HOW CASSIE* CAN LEARN NEW WORDS FROM CONTEXT

*A Computational Cognitive Agent Implemented in an Intensional Knowledge-Representation, Reasoning, and Acting System

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SUMMARY

- **Computational cognitive theory of how NLU system can automatically expand vocabulary**
  - **by determining word meaning from context:**
  - **text, grammatical info, background knowledge**
  - **no external sources (human; on-line dictionary)**
- **Def = current hypothesis about word's meaning**
  - **revised upon successive encounters with word**
- **Using formal notion of what a "good" definition is ...**
  - **system finds fillers for slots in definition frame**

What does ‘brachet’ mean?

What does 'brachet' mean?

According to the OED, a brachet is :

"a kind of hound which hunts by scent"

What does 'brachet' mean?

From Malory's Morte D'Arthur [page numbers in brackets]:

1.
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. [66]

2.
Then the hart went running about the Round Table; as he went by the sideboard, the white brachet bit him in the buttock and pulled out a piece. [66]

3.
Whereupon the heart leapt a great leap and overthrew a knight who sat at the sideboard. Therewith the knight arose, took up the brachet, went forth out of the hall, took his horse and rode away with the brachet. [66]

4.
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." [66]

5.
"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." [67]

6.
"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." [67]

7.
When Sir Tor was ready, he mounted upon his horse's back, and rode after the knight with the brachet. [71]

8.
"Ye shall say 'by the knight who went in quest of the knight with the brachet.' Now what are your two names?" [71]

9.
"I know you ride after the knight with the white brachet, and I shall bring you where he is," said the dwarf. [72]

10.
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. [7s]

11.
As soon as Sir Tor spied the white brachet, he took it by force and gave it to the dwarf. [72]

12.
With the noise, the lady came out of the pavilion with all her damosels. "What! Will ye take my brachet from me?" said the lady. [72]

13.
"Yes," said Sir Tor, "this brachet I have sought from King Arthur's court hither." [72]

14.
Then they heard a knight call loudly who came after them; he said, "Knight, stop and yield my brachet that thou took from my lady." [72]

15.
[They fight.] Sir Tor bade him yield. "That will I not," said Abelleus, "while my life lasteth and my soul is within my body, unless thou wilt give me the brachet."

16.
"That will I not do," said Sir Tor, "for it was my quest to bring back thy brachet, thee, or both." [73]

17.
"Earlier, when I would have granted you mercy, you would ask none unless ye had the brachet again that was my quest." [74]

18.
Then they were aware that the hart lay dead on a great water-bank; a brachet was biting on his throat, and other hounds came behind. [86]

19.
Now we leave them and speak of Sir Lancelot, who rode a great while in a deep forest where he saw a black brachet tracking as if it were on the trail of a hurt deer. [159]

20.
Therewith he rode after the brachet, and he saw on the ground a large trail of blood. [159]

21.
Then Sir Lancelot rode faster, and always the brachet looked behind her. ... [159]

22.
... She went through a great marsh and he followed; then he was aware of an old manor, and thither ran the brachet and so over a bridge. [159]

23.
Sir Lancelot rode over that bridge, which was old and weak; when he came into the middle of a great hall he saw a dead knight lying there who was a seemly man, and the brachet licked his wounds. [159]

24.
"Why say ye so?" said Sir Lancelot. "I never did this knight any harm, for hither by a trail of blood this brachet brought me." [159]

DEMO: I/P = formal-language version of simplified English.

... 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 ... [p. 66]

A hart runs into King Arthur's hall.

- **In the story, B17 is a hart.**
- **In the story, B17 runs into B18.**
- **In the story, B18 is a hall.**
- **In the story, the hall (B18) is a hall of its possessor, King Arthur (B3).**

A white brachet is next to the hart.

- **In the story, B19 is a brachet.**
- **In the story, the brachet has the property "white".**
- **Brachets are a subclass of physical object (deduced since only physical objects have color)**

```
--> (defn_noun 'brachet)

((CLASS INCLUSION      = (phys obj))
 STRUCTURE             = NIL
 FUNCTION              = NIL
 ACTIONS               = (NIL)
 OWNERSHIP             = NIL
 POSSIBLE PROPERTIES   = ((white))
 SYNONYMS              = NIL)
```

... The brachet bites the hart's buttock.

```
--> (defn_noun 'brachet)

((CLASS INCLUSION      = (animal))
 STRUCTURE             = NIL
 FUNCTION              = NIL
 ACTIONS =
  ((POSSIBLE ACTIONS = (bite)))
 OWNERSHIP             = NIL
 POSSIBLE PROPERTIES = ((white))
 SYNONYMS              = NIL)
```

... The knight picks up the brachet.
... The knight carries the brachet.

```
--> (defn_noun 'brachet)

((CLASS INCLUSION      = (animal))
 STRUCTURE             = NIL
 FUNCTION              = NIL
 ACTIONS =
  ((POSSIBLE ACTIONS = (bite)))
 OWNERSHIP             = NIL
 POSSIBLE PROPERTIES = ((small white))
 SYNONYMS              = NIL)
```

... The lady says that she wants the brachet.

```
--> (defn_noun 'brachet)

((CLASS INCLUSION      = (animal))
 STRUCTURE             = NIL
 FUNCTION              = NIL
 ACTIONS =
  ((POSSIBLE ACTIONS = (bite)))
 OWNERSHIP             = NIL
 POSSIBLE PROPERTIES =
                  ((small valuable white))
 SYNONYMS              = NIL)
```

... The brachet bays in the direction of Sir Tor.

```
--> (defn_noun 'brachet)

(A BRACHET IS A KIND OF (dog)
 ACTIONS =
  ((POSSIBLE ACTIONS = (bay bite)))
 FUNCTION              = ((hunt))
 STRUCTURE             = NIL
 OWNERSHIP             = NIL
 SYNONYMS              = NIL)
```

*** SYSTEM'S BEHAVIOR ≈ HUMAN PROTOCOLS ***
*** OED: A brachet is "a kind of hound which hunts by scent"**

A Computational Theory of Vocabulary Acquisition

Computational cognitive theory of how NLU system can automatically expand vocabulary

- by determining word meaning from context:

  = grammatical info + text
  + background knowledge

- no external sources (human, on-line)

- domain-independent

- definition =
  current hypothesis about word's meaning

  - revised each time word is seen

A Computational Theory of Vocabulary Acquisition

- Part of cognitive science project:
  Narrative text understanding
  Important for:
  message-processing systems,
  intelligent agents
  - There can be no complete lexicon
  - Such systems shouldn't have to stop to ask questions

Other applications:
language acquisition studies
computational lexicography
education

A Computational Theory of Vocabulary Acquisition

- 3 kinds of words:
  - unknown, misunderstood, new use ('brachet', 'smite', 'dress')
- Initial hypothesis
  - "Tommy broke a vase."
    'vase' $=_{df}$ phys. obj. breakable by human

Revision(s) upon further encounter(s)
Converges to dictionary-like def.
Settles down, but subject to revision

- Implementation:
  - SNePS + SNeBR + SNePSwD (+ GATN)

Why bother?

- To model ability to learn (vocabulary) from reading
- Can't manually encode fixed complete lexicon in advance
- { { Text-understanding / Message-processing / Information-extracting } systems / Intelligent agents }
  need to be (as) robust (as humans)
- Understanding understanding:
  - how semantics arises out of syntax
  - contra Chinese Room Argument

Fundamental Theses:

- **Linguistic contexts (& their mental counterparts) can provide meanings for expressions**

  - **including non-referential exprs (Meinong)**

  - **philosophical background:**

    - **Reader understands Narrative Text by interpreting NT's sentences**

    - **R's interpretation is a mapping from NT's sentences (syntactic domain) to R's mental concepts (semantic domain)**

    - **Meaning of word for R is its "location" in R's mental semantic network**
      - **Quine, Quillian**
      - **Conceptual Role Semantics, Holism**

* **Meaning of a word . . .**

  - **can be determined from any context**
  - **can be revised at each encounter**
  - **"converges" to a dictionary-like definition**

    (given enough context and encounters)

- **Context can be minimal or null:**

  - **"Tommy broke a vase."**
  - **(if null, then:)**

    vase = that which Tommy broke

    (if minimal knowledge, then:)

    vase = breakable physical object
  - **Cf.: Solving algebraic equation for unknown**

    (cf. Higginbotham)

- **Each encounter yields a definition (= hypothesis about meaning)**

* **Subsequent encounters allow for unsupervised revision of hypothesis**

* **No domain-specific background information is needed**
  - system need not be an expert in what it's reading

- **Larger context, more background info → better definition**

- **2 kinds of meaning:**

  - <u>idiolectic:</u> meaning of word for cog. agent is:

    * determined by idiosyncratic experiences with it
    * is its location in *entire* network of concepts (holistic)
      - too detailed

  - <u>dictionary-like:</u>

    * less info than full idiolectic meaning
    * info common to most speakers
    * network version: find subnet that abstracts certain conventional info

Long-term goal of the SNePS Research Group:

- to understand intelligent cognitive processes
- by developing & experimenting with a computational cognitive agent ("Cassie")
- who can use & understand NL
- who can reason & solve problems
- who can plan & execute actions, as well as reason about the plans

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computational psychology and computational philosophy

http://www.cse.buffalo.edu/sneps

The SNePS Knowledge Representation, Reasoning, & Acting System

Stuart C. Shapiro & SNeRG

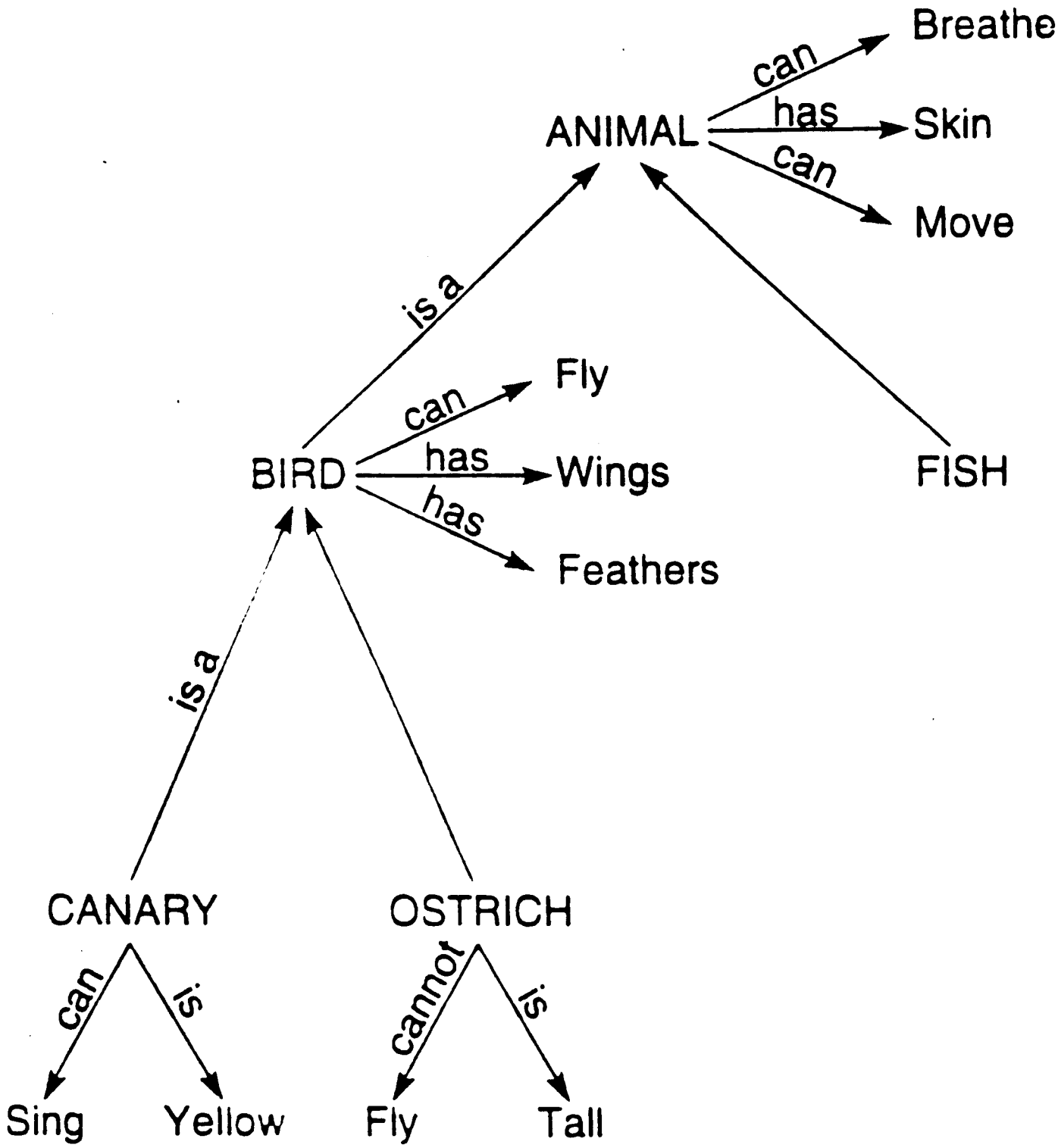
- KR:
  - Propositional semantic network
    - * NOT: taxonomic inheritance hierarchy
    - * propositions are represented by nodes
  - Fully intensional KR
    - ∴ can handle non-referring terms
      - & can distinguish betw. equivalent but ≠ items

- Reasoning:
  - node-based reasoning (w/ rules)
  - path-based reasoning (generalized inheritance)
  - belief revision (relevance logic)

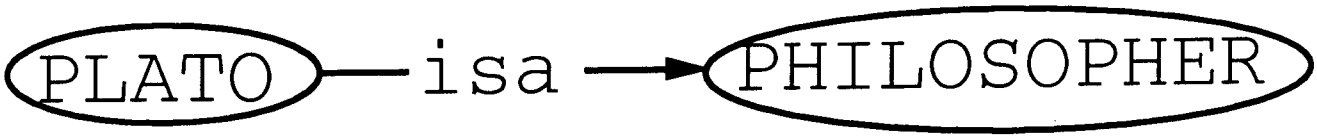
- Acting:
  - SNePS Rational Engine

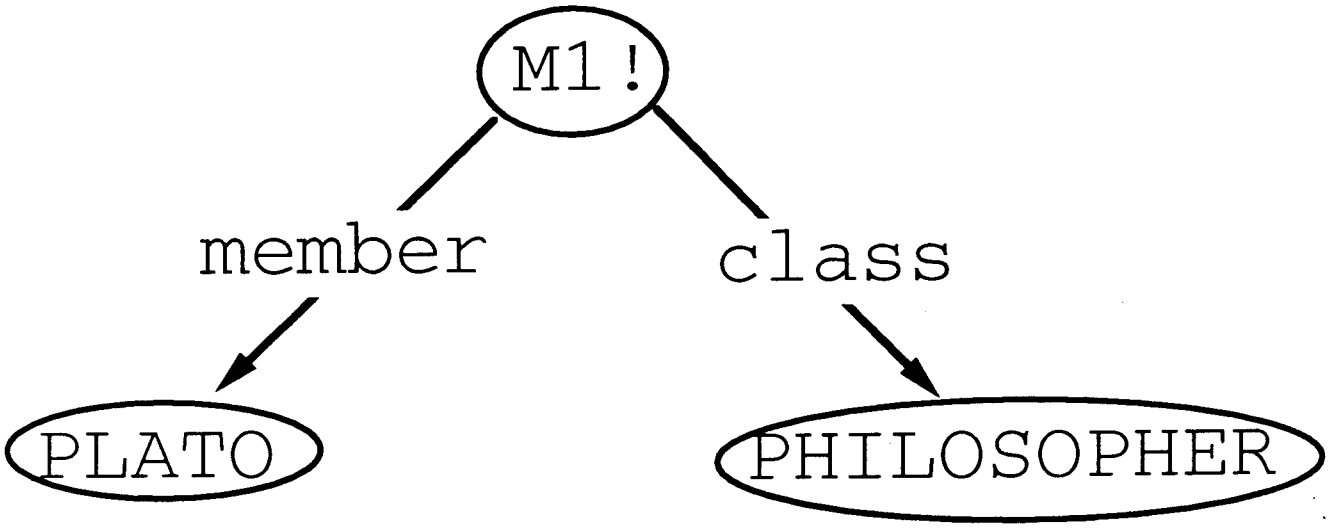
- Interfaces:
  - SNePSUL (Lisp-like)
  - SNePSLOG (logic-like)
  - Natural language understanding & generation

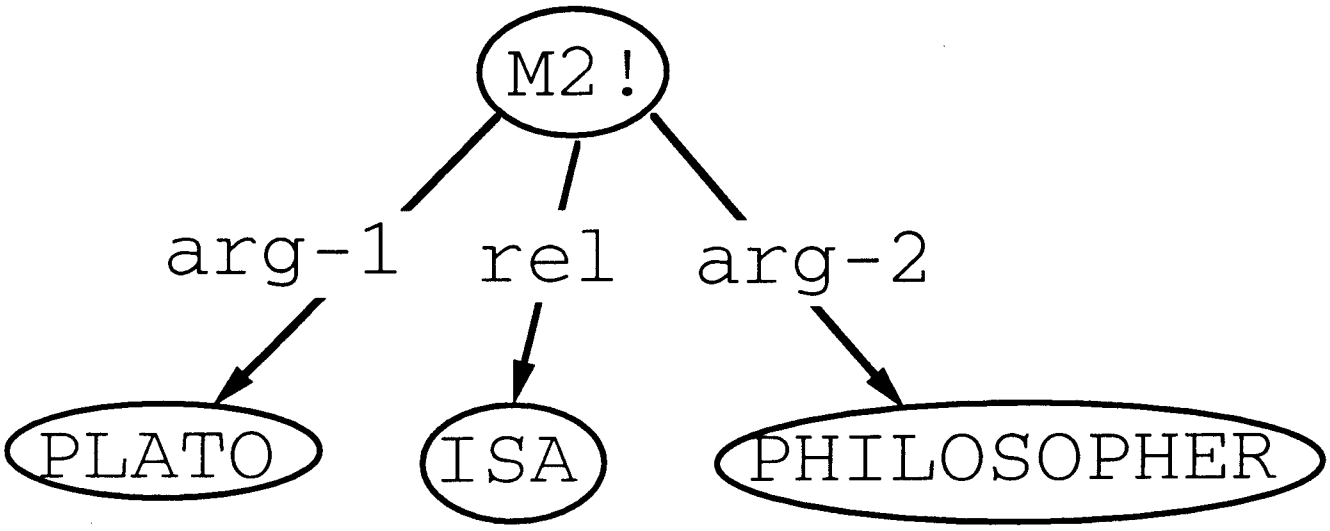
- propositional KR
- reasoning:
  - node-based (predicate logic)
  - path-based (inheritance)
  - belief revision
- intensional KR


Breathe
can
ANIMAL
has
Skin
can
Move
is a
Fly
can
BIRD
has
Wings
has
Feathers
FISH
is a
CANARY
OSTRICH
can
is
cannot
is
Sing
Yellow
Fly
Tall

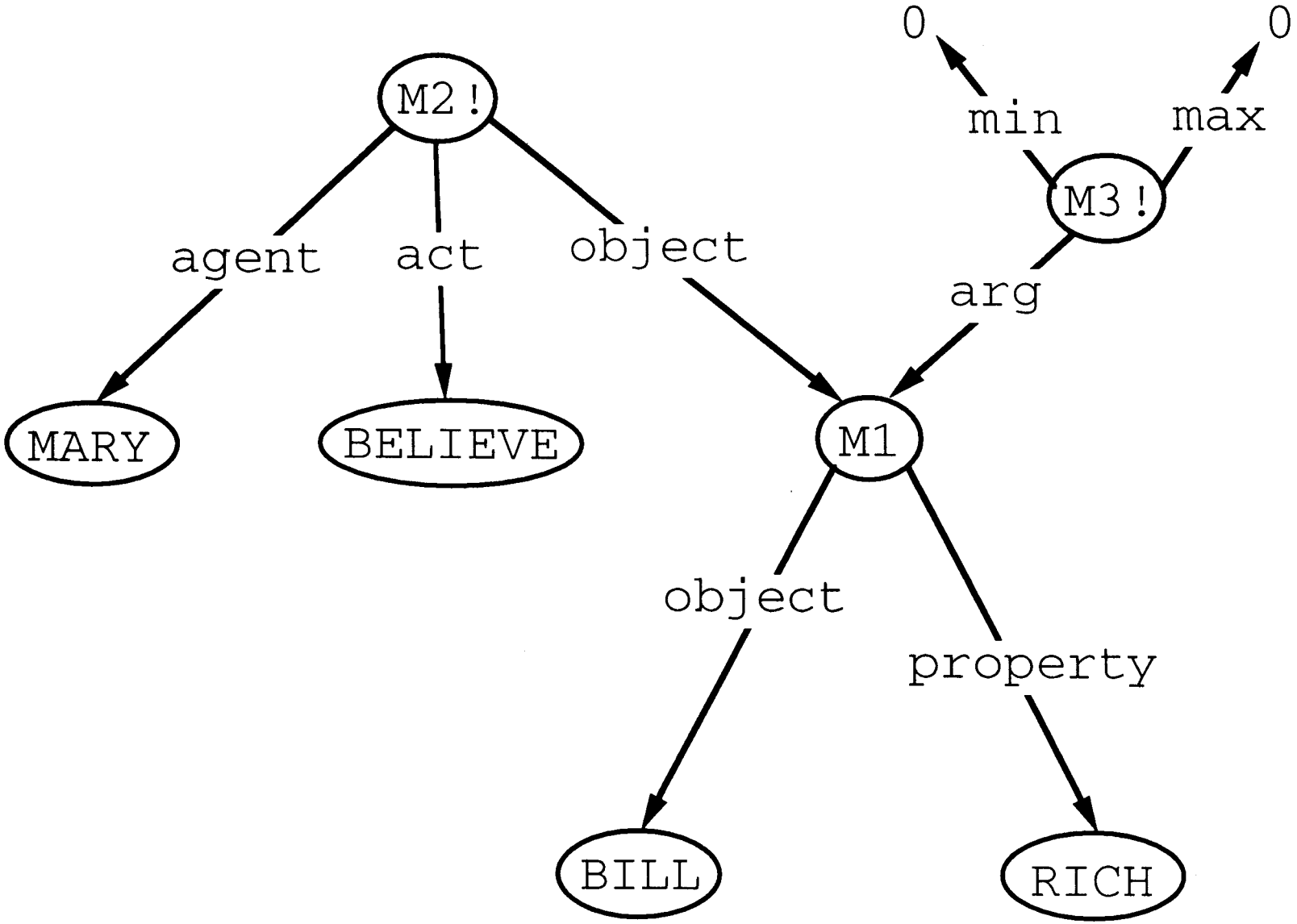
Propositional semantic networks:
"Plato is a philosopher"



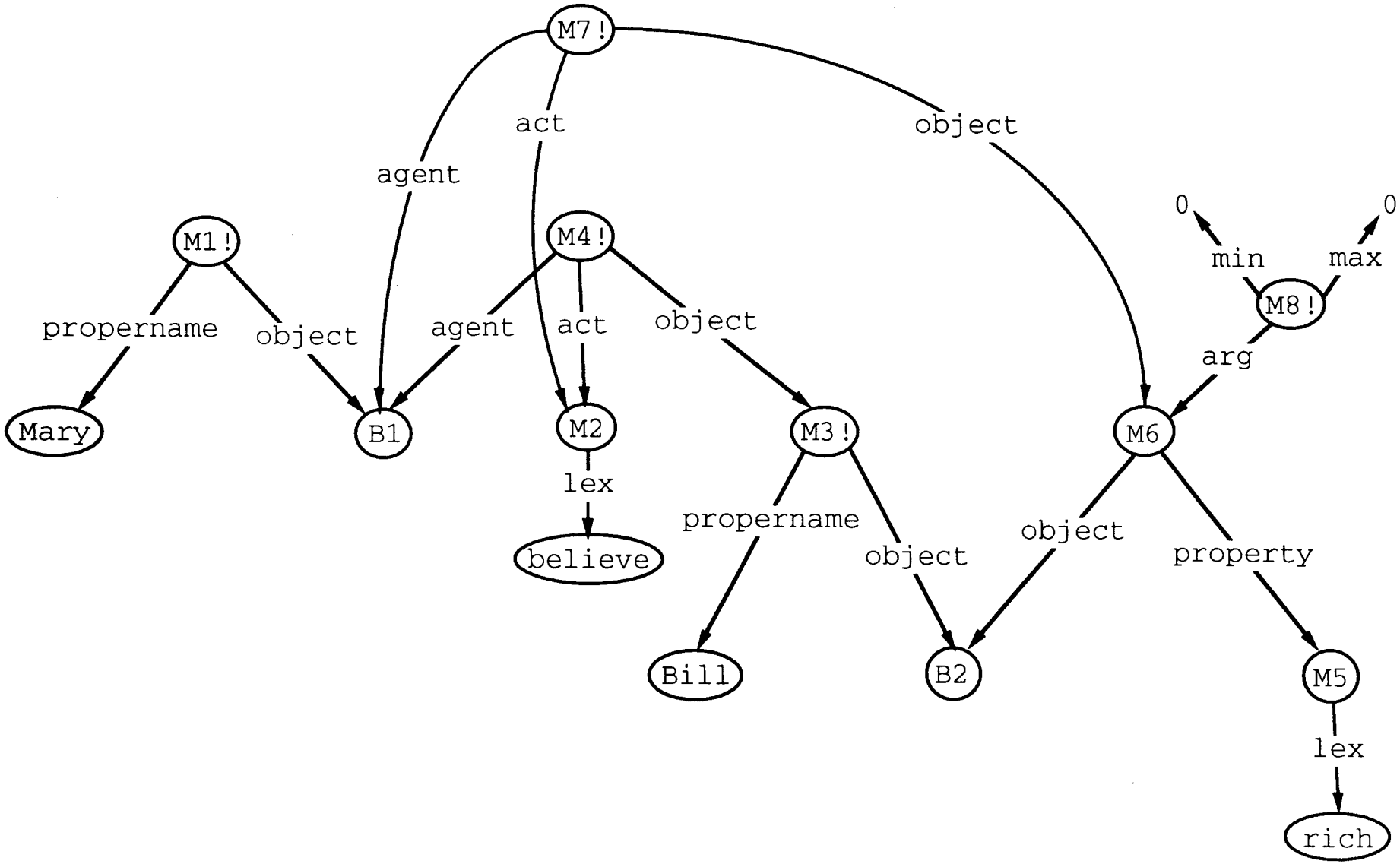


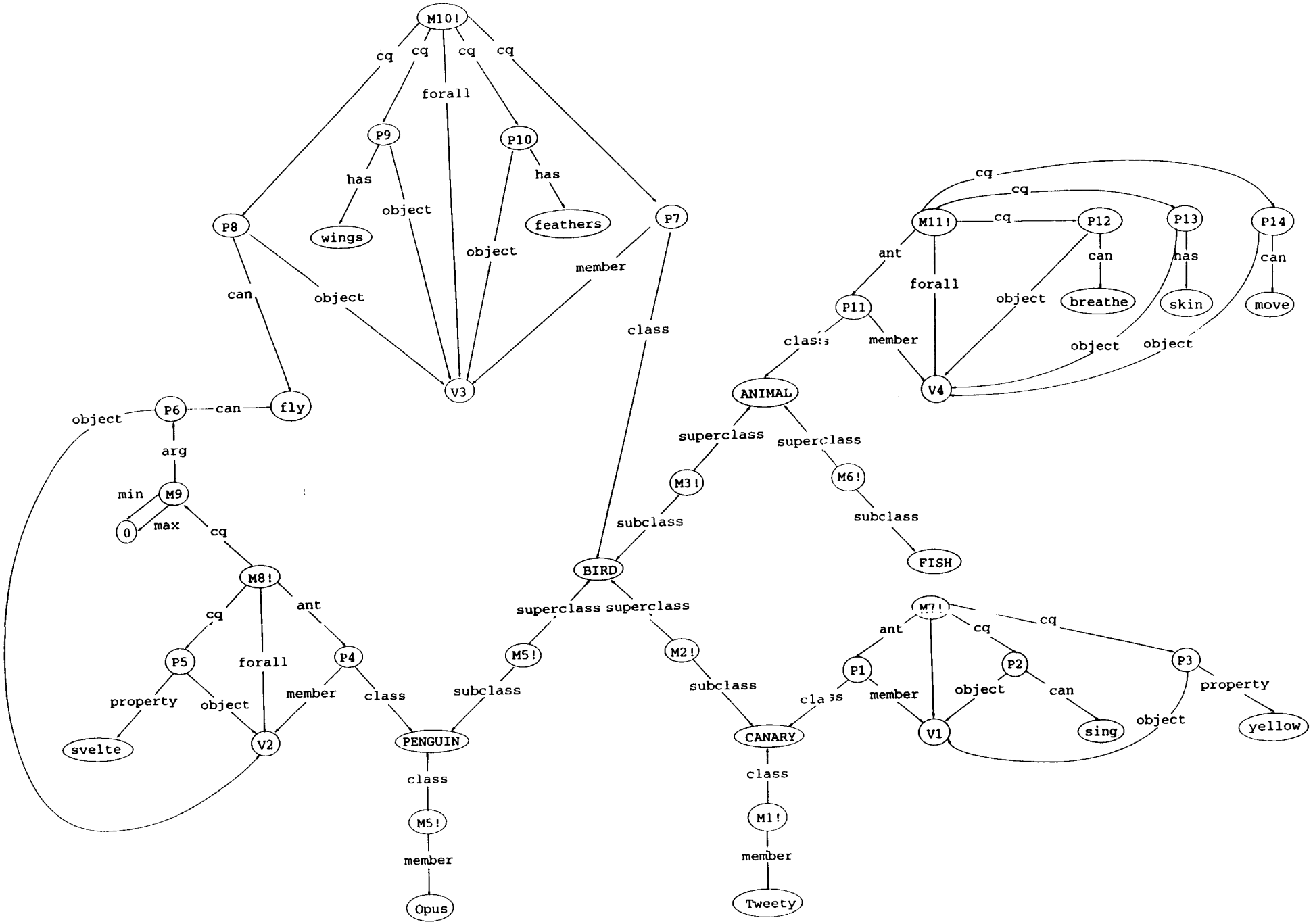


Propositional semantic networks:
"Mary believes Bill is rich, but he isn't."



Propositional semantic networks: **"Mary believes (de dicto) that Bill is rich, but he isn't."**

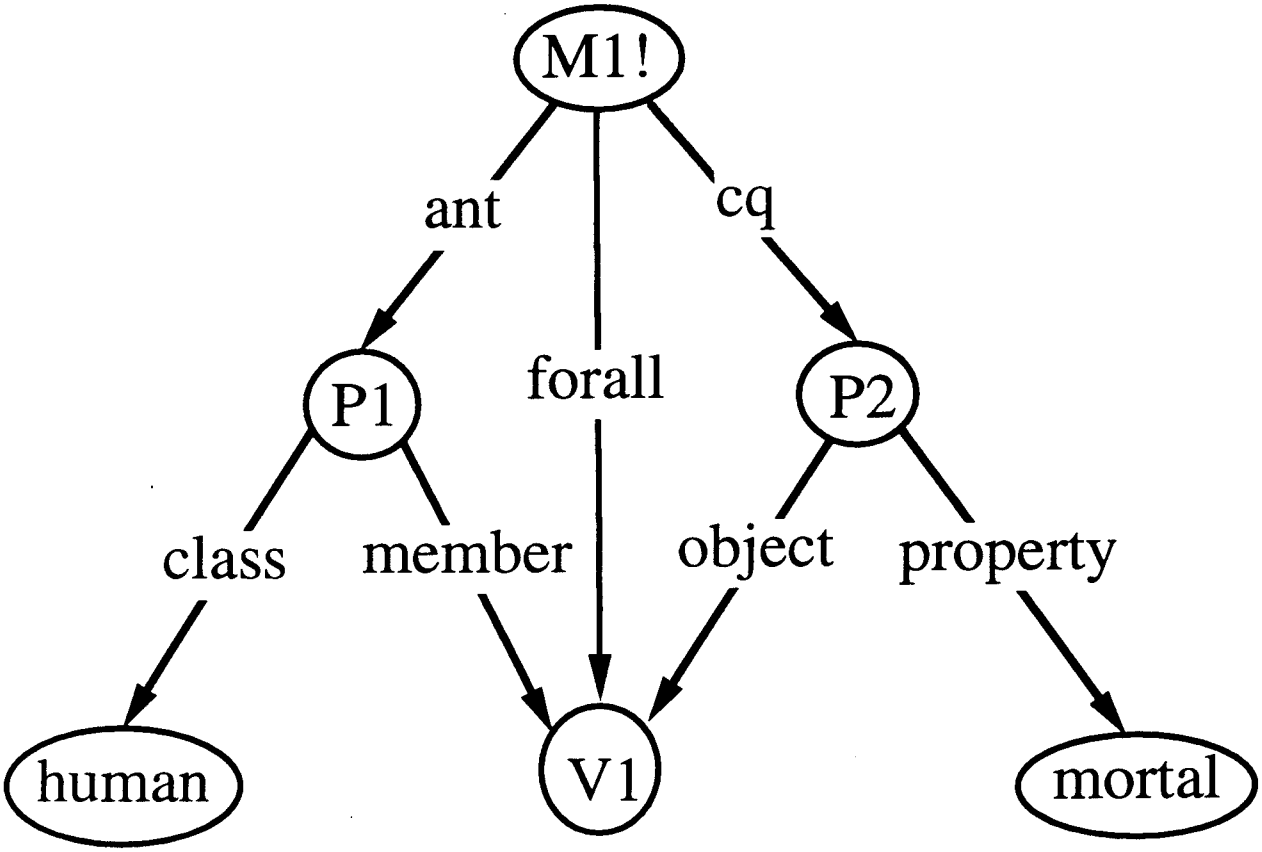



M10!
cq
cq
cq
cq
forall
P9
P10
has
has
wings
object
feathers
object
P8
P7
member
can
object
class
V3
P6
can
fly
object
arg
min
M9
0
max
cq
M8!
cq
ant
P5
forall
P4
property
object
member
class
svelte
V2
PENGUIN
class
M5!
member
Opus
BIRD
superclass
superclass
M5!
M2!
subclass
subclass
ANIMAL
superclass
superclass
M3!
M6!
subclass
subclass
FISH
M11!
cq
P12
P13
P14
ant
forall
can
has
can
P11
object
breathe
skin
move
class
member
object
object
V4
M7!
ant
cq
cq
P1
P2
P3
class
member
object
can
property
object
CANARY
V1
sing
yellow
class
M1!
member
Tweety

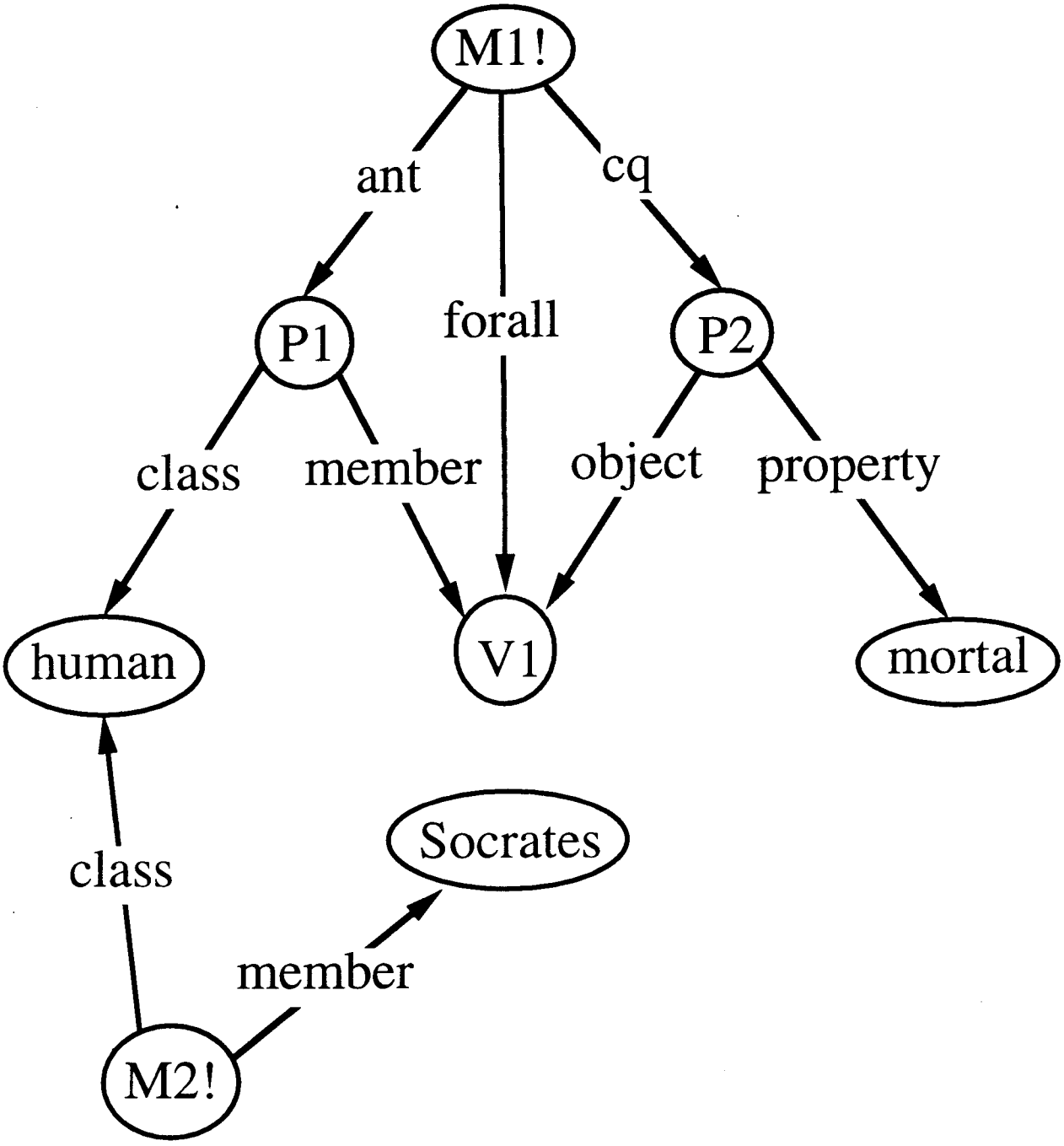
Node-based inference:

Rule node for "All humans are mortal"

$\forall V1[V1 \in human \rightarrow mortal(V1)]$



Node-based inference:
"All humans are mortal"
"Socrates is human"

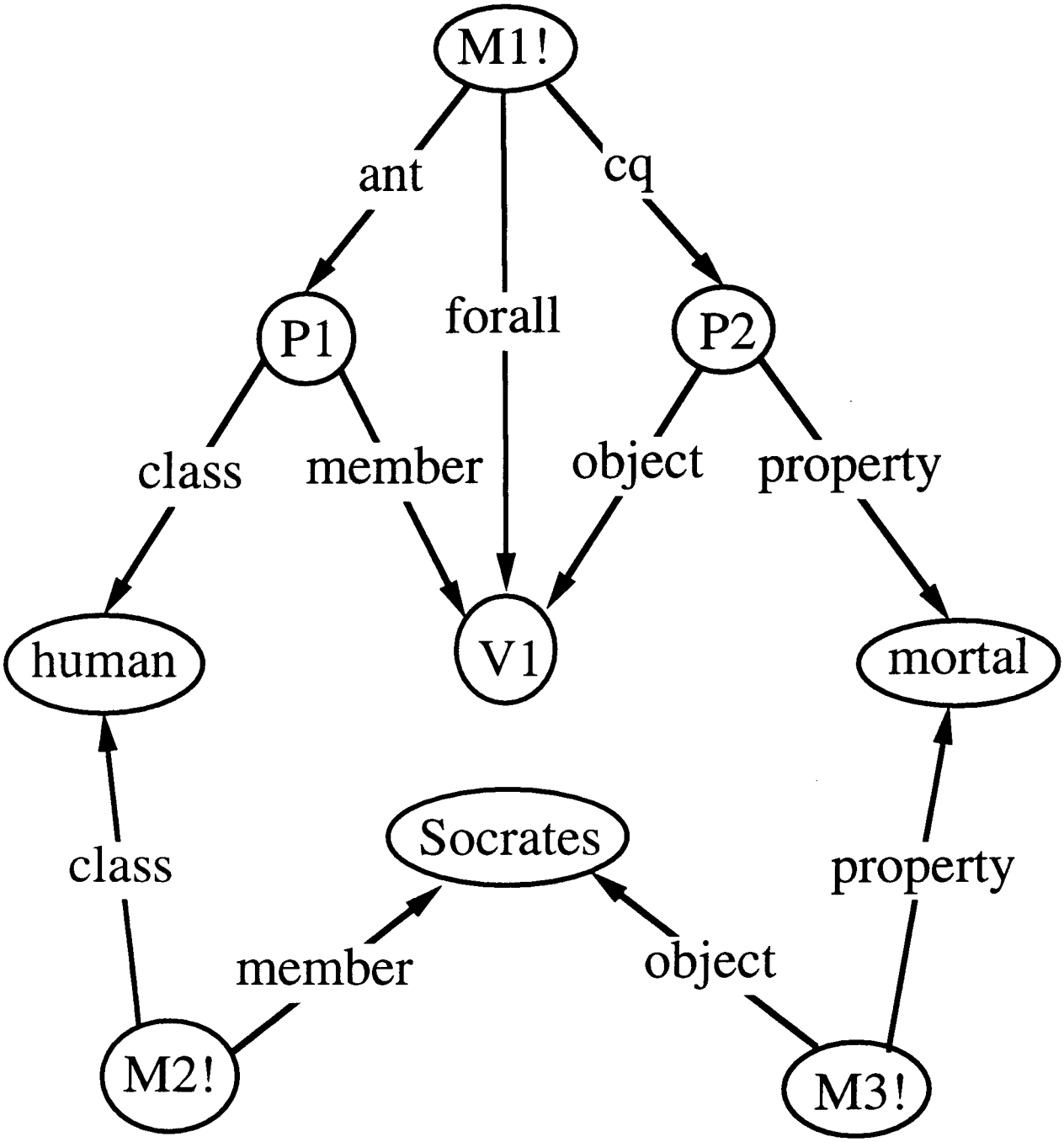


Node-based inference:

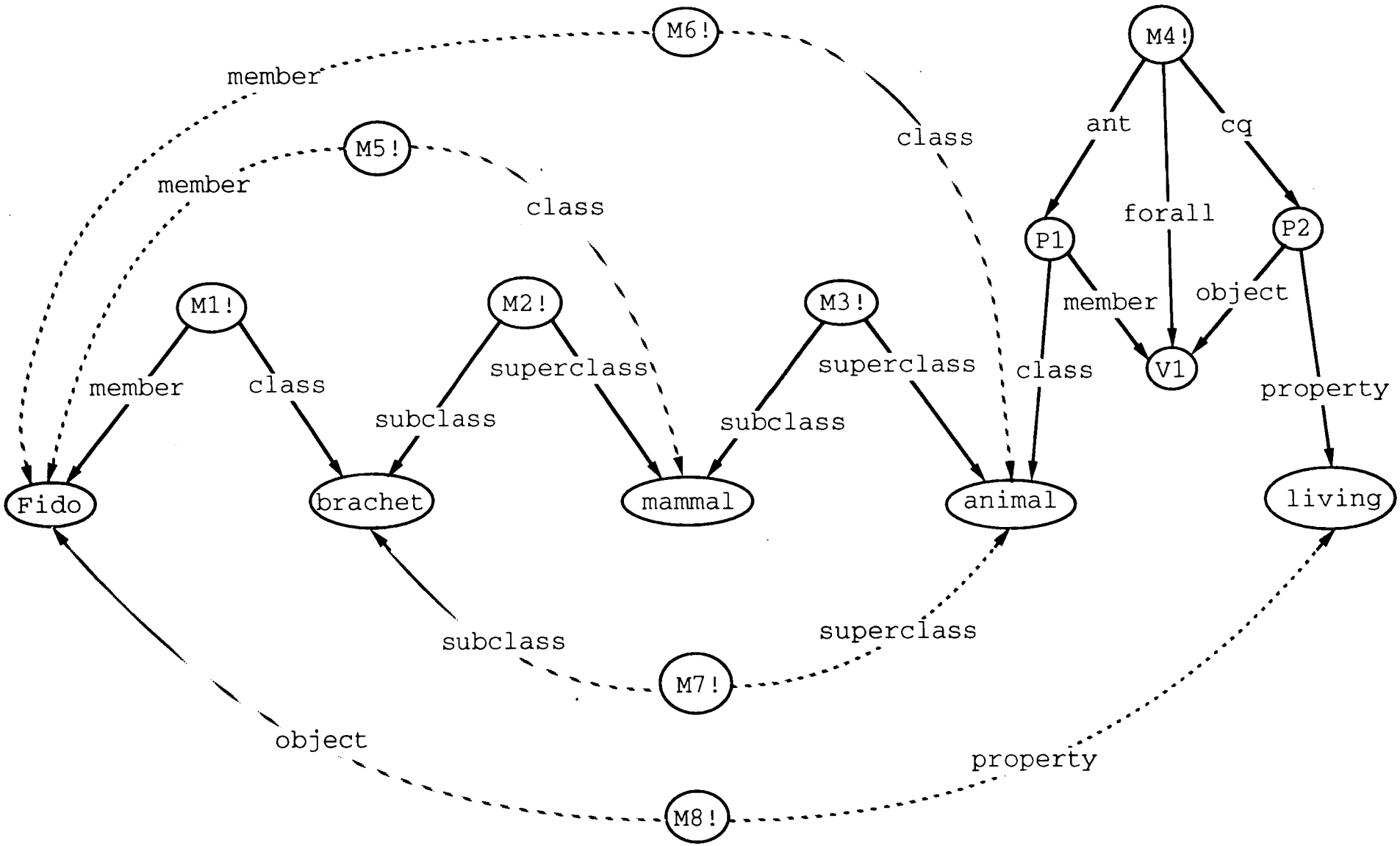
"All humans are mortal"

"Socrates is human"

∴ "Socrates is mortal"



Path-based inference:



INTENSIONAL KNOWLEDGE REPRESENTATION

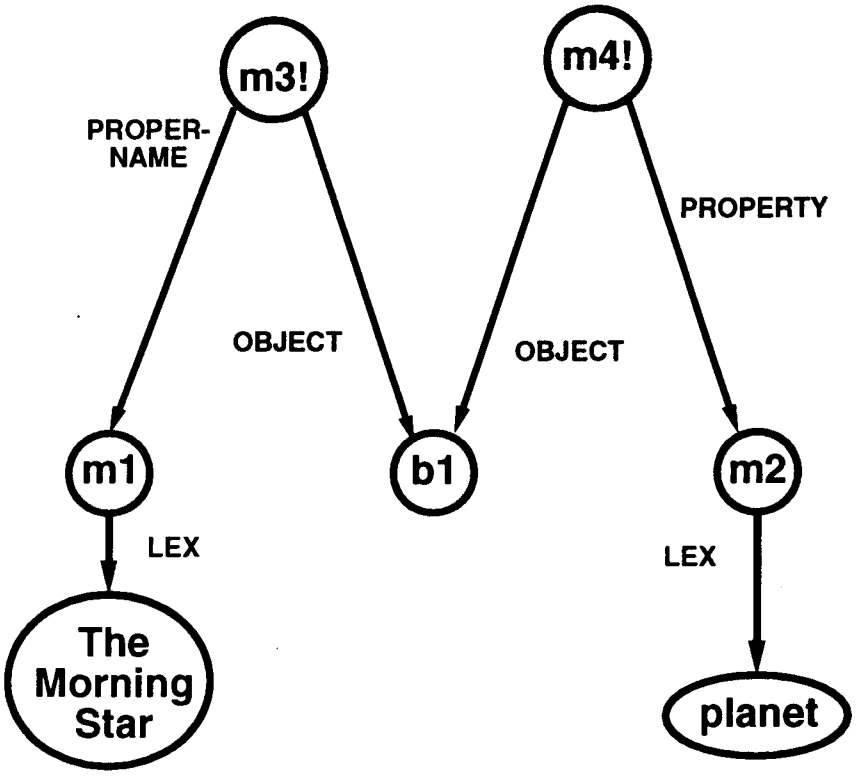
Kinds of Intensional Entities

- non-substitutible objects
  (e.g., the morning star, the evening star)
- indeterminate/incomplete objects
  (e.g., fictional entities)
- non-existent objects
  (e.g., unicorns, the golden mountain)
- impossible objects
  (e.g., the round square)
- objects of thought (intentional objects)
- intentionally distinct, but nec'ly =, objects
  (e.g., (a) the sum of 2 and 2, which nec'ly =
  (b) the sum of 3 and 1
  are distinct objects of thought)
- properties and relations "in intension"
- sets "in intension"
- propositions
- Kit Fine's arbitrary objects
  (e.g., the arbitrary triangle)

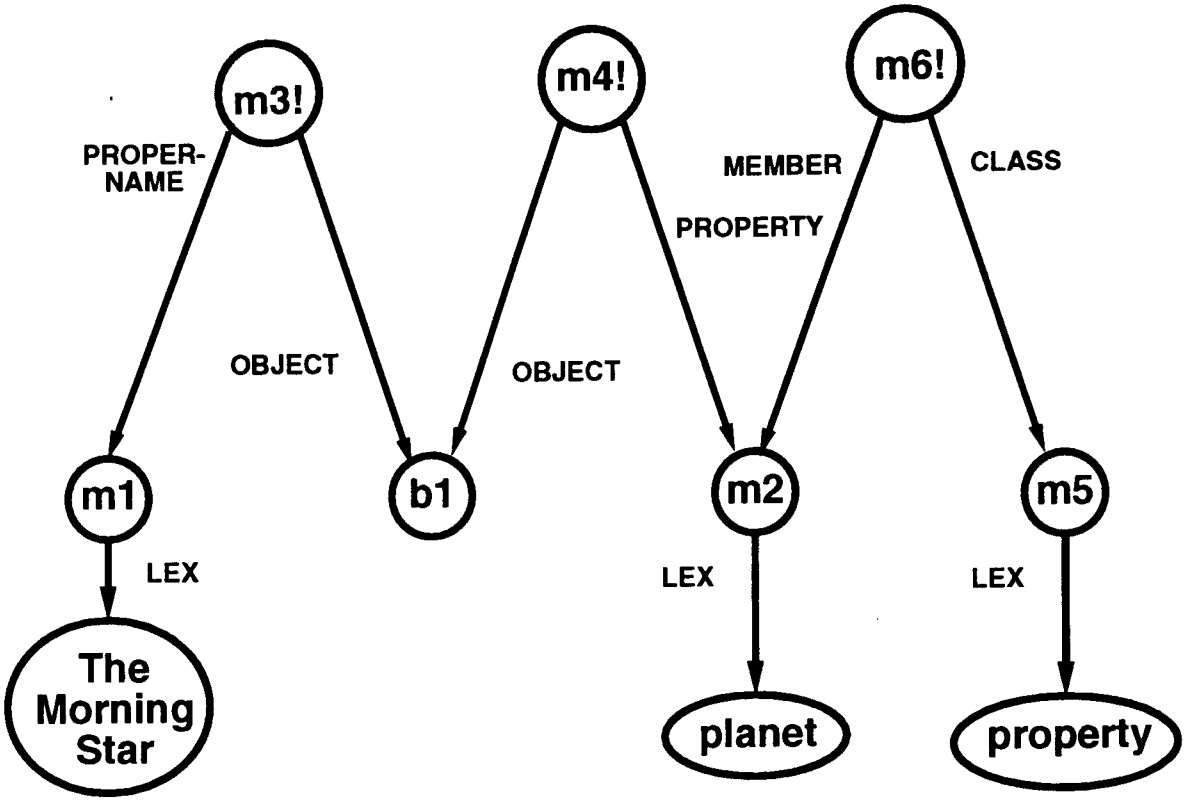
INTENSIONAL KNOWLEDGE REPRESENTATION

To model a mind, a KRR system
must model **only** intensional entities:

- *Fine-Grained Representation:*
  - IntenTional objects (objs. of thought) are intenSional
  - 2 objs. of thought, 1 extensional obj.
- *Displacement:*
  - Can think & talk about non-existent objects (fictional, impossible . . .)

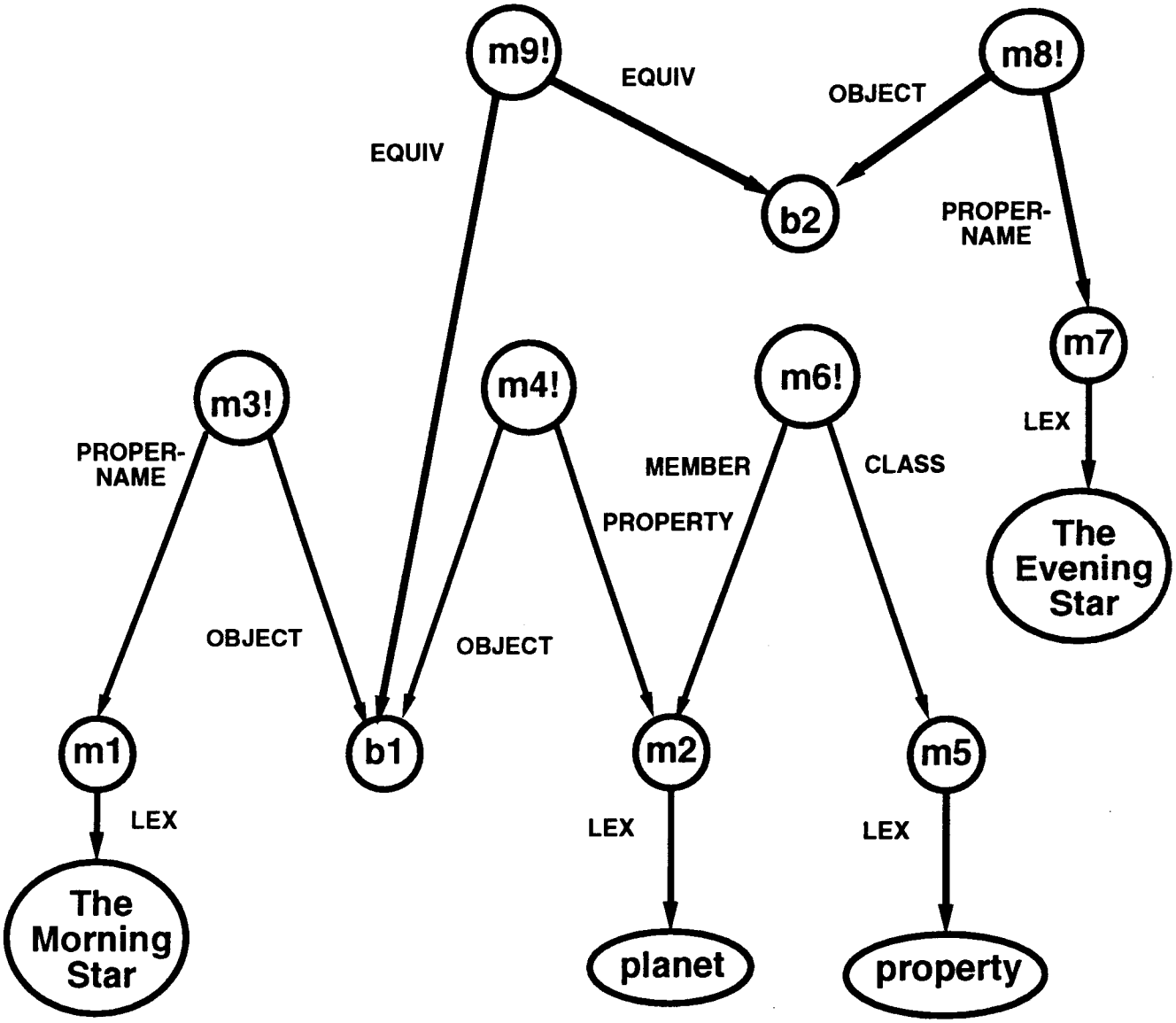


m4: The Morning Star is a planet



m4: The Morning Star is a planet

m6: being a planet is a property



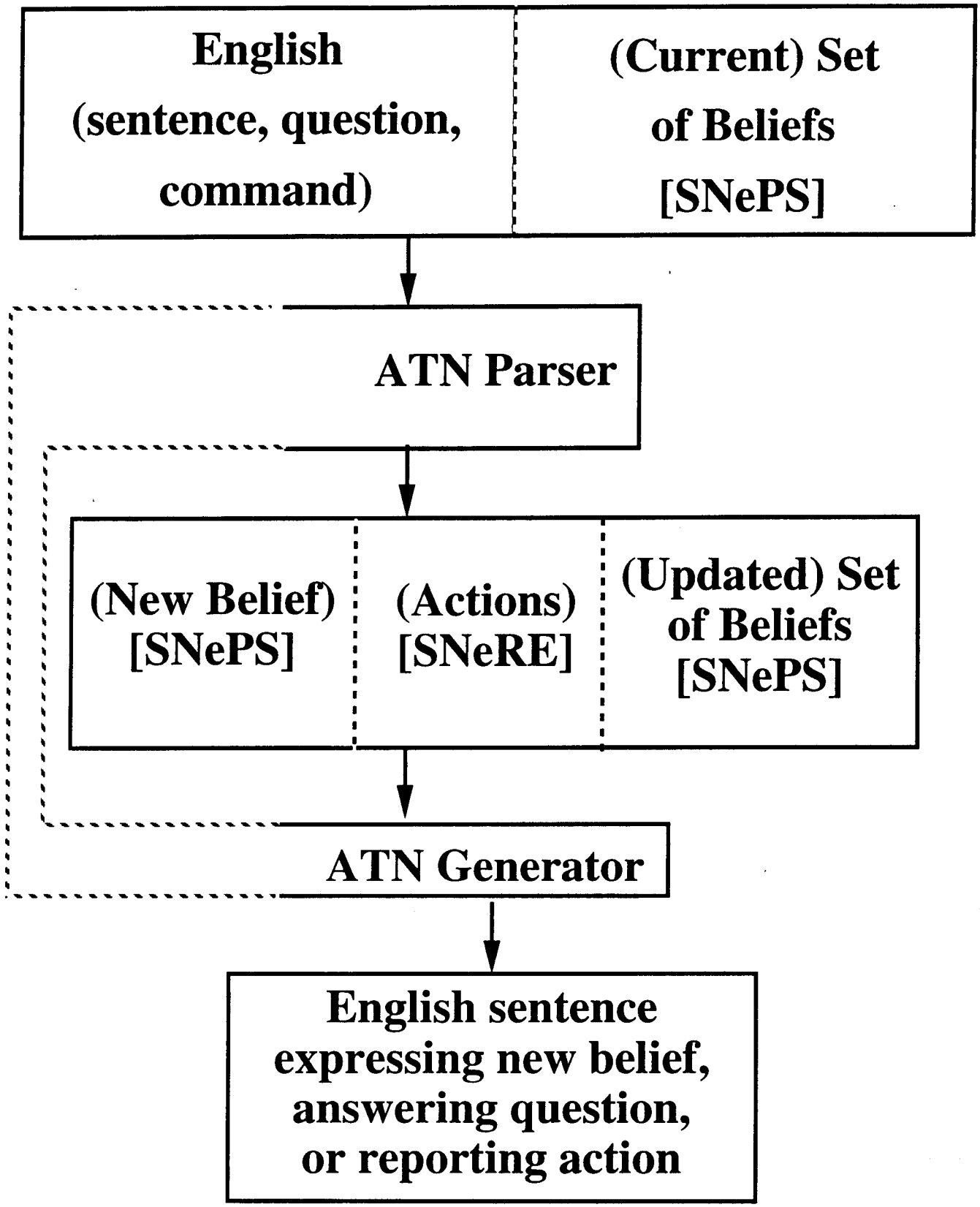
m4: The Morning Star is a planet

m6: being a planet is a property

m9: The Morning Star is the Evening Star.

CASSIE:

- Cognitive Agent of the SNePS System—an Intelligent Entity
- Nodes represent objects of Cassie's thoughts:
  - intenTional objects
- Cassie's "mind" grows (changes) as she reads/interacts
- Cassie believes what we tell her, as if it were fictional narrative


English
(sentence, question,
command)
(Current) Set
of Beliefs
[SNePS]
ATN Parser
(New Belief)
[SNePS]
(Actions)
[SNeRE]
(Updated) Set
of Beliefs
[SNePS]
ATN Generator
English sentence
expressing new belief,
answering question,
or reporting action

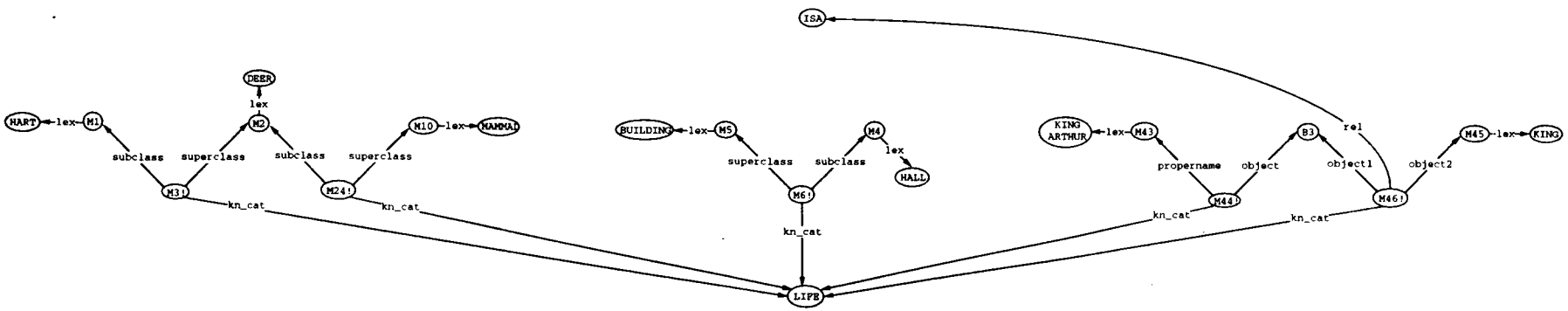
"Cat" is a basic-level category.
Presumably, cats purr.
Presumably, cats hunt.
Cats are mammals.
If x is a mammal, then it bears young.
If x bears young, then it is a mammal.
Cats are animals.
Cats are quadrupeds.
Mammals are animals.
Quadrupeds are vertebrates.
Vertebrates are animals.
Cats are predators.
Presumably, predators hunt.
Frisky is a cat.
Frisky sleeps in an armchair.
Predators are carnivores.
Presumably, carnivores eat meat.
Pyewacket is a cat.
Evelyn owns Pyewacket.
Evelyn is a person.
Pyewacket bears kittens.
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.
Deer are mammals
Deer are quadrupeds.
Deer are herbivores.
Carnivores are animals.
Predators are carnivores.
"Herbivore" and "carnivore" are antonyms.
"Predator" and "carnivore" 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 are persons.
"Person" is a basic-level category.
"Dog" 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.
If something is presumed to be an animal and a member of another class,
then presumably that class is a subclass of animal.
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.
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.

Background knowledge (`kn_cat` = "life")

M3: harts are deer
M6: halls are buildings
M24: deer are mammals
M46: King Arthur is a king

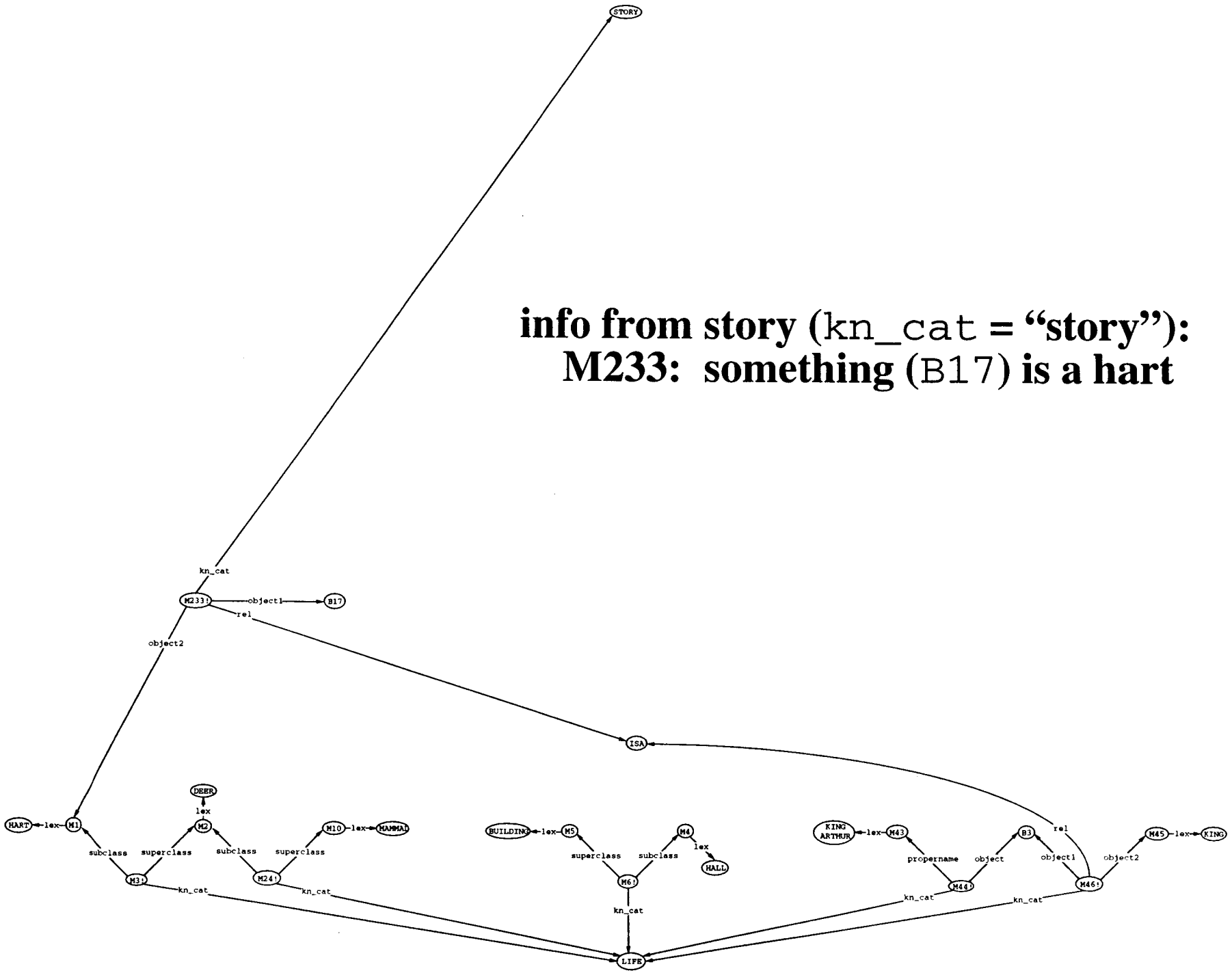


Right so as they sat, there came a white hart running into the hall with a white brachet next to him, and thirty couples of black hounds came running after them with a great cry. [p. 66]

A hart runs into King Arthur's hall.

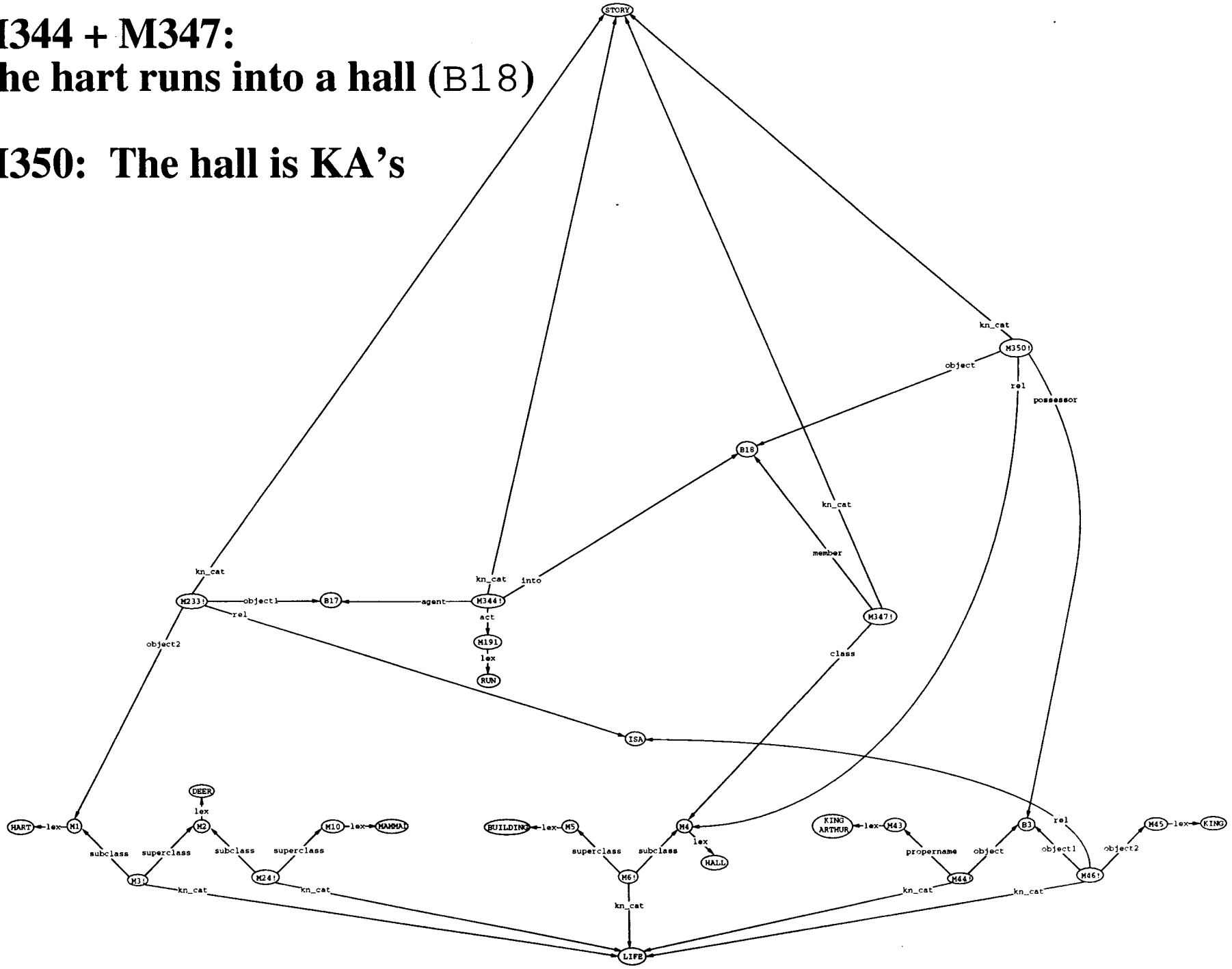
```
;M233: In the story, B17 is a hart.
(M233! (KN_CAT story)
       (OBJECT1 B17)
       (OBJECT2 (M1 (LEX hart)))
       (REL ISA))

;M344: In the story, B17 runs into B18.
(M344! (ACT (M194 (LEX run)))
       (AGENT B17)
       (INTO B18)
       (KN_CAT story))

;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))))
```

info from story (`kn_cat` = "story"):
M233: something (`B17`) is a hart

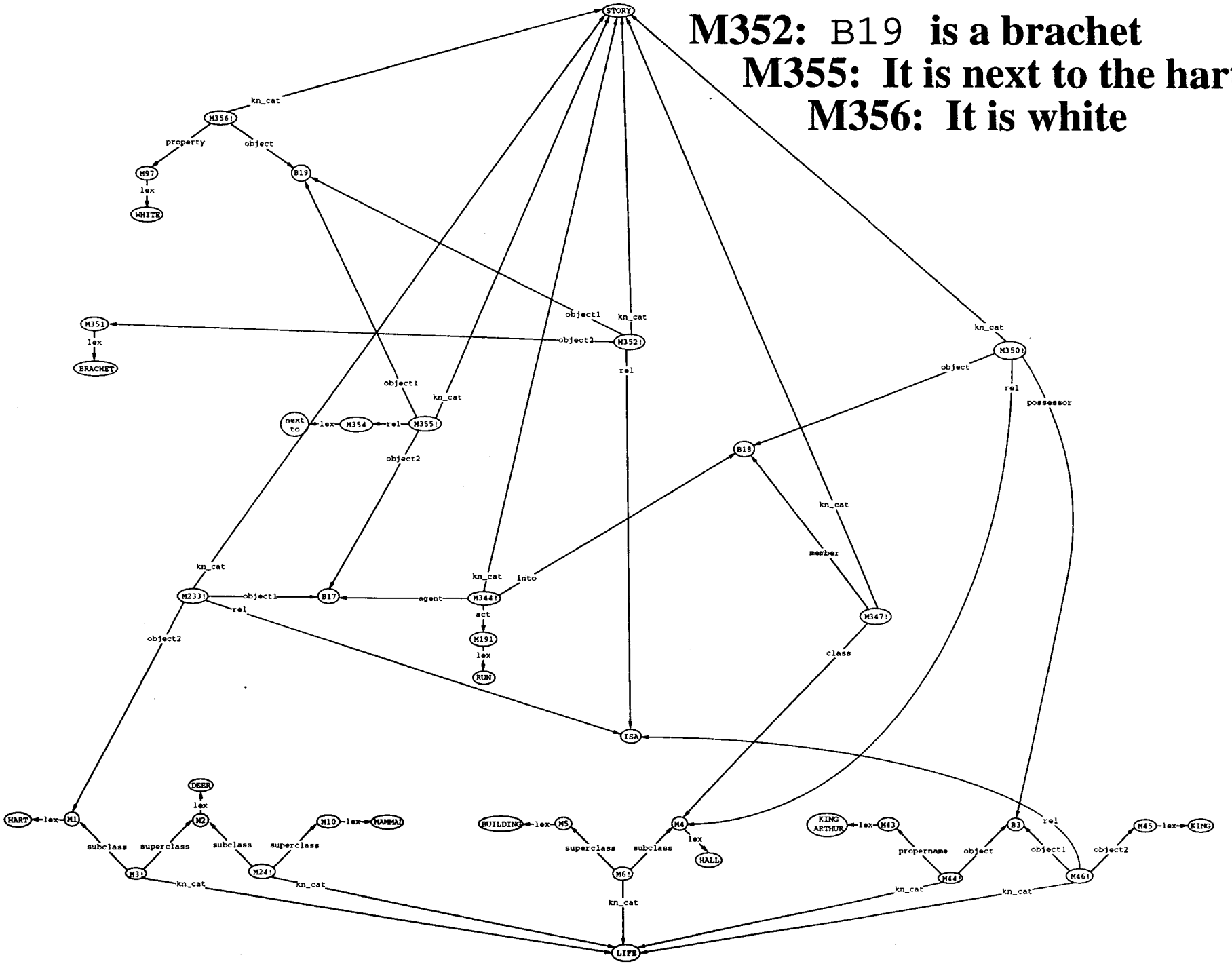


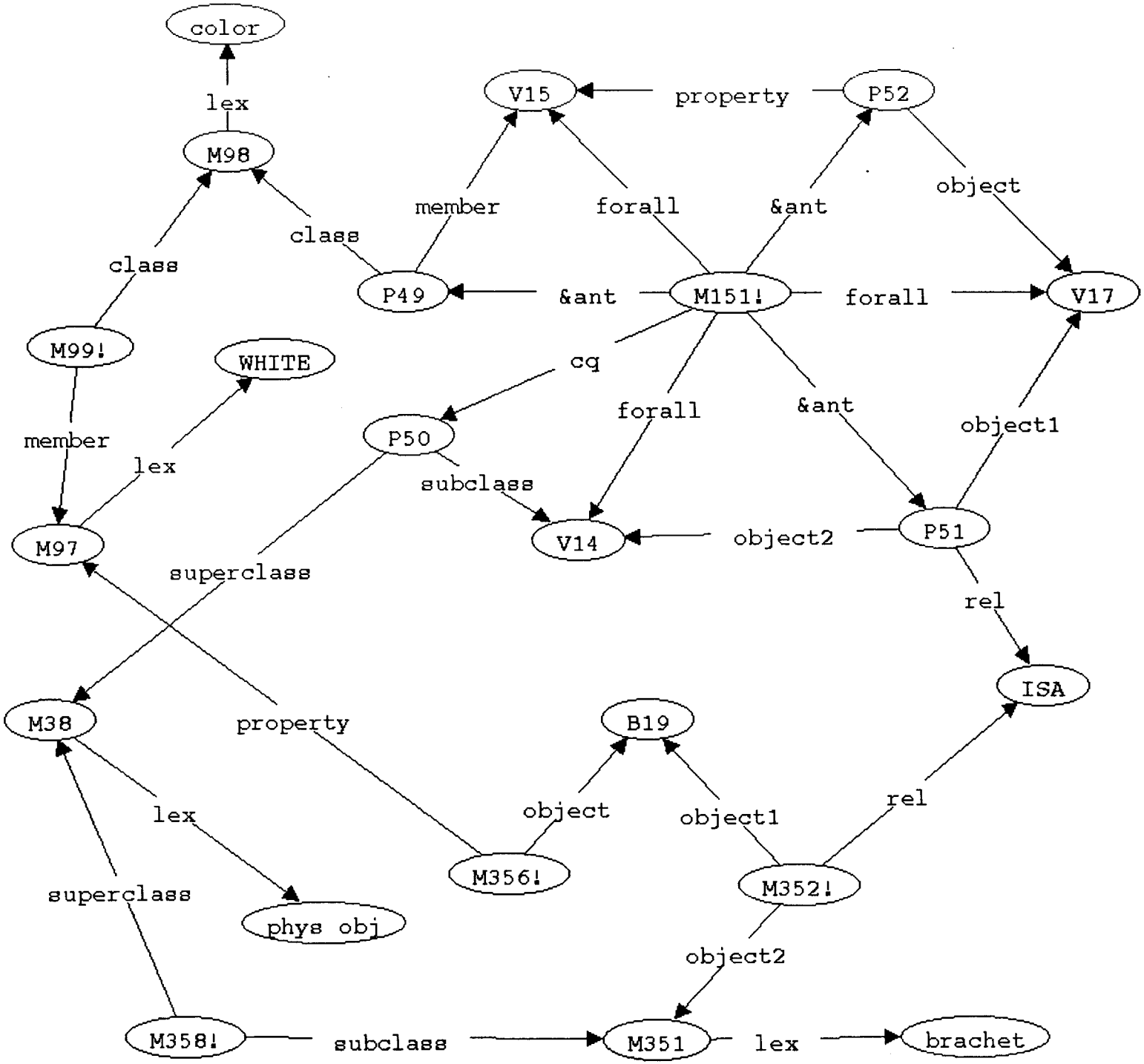
M344 + M347:
The hart runs into a hall (B18)

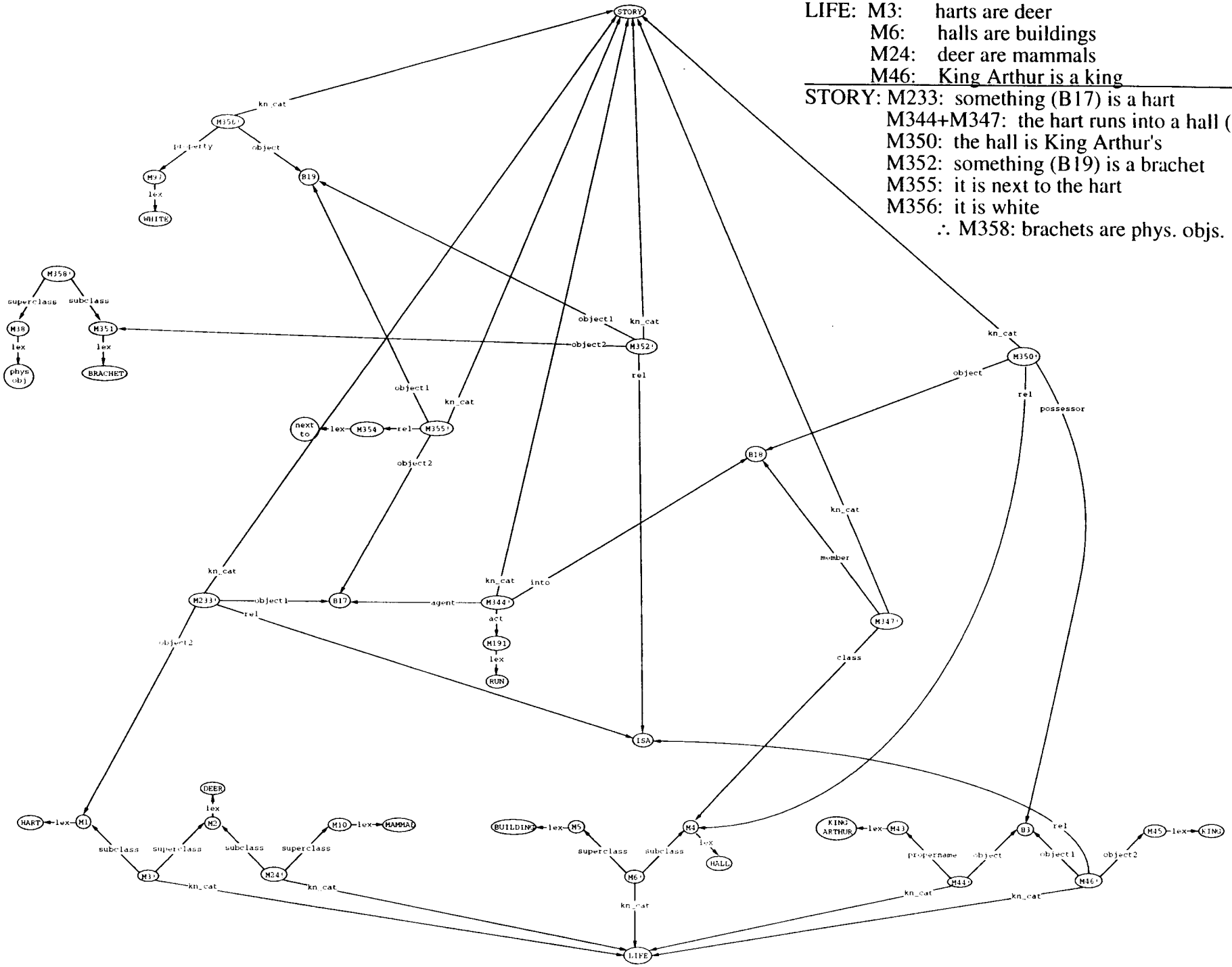
M350: The hall is KA's



M352: B19 is a brachet
M355: It is next to the hart
M356: It is white




color
lex
M98
V15
property
P52
member
forall
&ant
object
class
class
P49
&ant
M151!
forall
V17
M99!
WHITE
cq
member
lex
P50
forall
&ant
object1
subclass
M97
V14
object2
P51
superclass
rel
ISA
M38
property
B19
lex
object
object1
rel
M356!
M352!
superclass
phys obj
object2
M358!
subclass
M351
lex
brachet



LIFE: M3: harts are deer
M6: halls are buildings
M24: deer are mammals
M46: King Arthur is a king

STORY: M233: something (B17) is a hart
M344+M347: the hart runs into a hall (B18)
M350: the hall is King Arthur's
M352: something (B19) is a brachet
M355: it is next to the hart
M356: it is white
∴ M358: brachets are phys. objs.

```
--> (defn_noun 'brachet)

((CLASS INCLUSION= (phys obj))  STRUCTURE= NIL
FUNCTION= NIL ACTIONS= (NIL)  OWNERSHIP= NIL
POSSIBLE PROPERTIES= ((WHITE)) SYNONYMS= NIL)
```

- At this stage, Cassie says that 'brachet' means: "a physical obj that can be white"

- Because Cassie:
  - believes ∃ a brachet (B19)
  - believes B19 is white (*)
  - has inferred (from (*)) that brachets are physical objs

- N.B.: The "definition" does not appear in the net!

A knight arises.
The knight picks up the brachet.
The knight mounts his horse.
The knight rides his horse.
The knight carries the brachet.

```
--> (defn_noun 'brachet)

;A brachet is an animal that can bite, and may be small or white.
((CLASS INCLUSION= (animal))  STRUCTURE= NIL  FUNCTION= NIL
ACTIONS= ((POSSIBLE ACTIONS= (bite)))  OWNERSHIP= NIL
POSSIBLE PROPERTIES= ((small white))  SYNONYMS= NIL)
```

A lady says that the knight is taking the brachet.
The lady says that the brachet is hers.
The lady says that she wants the brachet.

```
--> (defn_noun 'brachet)

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

((CLASS INCLUSION= (animal))  STRUCTURE= NIL  FUNCTION= NIL
ACTIONS= ((POSSIBLE ACTIONS= (bite)))  OWNERSHIP= NIL
POSSIBLE PROPERTIES= ((small valuable white))  SYNONYMS= NIL)
```

Merlin says that Sir Gawain must bring the hart to King Arthur's hall.
Merlin says that Sir Tor must bring the brachet to the hall.
Merlin says that Sir Tor must either bring the knight to Arthur's hall or else slay him.

```
--> (defn_noun 'brachet)

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

((CLASS INCLUSION= (animal))  STRUCTURE= NIL  FUNCTION= NIL
ACTIONS= ((POSSIBLE ACTIONS= (bite)))  OWNERSHIP= NIL
POSSIBLE PROPERTIES= ((small valuable white))  SYNONYMS= NIL)
```

An elder says that a hart comes where he is.
The elder says that a group of hounds chased the hart.
The elder says that a white brachet is next to the hart.

```
--> (defn_noun 'brachet)

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

((CLASS INCLUSION= (animal))  STRUCTURE= NIL  FUNCTION= NIL
ACTIONS= ((POSSIBLE ACTIONS= (bite)))  OWNERSHIP= NIL
POSSIBLE PROPERTIES= ((small valuable white))  SYNONYMS= NIL)
```

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

```
--> (defn_noun 'brachet)

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

((CLASS INCLUSION= (animal))  STRUCTURE= NIL  FUNCTION= NIL
ACTIONS= ((POSSIBLE ACTIONS= (bite)))  OWNERSHIP= NIL
POSSIBLE PROPERTIES= ((small valuable white))  SYNONYMS= NIL)
```

A dwarf says that he knows that Sir Tor seeks the knight.
The dwarf says that he will bring Sir Tor to the knight.
Sir Tor goes to a pavilion.
The lady is sleeping in the pavilion
Sir Tor finds the lady at the pavilion.
Sir Tor finds the brachet at the pavilion.
The brachet bays in the direction of Sir Tor.

```
--> (defn_noun 'brachet)

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

(A BRACHET IS A KIND OF (dog)  ACTIONS= ((POSSIBLE ACTIONS= (bay
bite))) FUNCTION= ((hunt))  STRUCTURE= NIL  OWNERSHIP= NIL
SYNONYMS= NIL)
```

Sir Tor spies the brachet
Sir Tor takes the brachet
Sir Tor gives the brachet to the dwarf.
A noise causes the lady to come from the pavilion.
The noise causes a group of damosels to come from the pavilion.
The lady asks Sir Tor if he is taking the brachet from her
Sir Tor says to the lady that he is taking the brachet from her.
Sir Tor says that he sought the brachet from King Arthur's hall to here.

```
--> (defn_noun 'brachet)

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

(A BRACHET IS A KIND OF (dog)  ACTIONS= ((POSSIBLE ACTIONS= (bay
bite))) FUNCTION= ((hunt))  STRUCTURE= NIL  OWNERSHIP= NIL
SYNONYMS= NIL)
```

A Computational Theory of Vocabulary Acquisition

- TO DO:
  - grammar
  - augment verb algorithm
  - adjectives, adverbs, (prepositions?)
  - proper names
  - etymological & morphological clues
  - inducing generalizations
  - deciding what to revise (and how)
  - test with on-line corpora
  - formal model of category-definition by exemplars?
    - I/P: info about (single) individual
    - O/P: description of a category
  - tutoring system

A Computational Theory of Vocabulary Acquisition

Educational application:

> *Does Your Child Need a Vocabulary Boost? Huntington Can Help!*
>
> Huntington Learning Center offers a program called *Practicing Vocabulary in Context* which teaches the student to use the context of a sentence or paragraph to determine the meaning of a word. The student reads the story out loud and is asked to think about the meaning of the underlined words.

- Use text passages from different grade levels

- Cassie: "Here's how I figured it out"

- Cassie always gives an appropriate meaning for the text

CONTEXTUAL VOCABULARY ACQUISITION:
Development of a Computational Theory and Educational Curriculum

- to extend & develop algorithms for computational CVA (N, V, Adj+Adv)

- unify the psych, L1, L2, reading, compling lit

- use the knowledge gained from C-CVA system to develop & eval educational curriculum

  - for enhancing students' abilities to use <u>deliberate</u> CVA strategies in reading SMET

  - students = middle-school, undergrads

- teaching a machine, to see if what we learn in teaching it can help us teach students better

  – cf. Boden's def of AI

WHAT IS A.I.?

- "The science of making machines do things that would require intelligence if done by humans." – Marvin Minsky

  Using humans to tell us how to program computers.

- "The use of computers programs and programming techniques to cast light on the principles of intelligence in general and human thought in particular."
  – Margaret Boden

  Using computers to tell us something about humans.

- In fact: it's both—a 2-way street

Open Issues

- what kinds of contexts are there?
- which ones are helpful for CVA?
- what is role of background knowledge?
- what strategies (= algorithms) are there?
  - I/P = context, background knowledge, unknown word
  - O/P = hypothesis of word's def
- how to eval confidence in hypoth
- # of occurrences of word needed for confident hypoth

- 2 research strategies:
  - computational: study the known strategies
  - case studies of readers using CVA strategies
- feedback & feedforward between these
- then: design better curricula (for teaching CVA strategies for SMET texts)
  - "better": cf. Huntington Learning Centers

To Do (extend & apply the theory):

- computational stream (extend the theory):
  - improve grammar coverage
  - improve/develop algorithms for V, modifiers, proper names
    * possible term paper topics
  - develop algorithms to induce generalizations
    * e.g.) 'dress'
    * possible term paper topic for s.o. w/ bkgd in ML
  - store new defs?
  - foundational issues:

    * theory of how context operates

    * differing roles of context in different domains

- educational stream (curric. dev.)

  - phase 1: instructional methods & case studies:

    * develop instructional materials

    * case studies:

      · observations of teaching & students

      · structured interviews w/ teachers & students

    * apply insights to Cassie

  - phase 2: curric dev & eval'n

    * develop teaching methods

    * develop eval'n instruments

    * field tests & refinement

- phase 3: controlled experiments:

    * teacher training

    * student training

    * tests & follow-up studies

    * data analysis

DEMO: What does 'tomato' mean? **KB = nil!!**

- kn_cat = life:
  - **Tomatoes are fruits.**
  - **Tomatoes are vegetables.**
  - **'Tomato' is synonymous with 'love-apple'.**
  - **'Tomato' represents a basic-level category.**

- kn_cat = life-rule.1:
  - **Presumably, tomatoes are red.**
  - **Presumably, tomatoes are round.**
  - **Tomatoes have seeds.**
  - **Tomatoes have pulp.**
  - **Tomatoes have skins.**
  - **For all v, if v is a tomato, then presumbly there is a person p who eats v, and the function of v is to be eaten by p.**
  - **For all v1, v2, v3, if v2 is a v3 of its possessor v1, then v2 is a v3.**

```
--> (defn_noun 'tomato)

((CLASS INCLUSION = (fruit vegetable))
 STRUCTURE        = ((pulp seed skin))
 FUNCTION         = ("to be" eat)
 ACTIONS          = (NIL)
 OWNERSHIP        = NIL
 PROPERTIES       = ((red round))
 SYNONYMS         = (love-apple))
```

[Stative props of roundness, redness may be expected of tomatoes in general, ∴ reported even though both structural & functional info is present.]

Belief revision: 'dress'

<background info, including:

(1) dresses(x,y) ⇒ ∃z[clothing(z) & wears(y,z)],

(2) spears don't wear clothing (both `kn_cat=life_rule.1`)>

P1: King Arthur dressed himself.
D1: A person can dress itself;
result: it wears clothing

P2: King Claudius dressed his spear...
<Cassie infers: KC's spear wears clothing>
Q2: What wears clothing?

<SNeBR is invoked:

- **Contradiction!**
- **(1) replaced w/: dresses(x,y) ⇒∃z[...] ∨ S>**
- **replace (1), not (2), bec. of verb in antecedent (Gentner)**

P3: <passages in which dressing spears precedes fighting>
D3: A person can dress a spear or a person;
result: person wears clothing
or person is enabled to fight

Belief revision: 'smite'

• misunderstood word; 2-stage "subtractive" revision)

<background info, including:

(*) smite(x,y,t) ⇒ hit(x,y,t) & dead(y,t) &cause(hit(x,y,t),dead(y,t))>

P1: ... King Lot smote down King Arthur...

D1: If person x smites person y at time t,
then x hits y at t, and y is dead at t

Q1: What properties does King Arthur have?

R1: King Arthur is dead.

P2: ... King Arthur drew Excalibur.

Q2: When did King Arthur do this?

<SNeBR is invoked:

- KA's drawing E is inconsis w/ his being dead
- (*) replaced w/: - smiting only poss'ly entails killing
  - if smiting results in death,
    then the hitting caused the death>

D2: If person x smites person y at time t,
then x hits y at t, & possibly y is dead at t

P3: <another passage in which smiting ⇏ death>

D3: If person x smites person y at time t,
then x hits y at t.

Belief revision:
SNeBR (Martins & Shapiro)
SNePSwD (Cravo & Martins)

- **If inference leads to a contradiction, then SNeBR asks user to remove culprit(s)**
- **Once removed, all inferred propositions are also removed**
- **Used to revise definitions of words used differently from current meaning hypothesis**
- **Removal & revision is being automated by ranking all propositions with `kn_cat`:**

most certain
- `intrinsic`: **info about lang; fund. background info** (**"before is transitive"**)
- `story`: **info in text** (**"King Lot rode to town"**)
- `life`: **bkgd info w/o vars or inf** (**"dogs are animals"**)
- `story-comp`: **info inferred from text** (**"King Lot is a king", "King Lot rode on a horse"**)
- `life-rule1`: **everyday CS background info** (**"*x* bears young ⇒ *x* is a mammal"**)
- `life-rule2`: **specialized background info** (**"*x* smites *y* ⇒ *x* kills *y* by hitting *y* "**)

least certain
- `questionable`: **already-revised** `life-rule2`; **not part of input**

3 Kinds of Vocabulary Acquisition:

- **Construct new definition of unknown word (e.g., 'brachet')**

- **Fully revise definition of misunderstood word (e.g., 'smite')**

- **Expand definition of word used in new sense (e.g., 'dress')**

Related Work:

- Zernik & Dyer 1987
  - model of 2nd-language acquisition
  - figurative phrases
  - human informant

- Hastings & Lytinen 1994
  - KB = taxonomy
  - tries to locate new word in taxonomy,
  - . . . "correctly"

- Siskind 1996
  - model of 1st-language acquisition
  - I/P = utterance
    + visual perception of situation
    + mental representation of situation
    + assumption that utterance means rep'n
  - O/P = "correct word to meaning maps"
  - uses semantics to learn syntax
    (we use syntax to learn semantics)

Psychological Evidence:
Johnson-Laird

- Reader constructs model of state of affairs described by text
- Word senses can be derived from def'ns or instances of word in use
- Lexical representation consists of relations to other words + primitives
- Lexical entries in mental dictionary may be incomplete
- Definitions aren't stored

Psychological Evidence:
Sternberg

- **E.g.:**

... the couple there on the blind date was not enjoying the festivities in the least. An acapnotic, he disliked her smoking; and when he removed his hat, she, who preferred "ageless" men, eyed his increasing phalacrosis and grimaced. [Sternberg 1987: 91]

To acquire new words from context:

- distinguish relevant/irrelevant info
- selectively combine relevant info
- compare this info w/ previous beliefs

and look for:

- spatio/temporal cues
- value cues
- properties
- functions
- cause/enablement info
- class memberships
- synonyms/antonyms

Psychological Evidence:
Elshout-Mohr & van Daalen-Kapteijns

What does 'kolper' mean?

1. **When you are used to a broad view it is quite depressing when you come to live in a room with one or two kolpers fronting on a courtyard.**
   (superordinate info)

2. **He virtually always studied in the library, as at home he had to work by artificial light all day because of those kolpers.**
   (distinguishing info)

3. **During a heat wave a lot of people all of a sudden want to have kolpers, so the sales of sunblinds then reach a peak.**
   (distinguishing info)

4. **I was afraid the room might have kolpers, but when I went and saw it, it turned out that plenty of sunlight came into it.**
   (counterexample)

5. **In those houses, you're stuck with kolpers all summer, but fortunately once the leaves have fallen off that isn't so any more.**
   (counterexample)

---

kolper:
a window that transmits little light because of something outside it.

Psychological Evidence:
Elshout-Mohr & van Daalen-Kapteijns

- **Experiments w/ neologisms in contexts**

  - **When you are used to a ... view it is ... depressing when you ... live in a room with kolpers .... (superordinate info)**

  - **... at home he had to work by artificial light ... because of those kolpers. (distinguishing info)**

  - **I was afraid the room might have kolpers, ... but plenty of sunlight came into it. (counterex.)**

  * **kolper: window transmitting little light because of something outside it.**

- **Readers model new word on known word & look for differences**

- **Model is a frame-like structure**
  - **with slots to fill**
  - **defaults**

Verb search algorithm:

Find or infer information about:

- **predicate structure**
  - **categorization of arguments/case frame**

- **results of <verb>ing**
  - **effects caused**
  - **state changes that follow**

- **enabling conditions for <verb>**

- **classification of verb-type?**

- **synonyms?**

Noun search algorithm:

- **Look for:**
  - **definitely-true general rules**
  - **presumably-true general rules**
  - **individual instances**

- **Infer class inclusions (via node-based inference)**
  - **especially basic-level**
  - **check for animacy**

- **Search (via path-based inference) for:**
  - **function**
  - **structure (if physical object)**
  - **actions (not inanimate basic-level or subclass)**
  - **ownership**
  - **part/whole relations**
    (e.g., leg of animal/chair, whisker of cat)
  - **other stative, descriptive props**

- **Infer synonyms (if class inclusions found)**

- **If no class, or too high level,**
  & no structure, function, or acts
  then look for noun as `object`
  else as anything else

Search Algorithms (nouns, verbs)

(see handout & references in proceedings)

- Algorithm searches net for fillers for slots in definition frame
  - search guided by desired slots
  - e.g., ignores particular info if general info is present, else takes what it can get
- If queried at each occurrence , frame "develops" dynamically
  - if queried only at end, then only "final" frame is O/P

```
ALGORITHM Defn_Noun(N):
-----------------------

PROCEDURE List1 ::= list (1) structure of Ns, (2) functions of Ns,
                         (3) general stative properties of Ns

PROCEDURE List2 ::= list (1) direct class inclusions of N,
                         (2) actions of Ns not deduceable from class inclusions,
                         (3) ownership of Ns, (4) synonyms of 'N'.

PROCEDURE List3 ::= BEGIN List2;
                          IF there is structural or functional info about Ns,
                            THEN List1 END.

BEGIN {Defn_Noun}
  IF N represents a basic-level category, THEN List3
  ELSIF N represents a subclass of a basic-level category, THEN
    BEGIN report that fact;
          List1;
          list ownership of Ns, synonyms of 'N';
          IF Ns are animals, THEN list non-redundant acts that Ns perform END
  ELSIF N represents a subclass of animal, THEN List3
  ELSIF N represents a subclass of physical object, THEN
    BEGIN List2;
          IF system finds structural or functional information about Ns,
            THEN List1
          ELSIF system finds actions of N or synonyms of 'N', THEN
            BEGIN list them; list possible properties of Ns END
          ELSIF N is an object of an act performed by an agent, THEN
            BEGIN report that; list possible properties of Ns END END
  ELSIF N represents a subclass of abstract object, THEN
    BEGIN list direct class inclusions of N & ownership of Ns;
          IF system finds functional information about Ns, THEN
             list: function, synonyms for 'N';
                   actions of Ns not deduceable from class inclusions,
                   stative properties only if there are general rules,
          ELSE BEGIN list possible properties of Ns;
                     list actions of N & synonyms for 'N',
                     IF N is an object of an act performed by an agent,
                       THEN report that END END
  ELSE {we lack class inclusions, so:}
    BEGIN
      list: any named individuals of class N, ownership, possible properties;
      list: information on structure, function, actions
      IF N is object of act performed by agent, THEN report that END
END.


ALGORITHM Defn_Verb(V):
-----------------------

BEGIN
  report on cause and effect; categorize the subject;
  IF V is used with an indirect object,
    THEN categorize objects and indirect object
  ELSIF V is used with a direct object distinct from its subject,
    THEN categorize the object
  ELSIF V is used with its subject as direct object,
    THEN list the object as "itself"
END.
```