in the current context.
```

```
;Describe the new rule created to replace it.
* (describe M236)
```

;M236: It is a life-rule.2 that if V18 smites V19 at time V20, then
; V18 hits V19 at time V20.
(M236! (FORALL V18 V19 V20)
(ANT
(P23 (ACT (M37 (LEX smite))) (AGENT V18) (OBJECT V19) (TIME V20)))
(CQ (P24 (ACT (M38 (LEX hit))) (AGENT V18) (OBJECT V19) (TIME V20)))
(KN_CAT life-rule.2))

Define the verb “smite”

; A person can **smite** a person. If *x* smites *y* at time *z*,
; then *x* hits *y* at time *z*.

When Sir Brastias saw that his fellow fared so, he smote the duke with a spear so that horse and man fell down. King Claryaunce saw that and turned unto Sir Brastias; each smote the other so that horse and man went to the earth. They lay long stunned and their horses’ knees had burst to the hard bone. [p. 19]

Sir Brastias smote a duke with a spear, so that he and his horse fell down..

;M304: Brastias (B15) hit B27(a duke) at time B29 (deduced).

King Claryaunce turned to Sir Brastias and each smote the other so that they and their horses fell to the earth.

Sir Brastias and King Claryaunce were stunned and lay on the ground.

Define the verb “smite”

; A person can **smite** a person. If *x* smites *y* at time
; *z*, then *x* hits *y* at time *z*.

At this point in the text (passage 3) Cassie’s definition is equivalent to R’s definition.

He encountered a knight and smote him through with a spear so that he fell dead unto the earth. [...] King Carados was smitten to the earth; with that, the King with the Hundred Knights came and rescued King Carados mightily by force of arms, for he was a passing good knight and but a young man. [p. 22]

Someone encountered a knight.

He smote the knight with a spear, so that the knight fell dead to the earth.

Define the verb “smite”

; A person can **smite** a person. If *x* smites *y* at time
; *z*, then *x* hits *y* at time *z*.

We have now read of a case where smiting does result in death, but Cassie no longer considers the meaning of smite questionable, and so is not looking for further evidence. Rule M124! is still

present, however, so even if the cause of death were not explicitly stated in the story, Cassie could infer that *in this case* death was caused by B37 hitting B38. But possible death is no longer part of her definition of “smite”. At this point, R introduced the possible-death clause that Cassie introduced after the first passage led to a contradiction with the original definition.

*King Carados was smitten to the earth.
Another king rescued him.*

[A shield was hanging from a tree.] **Then Gryflette smote on the shield with the butt of his spear, so that the shield fell down on the ground. With that the knight came out of the pavilion and said, ‘Fair knight, why smote ye down my shield?’**

‘Because I will joust with you,’ said Gryflette.

[...]

Then the two knights ran together, so that Gryflette’s spear broke into pieces. Therewith the knight smote Gryflette through the shield and the left side and broke his spear so that the truncheon stuck in Gryflette’s body; both horse and knight fell down. [pp. 32-33]

*A shield hung from a tree.
Gryflette smote on the shield with his spear, so that the shield fell down to the ground.*

;M413: B48 hit B45 (a shield) at time B50 (deduced).

*A knight came out of a pavilion.
The knight asked Sir Gryflette why he smote down the knight’s shield.
Sir Gryflette said that he would joust with the knight.*

At this point, R permanently dropped the concept of killing from the definition of “smite”, at least in part because shields cannot be killed. Since the KB for this run contained no information about the types of things that can or cannot be killed, Cassie could perform no such reasoning, but since the decision to omit the clause about possible death had already been made before this point, there would be no change to the definition even if she had had such information. R now raised the possibility that smiting might imply hitting and knocking down. If Cassie had not had the general rule that smiting implies hitting, she would list the smitee falling down as a possible result, but since she has a general rule, she does not look for results from individual cases.

Then the two knights ran together, so that Gryflette’s spear broke.

*Then the knight smote Gryflette in the left side and broke his
spear so that the truncheon stuck in Gryflette.
Both Sir Gryflette and his horse fell down.*

Define the verb “smite”

; A person can **smite** a person or shield. If x smites y
; at time z , then x hits y at time z .

This passage resulted in no change for Cassie. R continued to consider the possibility that to smite something meant to hit it and knock it down. The next passage (passage 7 from the “smite” protocol) involved Balyn and Balan repeatedly smiting one another, without any reference to them falling down, at which point R dropped the “knock down” hypothesis and reverted to defining “smite” as “hit very hard”. The subsequent passages from the protocol involved no change in R’s definition, nor would they change Cassie’s reported definition, so they were not included as part of this run.

7.4.1. Alternate “Smite” Demonstration

As described in chapter six, our algorithm for subtractive revision is a two-step process. When a rule’s consequent leads to a contradiction, it is softened to a *possible* consequent. Then, if Cassie learns of a second case where that possible consequent does not apply, it is removed entirely. On the other hand, if Cassie learns of a case where it does hold before she learns of a second case where it doesn’t, then the possible consequence is made a more or less permanent part of the rule. In the run shown above, Cassie quickly found a second case where a smitee survived. In the run below, we use the same text from Malory’s story, but the KB does not include the rule that being hurt implies being alive. Since much of the run is virtually identical to the previous demo, it is elided here. The full run appears in the appendix.

*King Arthur turned his horse and himself. He smote before and behind.
King Arthur’s horse was slain. Lot smote down Arthur.*

What property did King Arthur have at time B7?

;M55: King Arthur was dead at time B7.

King Arthur's knights rescued him. The four knights set Arthur on a(nother) horse. King Arthur drew Excalibur.

Rank your beliefs in order of certainty.

When did Arthur draw?

A contradiction was detected within context DEFAULT-DEFAULTCT.

The contradiction involves the newly derived wff:

(M101! (MIN 0) (MAX 0)
(ARG (M73! (ACT (M71 (LEX (draw)))) (AGENT (B1)) (TIME (B12))))
(M96 (ACT (M71 (LEX (draw)))) (AGENT (B1)) (TIME (B7))))))

and the previously existing wff:

(M73! (ACT (M71 (LEX (draw)))) (AGENT (B1)) (TIME (B12)))

[. . .]

Removed: (M37!) Added: (M104)

* (describe M103!)

;M103: It is a questionable rule that if V16 smite V17 at time V18,
; then V16 hits V17 at time V18 and possibly V17 is dead at time V18.

* (describe M104!)

;M104: It is a life-rule.2 that if V16 smites V17 at time V18, and V17
; is dead at time V18, then V16 hitting V17 is the cause of V17
; being dead at time V18.

List all terms whose meaning is you believe to be questionable

;(smite)
(M35)

Define the verb "smite"

; A person can **smite** a person. If *x* smites *y* at time *z*,
; then *x* hits *y* at time *z* and possibly *y* is dead
; at time *z*.

So far the run is exactly like the previous one. The same contradiction is noted and the same strategy is followed for revising the rule about what it means to smite.

Two of King Claudas's knight rode toward a passage. Sir Ulfyus rode ahead. Sir Brastias rode ahead. Sir Ulfyus smote down one of King Claudas's two knights.

;M148: Sir Ulfyus (B14) hit B16 at time B21 (deduced).

;M150: Possibly B16 was dead at time B21 (deduced).

Sir Brastias smote down the other knight.

;M164: Possibly B19 was dead at time B21 (deduced).

*Sir Ulfyus and Sir Brastias rode ahead. Sir Ulfyus fought and unhorsed another of Claudas's knights.
Sir Brastias fought and unhorsed the last of King Claudas's knights.
Sir Ulfyus and Sir Brastias laid the knights of King Claudas on the ground.
All of King Claudas's knights were hurt and bruised.*

*See whether the possible consequents of any questionable rules
have been shown to be true or false.*

;No definite affirmation or negation yet.

Define the verb "smite"

; A person can **smite** a person. If x smites y at time z ,
; then x hits y at time z and possibly y is dead
; at time z .

Now we see a difference between this run and the previous run. Without the rule that "hurt" implies "not dead", Cassie cannot say whether King Claudas's knights survived being smitten or not. Therefore M103 remains a questionable rule, and "smite" remains on the list of terms whose definition is in doubt.

Sir Brastias smote a duke with a spear, so that he and his horse fell down.

;M262: Brastias hit B27 at time B29 (deduced).

;M264: Possibly, B27 was dead at time B29 (deduced).

*King Claryaunce turned to Sir Brastias and each smote the other so that they
and their horses fell to the earth.*

;M285: Brastias (B15) hit (M36) Claryaunce (B31) at time B33 (deduced).

;M287: Possibly, Claryaunce was dead at time B33 (deduced).

;M299: Claryaunce (B31) hit Brastias (B15) at time B33 (deduced).

;M301: Possibly, Brastias was dead at time B33 (deduced).

Sir Brastias and King Claryaunce were stunned and lay on the ground.

List all terms whose meaning is understood to be questionable.

;(smite)
(M35)

See whether the possible consequents of any questionable rules have been shown to be true or false.

;No definite affirmation or negation yet.

Define the verb "smite"

; A person can **smite** a person. If x smites y at time z ,
; then x hits y at time z and possibly y is dead
; at time z .

(A (person) CAN SMITE A (person) RESULT= ((P21 P50)) ENABLED BY= NIL)

If the KB had contained a rule that one cannot be dead and be stunned at the same time, then Cassie could now drop the "possible death" consequence, but no such rule was present, and she does not know whether Brastias and Claryounce have survived or not.

Someone encountered a knight. He smote the knight with a spear, so that the knight fell dead to the earth.

;M360: In the story, M347 is the cause of M358 and M359.

;M347: In the story, B37 smote the knight B38 with B40 at time B39.

;M358: In the story, the knight fell to the earth at time B39.

;M359: In the story, the knight was dead (M19) at time B39.

;M352: B37 hit the knight (B38) at time B39 (deduced).

;M354: Possibly the knight B38 was dead at time B39 (deduced).

Now we have a case in which smiting does lead to death. This is the first case (since the passage that led to a contradiction with the original understanding) where Cassie can say for certain whether being smitten occasioned one's death or not. This means that the possible death consequence will not be dropped from the rule, but that the rule as it stands will have its KN_CAT upgraded.

See whether the possible consequents of any questionable rules have been shown to be true or false.

Print all terms whose meaning is understood to be questionable.

;No such terms remain.
NIL

Describe M362!

;M362: It is a life-rule.2 that if V16 smites V17 at time V18, then
; V16 hits V17 at time V18 and possibly V17 is dead at time V18.

Describe M103 [the questionable original revision]

;No response, which means that M103 no longer exists in the current context.

Define the verb “smite”

; A person can **smite** a person. If x smites y at time z ,
; then x hits y at time z and possibly y is dead
; at time z .

King Carados was smitten to the earth. Another king rescued him.

Define the verb “smite”

; A person can **smite** a person. If x smites y at time z ,
; then x hits y at time z and possibly y is dead
; at time z .

*A shield hung from a tree. Sir Gryflette smote on the shield with his spear,
so that the shield fell down to the ground.*

;M392: Gryflette (B48) hit (M36) the shield (B45) at time B50 (deduced).
;M394: Possibly the shield (B45) is dead at time B50 (deduced).

*A knight came out of a pavilion. The knight asked Sir Gryflette why he smote down
the knight’s shield. Sir Gryflette said that he would joust with the knight.*

Define the verb “smite”

; A person can **smite** a person or a shield. If x smites y at
; time z , then x hits y at time z and possibly y is
; dead at time z .

As was the case in the first “smite” demonstration, the KB for this run said nothing about what kinds of things can die, but the definition would be unaltered even if it did, since death is listed as only a possible consequence of smiting.

Our current implementation has Cassie first soften a contradicted consequent of a “life-rule.2” to a possible consequent, and then decide whether to drop or keep that possible consequent on the evidence of the single next case in which she can determine whether that possible consequent applies. There are,

however, “hooks” set in the code so that we could require Cassie to examine more than a single piece of evidence before deciding whether to keep or drop a questionable understanding. Essentially, instead of maintaining a single list of doubtful terms, Cassie would maintain lists corresponding to two or three degrees of doubt. If evidence appears both for and against the questionable understanding, Cassie could then vacillate for a while before eventually making her decision.

7.5. SOME GENERAL ANALYSIS OF THE MALORY-BASED DEMONSTRATIONS

In each of the demonstrations that had a corresponding protocol in section 3, we have made some mention of the way in which Cassie’s behaviour compared with that of the human readers. There are some points, however, which can be made concerning a general comparison of these runs with those protocols.

In general, Cassie was rather less flexible than the human readers. Although it appears that we humans tend to look more for evidence to support our hypotheses than for evidence to refute them, we are still more able than is Cassie (at present) to entertain, on the basis of little data, a conjecture that we can withdraw easily, since it was never really a belief. Our system does not currently allow Cassie to construct such conjectures without believing *something* about them, something that may need to be retracted quickly, so she must wait until she can deduce that a proposition is either true or presumably true before using it in a definition.

The human readers also showed more flexibility in selecting aspects of meaning to report. Cassie has a relatively small set of definitional frameworks from which to choose: a noun may be defined using the framework for a basic-level category, a subclass of a basic-level category, a physical object not known to belong to a basic-level category, an abstract object, or a class that cannot (yet) be typed as any of these. A verb is defined using the verb definition framework (or, if we view the number of arguments as establishing a separate framework, a verb is defined using the framework for a bitransitive, transitive, reflexive, or intransitive verb). But humans do not always use the same framework for all

words that fit one of these classifications. *Webster's Second* [1937: p. 1342], for example, adds what is essentially an “instrument” slot to one definition of the verb “joust” by saying that to joust is to “engage in combat . . . with lances”. But most intransitive verbs do not require an “instrument” slot in their definitions. (Actually, the sense in which the verb “joust” is used in the passages from Malory doesn't require a slot for instrument).

While our frameworks are fairly reasonable for most of the words they would be used to define, there are many special cases in English that may need an extra slot, or that may not need one of the slots that is present. A human reader can, if need be, add a slot in a special case, or decide that a slot is unimportant to the definition of a particular word, and omit it. Cassie does not have either option. Some slots may remain empty, if no information is found to fill them, but Cassie will always *look* for information to fill all and only the slots present in the framework currently being used.

