Attempto Controlled English: Language, Tools and Applications

Reasoning in ACE

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The Problem

- Is an ACE text consistent (*)?
- Given an ACE text T1 and an additional ACE text or sentence or query T2, does T1 entail T2?

(*) proof-theoretic definition of consistency: a set of first-order formulas is consistent if one cannot derive the false formula ⊥

model-theoretic definition of consistency: a set of first-order formulas is consistent if it has a model

(Non-) Entailments

- given an ACE text T and an additional ACE sentence S there are 4 possibilities
- T entails S
  - S can be deduced from T
  - usually shown by the inconsistency of $T \cup \neg S$
  - if S is a question then S can be answered on the basis of T
  - if S should be added to T then we need not bother
  - S is redundant, is not informative

(Non-) Entailments

- T entails $\neg S$
  - $T \cup S$ is inconsistent
  - if S should be added to T then we must decide to delete the conflicting part of T or not to add S
- T can be split into $T1 \cup T2$ and $T1 \cup S$ entails T2
  - elimination of redundancy or optimisation possible
  - computationally problematic

(Non-) Entailments

- T and S are not related by entailment
  - neither S nor $\neg S$ follow from T
  - question S cannot be answered
  - if S should be added to T we can safely do so

Requirements for the ACE Reasoner RACE

- all input and output in ACE
- generate all proofs
- give a user-friendly justification of a proof
- allow for auxiliary first-order axioms to express background knowledge that cannot (easily) be expressed in ACE
- interface to evaluable functions and predicates
- combine theorem proving with model generation
- hide internal working from casual user

A Basis for RACE

- development of a new theorem prover for DRSs
  - DRS deduction rules (Gabbay & Reyle)
  - correct & complete
  - no efficient proof strategy

- off-the-shelf first-order theorem provers and model generators as potential basis
  - leanTAP
  - EP Tableaux
  - Otter & Mace
  - do not satisfy all requirements

A Basis for RACE

- Satchmo (Manthey & Bry 1988)
  - basically a model generator
  - can also be used a theorem prover
  - uses first-order clauses Body ---> Head
  - generates minimal finite Herbrand models of clauses (if existent)
  - correct for unsatisfiability of range-restricted clauses
  - complete for unsatisfiability if used level-saturated
  - efficient Prolog core allowing ...
  - ... local extensions and modifications in Prolog

Original Satchmo

```
satisfiable :-
  setof(Clause, violated_instance(Clause), Clauses),
  !,
  satisfy_all(Clauses),
  satisfiable.
satisfiable.

violated_instance((B ---> H)) :-
  (B ---> H),
  B,
  \+ H.

satisfy_all([]).
satisfy_all([(_B ---> H) | RestClauses]) :-
  H,
  !,
  satisfy_all(RestClauses).
satisfy_all([(_B ---> H) | RestClauses]) :-
  satisfy(H),
  satisfy_all(RestClauses).

clauses: B ---> H
B conjunction of atoms or true
H disjunction of Atoms or false
no explicit negation
```

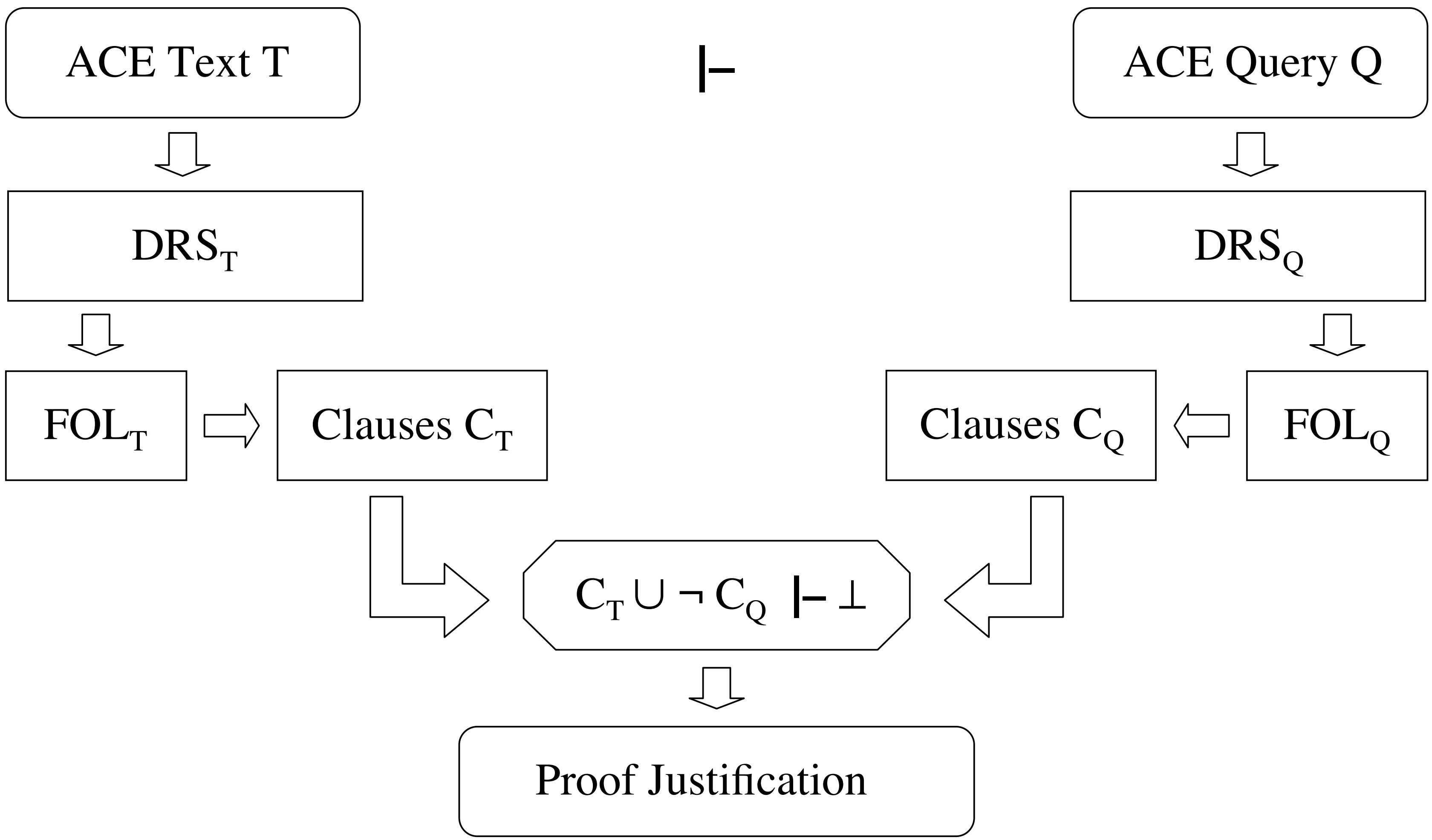
```
satisfy((A;B)) :-
  !,
  (satisfy(A) ; satisfy(B)).
satisfy(Atom) :-
  \+ Atom = false,
  assume(Atom).

assume(Atom) :-
  asserta(Atom).
assume(Atom) :-
  retract(Atom),
  !,
  fail.
```

RACE Extensions of Satchmo

- RACE extensions should preserve Satchmo's correctness, completeness and efficiency
- RACE generates all proofs
  - Satchmo stops immediately if it detects unsatisfiability
  - RACE finds *all* minimal unsatisfiable subsets of clauses
- RACE gives a justification of every proof
  - RACE collects indices of logical atoms used for a proof
  - RACE generates for each proof a report showing which ACE sentences were used to derive which ACE query
- input and output in ACE

Structure of RACE



RACE Detects Entailments

Text *Every company that buys a standard machine gets a discount.*
A British company buys a standard machine.
A French company buys a special machine.

Query *A company gets a discount.*

RACE proved that the sentence(s)
A company gets a discount.
can be deduced from the sentence(s)
Every company that buys a standard machine gets a discount.
A British company buys a standard machine.

RACE Answers Questions

Text *Every company that buys a standard machine gets a discount.*
A British company buys a standard machine.
A French company buys a special machine.

Query *Who buys a machine?*

1. RACE proved that the query (-ies)
   Who buys a machine?
   can be answered on the basis of the sentence(s)
   A British company buys a standard machine.

2. RACE proved that the query (-ies)
   Who buys a machine?
   can be answered on the basis of the sentence(s)
   A French company buys a special machine.

RACE Detects Inconsistencies

Text *Every company that buys a standard machine gets a discount.*
A British company buys a standard machine.
A French company buys a standard machine.
There is no company that gets a discount.

1. RACE proved that the sentence(s)
   Every company that buys a standard machine gets a discount.
   A British company buys a standard machine.
   There is no company that gets a discount.
   are inconsistent.

2. RACE proved that the sentence(s)
   Every company that buys a standard machine gets a discount.
   A French company buys a standard machine.
   There is no company that gets a discount.
   are inconsistent.

Auxiliary Axioms for RACE

- ACE can express plural sentences

  Six Swiss companies buy a machine. (collective)

  Each of six Swiss companies buys a machine. (distributive)

- first-order representation of plurals
  - additional group objects with lattice-theoretic structure
  - requires additional (domain-independent) knowledge
    - auxiliary axioms for lattice-theory, numbers, equality, …
    - evaluable functions and predicates
- flat notation allows us to integrate axioms in FOL

Proof with Auxiliary Axiom

ACE Text

Every company that buys a machine gets a discount.
Each of six Swiss companies buys a machine.

?

ACE Query

A company gets a discount.

DRS_T [A, …]
object(A,group,...)-2 …

DRS_Q [B, …]
object(B,atomic,...)-1 …

FOL_T
∃A(object(A,group,...) ∧ …)

∧

FOL_{Ax}
∀X(object(X,group,...) →
∃Y(object(Y,atomic,...) ∧ part_of(Y,X))

⊢

FOL_Q
∃B(object(B,atomic,...) ∧ …)

Proof Justification

Entailment Example with Axioms

Text	*Every company that buys a machine gets a discount.*
	Each of six Swiss companies buys a machine.
Query	*A company gets a discount.*

RACE proved that the sentence(s)
A company gets a discount.
can be deduced from the sentence(s)
Every company that buys a machine gets a discount.
Each of six Swiss companies buys a machine.
using the auxiliary axiom(s)
(Ax. 9): Definition of proper_part_of.
(Ax. 10-1): Every group consists of atomic parts.
(Ax. 22-1): Number Axiom.

Question Answering with Axioms

Text	*Each of six Swiss companies buys a machine.* *A German company buys a special machine.*
Query	*Who buys machines?*

1. RACE proved that the query (-ies) *Who buys machines?* can be answered on the basis of the sentence(s) *Six Swiss companies each buy a machine.* using the FOL axiom(s)	(Ax. 10-2): Groups have atomic parts. (Ax. 2): atomic => dom (Ax. 9): Definition of proper_part_of. (Ax. 11): Atoms have no proper parts. (Ax. 15-1): Identity axiom for objects. (Ax. 22-1): Number Axiom.
2. RACE proved that the query (-ies) *Who buys machines?* can be answered on the basis of the sentence(s) *A German company buys a special machine.* using the FOL axiom(s)	(Ax. 2): atomic => dom (Ax. 11): Atoms have no proper parts. (Ax. 15-1): Identity axiom for objects. (Ax. 22-1): Number Axiom.

Example Auxiliary Axioms

- internal representation: fol_axiom(Index, Axiom, Text)
- groups have atomic parts
  $\forall X(\text{object}(X,\text{group},...) \rightarrow \exists Y(\text{object}(Y,\text{atomic},...) \wedge \text{part\_of}(Y,X)))$
- atoms have no proper parts.
  $\forall X \forall Y(\text{object}(X,\text{atomic},...) \wedge \text{part\_of}(X,Y) \rightarrow \text{is\_equal}(X,Y))$
- identity axiom for objects
  $\forall X \forall Y \forall \underline{P}(\text{object}(X,\underline{P}) \wedge \text{is\_equal}(X,Y) \rightarrow \text{object}(Y,\underline{P}))$
- problems: Satchmo core offers no equality reasoning, some axioms cause inefficiency

Add Evaluable Prolog Predicates

- problems involving natural numbers …

Text	*Every company that buys at least three machines gets a discount. A German company buys four machines.*
Query	*A company gets a discount.*

- … require knowledge about natural numbers, but ...

∀X∀C(object(X,...,C,eq,4) ⇒ object(X,...,,C,geq,3))

- ... it is much better to use Prolog instead

```
object(A,Structure,Object,Type,cardinality,count_unit,geq,NewN):-
        number(NewN),
        object(A,Structure,Object,Type,cardinality,count_unit,eq,GivenN),
        number(GivenN),
        NewN =< GivenN.
```

Evaluation of RACE

- example: Steamroller

Representation	Standard	Attempto DRS
Satchmo (original)	15 ms	1990 ms
RACE	70 ms	375 ms

- open problems
  - finding *all* solutions increases search space
  - scalability, robustness to be shown

Current & Future Research

- improve question answering using Satchmo models
- extensions to support modality
- hypothetical reasoning ("What happens if …?")
- abductive reasoning ("Under which conditions …?")
- temporal reasoning