The Open University

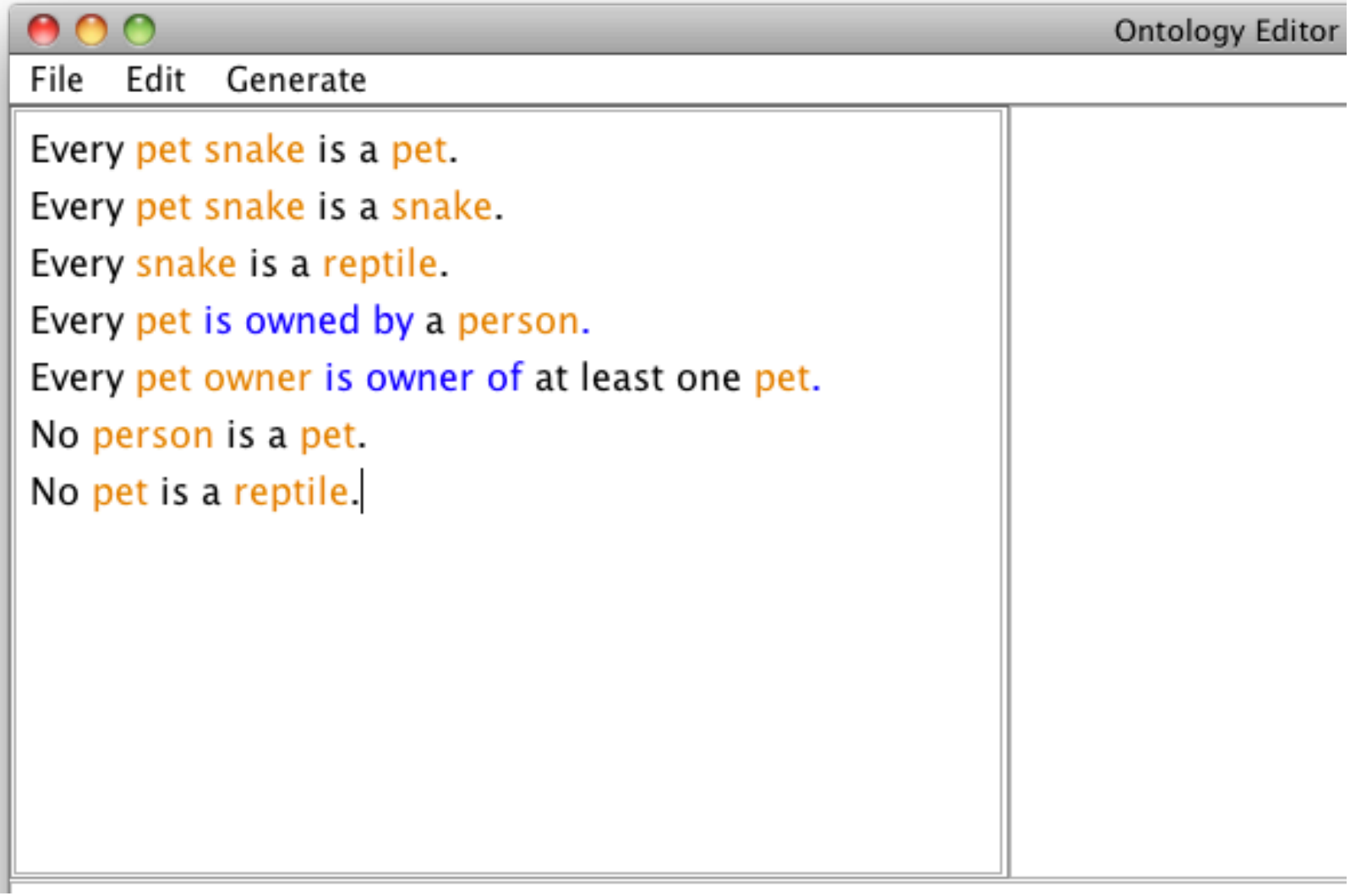
Predicting the Understandability of OWL Inferences

Tu Anh Nguyen
Richard Power
Paul Piwek
Sandra Williams

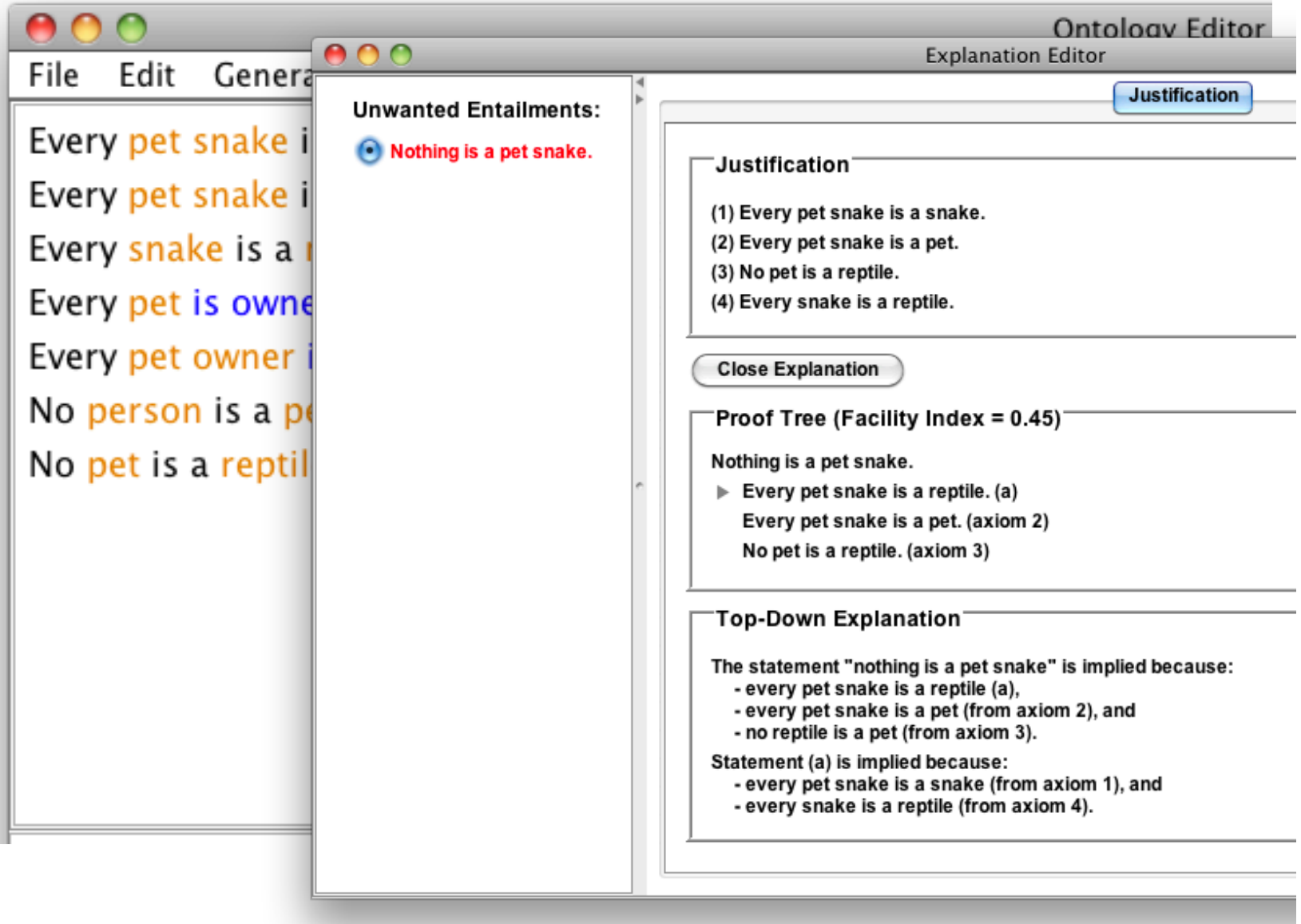
Semantic Web Authoring Tool
(EPSRC, 2009-2012)

- Developed tools for viewing and editing OWL ontologies in natural language
  - Ontology verbaliser
  - Editing tool (using CNL)
  - Suggesting entity names and axioms
- Generating explanations for entailments
  - Tu Anh Nguyen's PhD project

Ontology editor



Explanation



Debugging task

- Recognise undesired entailment
  - There are no snakes
  - Everything is a snake
  - Every pet is a snake
- Understand why the undesired entailment was inferred by the reasoner
- Modify one or more axioms so that the undesired entailment is eliminated

General approach

- Identify a set of relevant axioms from which the undesired entailment follows
  - Minimal set is called a “justification” ⋆
- Construct a proof tree leading from the justification to the entailment
  - This will usually include intermediate steps, sometimes called “lemmas”
- Present the proof tree through a text in natural language

⋆ Horridge et al. “The Cognitive Complexity of OWL Justifications” ISWC 2011

Understandable justification?

JUSTIFICATION

```
SubClassOf(A,B)
SubClassOf(A,C)
SubClassOf(C,D)
DisjointClasses(B,D)
```

ENTAILMENT

```
SubClassOf(A,Nothing)
```

Every pet snake is a pet.
Every pet snake is a snake.
Every snake is a reptile.
No pet is a reptile.

Nothing is a pet snake.

Justification not enough

JUSTIFICATION

```
EquivalentClasses(A,ObjectAllValuesFrom(P,B))
ObjectPropertyDomain(P,C)
SubClassOf(A,C)
```

ENTAILMENT

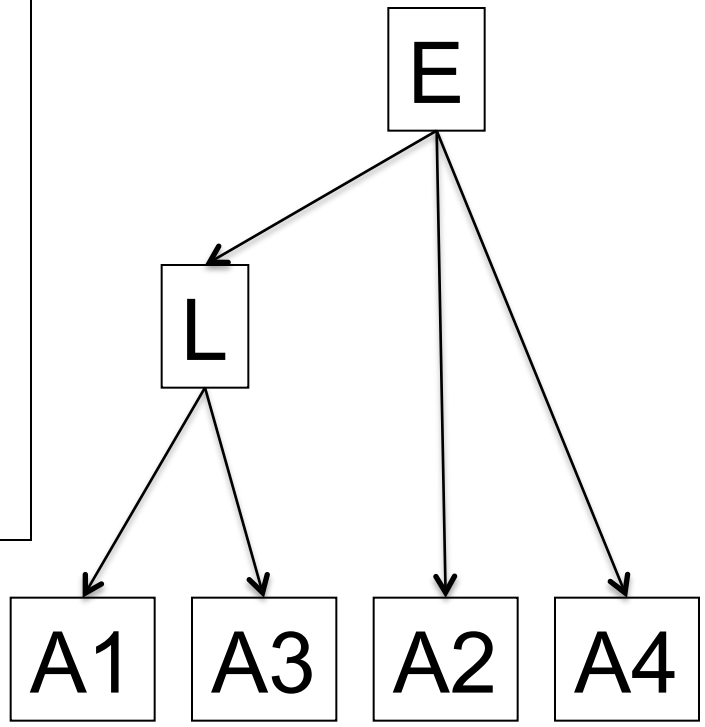
```
SubClassOf(Everything,C)
```

A vegan is anything that eats only plants.
Anything that eats something is an animal.
Every vegan is an animal.

Everything is an animal.

Proof tree

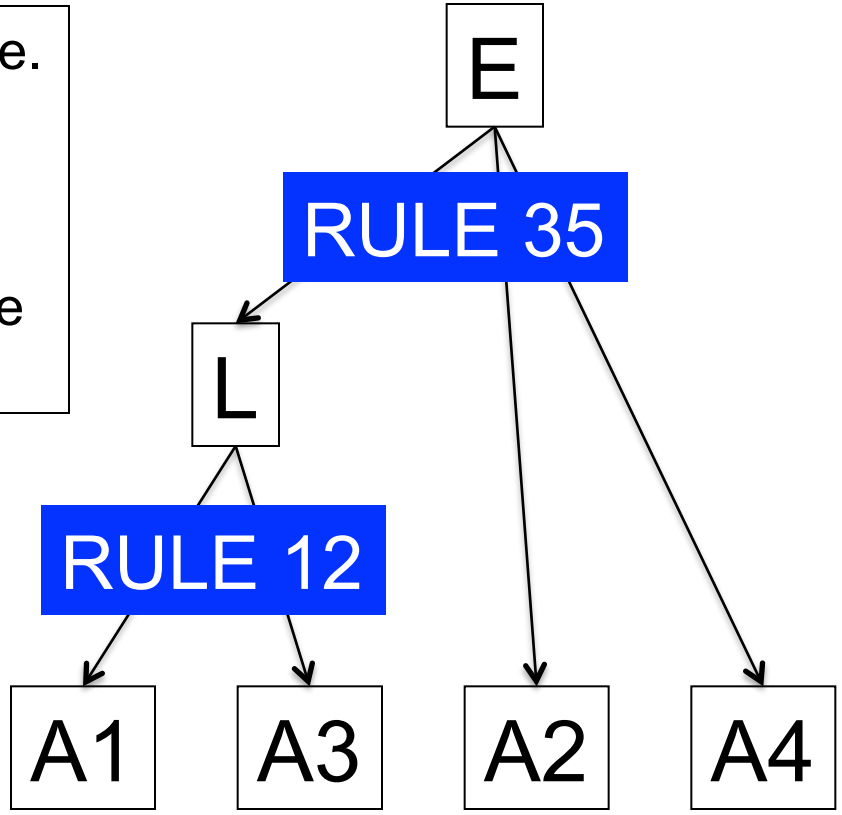
(A1) Every pet snake is a snake.
(A2) Every pet snake is a pet.
(A3) Every snake is a reptile.
(A4) No pet is a reptile.
(L) Every pet snake is a reptile
(E) There are no pet snakes



A Axiom
L Lemma
E Entailment

Deduction rules

(A1) Every pet snake is a snake.
(A2) Every pet snake is a pet.
(A3) Every snake is a reptile.
(A4) No pet is a reptile.
(L) Every pet snake is a reptile
(E) There are no pet snakes



Rule 12: Subclass transitivity

SUBCLASS TRANSITIVITY

```
SubClassOf(A,B)
SubClassOf(B,C)
```

```
SubClassOf(A,C)
```

Every pet snake is a snake.
Every snake is a reptile.

Every pet snake is a reptile.

Rule 35: Incompatible superclasses

INCOMPATIBLE SUPERCLASSES

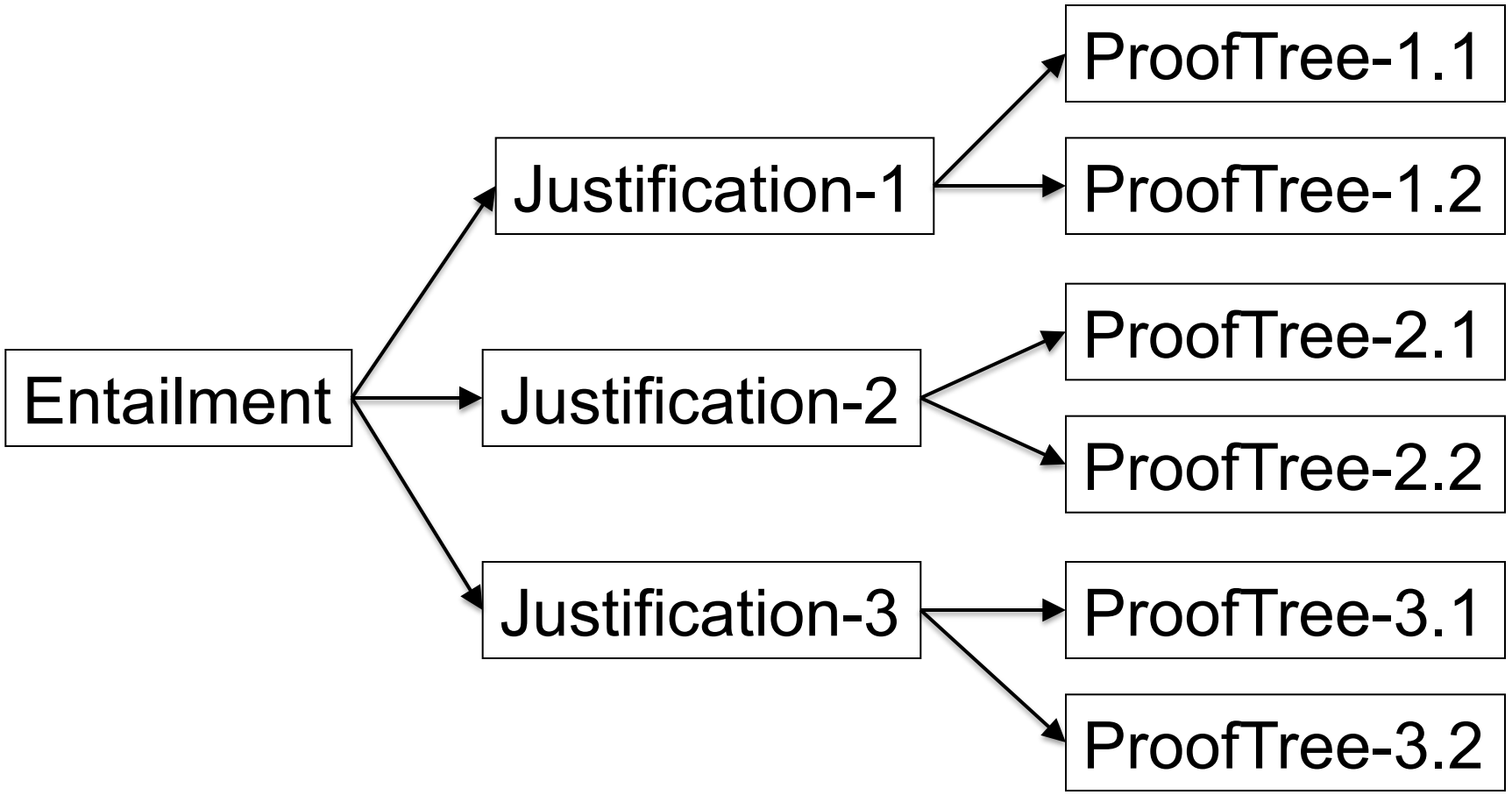
```
SubClassOf(A,B)
SubClassOf(A,C)
DisjointClasses(B,C)
```

```
SubClassOf(A,Nothing)
```

Every pet snake is a pet.
Every pet snake is a reptile.
No pet is a reptile.

Nothing is a pet snake.

Multiple explanations

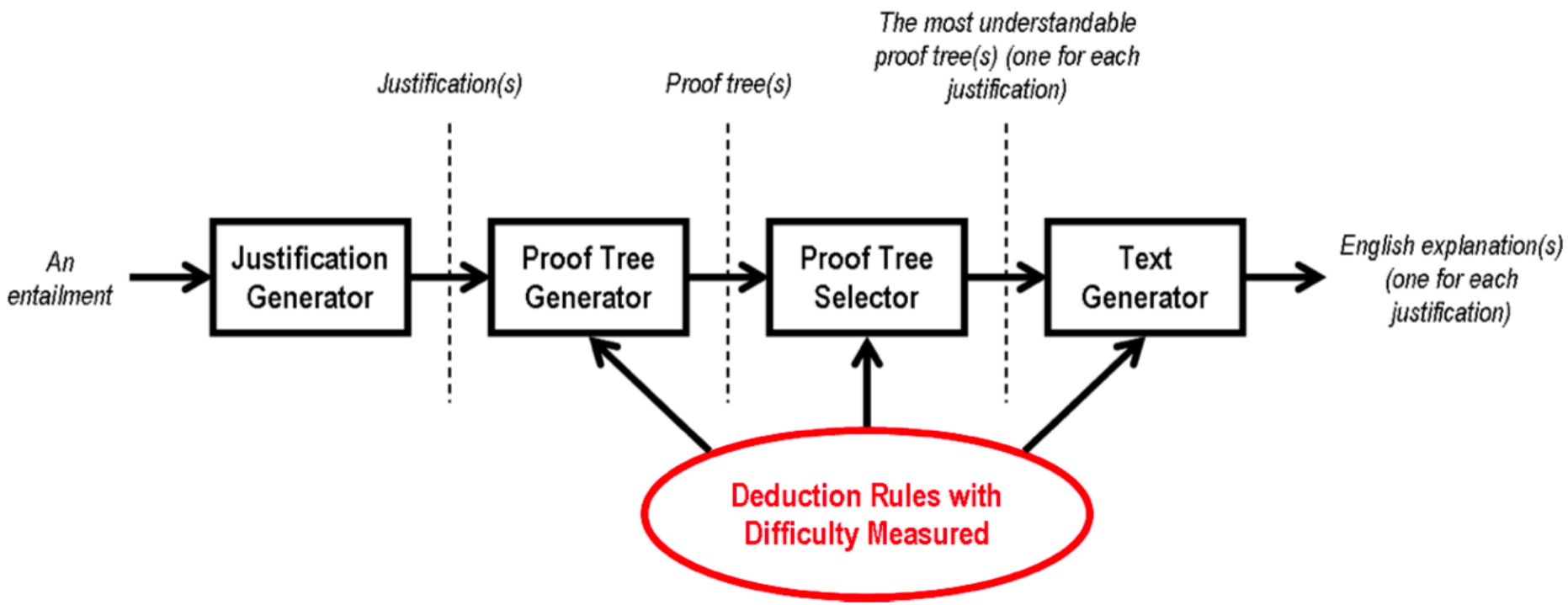


How do we decide which proof tree to use?

Specific approach

- Collect a set of deduction rules by finding frequent, short justification patterns in an ontology corpus
- Measure the understandability of each deduction rule empirically
- Generate proof trees from these rules
- Combine the measures for each rule to obtain an understandability measure for a proof tree

Architecture



Collecting deduction rules

- Justification patterns for SubClassOf entailments were collected through a corpus study (500+ ontologies)
- Rules were derived from simple and frequent justification patterns ...
- ... And from commonly occurring parts of more complex justification patterns
- At present we have 57 rules covering 48% of justifications for the entailments studied

Understandability of rules

- We performed an empirical study to associate a Facility Index (FI) with each deduction rule in our set
- Subjects judged whether a conclusion followed from premises stated in natural language using unfamiliar terms
- The FI is the frequency of correct responses, interpreted as a probability that a person will understand the deduction

Sample question

Everything that has a worship leader is a fomorian.
Everything that has no worship leader is a fomorian.

Which conclusions follow from these statements?

Everything that has a worship leader is a hiatea.

- Follows
- Does not follow

Everything is a fomorian.

- Follows
- Does not follow

Results from study

ID	Deduction Rule	Testing Problem	Facility Index
1	EqvCla(X,Y...) →SubClaOf(X,Y)	A hiatea is defined as a milvorn. →Every hiatea is a milvorn.	1.00 (49/49)
2	SubClaOf(X,ObjIntOf(Y,Z...)) →SubClaOf(X,Y)	Every ormyrr is both a gargoyle and a harpy. →Every ormyrr is a gargoyle.	0.96 (47/49)
3	ObjPropDom(r0,X) ∧ SubClaOf(X,Y) →ObjPropDom(r0,Y)	Anything that has a supernatural ability is a bulette. Every bulette is a manticore. →Anything that has a supernatural ability is a manticore.	0.96 (45/47)
...	...	...	...
48	SubClaOf(X,ObjAllValF(r0,Y) ∧ InvObjProp(r0,r1) →SubClaOf(ObjSomValF(r1,X),Y)	Every tabaxi toves from only lamias. X toves from Y if and only if Y toves into X. →Everything that toves into a tabaxi is a lamia.	0.32 (16/50)
49	...	...	...
50	DatPropRng(d0,DR0) ∧ SubClaOf(X,DatSomValF(d0,DT1)) where DR0 & DT1 are disjoint →SubClaOf(X,⊥)	Any value that something has as mazek is an integer. Every tiefling has as mazek a double value. Double values are unconvertible to integer values in OWL. →Nothing is a tiefling.	0.18 (9/49)
51	EqvCla(X,ObjAllValF(r0,Y)) →SubClaOf(ObjAllValF(r0,⊥),X)	A hiatea is anything that eats only lamias. →Everything that eats nothing at all is a hiatea.	0.04 (2/49)

Rule 12: Subclass transitivity

SUBCLASS TRANSITIVITY

```
SubClassOf(A,B)
SubClassOf(B,C)
```

```
SubClassOf(A,C)
```

FI=0.80

Every pet snake is a snake.
Every snake is a reptile.

Every pet snake is a reptile.

Rule 35: Incompatible superclasses

INCOMPATIBLE SUPERCLASSES

```
SubClassOf(A,B)
SubClassOf(A,C)
DisjointClasses(B,C)
```

```
SubClassOf(A,Nothing)
```

FI=0.56

Every pet snake is a pet.
Every pet snake is a reptile.
No pet is a reptile.

Nothing is a pet snake.

Rule 51: Trivial satisfaction

TRIVIAL SATISFACTION

```
EquivalentClasses(A,
  ObjectAllValuesFrom(P,B))
```

```
SubClassOf(
  ObjectAllValuesFrom(P,Nothing),A)
```

An A is anything that Ps only Bs.

Everything that Ps nothing is an A.

FI=0.04

Generating proof trees

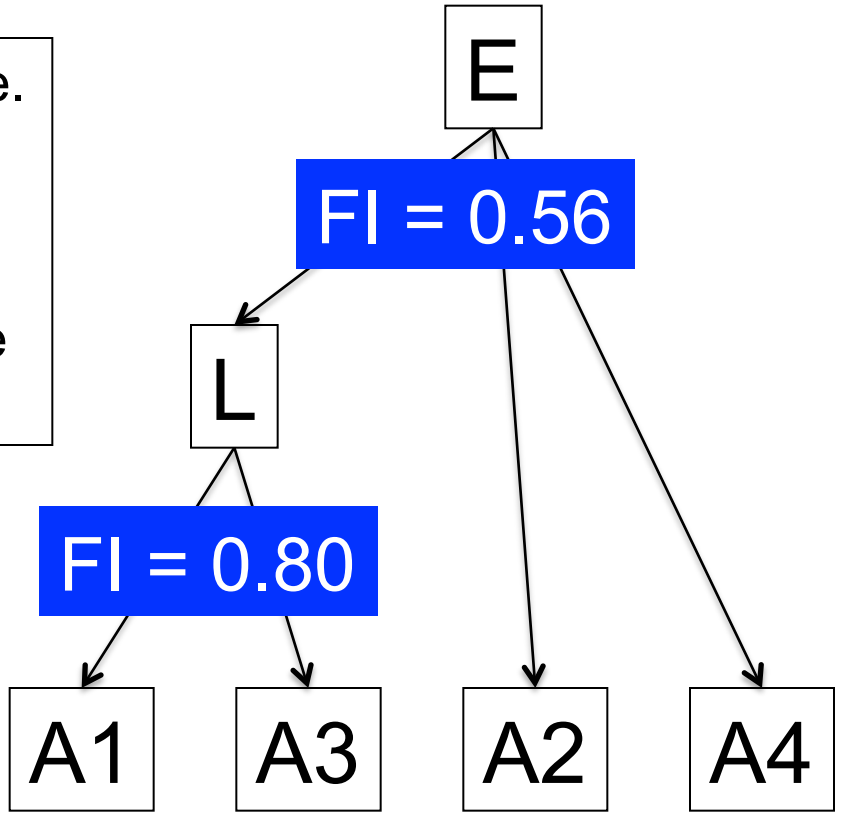
- Problem: given a justification, an entailment, and a set of deduction rules, build a tree for which root is entailment and terminal nodes are axioms in the justification
- This is done through an exhaustive search algorithm ...
- Making this algorithm efficient was not one of our research objectives

Understandability of proof trees

- To judge which proof tree is best, we need an understandability measure for the whole tree
- Proof trees are constructed from deduction rules, for which we have facility indexes
- Simplest hypothesis: understandability of proof tree is product of FIs of constituent deduction rules (joint probability)
- Our aim here is to validate this hypothesis

Combining facility indexes

(A1) Every pet snake is a snake.
(A2) Every pet snake is a pet.
(A3) Every snake is a reptile.
(A4) No pet is a reptile.
(L) Every pet snake is a reptile
(E) There are no pet snakes



FI(Tree) = 0.8 * 0.56
= 0.45

Survey design

- We chose 15 two-step inferences with predicted FIs varying from 0.03 to 0.96
- All problems asked subjects to judge whether an explanation was valid (Yes/No)
- 15 test problems using valid explanations
- 15 control problems checking for response bias and scammers
  - 5 trivially correct
  - 5 first step invalid, 5 second step invalid

Participants

- Participants were Mechanical Turkers recruited using CrowdFlower
- After eliminating scammers we obtained results for 52 subjects
- Only one subject reported familiarity with OWL
- Not all subjects finished (but problems presented in different random orders)

Sample question

Assume these statements are true:

(a) A suffment is anything that esiles only momes.
(b) Anything that estiles something is a suffment.

We are interested in whether it follows that everything is a suffment. A person tried to justify this conclusion as follows:

From statement (a) we infer that (c) anything that estiles nothing at all is a suffment. From statements (b) and (c) we infer that everything is a suffment.

Is this reasoning correct?

- Yes
- No

Response bias

	+Yes	**−Yes**	**Total**
+Correct	774	458	1232
−Correct	59	265	324
Total	833 (54%)	723 (46%)	1556

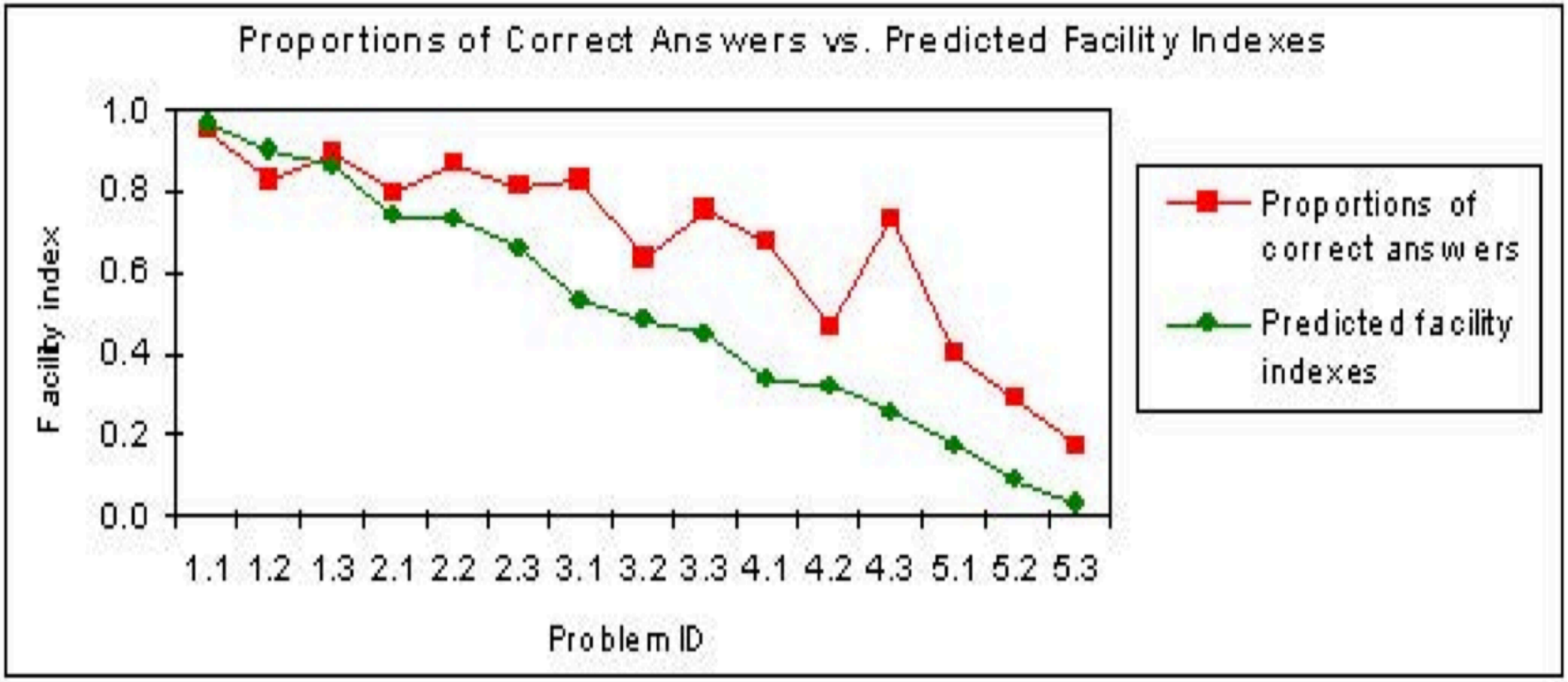
No evidence of a response bias favouring “Yes”

Subjects err through rejecting a valid explanation (265) far more often than through accepting an invalid one (59)

Testing the main hypothesis

- Using the understandability measures predicted by our model, we grouped the inference problems into 5 bins
- A Friedman test showed highly significant differences among the bins ($p<0.0001$)
- Pairwise comparisons showed differences between any bin pair ($p<0.05$) except for bins 2 and 3

Obtained vs Predicted

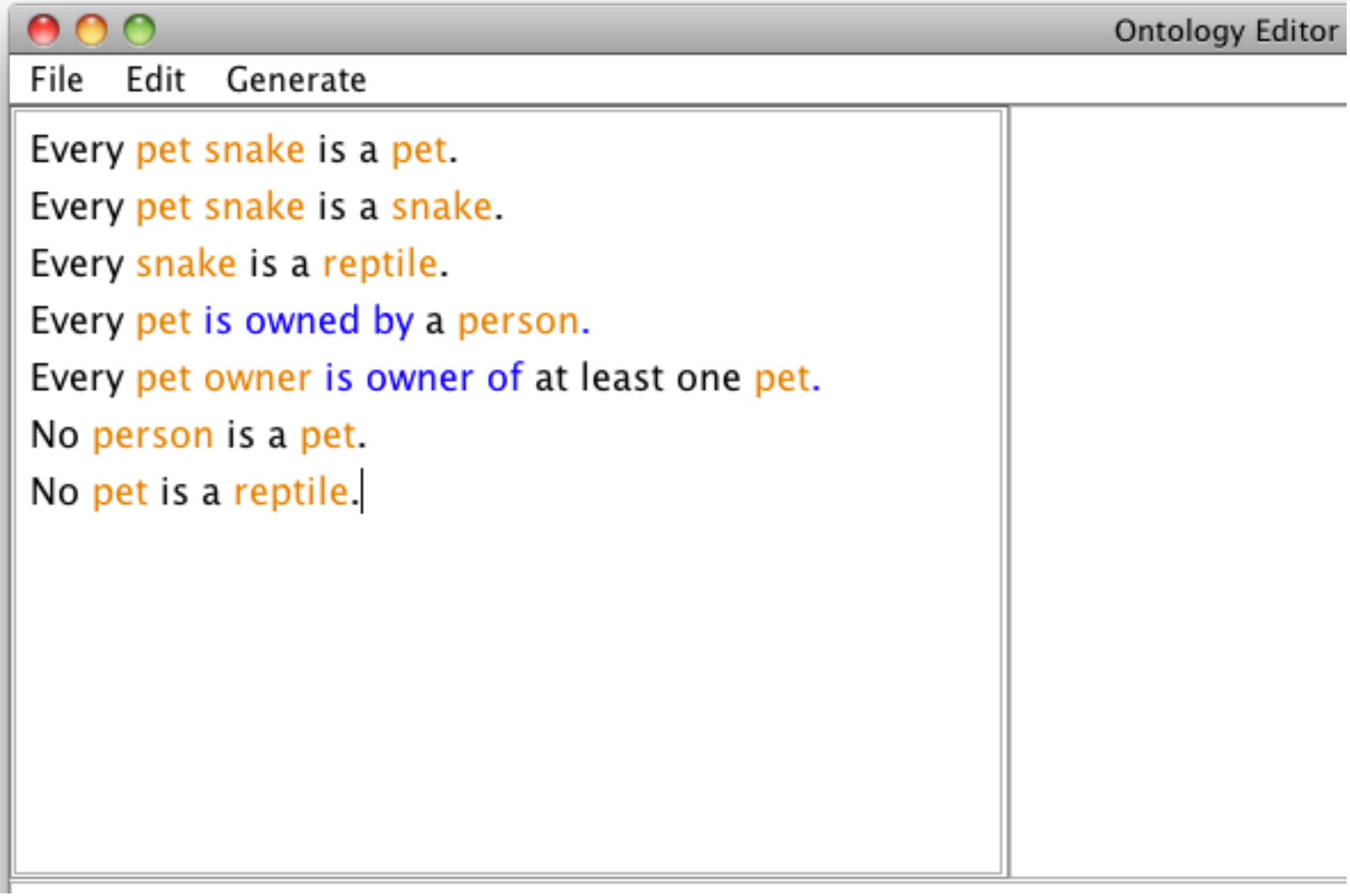


Some values (e.g., 4.3) might be influenced by improvements in wording in the second survey

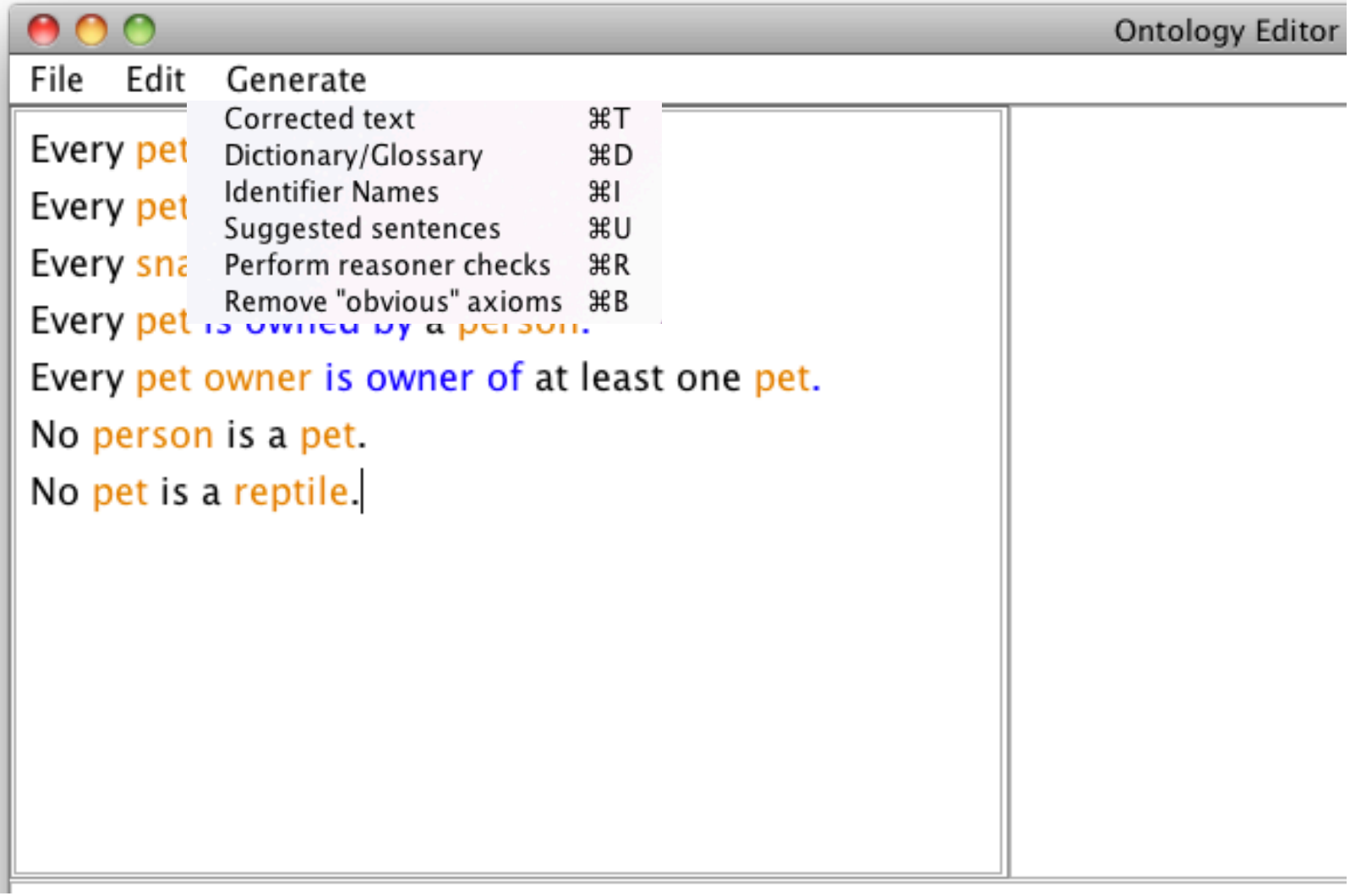
Alternative models

- We assume that success or failure on each step is independent of the other steps
- In reality there might be interactions, e.g. due to warming up (positive effect) or tiredness (negative)

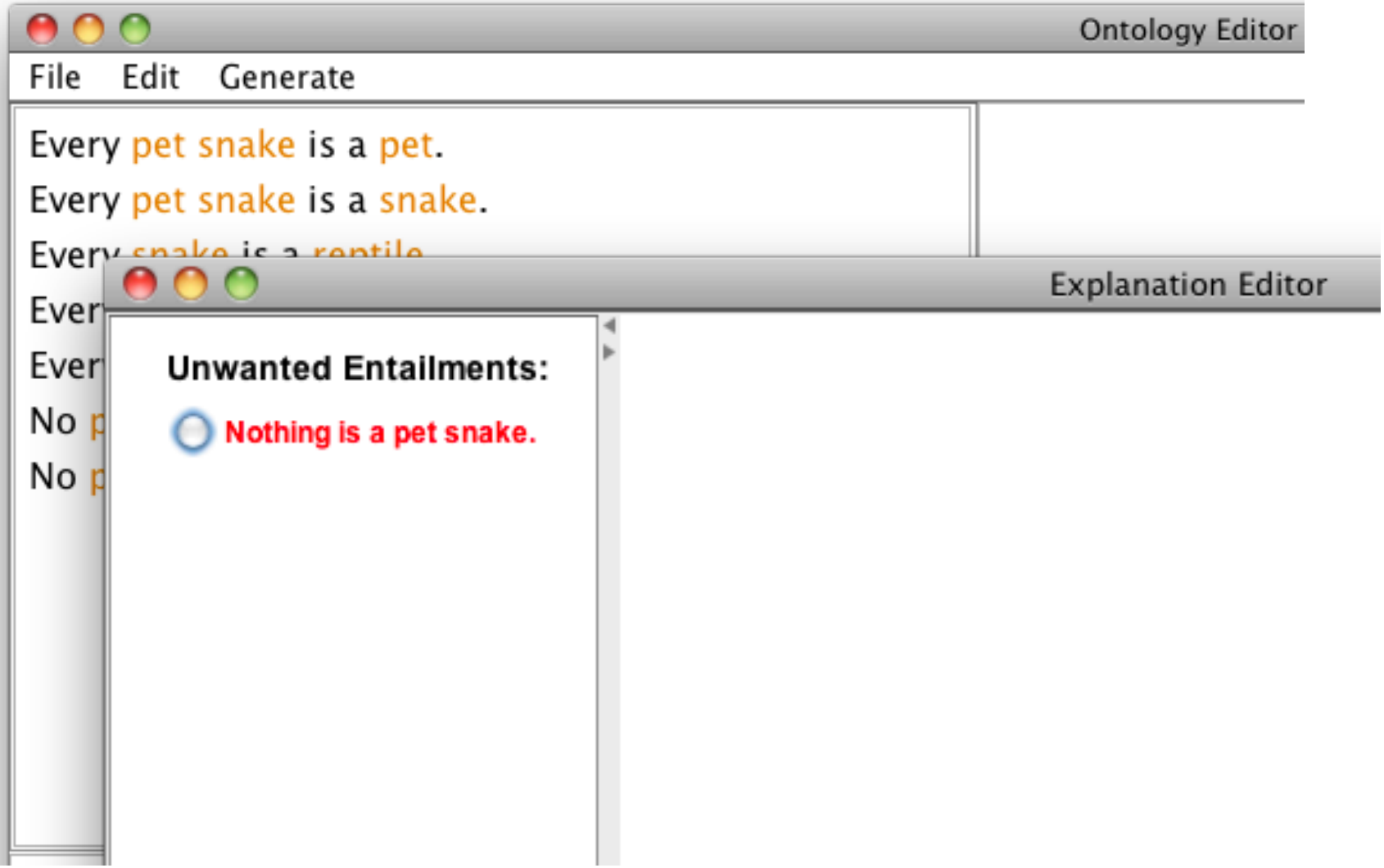
Explanation tool



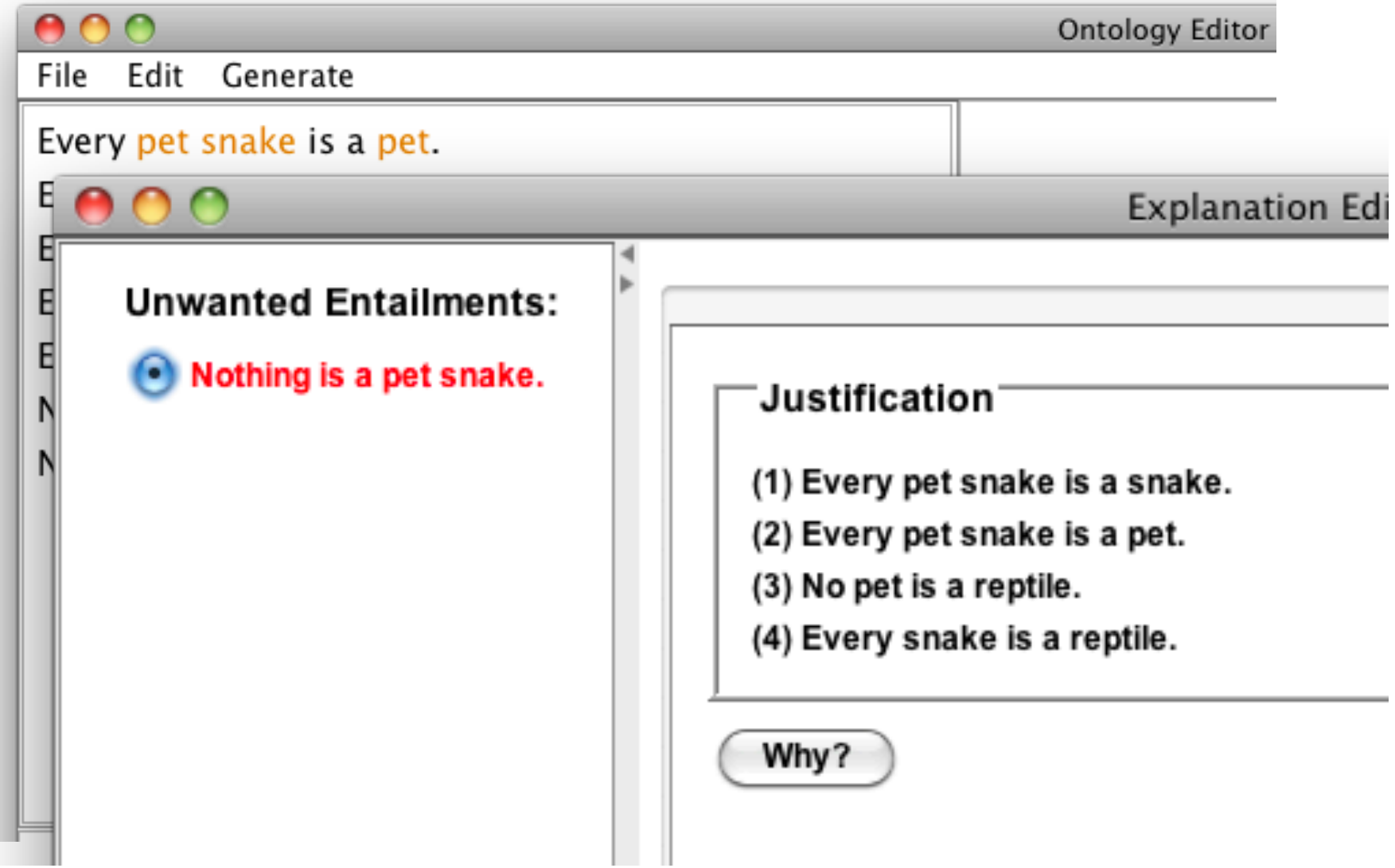
Reasoner checks



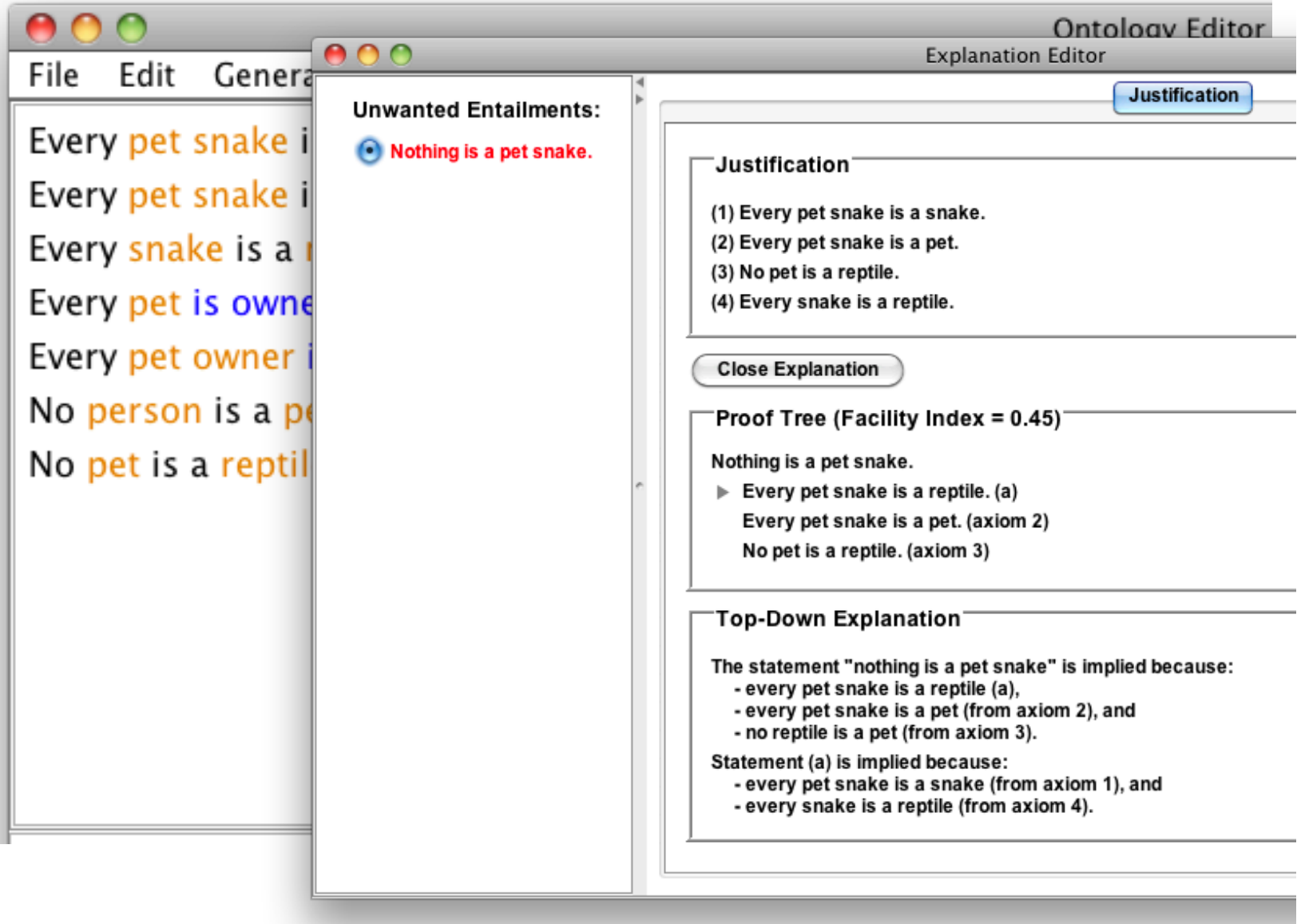
Explanation editor



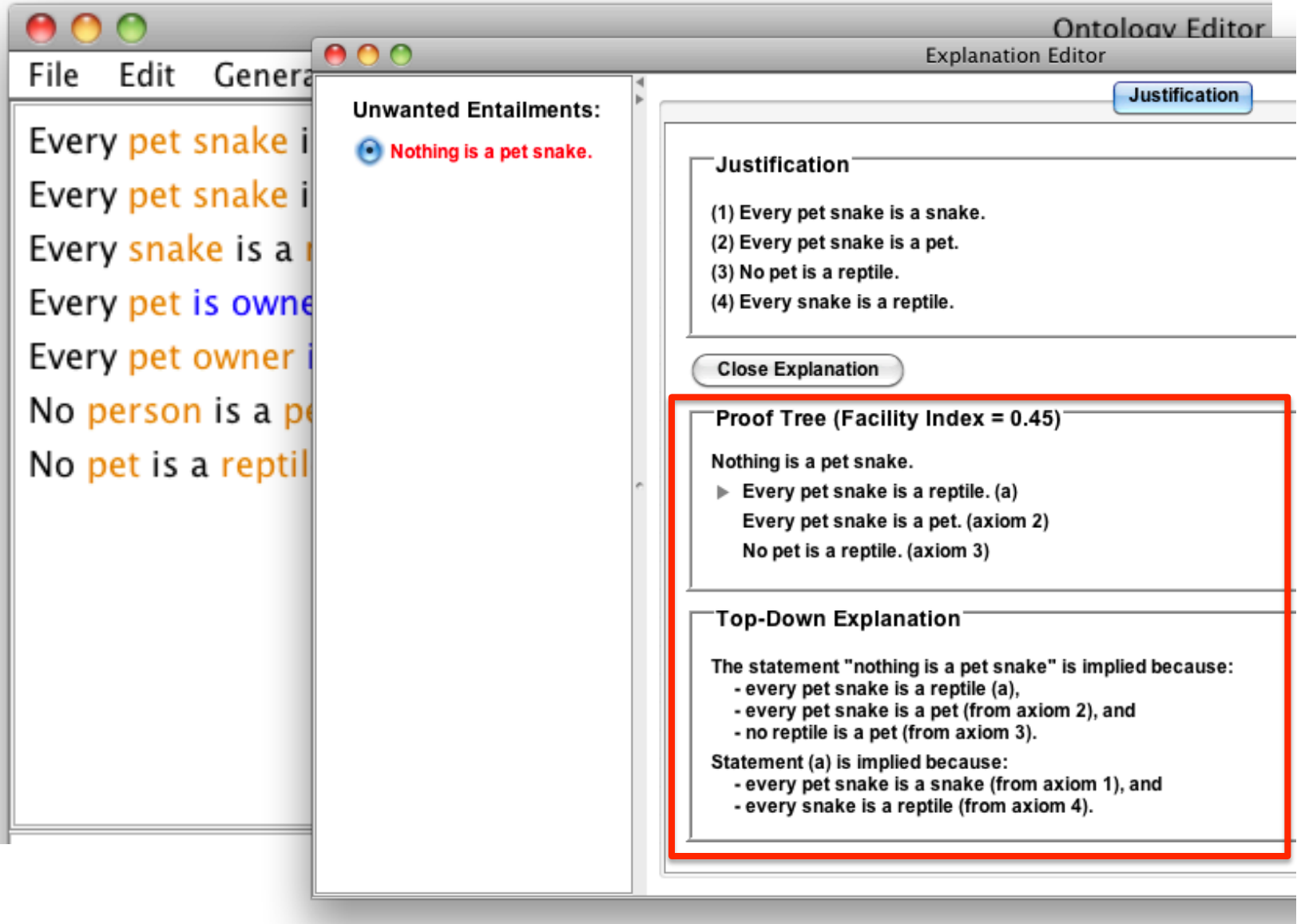
Justification



Explanation



Explanation



Explanation

Proof Tree (Facility Index = 0.45)

Nothing is a pet snake.

- Every pet snake is a reptile. (a)

  Every pet snake is a pet. (axiom 2)

  No pet is a reptile. (axiom 3)

Top-Down Explanation

The statement "nothing is a pet snake" is implied because:
- every pet snake is a reptile (a),
- every pet snake is a pet (from axiom 2), and
- no reptile is a pet (from axiom 3).

Statement (a) is implied because:
- every pet snake is a snake (from axiom 1), and
- every snake is a reptile (from axiom 4).

Proof tree

Proof Tree (Facility Index = 0.45)

Nothing is a pet snake.

- Every pet snake is a reptile. (a)

  Every pet snake is a pet. (axiom 2)

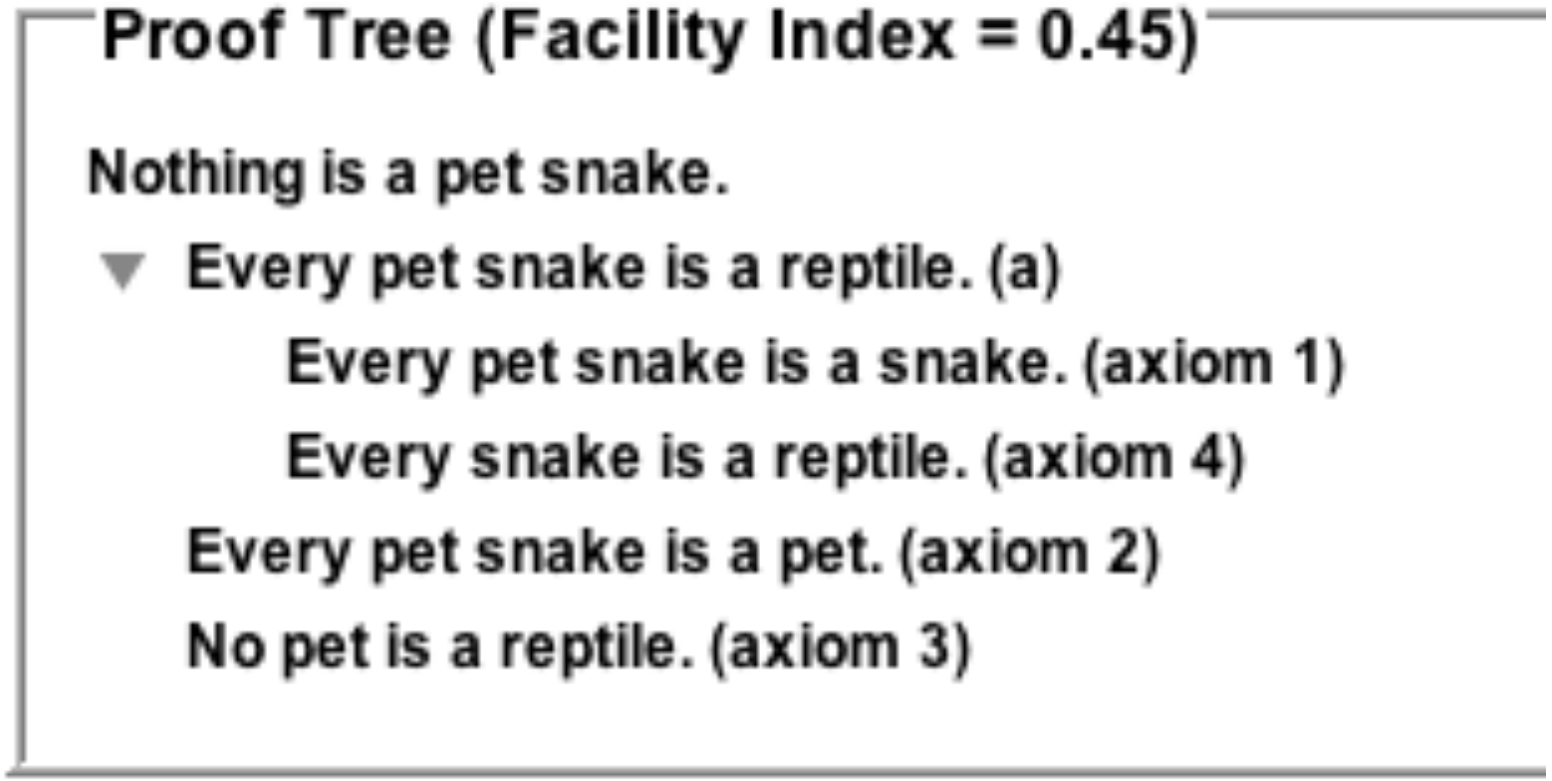
  No pet is a reptile. (axiom 3)

Top-Down Explanation

The statement "nothing is a pet snake" is implied because:
- every pet snake is a reptile (a),
- every pet snake is a pet (from axiom 2), and
- no reptile is a pet (from axiom 3).

Statement (a) is implied because:
- every pet snake is a snake (from axiom 1), and
- every snake is a reptile (from axiom 4).

Proof tree (expanded)



Conclusion

- Explanations of entailments can be based on proof trees
- Since there may be multiple proof trees we need a criterion for which is best
- Our proposal is to use the joint probability of understanding all the steps
- An empirical study shows that this gives a good prediction for two-step explanations

Questions?

Tu Anh Nguyen, Richard Power, Paul Piwek and Sandra Williams (2012). *Measuring the understandability of deduction rules for OWL.* Proceedings of First International Workshop on Debugging Ontologies and Ontology Mappings. Galway, Ireland.

Tu Anh Nguyen, Richard Power, Paul Piwek and Sandra Williams (2012*) Planning Accessible Explanations for Entailments in OWL Ontologies*. Proceedings of the 7th International Natural Language Generation Conference (INLG 2012), Starved Rock, IL, USA.

Thanks for your attention