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Charting the Potential of Description Logic for the Generation of Referring Expression

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Background

- Generation of Referring Expressions (GRE) algorithms *identify a target* referent:
- Express info known to be
  true of target
  false of all else

- But how does GRE model knowledge?

Knowledge Representation in classic GRE

- Sets of <Attribute,Value> pairs, e.g.
  - <Type, Poodle>
  - <Colour, Grey>
- These are *atomic* facts. Can't say
  - **All** poodles are grey
  - Kees is Dutch **or** Belgian
  - **If** x is part of y
and y is part of z
then x is part of z

Modern KR can do all this (and more)

- KL-One and semantic nets
- Modern descendants: Conceptual Graphs and Description Logic
  - Represent complex knowledge
  - Perform efficient automatic deduction

- Why not use modern KR for GRE?
- This talk: Description Logic (DL)
  - DL/OWL is now the language of the semantic web

Advantages

- A richer model of reference
  - New targets become identifiable
- Re-use
  - existing algorithms
  - existing ontologies
  - deduction for proving uniqueness
- Info represented *succinctly*, e.g.
  - *a* part of *b*, *b* part of *c*, *c* part of *d*, …
  - **For all** *x,y,z*: **if** *x* part of *y* **and** *y* part of *z* **then** *x* part of *z*

Remainder of this talk

- Introduction to DL
- Areces et al. on DL and GRE
- Extending the expressivity
- Extending the algorithm

Caveat: few empirical claims

This talk is about *what's possible* in GRE

Description Logics?

- A family of logic-based KR formalisms
- Describe domain in terms of concepts (classes), roles (relations) and individuals
- Smallest propositionally closed DL is **ALC** (**equivalent to $K_{(m)}$**)
  - Concepts constructed using ∪ , ∩, ∀, ∃

  E.g., domain elements that have a child who is a Doctor:

$$(\exists hasChild.Doctor)^{\mathcal{I}} = \{x | \exists y. \langle x, y \rangle \in hasChild^{\mathcal{I}} \text{ and } y \in Doctor^{\mathcal{I}}\}$$

DL Knowledge Base

- A TBox is a set of "schema" axioms (sentences), e.g.:

  { Dog ⊂ Animal, Dog ⊂ ¬ Woman
  hasFather ∘ hasBrother ⊂ hasUncle, feed ∘ love ⊂ feed }

  – i.e., a **background theory**

- An ABox is a set of "data" axioms (ground facts), e.g.:

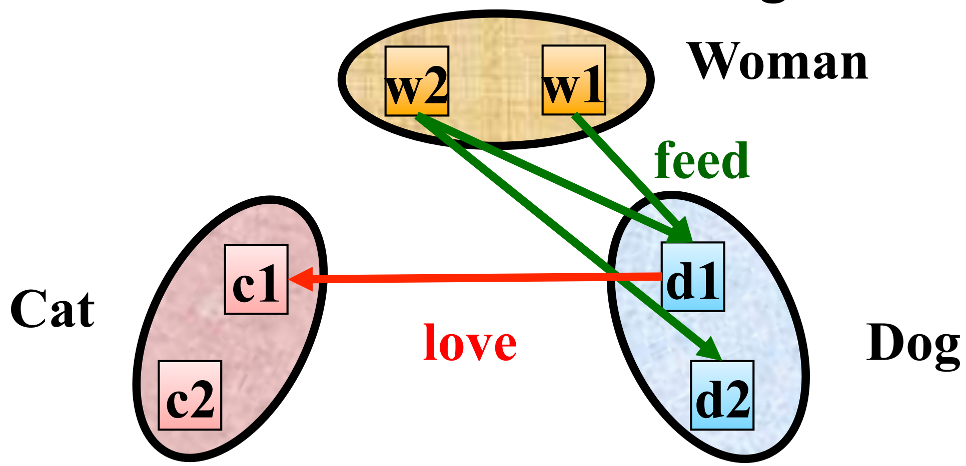
  {d1:Dog, w1:Woman, c1:Animal,
  (w1,d1):feed, (d1,c1):love
  }

- An NBox (Negation as Failure Box) is a set of "complete" concepts and properties e.g.:

  {Dog, Animal}

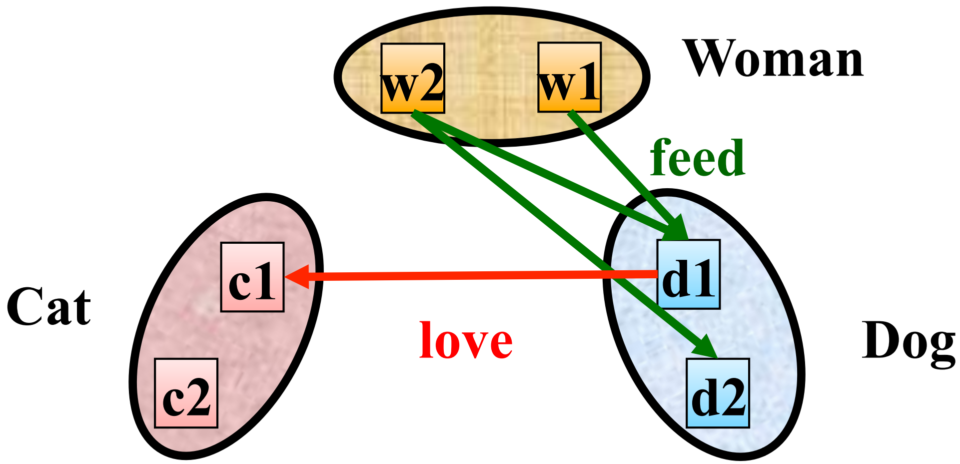
GRE example

- Uniquely identifying an object in context.
  - d1: the Dog that loves some Cat
  - w2: the Woman who feeds a Dog that doesn't love a Cat



From the DL point of view

- ABox assertion axioms
  - w1:Woman
    w2:Woman
  - d1:Dog, d2:Dog
  - c1:Cat, c2:Cat
  - (w1,d1):feed
    (w2,d2):feed
    (w2,d1):feed
  - (d1,c1):love



DL for GRE: the story so far

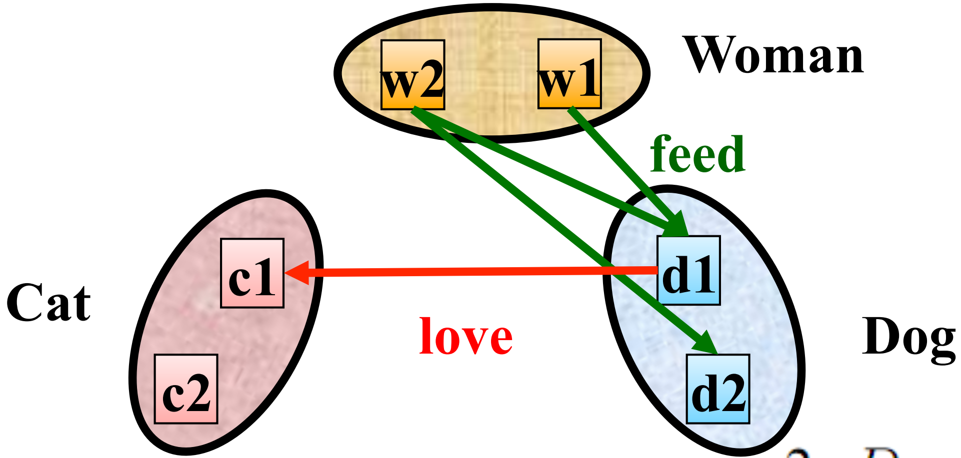
- Areces et al. (2008) re-interpret GRE as a problem of computing ALC formulas.

$\mathcal{L}$-GRE PROBLEM	
Input:	A model $\mathcal{M}$ and a target set $A \subseteq \Delta$.
Output:	A formula $\varphi \in \mathcal{L}$ such that $\|\varphi\| = A$ (if such a formula exists).

- An algorithm to compute distinguishing REs (if one exists) for all objects:
  - Generate & Test strategy
  - Start from atomic concept names, then extend with (negative) existential quantifier.

DL for GRE example

- Referring Expression as a DL formula



1. $Dog = \{d1, d2\}$,
   $\neg Dog \sqcap Woman = \{w1, w2\}$,
   $\neg Dog \sqcap \neg Woman = \{c1, c2\}$.

2. $Dog \sqcap \exists love.(\neg Dog \sqcap \neg Woman) = \{d1\}$,
   $Dog \sqcap \neg \exists love.(\neg Dog \sqcap \neg Woman) = \{d2\}$.

3. $(\neg Dog \sqcap Woman) \sqcap \exists feed.(Dog \sqcap \neg \exists love.(\neg Dog \sqcap \neg Woman)) = \{w2\}$,
   $(\neg Dog \sqcap Woman) \sqcap \neg \exists feed.(Dog \sqcap \neg \exists love.(\neg Dog \sqcap \neg Woman)) = \{w1\}$.

Logical foundations of GRE

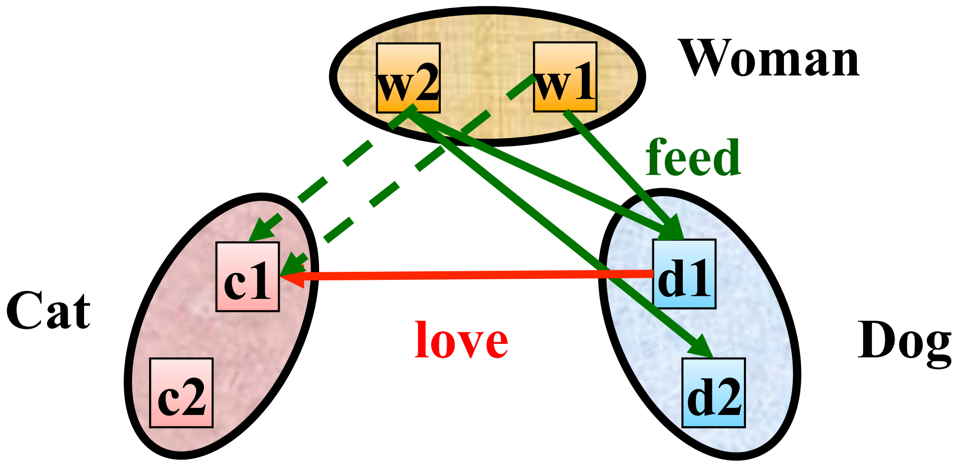
DL forces us to make these explicit, allowing subtle distinctions

- GRE relies on a Unique Name Assumption (UNA)
  - If Dog={d1,d2} but d1=d2 then Dog refers uniquely
  - In DL, we can use UNA, or write d1=/=d2, etc.

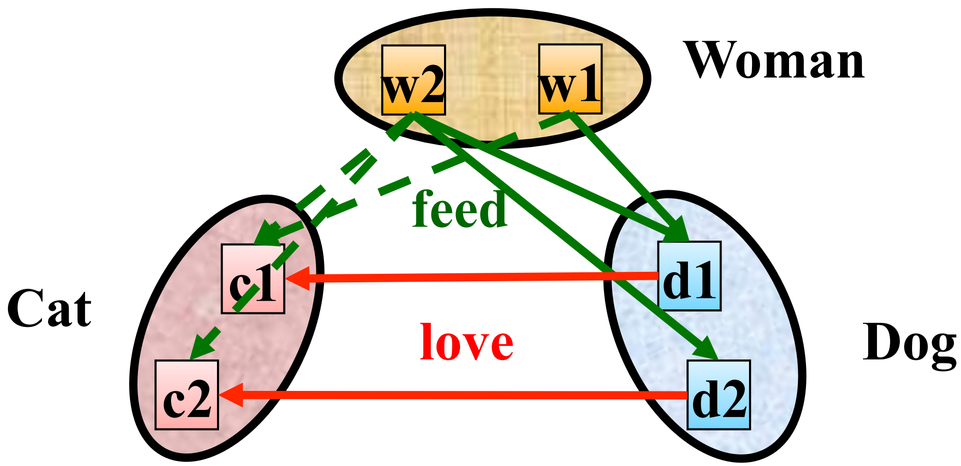
- GRE relies on a closed world assumption (CWA)
  - In the earlier example, there are no more than two dogs, no more than two women, etc.
  - Without this, we would never be sure of uniqueness
  - DL: we can localise CWA, using an NBox

ABox Not Enough

- Tbox:
  - Woman ⊂ ¬Dog
  - Dog ⊂ ¬ Cat
  - Cat ⊂ ¬ Woman
  - T ⊂ Dog ∪ Woman ∪ Cat
  - feed ∘ love ⊂ feed
- Nbox:
  - {Dog,Woman,Cat,love,feed}



Additional Quantifiers



- Now Areces et al. cannot identify any of the 6 objects
- Additional quantifiers make them referable
  - c1: The cat which is fed by (at least) 2 women
  - w1: The woman feeding only those fed by at least 2 women
  - w2: The woman who feeds all dogs

Representing Quantifiers in Ontologies

We can use Generalised Quantifiers, e.g.,

"only", "five" *(5)*, "at least two" *(≥2)*

Example:

- English: *"The woman who loves at least two dogs"*
- Set theory + GQ: *{y ∈ Woman: **≥2** (Dog,{z: Love(y,z)})}*

But which **quantifiers** exactly?

Proposal: use the numerical quantifiers

Table 1: Expressing GQ in DL

	QAB	DL
1	$\geq nN2\{z : Ryz\}$	$y :\geq nR.N2$
2	$\geq nN2\neg\{z : Ryz\}$	$y :\geq n\neg R.N2$
3	$\geq n\neg N2\{z : Ryz\}$	$y :\geq nR.\neg N2$
4	$\geq n\neg N2\neg\{z : Ryz\}$	$y :\geq n\neg R.\neg N2$
5	$\leq nN2\{z : Ryz\}$	$y :\leq nR.N2$
6	$\leq nN2\neg\{z : Ryz\}$	$y :\leq n\neg R.N2$
7	$\leq n\neg N2\{z : Ryz\}$	$y :\leq nR.\neg N2$
8	$\leq n\neg N2\neg\{z : Ryz\}$	$y :\leq n\neg R.\neg N2$

Example:

N2 -- Dog
R -- Love

- Quantifiers of Type 1,
  e.g., n = 1: the *existential* quantifier
- Quantifiers of Type 7,
  e.g., n = 0: the *only* quantifier
- Quantifiers of Type 6,
  e.g., n = 0: the *all* quantifier

Generating SROIQ-enabled REs

- GROWL: a GRE algorithm using OWL-2
  - Generate-and-test strategy
  - Using DL reasoning
  - Generating increasingly complex descriptions
    - Complexity measured by the structure of the expressions
      - 1 Dog
        complexity of (negated) atomic concept is 1
      - 2 $\neg Dog \sqcap Woman$
        complexity of conjunction (disjunction) is the maximal complexity of conjuncts (disjuncts) +1
      - 4 $Dog \sqcap \neg \exists love.(\neg Dog \sqcap \neg Woman)$
        complexity of existential (universal) restriction is the complexity of filler + 1

Generating SROIQ-enabled REs

- GROWL: a GRE algorithm using OWL-2
  - Starting from the basic terms, such as
    - Names (e.g. Dog, feed)
    - Inverse of named roles (such as $feed^-$)
    - Negation of another basic term
      (e.g., ¬Dog, ¬feed, ¬$feed^-$)
  - For each existing term / description, create new description by
    - Extending with conjunction/disjunction
    - Extending with existential/universal restriction
    - Extending with cardinality restriction
  - Until no new non-empty description can be created

Generating SROIQ-enabled REs

- Deciding whether a new description should be accepted
  - Accept if no existing description has same extension
  - But still non-empty
- Using standard reasoning services
  - Concept subsumption checking
  - Concept satisfiability checking

Algorithm A-2: $Add(D, e)$

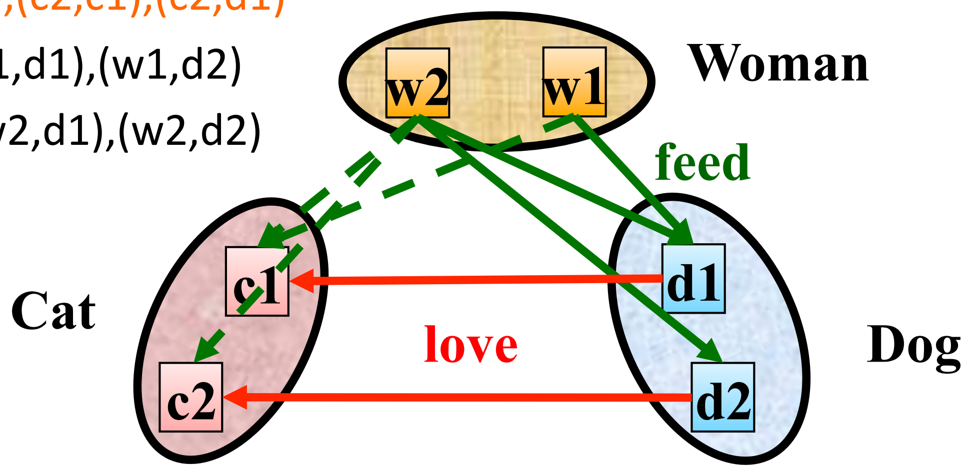
INPUT: D, e

OUTPUT: (Extended)Description Queue D

```
1: for d ∈ D do
2:     if Ins(d) = Ins(e) then
3:         return D
4: if Ins(e) ≠ ∅ then
5:     D := D ∪ {e}
6: return D
```

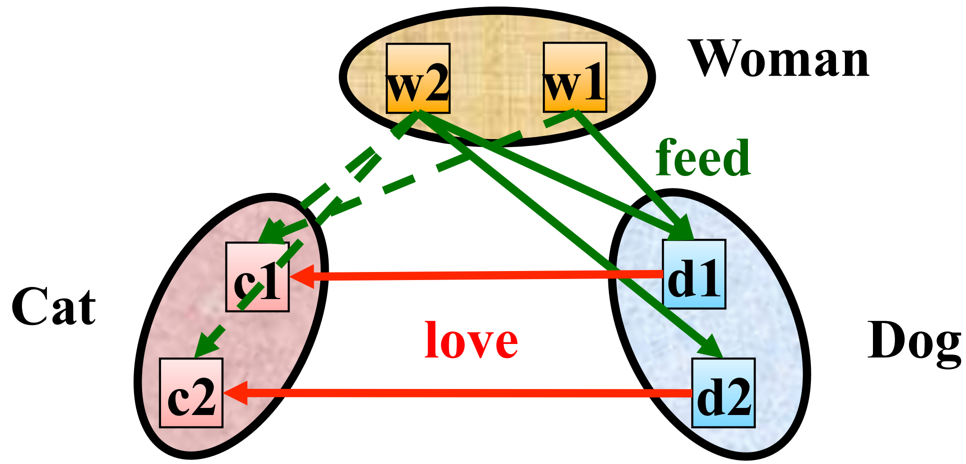
Example Revisited

- Starting from basic terms
  - D={Woman, Dog, Cat, ¬ Woman, ¬ Dog, ¬ Cat, feed, feed$^-$, ¬feed$^-$ etc.}
  - Ins(Woman) = {w1,w2}
  - Ins(Dog) = {d1,d2}
  - Ins(Cat) = {c1,c2}
  - Ins(¬Woman) = {c1,c2,d1,d2}
  - …
  - Ins(feed) = {(w1,d1),(w1,c1), (w2,d1), (w2,c1),(w2,d2),(w2,c2)}
  - Ins(feed$^-$)= {(d1,w1),(c1,w1), (d1,w2), (c1,w2),(d2,w2),(c2,w2)}
  - Ins(¬feed$^-$) = {(d1,d2),(d1,c1),(d1,c2),(d1,d1),(d2,d1),(d2,d2),(d2,c1),(d2,c2),(d2,w1) (c1,c1),(c1,c2),(c1,d1),(c1,d2),(c2,c2),(c2,c1),(c2,d1) (c2,d2),(c2,w1),(w1,w1),(w1,w2),(w1,d1),(w1,d2) (w1,c1),(w1,c2),(w2,w1),(w2,w2),(w2,d1),(w2,d2) (w2,c1),(w2,c2),}



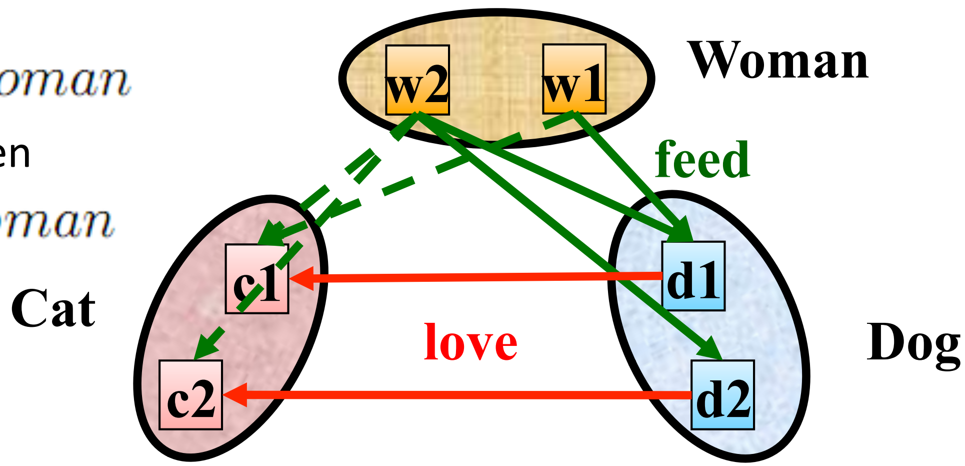
How to Refer to c1?

- Extending Woman with maximal Cardinality restriction
  <=0(¬feed$^-$).Woman (things that are fed by all women)
- Ins(<=0(¬feed$^-$).Woman) = {**c1,d1**}. This is non-empty and not identical to any existing description
- Therefore, the new concept is added to D:
- D = {Woman, Dog, Cat, ¬Woman, ¬Dog, ¬Cat, **<=0(¬feed$^-$). Woman**, etc.}
- Conjoining this with Cat:
  - Ins(Cat **&** <=0(¬feed$^-$).Woman) = {**c1**}, c1 identified!



All objects become referable

- w1: the woman that does not feed all cats;
  $\{w1\} = Woman \sqcap \exists \neg feed.Cat$
- w2: the woman that feeds all cats;
  $\{w2\} = Woman \sqcap \leq 0 \neg feed.Cat$
- d1: the dog that is fed by all women;
  $\{d1\} = Dog \sqcap \leq 0 \neg feed^{-}.Woman$
- d2: the dog that is not fed by all women;
  $\{d2\} = Dog \sqcap \exists \neg feed^{-}.Woman$
- **c1: the cat that is fed by all women;**
  $\{c1\} = Cat \sqcap \leq 0 \neg feed^{-}.Woman$
- c2: the cat that is not fed by all women
  $\{c2\} = Cat \sqcap \exists \neg feed^{-}.Woman$



Conclusion (1)

We advocate using modern KR

- background knowledge should be considered
- expressing complex as well as atomic info
- reusing reasoning algorithms

Conclusion (2)

- Specific contributions:
  - Using DL reasoning to infer implicit knowledge (i.e., computing non-asserted information)
  - Generating REs taking into account incomplete knowledge
  - Extending the expressivity of GRE to OWL-2 (i.e., using new quantifiers, such as ≥2feed.Dog)
  - Introducing Nbox for a partially closed world
- Open issues:
  - How useful are the newly generated REs?
  - How to choose the "best" RE?

Conclusion (2)

- Choosing the numerical quantifiers, have we used the "best" class?
- Note: GROWL generates descriptions of sets as well as individuals
- Description of sets will require new quantifiers
  - The dogs fed by between 3 and 7 women
- Some of these may even be non-first order, e.g.,
  - The dogs fed by most women
  - The dogs fed by an even number of women
- In finite domains, these were already expressible (though maybe less succinctly)