Logic, Logicism and the Semantics of Word Formation

The Plan

- I'll begin by trying to motivate a research program.
- Then I'll formulate a proposal.
- Then I'll illustrate it with some case studies.

Some Linguistic Background

- The semantics of the lexicon is a weak point in Montague's framework. Montague was content with accounting for logical words, especially quantifiers.
- David Dowty in his 1979 book attempted to account for systematic relations among lexical items using a somewhat conservative extension of Montague's framework, with limited success.
- Using events, Terence Parsons achieved better success in his 1990 book, confining himself mainly to tense and aspect. But Parsons' account of events is skeletal, making the theory less explanatory than one would like.
- In his 1989 Tianjin lectures, Emmon Bach coined the term "natural language metaphysics" and sketched some examples.

Philosophical Background

- **Carnap's ideas about how to deploy "meaning postulates" were ahead of his time—and ahead of the logical resources available to him.**
- **In *Testability and Meaning* (1936) Carnap abandons the idea of defining "dispositional" predicates like *soluble*, but instead deploys (rather simplistic) postulates about the phenomenon of dissolving.**
- **Carnap called these "bilateral reduction sentences."**
- **Later (1952) he included such postulates, as well as e.g. transitivity postulates for comparatives, under the heading of "meaning postulates."**
- **They do, of course, have to do with meaning. But they are also microtheories of the common sense world.**

Common Sense Logicism

- **In work going back to 1969, John McCarthy (the computer scientist, not the linguist) recommended understanding common sense as the key to success in Artificial Intelligence, . . .**
- **and logical formalization as the method for obtaining this understanding.**

- **McCarthy's program attacted many talented people, and led to specific formalizations of several commonsense domains, . . .**
- **including reasoning about actions and change, . . .**
- **and to logical innovations, including McCarthy's Situation Calculus and other formalisms for planning and temporal reasoning, . . .**
- **and nonmonotonic logics.**

Coverage

- **Formalizing commonsense reasoning overlaps with another area of AI: commonsense physics.**
- **Topics that have been addressed (from Ernest Davis' *Representations of Commonsense Reasoning*, 1990) include:**
  1. **Measurements**
  2. **Reasoning about time**
  3. **Reasoning about space**
  4. **Reasoning about solids and liquids**
  5. **Reasoning about minds**
  6. **Planning and goal formation**

The Methods Are Different from Those of Philosophical Analysis

- **Philosophical analysis is concerned with definitions, not postulates.**
- **Philosophical analyses will only sustain a moderate degree of complexity until they become unmanageable. Therefore they are not well suited to complex domains.**
- **Philosophical analyses are not exception-tolerant, which makes them brittle.**

- **Computer scientists are familiar with techniques for managing large and complicated formalizations.**
- **Software engineering techniques provide a model for how to do this that is part of the common knowledge of the discipline.**
- **These techniques can be extended to axiomatizations, and include computerized techniques for managing, testing, and debugging axiomatizations (e.g., theorem-proving, simulation, actual robot-based implementations).**
- **These have been tested by the common sense knowledge community on several benchmark challenges, e.g. the "egg-cracking problem."**

Nonmonotonic Logic

- **Commonsense generalizations can involve exceptions.**
- **It is much easier to maintain an axiomatization by adding axioms rather than by withdrawing and qualifying old axioms.**
- **This makes exception-tolerant logics very useful in axiomatizing comonsense domains.**
- ***Important for our purposes:* Some versions of NM logic support explicit statements of commonsense normalities.**

McCarthy's Circumscription

- McCarthy's proposal for nonmonotonic logic was *Circumscription*.
- It is logically conservative—it is based on classical logic—and uses higher-order logic.
- Exception tolerant generalizations are formulated using *abnormality* predicates: for instance, 'A car will start if you turn the key in the ignition' would be formalized as:

$$[\texttt{Car}(x) \wedge \texttt{Key}(x,y) \wedge \texttt{TurnKeyInIgnition}(x,y,t)] \\ \wedge \neg \mathrm{Ab1}(x,y,t) \rightarrow \\ \texttt{Start}](x,t)$$

- Here, Ab1 is an *abnormality predicate*. The entire generalization is a *normality* or *normality condition*.

- **Models for circumscription simultaneously minimize abnormalities: that is, a theory T implies a formula ϕ not if every model whatsoever that satisfies T satisfies ϕ, . . .**
- **but if every abnormality-minimal model that satisfies T satisfies ϕ. (This should remind you of how the semantics for conditional logics works, only here we are talking about preferred models, not preferred worlds.)**
- **Abnormality minimization can be explicitly defined using higher-order quantification over the abnormality predicates.**

- **You can refine nonmontonic axiomatizations by adding qualifications to the abnormality theory.**
- **For instance, if you discover that a dead battery is an exception to the car-starting regularity, you do not have to withdraw the axiom.**
- **You can *add* an axiom:**

$$\texttt{DeadBattery}(x, t) \rightarrow \mathrm{Ab1}(x, y, t)$$

- **The inventory of abnormality predicates is open-ended.**
- **So, if you like, you can add abnormality predicates to the exceptions, and qualify them later as well.**

Summarize the Motivation

- **We should expect commonsense knowledge to be built into many of the basic processes of word formation, . . .**
- **because, for instance, *Aktionsarten*, mass-count distinction, and temporal and causal locutions should reflect and reveal that knowledge.**
- **So the semantics of word-formation should appeal to formalizations of commonsense theories of the physical, cognitive, and social world.**
- **Work AI on commonsense knowledge and reasoning shows us how to do this.**
- **The task, of course, is open-ended, but work in this field to date has been encouraging.**

Part II: The Proposal

- **To make Montague's framework capable of dealing with lexical semantics, make two additions:**

  1. **Add a domain of eventualities to the theory. (Eventualities can be treated as individuals, so this is not a modification of the logic, but an ontological extension.)**
  2. **Make the logic nonmonotonic, using circumscription. (This is a very conservative extension, consisting merely of the addition of an open-ended special class of abnormality predicates, and of a restriction of models to those that are abnormality-minimized.)**

Part III: Case Studies

Case 1: the *-able* Suffix

According to Laurie Bauer *English Word-Formation*,

> **there are, however, a number of processes which are usually considered to be derivational and which do display semantic regularity: consider, for example, the formation of English adjectives in *-able* from transitive verbs. This is probably a case where there are no gaps in the derivational paradigm (any transitive verb can act as the base) and the adjectives are semantically regular, meaning 'capable of being Ved' (where V is the verb in the base).**

It is Not as Simple as This

- In fact, the *-able* suffix illustrates a number of challenging characteristics.

  1. There is variation in the meanings it assumes, but the variations are closely related shades of meaning. It is hard to tell whether listing senses, to look for a single underlying meaning allowing for different uses, to make the meaning context-dependent.
  2. The meanings themselves are difficult to formalize.
  3. These meanings seem to invoke commonsense real world knowledge rather than linguistic knowledge.
  4. While it is possible to formalize separate instances in a class of semantically similar group, it can be difficult to formulate a general template for the entire class.
  5. There are exceptional patterns.

- **Typically, the -*able* construction works with verbs, and these are transitive and broadly telic. (There are some exceptions—e.g. Consider *knowledgeable* and *palatable*.**
- **Often, these verbs have three characteristics.**
  - **(i) They correspond to procedures that are in the normal repertoire of actions of human agents.**
  - **(ii) Often there are normal or standard ways of initiating these actions, and there is an end state associated with the performance of the actions.**
  - **(iii) Often, this end state can be evaluated in terms of its success in aiding the execution of a plan.**
- **In the simplest and easiest to analyze cases, all of these features are present.**

Patterns

- From examining a corpus of *-able* words, I've identified three major semantic patterns:

  1. Conditional 'if-will' (this can be more or less occasional or generic). The generic usage is what philosophers call the "dispositional" case. (*soluble* is an example.)
  2. Unharmful outcome. (*edible* is an example.)
  3. Worthiness or obligatoriness. (*honorable* and (*payable* are examples.)

- The idea would be to concoct a family of similar meaning postulate templates, one for each semantic pattern.

Formalise the Conditional Pattern

- **I rely on a compositional theory of telic eventualities, an idea I got from from Marc Moens and Mark Steedman, though it isn't unique to them.**
- **A typical telic eventuality consists of:**

  (1) An inception (an event, which often has an agent),

  (2) A body (a process, which progresses, often by measurable stages, towards

  (3) A culminating state.

- **There are causal connection between these parts.**

- **I'm skipping some details here, but ...**
- **for any telic eventuality there will be default normalities linking (1) the initiation with the body, and (2) the body with a culminating state.**
- **These normalities may be more or less qualified, *ad hoc* and depending on the specifics of the case.**
- **The normalities represent causal connections, but I'm not presenting this as an analysis of causality.**

Formalization of ***Water-Soluble***

$$
\begin{array}{l}
\forall x[\, \textbf{\textit{Water-Soluble}}(x) \leftrightarrow \\
\quad \forall e[\ [\textbf{\textit{Put-In}}(e) \wedge \mathbf{theme}(e) = x \wedge \mathbf{Water}(\textsc{medium}(e)) \\
\qquad \wedge \textsc{Occur}(e) \wedge \neg \mathbf{Ab}_{\text{Initiate-Dissolve}})(e)] \rightarrow \\
\qquad \exists e'[\ \textsc{Telic}(e') \wedge \textbf{\textit{Dissolution}}(e') \wedge \textsc{Occur}(e)' \\
\qquad\qquad \wedge \textsc{theme}(e') = x \wedge \textsc{inception}(e)' = e \\
\qquad\qquad \wedge [\neg \mathbf{Ab}_{\text{Process-Dissolve}}(e') \rightarrow \\
\qquad\qquad\quad \exists e''[\textsc{culmination}(e') = e'' \wedge \textsc{Occur}(e'') \\
\qquad\qquad\qquad \wedge (\textbf{\textit{In-Solution}}(e'') \wedge \textsc{theme}(e) = x \\
\qquad\qquad\qquad \wedge \textsc{medium}(e'') = \textsc{medium}(e)]\ ] \\
\qquad\qquad] \\
\qquad] \\
\quad]
\end{array}
$$

Remarks on the Formalization

- The main connective is a biconditional, so contrary to what Carnap thought was possible, this is a definition of a dispositional property • • •
- but the definition involves normality conditions.
- Many features of the postulate would be inherited from generalizations about the formalization of telic eventualities.
- Any one-off formalization such as this must be provisional. Large scale axiomatic knowledge bases need to be developed and tested before one can have much confidence about particular examples.
- I haven't tried to incorporate time into the formalization. Doing so raises many difficulties.

Normality Conditions

- **Almost everywhere you look in lexical semantics, you find normality conditions.**

  1. **A wastebasket is a basket-sized container that is normally used to contain waste.**
  2. **A pencil sharpener is a device that is normally used to sharpen pencils.**
  3. **To oar a boat is to move the boat by means of oars, used in the way oars are normally used to move boats.**
  4. **To wipe a table dry is to dry the table by wiping it with something, in the normal way that tables are wiped with something in order to dry them.**

- **The pervasiveness of such examples is a powerful argument for a nonmonotonic logical framework**

Case 2: Causatives

- **I agree with Dowty about the nature of the overall problem: provide an account of the semantic derivation of, for instance, causative *open* from stative *open*.**

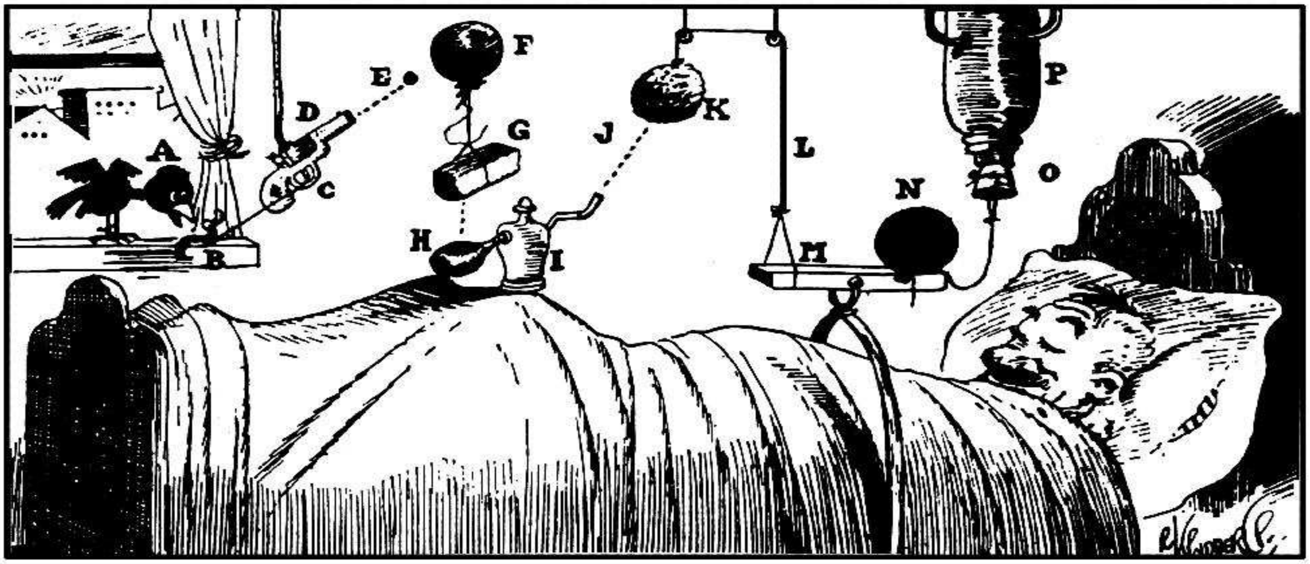
- **But I believe that the idea of using a propositional CAUSE relation (of type $\langle\langle e, t\rangle, \langle\langle e, t\rangle, t\rangle\rangle$) to do this is poorly motivated and unworkable.**

- **That idea runs into logical problems.**

- **Also—and I regard this as a central problem—you can cause a window to be open without opening it. (You get someone else to open the window.)**

- **Some people think of this as a matter of "immediate causality." But the notion of "immediate causality" is suspicious, and anyway it's clearly wrong for this purpose.**

Simple Alarm Clock



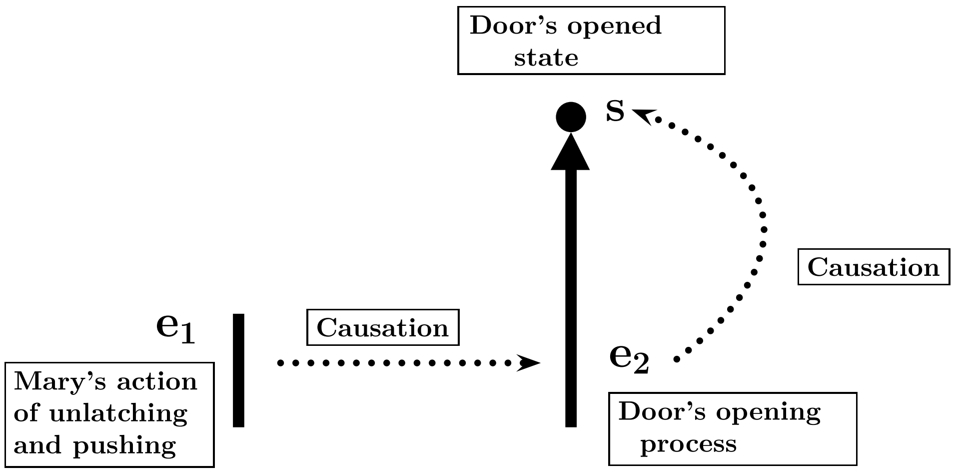
The early bird (**A**) arrives and catches worm (**B**), pulling string (**C**) and shooting off pistol (**D**). Bullet (**E**) busts balloon (**F**), dropping brick (**G**) on bulb (**H**) of atomizer (**I**) and shooting perfume (**J**) on sponge (**K**)–As sponge gains in weight, it lowers itself and pulls string (**L**), raising end of board (**M**)–Cannon ball (**N**) drops on nose of sleeping gentleman–String tied to cannon ball releases cork (**O**) of vacuum bottle (**P**) and ice water falls on sleeper's face to assist the cannon ball in its good work.

- **I have telic eventualities in my ontology.**
- **These are ready-made causal mechanisms, with their own causal dynamics.**
- **So I don't need to get the causality of causatives from elsewhere.**
- **From my point of view, the problem is this: if a telic eventuality culminates in a state of type X, . . .**
- **then what is its agent?**
- **It's a matter of agency, not causality *per se*.**

The Simple Case is Easy

- **The telic eventuality consists of an inception, a body and a culminating state.**
- **It's a causally isolated microsystem.**
- **The inception has an agent.**
- **Then the agent of inception is the agent of the containing telic eventuality.**

The Simple Picture



- **In the diagram, we've added causal links to complex eventualities, . . .**
- **borrowing ideas from causal modeling in statistics and qualitative causal reasoning.**
- **Among other things, event complexes can be *causal graphs*.**

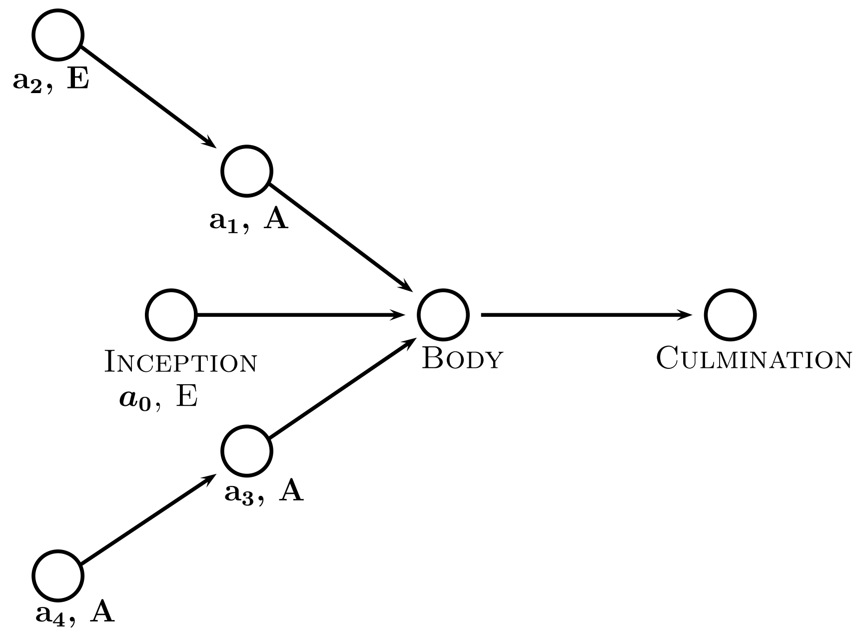
But the Story is More Complicated

- **Telic complexes can involve other eventualities.**
- **Some of these can be contributing causes.**
- **And some of the contributing causes can have agents.**
- **Which agent is the agent of the telic eventuality?**

- **We need to appeal to a version of the distinction between *animate* and *inanimate* agents here.**
- **I'll invent my own terminology: "efficient" versus "automatic" agents. The latter are self-initiating sources of causality. The former merely transmit causality.**
- **In the following hypothetical diagram, automatic agents are labeled with "A", efficient agents with "E".**

E: efficient agent

A: automatic agent



Illustrating the Diagram

- **Mary is directing a blacksmithing operation.**
- **a_0: An assistant, Frank, initiates the process by putting bar stock on the anvil.**
- **a_2: Mary turns on a power hammer, which a_1 hammers the stock.**
- **a_4: A switch turns on a bellows a_3 which maintains the heat of the forge.**

Conditions for Assigning an Agent

- **An efficient agent is precluded by any efficient agent between it and the body.**
- **An automatic agent is precluded by any agent between it and the body, and by any causal ancestor of the body with a efficient agent.**
- **The agent of the inception is precluded by any efficient agent elsewhere in the causal ancestry of the body.**
- **These conditions make Mary the agent in the example. She forged the metal.**

Progressive

Inertial Histories and the Modal Approach

- **Dowty uses branching time and "inertial histories" to account for progressive.**
- **The idea of inertia is close to the idea that I'm recommending, of normal causal development of processes.**
- **But Dowty's approach is modal: what is modal is closed under conjunctions, and this is problematic.**

- **The problem is that simultaneous causal processes can conflict.**

  1. **While he was composing a requiem mass, Mozart was dying.**
  2. **Two trains are speeding down a single-track line, heading srraight for a collision. One is going west to Chicago, the other is going east to Detroit.**
  3. **Judy is boiling a kettle of water on her gas stove. At the same time, unknown to her, workmen are shutting off her gas.**

- **I conclude that we don't want global inertia, but local inertia, confined to coherent causal microsystems ...**
- **Even if the evidence isn't entirely unequivocal.**

Continuous and Discrete Processes

- It's natural to think of some commonsense processes as discrete, and some as continuous. So it's important to provide a theory of becoming that works for both cases.
- 'She filled the tub with water'.
- 'She filled the jar with marbles'.

What's in a State?

- **I want to think of states as loci of information, represented by variables.**
- **These variables can track matters of degree. If a door is capable of being open or closed, a variable will track the extent to which it is closed—perhaps the same variable, inversely, tracks extent to which it is open.**
- **Processes also supply values to variables.**
- **If a process P typically culminates in a state S, the two will share many variables—there will be a match between the two eventuality types.**

Becoming as Approaching a Limit

- **The idea is that a telic process, if it follows its inner inertia, will approach its culmination, is very appealing.**
- **The standard epsilon-delta definition of approaching a limit (from below) for a continuous function f tells us this:**

> **f approaches a certain value y as its argument approaches x if for every range of values close to the target value y there is an argument interval including x such that all arguments in this interval take values in the target range.**

- **That is, if we want the values of f to be *this* close to y, we can always do that by choosing arguments for f *this* close to f.**

Proposed Definition for Successful Becoming

At time t_0 and history h, e is a process culminating in a state s in which a has feature F.

Definition: $\textsc{Become}(e, s, h, t_0, F, a)$.

Let e be a process, s a state, a an individual, F a feature, h a history, and t_0 a time. Then $\textsc{Become}(e, s, h, t_0, F, a)$ iff:

(1) $\text{THEME}(e) = a$, $\textsc{Holds}(e, t_0, h)$, **and** $\textsc{Supports}(s, F, a)$.

(2) The following conditions hold:

- **(i) There is a least upper bound t_1 for** $\{t \mid \textsc{Holds}(e, h', t)\}$.
- **(ii) For all states s_1 such that** $\textsc{Comparable}(s, s_1, F, a)$, **there is a time $t_2 \leq t_3$ such that for all $t' \in [t_2, t_3]$:** $\textsc{NoLess}(s', s_1, F, a)$, **where** $\textsc{Exhibits}(e, s', h, t')$.

The idea is that if you choose any possible state of F-edness for a, you can find a time in the process where $F(a)$ is persistently at least as true as is in this state.

We then say that becoming is a matter of successful becoming in all inertial histories.

At time t_0 and history h, e is a process tending toward a culminating state in which a has feature F. Let e be a process, a an individual, F a feature, h a history, and t_0 a time.

Definition: $\textsc{Become}(e, s, h, t_0, F, a)$ **iff:**

> **for all appropriately nonabnormal histories h' that are nonabnormal with respect to e, there is a state s such that $\textsc{Become}(e, s, h', t_0, F, a)$.**

There are Two Cases

- In the case of a continuous process—for instance, a process in which Judy goes home—
- this is equivalent to the standard limit definition.
- It says that in each inertial history Judy arrives home, and her distance from home approaches 0 as a limit as time approaches the time of her arrival.

- **In the discrete case—for instance, a process of filling a shelf with books—the condition simply means that the process has the right type and that in any inertial history the last state of the process is one in which the shelf is full.**
- **This may seem too simple a condition, but as far as I can tell it is hard to find convincing counterexamples.**

An Exceptional Verb

- **In lexical semantics, one comes to expect elements, one finds exceptional semantic subpatterns.**
- **I have only found one such pattern for progressive: this is 'winning', as applied, for instance, to games.**
- **To say that a player is winning a game doen't mean that in all normal continuations the player will win.**
- **It seems simply to mean that the player has a higher score.**
- **There may be other exceptional cases, but so far I haven't found any.**

Conclusion

- **I've convinced myself that this is a promising and worthwhile research program.**
- **Hopefully, the case studies helped to convey why I think that.**
- **The trouble is that pursuing this project properly is just as much a matter of computer science as of linguistics or logic, . . .**
- **and interdisciplinary projects can be difficult to sustain.**
- **Also, I don't think the prospects for funding this research are very encouraging, at least in the US.**
- **As far as I can see, this is not a project with commercial applications.**

Bibliography

[Bach, 1989] Emmon Bach. *Informal Lectures on Formal Semantics.* State University of New York Press, Albany, NY, 1989.

[Davis, 1991] Ernest Davis. *Representations of Common Sense Knowledge.* Morgan Kaufmann, San Francisco, 1991.

[Dowty, 1979] David R. Dowty. *Word Meaning in Montague Grammar.* D. Reidel Publishing Co., Dordrecht, Holland, 1979.

[Group, 2000] Formal Reasoning Group. Web pages for the formal reasoning group. http://www-formal.stanford.edu/, 2000.

[Lifschitz, 1988] Vladimir Lifschitz. Circumscriptive theories: A logic-based framework for knowledge representation. *Journal of Philosophical Logic*, 17(3):391–441, 1988.

[Morgenstern, 2001] Leora Morgenstern. Mid-sized axiomatizations of common-sense problems: A case study in egg-cracking. *Studia Logica*, 67(3):333–384, 2001.

[Parsons, 1990] Terence Parsons. *Events in the Semantics of English: a Study in Subatomic Semantics.* The MIT Press, Cambridge, Massachusetts, 1990.

[Shanahan, 2001] Murray Shanahan. An attempt to formalize a nontrivial benchmark problem in common sense reasoning. *Artificial Intelligence*, 153(5–6):141–165, 2001.

[Thomason, 1999] Richmond H. Thomason. Formalizing the semantics of derived words. Unpublished manuscript, available at http://www.eecs.umich.edu/~rthomaso/documents.html., 1999.

[Thomason, 2004] Richmond H. Thomason. Non-monotonic formalisms for natural language semantics. http://web.eecs.umich.edu/ rthomaso/documents/nls/nms.pdf, 2004.

[Thomason, 2005] Richmond H. Thomason. Formalizing the semantics of derived words. http://web.eecs.umich.edu/ rthomaso/documents/nls/nmslite.pdf, 2005.

[Thomason, 2015] Richmond H. Thomason. Formal semantics for causal constructions. In Bridget Copley and Fabienne Martin, editors, *Causation in Grammatical Structures*, pages 58–75. Oxford University Press, Oxford, 2015. http://web.eecs.umich.edu/ rthomaso/documents/nls/cause.pdf.