Description Logics for Natural Language Inference

Dick Crouch, Amazon Search

Cross Framework Meaning Representations, Oslo, May 2018

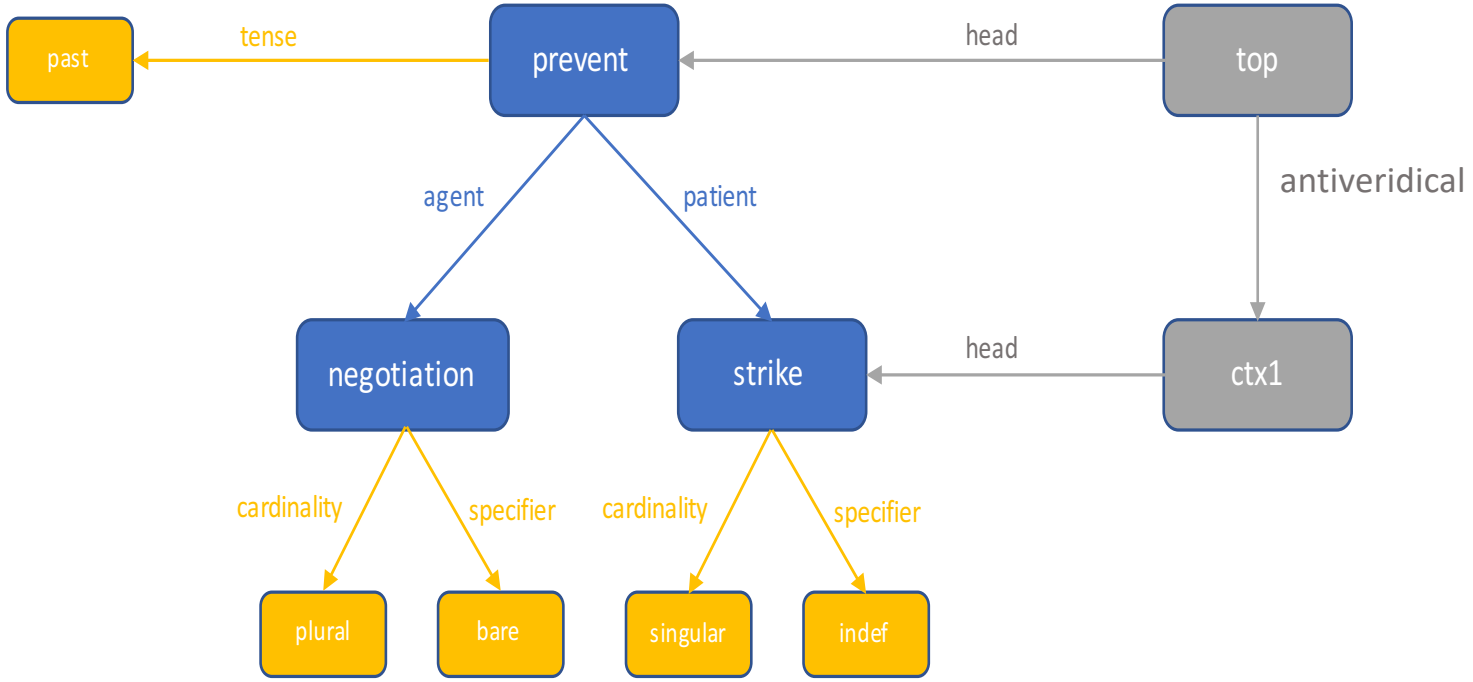
Overview

- AKR & GKR: named graphs
  - Concepts and contexts
  - Description logics for concepts
- Inference
  - World knowledge, robustness, ambiguity
- Dirty laundry

Knowledge Graphs and Semantics

- Knowledge graphs are popular for the semantic web
  - Graphs of RDF subject-predicate-object triples
  - They have a graph semantics in addition to a model-theoretic one
    - Knowledge can be viewed as a graph and not just represented by one
    - Focus on efficient inference including graph algorithms
- You might think they would be ideal for NL semantics, but:
  - They are intended to represent collections of positive facts / assertions
  - NL semantics must also handle negative, disjunctive and hypothetical assertions.
    - RDF doesn't do negation
- Named graphs extend RDF in a simple way that is better for NL
  - Goal: semantic objects are graphs, not just represented by them

AKR: Bobrow et al



GKR: Kalouli 2018,
Boston et al 2018, Shen et al 2018

- Layered graph representation
  - Blue: conceptual / predicate argument
  - Gray: contextual / boolean
  - Yellow: attributes / properties
  - Coreference links
  - World knowledge
  - Temporal relations
  - Task constraints
  - …

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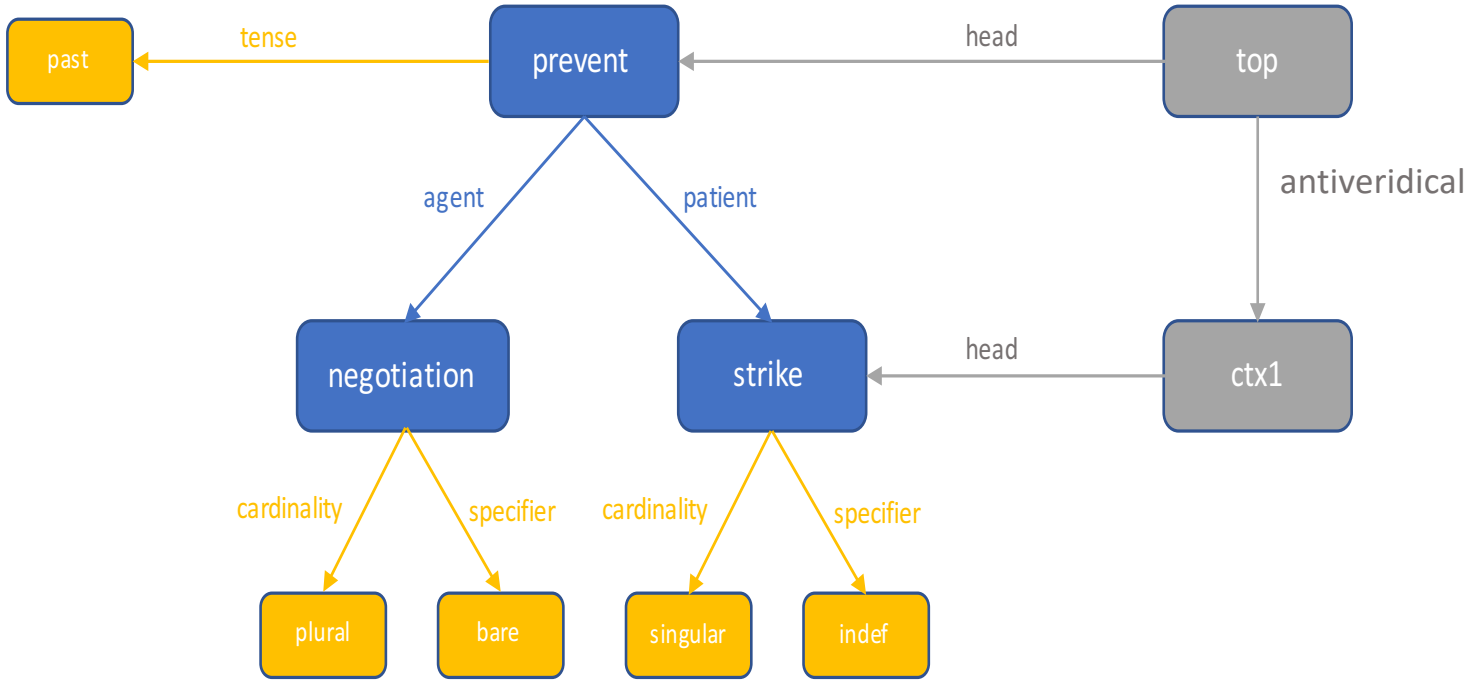

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Conceptual level:

∃p, n, s. prevent(p) & negotiations(n) & strike(s) & arg0(p, n) & arg1(p, s)

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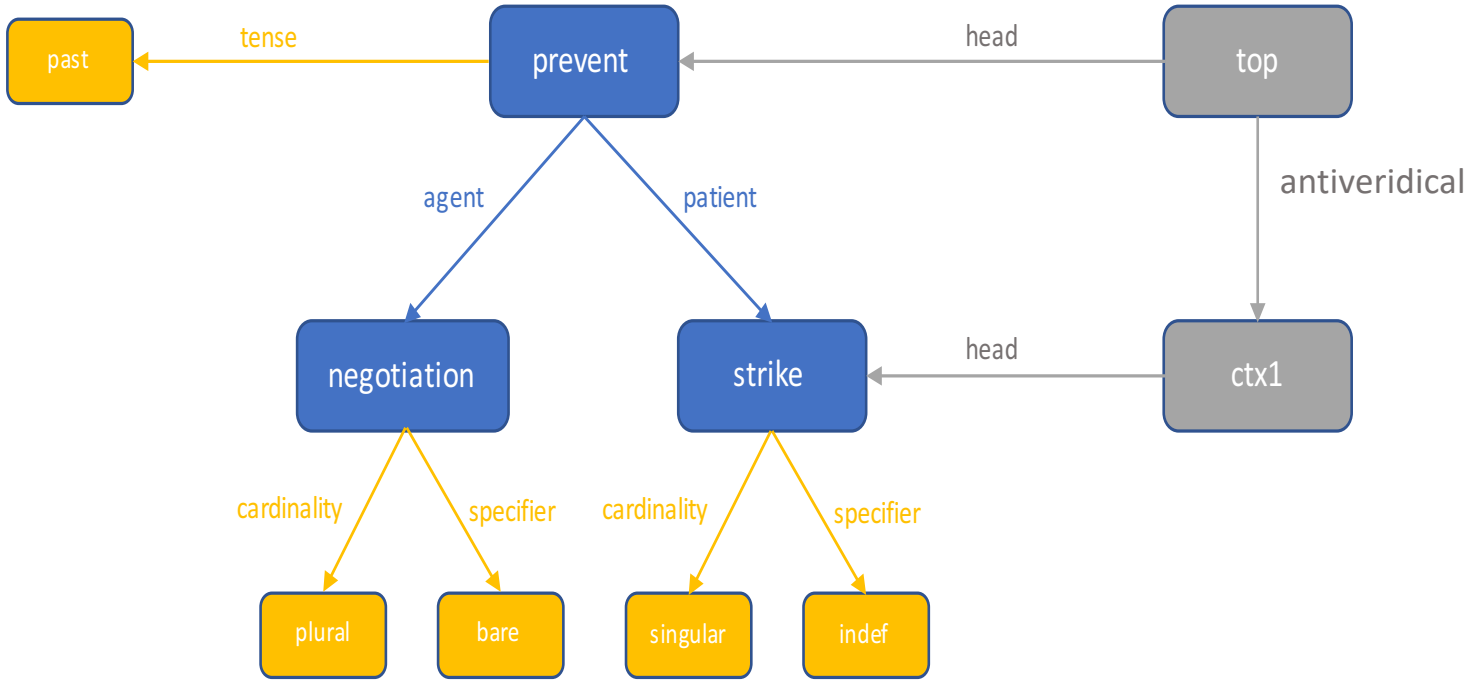

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Conceptual level:

∃p, n, s. prevent(p) & negotiations(n) & strike(s) & arg0(p, n) & arg1(p, s)

≡

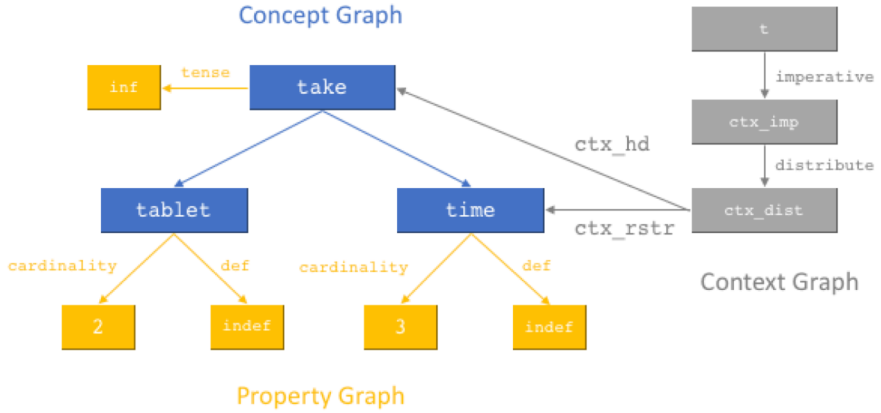
∃p, n, s. p⊑ prevent & n⊑ negotiations & s⊑ strike & restr(p, n, arg0) & restr(p, s, arg1)

Incompleteness vs incorrectness

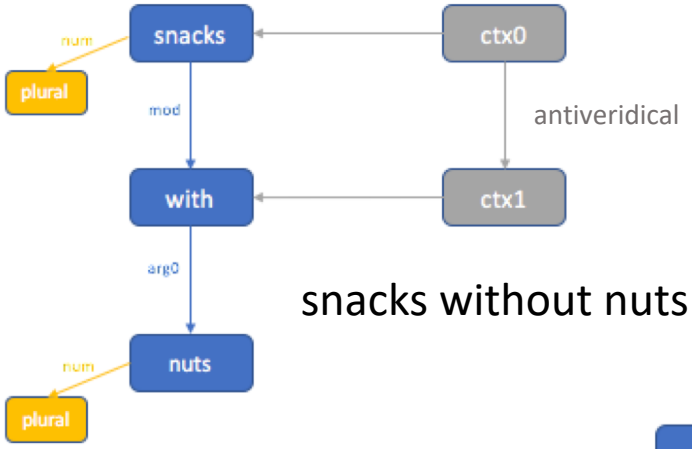
- Terms in concept layer denote concepts, not individuals:
  - ∃p, n, s. p⊑ prevent & n⊑ negotiations & s⊑ strike & restr(p, n, arg0) & restr(p, s, arg1)
- Concept layer provides incomplete information, not incorrect
  - Says nothing about the existence of individuals satisfying those concepts
  - The contextual layer is required to assert existential commitment
- Conceptual layer alone
  - Supports semantic similarity (sub-concept, super-concept)
  - Similarity can be further refined by attribute layer (cardinality, definiteness)
- Conceptual and contextual layer
  - Supports entailment

What goes into the context layer?

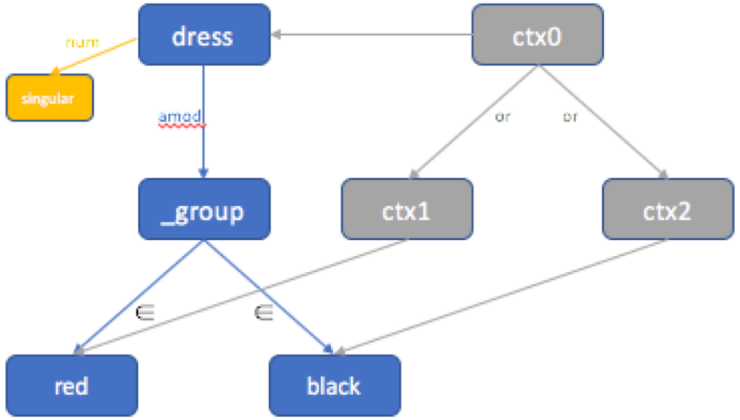
- Intensional contexts
  - know, want, believe, prevent
- Boolean operations
  - negation, disjunction, if-then
- Distributivity
  - aka quantifier scope effects



Take two tablets three times



snacks without nuts



red or black dress

What are contexts?

- Model Theoretically:
  - Possible worlds, contexts of evaluation, …
- Graphically
  - Named sub-graphs of the concept graph
- Named graphs (Carroll et al 2005)
  - Start with (conjunctive) graphs of RDF subject-predicate-object triples
    - Each triple is a proposition/assertion
  - Allow sub-graphs to be labeled/named
  - Allow graph names to occur as subjects or objects
  - Graph semantics is a simple extension of RDF graph semantics
    - Though named graphs are not asserted

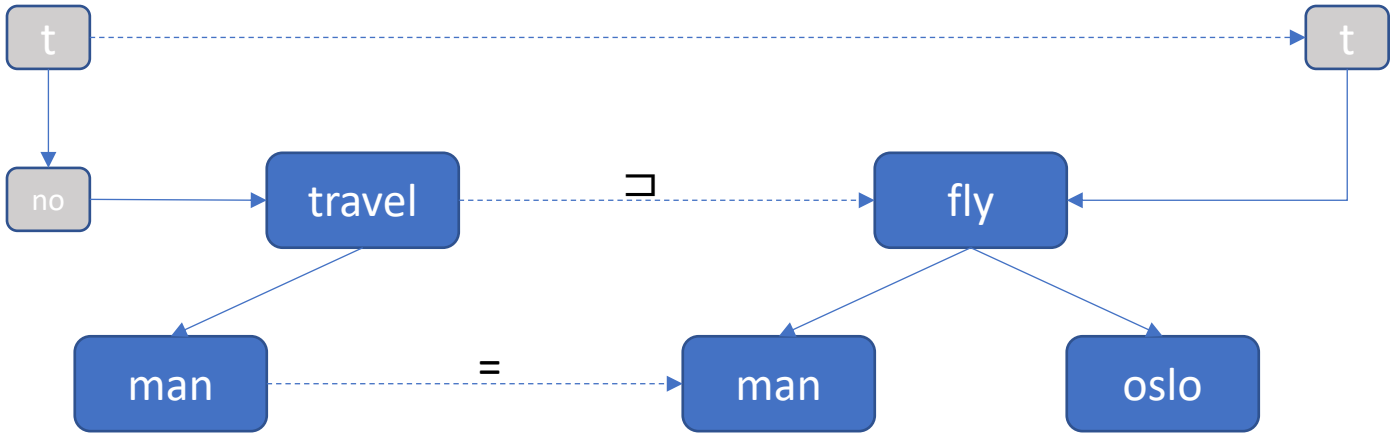
What are concepts?

- Lexical concepts and roles taken as primitive
- Combine to form complex concepts with a description logic
  $\mathcal{FL}_0$: C,D ⇒ A | C ⊓ D | ∀R.C
  - Bite ⊓ ∀subj.Dog ⊓ ∀obj.Man: the concept of bitings of men by dogs
  - Simple, polynomial subsumption algorithms

  $\mathcal{FLN}_0$: adds cardinality restrictions

- Since negation, disjunction etc handled by contexts, don't need the full power of OWL (concept union, complement, existential role restriction)

GKR inference



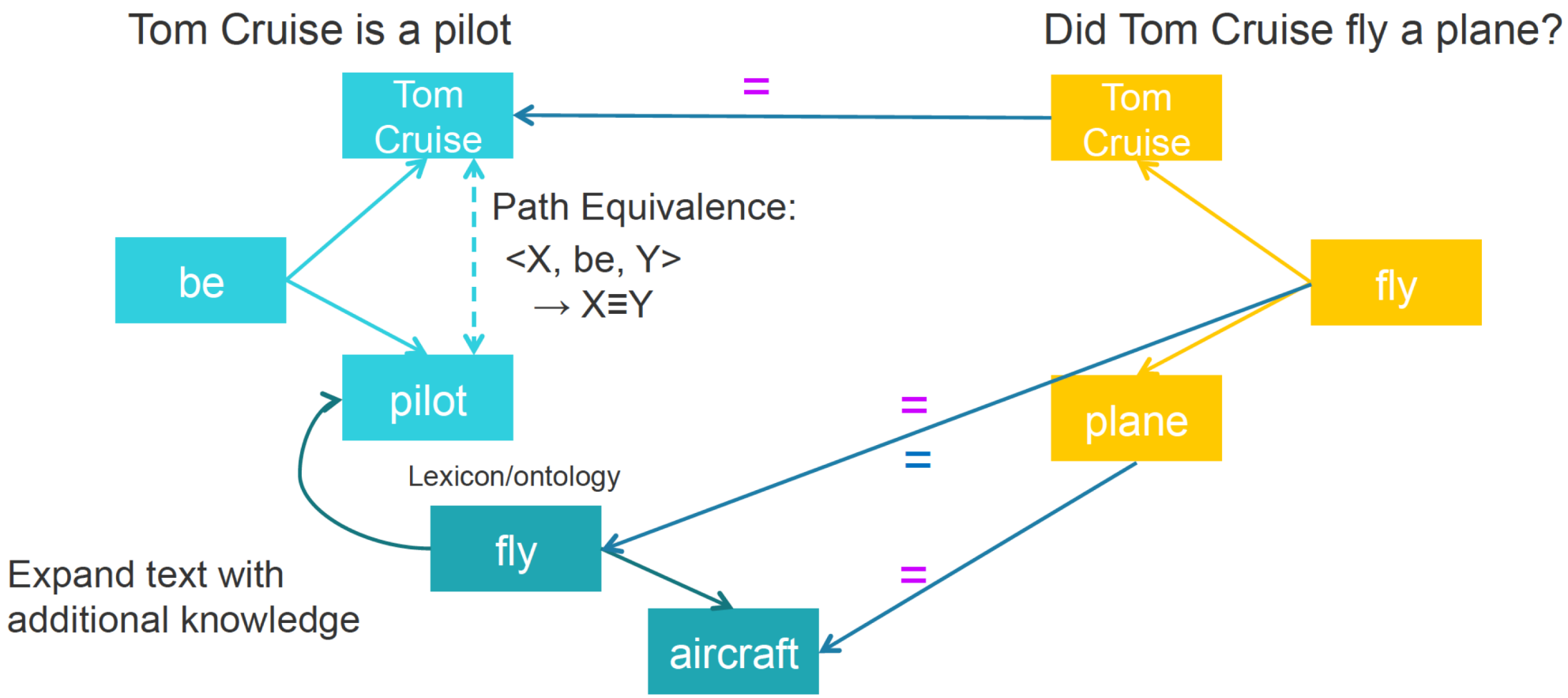
1. travel.restr(man,arg0) ⊐ fly.restr(man,arg0).restr(oslo,loc)
2. travel instantiated in context no
3. travel uninstantiated in context t
4. fly instantiated in context t
5. Hence contradiction

No man traveled

A man flew to Oslo

Entailment and Contradiction Detection (ECD): Crouch & King 2006

Adding (lexical) world knowledge

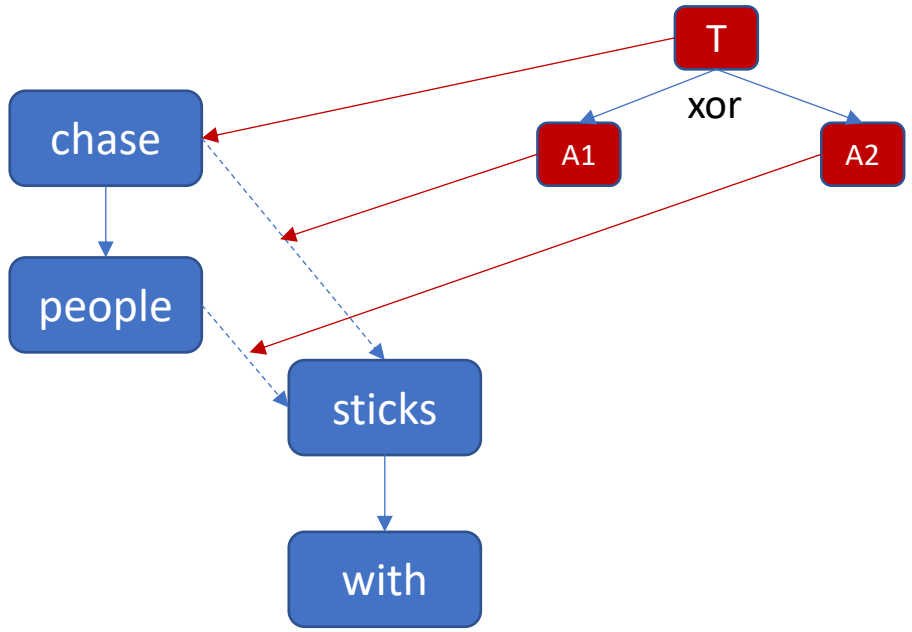


Robust Inference

- ECD as one feature in an ensemble (Nuance NLIE)
- Cosine distance of vectors for concept alignment
- Adding plausible lexical entailments (under hypothetical contexts)

- Abductive concept subsumption
  - If $C_0 \sqsupset C_0'$ and $C_1 \sqsupset C_1'$, then assume $C_0.r_1.C_1 \sqsupset C_0'.r_2. \ldots .r_n.C_1'$
    - Unless reason to suppose otherwise, assume all roles are the same.
  - Collect paths equivalences from training data: $r_1 \equiv r_2 \ldots r_n$
  - Learn path plausibilities (weights)

Packing Ambiguity



Chase people with sticks

Ambiguity contexts name different sub-graphs:

- T: chase.obj.people
  sticks.prep.with
- A1: chase.mod.sticks
- A2: people.mod.sticks

Claims

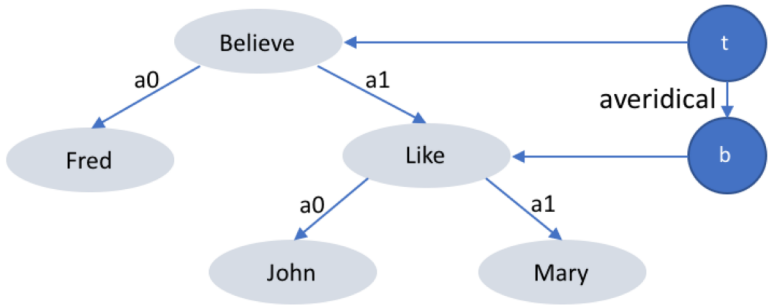
- You can go a long way with a very simple description logic:
  - $\mathcal{FL}_0$: conjunction and role restriction of concepts.
  - $\mathcal{FLN}_0$: plus cardinality restrictions
- But you need to sharply separate conceptual predicate-argument structure from Boolean and hypothetical contextual structure.
- RDF named graphs provide a way of making this separation clear.
- Named graphs also facilitate:
  - Packing of ambiguity
  - Layering in additional levels of meaning (coreference, world knowledge)
- $\mathcal{FLN}_0$ conceptual structure *may* be a good match for distributional vector spaces

Dirty Laundry

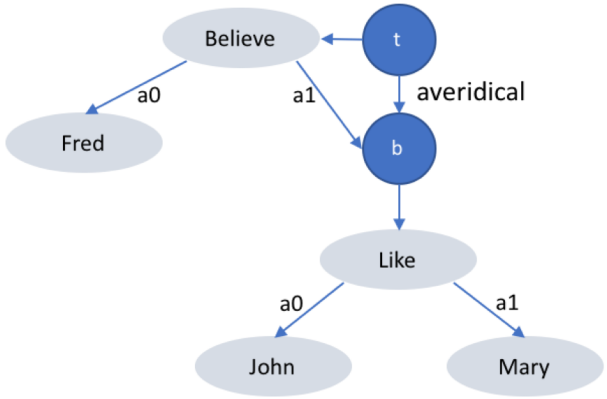
- Can we avoid contexts as role arguments?
- Do conjunction and disjunction require concept union?
- Do roles always restrict contexts?
- …

Contexts as Role Arguments

GKR: Contexts cannot be role arguments



Named graphs: allows intermingling of concepts & contexts

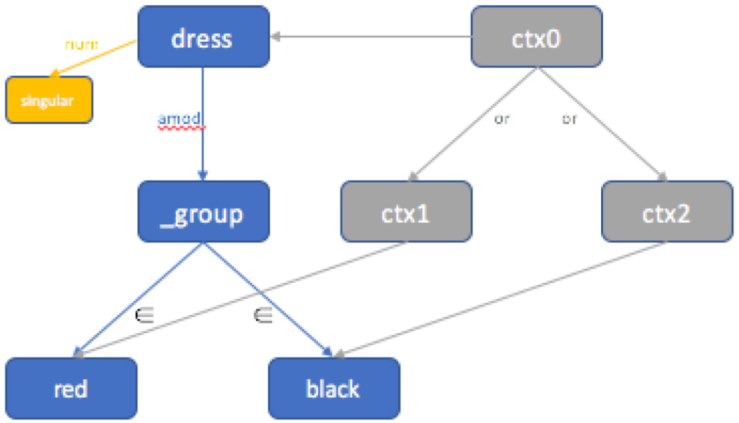


- Keeping contexts out of roles stays in $\mathcal{FL}_0$ territory

But:

- *people with money* vs *people with no money*
  - Surely these express different concepts?
- Solution? Determiner *no* adds a cardinality restriction to the concept graph
- But what about relative clauses?
  People that do not have money

Conjunction, Disjunction, Concept Union



red or black dress

What is the _group concept?
Red ⊔ Black ?

- Why is concept union an issue?
- Gardenfors: connectedness and convexity of natural concepts
  - No holes, breaks or gerrymandering
- Concept intersection and role restriction (probably) preserve connectedness and convexity
- Concept union almost certainly doesn't preserve it

Does role restriction always restrict?

- Privative adjectives – *fake diamond*
  - Partee: fake diamonds are diamonds in an extended sense
- *A man flew to Oslo → A man traveled*
  - *Travel:* move to a destination
  - *Fly:* move (through the air)
  - ECD alignment assumed Fly ⊏ Travel
    - Need to rethink lexical concept alignment