

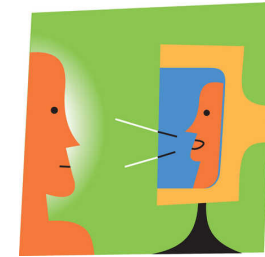


# Semantic Representation

*Lenhart Schubert*  
*University of Rochester*

## Motivation for this survey

*Revival of interest in representing the semantic content of language (in a way that enables understanding and inference), as indicated by*



- ❑ an increasing number of “challenges”:

**RTE:** Recognizing Textual Entailment (Dagan, Glicksman & Magnini 2006)

**COPA:** Choice of plausible alternatives (Roemmele, Bejan, & Gordon 2011)

**WSC:** Winograd Schema Challenge (Levesque, Davis & Morgenstern 2012)

**Aristo** Challenge (Clark 2015)

- ❑ Recent ACL Workshop on Semantic Parsing (Artzi, Kwiatkowski, & Berant 2014)
- ❑ Dialogues with robots (e.g., Eliasson 2007, Howard, Tellex, & Roy 2013)
- ❑ Semantically guided machine translation (Jones et al. 2012)

### Outline:

- ❑ Desiderata for broad-coverage semantic representation
- ❑ Approaches (with pros and cons)
- ❑ Conclusions

## Desiderata for a general SR

### 1. *Language-like expressivity*

All languages allow for

- predicates, connectives, quantifiers, equality => FOL
- generalized quantifiers (*most men who smoke*)
- intensional predicates (*believe, intend, resemble*)
- predicate and sentence modification (*very, gracefully, nearly, possibly*)
- predicate and sentence reification  
(*Beauty is subjective; That exoplanets exist is now certain*)
- reference to events and situations  
(*Many children had not been vaccinated against measles;  
this situation caused sporadic outbreaks of the disease*)



*Does high expressivity impede efficient inference? Not at all – cf. PL's!*

### 2. *Simple transduction between surface structure and SR*

- modular, easily understood, easily edited; e.g.,  $S \rightarrow NP VP$ ;  $S' = VP'(NP')$
- Montague demonstrated a beautiful, direct correspondence between phrase structure and meaning structure, accounting for (non)entailments



## Desiderata, cont'd

### 3. *Accord with semantic intuitions*



The SR should

- be able to capture the distinct “readings” of ambiguous words/phrases/sentences  
(“Mary had a little lamb” – possession/consumption of animal/meat)
- correctly capture temporal relationships  
(Mary knew she would win the race → know precedes win, time-of-speech)
- be able to model the entailments of sentences (& smaller units)  
(Mary’s son learned to swim today → A child of Mary’s acquired a skill this week)

### 4. *Availability of referents for anaphoric expressions*

Pronouns and other anaphoric expressions can refer to

- entities introduced by noun phrases (Children love their parents)
- events/situations/actions/etc., described by sentences (previous “measles” example)
- kinds of all of these (David likes to juggle knives; that’s a hazardous activity)
- propositions, facts asserted by sentences (There’s water on Mars; that’s indisputable)
- questions (I wonder whether cuttlefish are conscious; that question remains open)
- the surface text (Congress is ineffectual, to put it mildly)

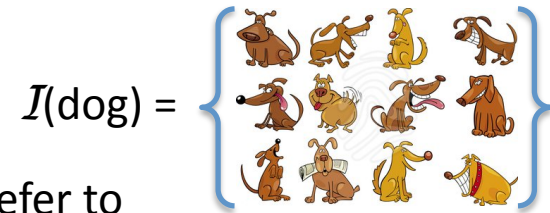


## Desiderata, cont'd

### 5. *Formal interpretability*

It surely helps to be clear about

- what types of symbols/expressions can be used to refer to
- what types of entities, relations, functions in the domain of discourse;
- the conditions under which an SR formula is to be considered true in a presumed domain of discourse;



Standard tools: set theory, inductive definitions (& perhaps algebras).

Benefits: avoiding inconsistency (e.g., ISA-fallacy); justifying inference;

**BUT:** Expressivity/inference rules often precede a fully formal model theory

### 6. *Ease of use for inference during/after interpretive processing*

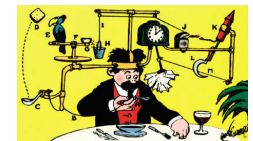
People continually use lexical/world/schematic knowledge to understand and predict; the SR should support such processes;



(Mary's AI Journal submission was accepted → the submission was a paper;  
Mary was a chief author of the paper; the paper was reviewed by anonymous referees; it was revised; it was scheduled for publication; Mary was happy; etc.

### 7. *Ease of integration with specialized methods*

Specialized taxonomic, partonomic, temporal, spatial, imagistic, explicitly notational (linguistic, mathematical, musical, programming) methods are needed for human-like general understanding and reasoning.



## Desiderata, concluded

### 8. *Trainability, ease of semantic-rule /entailment /schema learning*

Deriving the correct SR for a linguistic input depends on

- the correspondence between surface form and SR;
- many syntactic & semantic factors, especially familiar syntactic, semantic, and schematic patterns

Simple mapping rules → less training data needed to derive correct SRs, or to learn the rules themselves.

Good fit of LFs into entailment rules and larger schemas → easier inference, understanding, and learning of entailments and schemas.



## Approaches to SR, with pros and cons

### 1. **FOL: predication + connectives + $\forall, \exists$ + equality**

(e.g., see mapping rules in Allen '95, Jurafsky & Martin '09)

$\exists x, e.$  blood(x) & past(e) & donate(e,John, RedCross,x)

**Pros:** Captures meaning adequately in many “objective” domains;  
well-developed inference machinery;

**Cons:** Recall desiderata; or try this [from www.twcenter.net]:

*Very few people still debate the fact that the earth is heating up*

(*Holds/True* devices: inadequate for generalized or embedded quantifiers)

### 2. **Discourse representation theory (DRT) – FOL-like, but dynamic variable binding**

(Kamp '81, Heim '82) Aimed at systematic anaphoric binding; can map to FOL

### 3. **Semantic networks – graphical rep.'s of pred-arg, operator-operand structure**

**Pros:** as diagrams, suggestive of effective knowledge storage & inference methods;

**Cons:** as diagrams, confusing for nontrivial sentences; some versions are closely related to FOL, others are resolutely informal (*Dog best-friend-of Man*) -- ok for similarity-based inference, but not stronger forms.

### 4. **Description logics – aimed at decidable concept subsumption inference**

(e.g., OWL-DL for the semantic web, as used by Cimiano *et al.* '14)

**Pros:** Well-developed subsumption machinery (*married couple + 2 kids  $\rightarrow$  family*);  
good for “cut-and-dried” applications, well-defined concept hierarchies;

**Cons:** Very weak assertion language – essentially, atomic predications.

## Approaches to SR, cont'd

### 5. *Conceptual meaning representations – primitives + thematic roles + schemas*

(e.g., Schank & Abelson '77, Jackendoff '90, Baker *et al.* '98); e.g.,



**Pros:** Primitives reduce paraphrastic variety, provide common inferences; larger *schemas (scripts, frames)* fill in presumed/predicted information;

**Cons:** Subtleties lost; expressive weaknesses (quantifiers, events/times, tacked-on modifiers, etc.); simple facts (*John dined out*) become complex networks; no model theory (does *blood* refer to a specific entity?)

### 6. *Thematic role representation – (nonprimitive) predications, thematic roles*

(e.g., Palmer, Gildea, & Xue '10); e.g.,

*donate(e), blood(b), donor(e,John), theme(e,b), recipient(e,RedCross)*

### 7. *Abstract meaning representation – canonicalized predications (etc.), free var's*

(Banarescu *et al.* '13); e.g., (*g / give-3 :arg0 (j / John) :arg1 (b / blood) :arg2 (r / RedCross)*)

### 8. *Hobbs' "flat" representation – sentences as conjoined word-level predications*

(e.g., Hobbs '06); every word of a sentence conveys a predication; e.g.,

$(\exists e_1, e_2, x, y)$  *John(x) & blood(y) & RedCross(y) & donate'(e<sub>1</sub>, x, y) & Past(e<sub>0</sub>, e<sub>1</sub>) & Rexist(e<sub>0</sub>)*

**Pros:** There's a variable for every possible referent; FOL machinery is applicable;

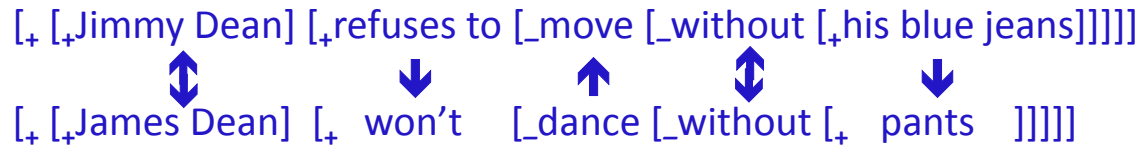
**Cons:** *Conflations* – {events, propositions}; {predicates, quantifiers, connectives}; e.g., John's firing a gun can wake the neighbors; the proposition that he did so cannot. "Typical elements" can't do the job of quantifiers (needed for axioms anyway).



## Approaches to SR, cont'd

### 9. Structured English – phrase or dependency structure + polarity

(e.g., MacCartney & Manning '09, Dagan et al. '08, Clarke '12); e.g.,

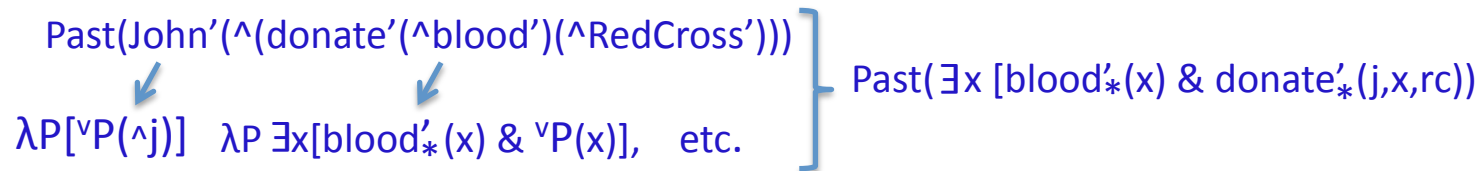


**Pros:** Can apply **Natural Logic (NLog)** for entailments; also **Vector Semantics**;

**Cons:** Indexicality, ambiguity, anaphora can't really be ignored; no multiple premises.

### 10. Montague-style intensional logics – close to structured English (+ models)

(e.g., Dowty '79, Chierchia & McConnell-Ginet '00); e.g.,



**Pros:** Uniform, compositional syntax → semantics mapping;

intuitions about entailments accurately captured (even for *seeks*, *imagines*);

**Cons:** Much use of type-shifting via '^', '^', '^', λ-abstraction, etc.;

most of it can be avoided with a simple change in the intensional semantics;

### 11. Extensional Montague fragments (MG-lite)– no intension/extension (^/∇) op.'s

(e.g., McAllester & Divan '92, Artzi & Zettlemoyer '13);

**Pros:** Montague's compositional semantics, with less type-shifting;

hence readily learnable for restricted applications

**Cons:** Expressive limitations, no events or times, ...

## Approaches to SR, concluded

### 12. DCS trees – db queries as constraint-trees over predicate denotations

(Liang et al. '11); e.g., given the set of triples for 'donate', check if  $\langle \text{John}, x, \text{RedCross} \rangle$  is among them for some  $x$  in the given set of instances of 'blood'.

**Pros:** Efficient set handling, including counts, superlatives, & quantifiers like *no*, *most*;

**Cons:** No attitudes, etc.; general NLU depends heavily on *generic* knowledge (vs. data)

### 13. Situation semantics – situations described by sets of 'infons' ( $P, \text{arg}_1, \dots, \text{arg}_n, Y/N$ )

**Pros:** "fine-grained" meanings; situations/events can have complex descriptions;

**Cons:** abstruse, complex metaphysics; mapping from language, & inference unclear

### 14. Episodic Logic (EL) – Montague-inspired, first-order, situational, intensional

[John1 <past donate.v> (K blood.n) Red\_Cross] {initial representation}

↓

(some e: [e before Now3] (some x: [x blood.n] [[John1 donate.v x Red_Cross1] ** e]	Skolemize, split →	[E1.sk before Now3], [Blood1.sk blood.n], [[John1 donate.v Blood1.sk Red_Cross1] ** E1.sk ]
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*Very few people still debate the fact that the earth is heating up* (final representation):

[Fact4.sk fact.n], [Fact4.sk = (that (some e0: [e0 at-about Now0]  
[[The z [z earth.n] [z heat\_up.v]] \*\* e0]]),  
((fquan (very.adv few.a)) x: [x (plur person.n)] (still.adv (I v [v debate.v Fact4.sk]])))]

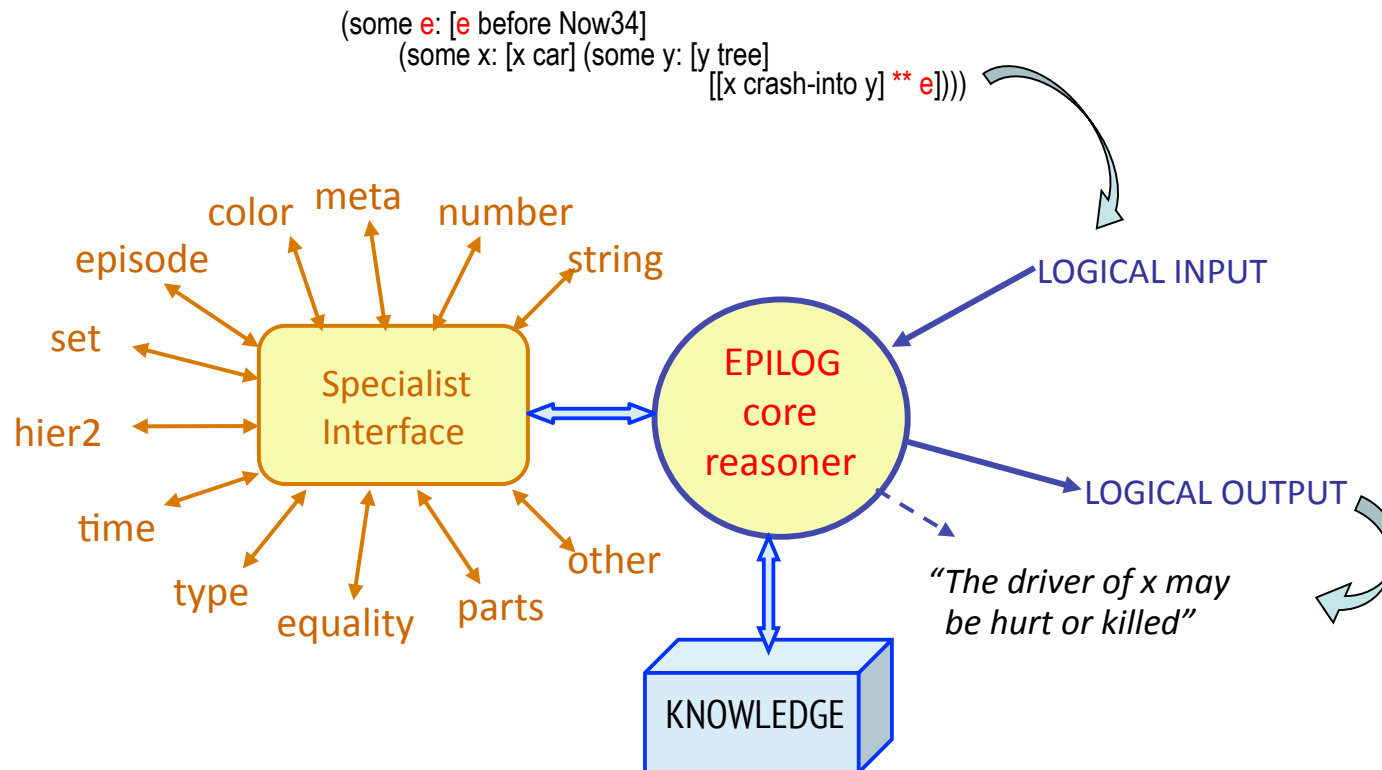
**Pros:** Handles most semantic phenomena shared by NLS; all types of referents;  
allows complex situations/events, with temporal/causal relations; little type-shifting.

**Cons:** Inference remains brittle, uncertainty handling remains heuristic

# Episodic Logic and the EPILOG system

(L. Schubert, C.-H. Hwang, S. Schaeffer, F. Morbini, Purtee, ...)

*“A car crashed into a tree. ...”*



***Expressive richness does not impede inference:***

EPILOG 2 holds its own on large FOL problems (Morbini & Schubert '09)

## Conclusions – how fully are the desiderata met?

Desideratum	Frameworks
NL-like expressivity	Structured English, Montague-like logics, EL
Ease of (broad) transduction	Structured English, EL, Montague-like logics, Hobbs' LF
Accord with semantic intuitions	Structured English, EL, Montague-like logics
Availability of referents (Ontological promiscuity)	EL, Hobbs' LF
Formal interpretability	FOL, Montague-like logics, DRT, DLs, Hobbs' LF, EL, DCS trees
Ease of use for general inference	FOL (?), Hobbs' LF (?), EL (?)
Ease of specialist integration	EL, FOL (? constraint LP)
Trainability, entailment learning	Structured English (??), thematic role rep.'s, MG-lite, (casual) semantic nets, AMR (?), DCS trees (??), ...?