

# Computing Dynamic Meanings: From Montagovian Compositionality to Incremental Processing

## Course Description & Syllabus

Seminar in Semantics (Graduate, UCSC Linguistics), Spring 2015

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### 1 Organizational matters

- Class: Th 12:30PM–4:00PM, The Cave
- Instructor: Adrian Brasoveanu

#### Office hours

- Th 4:00PM–5:00PM and by appointment, Stevenson 259, [abrsvn@ucsc.edu](mailto:abrsvn@ucsc.edu)

#### Web access

- There is a shared dropbox folder for this course. If you do not have access to it, email the instructor to be granted access.

## Important note

If you qualify for classroom accommodations because of a disability, please get an Accommodation Authorization from the Disability Resource Center (DRC) and submit it to me in person outside of class (e.g., office hours) within the first two weeks of the quarter. Contact DRC at 459-2089 (voice), 459-4806 (TTY), or <http://drc.ucsc.edu> for more information on the requirements and/or process.

## 2 General Description

The big-picture goal of the course is to explore avenues for integrating formal semantics as (some) linguists have been practicing it for 40+ years (roughly, since Montague 1970, 1973) into a broader, formally explicit and unified theory of human cognition and cognitive behavior as (some) cognitive psychologists have been practicing it for about the same amount of time (roughly, since Newell 1973a,b).

Our more specific focus: on the formal semantics side, we will look at Discourse Representation Theory (DRT) and related dynamic semantic systems, and on the cognitive psychology side, at ACT-R (Adaptive Control of Thought – Rational) and related cognitive architectures. Thematically, we want to explore in detail the ways in which the notion of incremental information update / processing in dynamic semantics and the corresponding notion in ACT-R converge and diverge.

Bibliographically, we will start with (probably) the reference book in dynamic semantics, namely Kamp and Reyle (1993), and (probably) the reference book in ACT-R, namely Anderson and Lebiere (1998).

We will explore the sometimes striking parallels between their overall conceptions of human cognition, and the specific formalisms they employ to theorize about it. For example: construction-rule based algorithms for building discourse representation structures (DRSs) on the DRT side, and production systems encoding procedural knowledge on the ACT-R side; or syntactic representations in terms of feature structures / attribute-value matrices for DRT, and declarative knowledge organized in chunks (effectively, attribute-value matrices) for ACT-R.

We will also explore some of the fundamental differences between them. For example, the essential use of model-theoretic notions to define natural language meaning and interpretation in DRT has no obvious counterpart on the ACT-R side. Similarly, the subsymbolic level in ACT-R, which integrates neural-like activation processes and probabilistic components into the symbolic level (rules and chunks) – needed to capture qualitative generalizations about human cognition and cognitive behavior – has no obvious counterpart on the DRT side.

### 2.1 As semanticists, why do we care?

Exploring the formal semantics / cognitive psychology divide and searching for ways to bridge it is firmly rooted in the tradition of dynamic semantics. Recall the very beginning of the foundational Kamp (1981) paper:

Two conceptions of meaning have dominated formal semantics of natural language. The first of these sees meaning principally as that which determines conditions of truth. This notion, whose advocates are found mostly among philosophers and logicians, has inspired the disciplines of truth-theoretic and model-theoretic semantics. According to the second conception meaning is, first and foremost, that which a language user grasps when he understands the words he hears or reads. This second con-

ception is implicit in many studies by computer scientists (especially those involved with artificial intelligence), psychologists and linguists – studies which have been concerned to articulate the structure of the representations which speakers construct in response to verbal input.

It appears that these two conceptions, and with them the theoretical concerns that derive from them, have remained largely separated for a considerable period of time. This separation has become an obstacle to the development of semantic theory, impeding progress on either side of the line of division it has created.

The theory presented here is an attempt to remove this obstacle. It combines a definition of truth with a systematic account of semantic representations. (Kamp, 1981, p. 189)

## 2.2 What can we learn from cognitive architectures?

As generative linguists, and formal semanticists in particular, the main lesson we can probably learn from the ACT-R community is that we should try to give a formally explicit account of natural language interpretive *behavior*. That is, we should aim for a mathematically explicit, unified theory of semantic/pragmatic competence *and* performance – to use the traditional, methodologically productive, but ultimately ill-defined distinction between competence and performance.

The traditional idealization that as linguists / semanticists, we should focus on a core semantic ‘competence’ and abstract away from performance issues was a very good way to start the investigation 40+ years ago (even earlier on the syntax side). We now have rich, explicit logical systems that capture intricate ways of composing meanings and intricate relations between meanings.

But introspective judgments about entailment or truth / felicity relative to a situation and/or discourse context are not a privileged way of getting direct access to our core semantic competence. They are just one type of performance / verbal protocols / verbal behavior, and they provide us with one type of empirical data that we need to account for. Our ultimate goal should be to account for the whole competence & performance package because there is no *a priori* clear way to separate one from the other. It was methodologically productive to (maybe implicitly) make this distinction early on in the development of the field, but it is not a given at all that the distinction itself is ‘out there’ in nature – and if it is out there, that it is as sharply defined as we might have initially assumed. Furthermore, for any particular phenomenon, the decision to analyze it in purely competence / grammatical terms or not is not an *a priori* decision, but an empirical one – just as it is an empirical issue whether any particular comprehension-related phenomenon should be analyzed in syntactic, semantic, and/or pragmatic terms.

The kind of work that the ACT-R community does is particularly attractive to us as theoretical generative linguists, and formal semanticists in particular: the goal is the formulation of a formally explicit theory of cognitive behavior and cognitive mechanisms. In particular, the idea is to go beyond a healthy, but narrow focus on specific experimental investigations, and beyond a thin layer of informal theoretical discussion wrapped around the experimental results. This was one of the main points in Newell (1973b), and it is an integral part of the way we do formal semantics.

The price of admission is taking behavior and performance seriously (to paraphrase the title of Sag 1992). At the empirical level, this translates into pursuing experimental investigations with various methodologies (among other things). At the theoretical level, this translates into an effort to understand and use cognitive architectures like ACT-R and incorporate formal semantics systems into such architectures (among other things).<sup>1</sup>

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<sup>1</sup>This is not a new point – see the quote from Abney (1996) below, for example. We are simply rehearsing it here

## 2.3 Sidebar: methodological vs. theoretical behaviorism

Understanding that all our primary data is behavioral data and our primary object of study is the human cognitive behavior is not a return to pre-generative structuralism. The following extensive quote from Anderson (1989) distinguishes between methodological behaviorism (the right thing to do) and theoretical behaviorism (what generative linguistics effectively superseded). The quote recaps the history of cognitive psychology, and discusses why methodological behaviorism is a necessity, while theoretical behaviorism is definitely not (which we already know).

Psychology started out in the late 1800s as a science with one of its main goals to settle empirically the issue of the origins of knowledge. The field had a great deal of difficulty initially in making any headway on the issue. The problem is that scientists need to have agreed-upon data and it took psychology a while to establish consensus about what its data were. The introspectionists [...] took as their data self-observations of the content of thought. The problem was that different researchers with different theories would observe different things about their internal thoughts that confirmed their different theories. For instance, some introspectionists claim they could have thought devoid of sensory content while others claimed they could not. Because of irresolvable controversies like this, it became clear that a more objective data source was required.

This was one of the stimuli for the behaviorist movement that began around 1920, a movement much misunderstood, particularly by many of the behaviorists who practiced it. The behaviorist movement began with the observation that the prime source of objective data was recordings of the behavior of people. There were other possible sources of objective data such as physiological recordings but these turn out to be much harder to obtain than behavior. There are two essential features that distinguish behavioral data from introspective data. The first is that it is equally available to all scientists and not the private domain of the scientist who is having the introspection. Second, the psychologist is not constrained as to how to theoretically interpret the data. Thus, if a subject of a psychological experiment says 'I have a visual image of a cat', the scientist is free to propose any theory that will produce that verbal protocol and is not required to propose visual images as part of the theory. Because of the similarity of verbal protocols to introspective reports, many behaviorists have refused to admit verbal protocol data. However, [...] verbal protocols are very appropriate and powerful sorts of behavioral data, when treated as behavioral data and not as introspective data.

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with a focus on formal semantics and the ACT-R cognitive architecture.

[L]et me repeat the main line of argument as concisely as I can. Statistical methods – by which I mean primarily weighted grammars and distributional induction methods – are clearly relevant to language acquisition, language change, language variation, language generation, and language comprehension. Understanding language in this broad sense is the ultimate goal of linguistics.

The issues to which weighted grammars apply, particularly as concerns perception of grammaticality and ambiguity, one may be tempted to dismiss as performance issues. However, the set of issues labelled "performance" are not essentially computational, as one is often led to believe. Rather, "competence" represents a provisional narrowing and simplification of data in order to understand the algebraic properties of language. "Performance" is a misleading term for "everything else." Algebraic methods are inadequate for understanding many important properties of human language, such as the measure of goodness that permits one to identify the correct parse out of a large candidate set in the face of considerable noise. (Abney, 1996, p. 24)

However, there was a second point of motivation in stressing behavior as the measure by which a theory of knowledge will be assessed. This arose out of an emphasis on the functional nature of human knowledge. There was no point in making distinctions about knowledge that did not have consequences for behavior. If the person behaved the same whether he possessed knowledge X or not, in what sense does he really know X? If two pieces of knowledge result in the same behavior in what sense are they really different? Such arguments should be quite familiar to the AI community where we commonly talk about equivalence among different knowledge representation schemes. This point of view also anticipates the Turing-type tests for deciding if a system is intelligent.

The behaviorists frequently argued that there was no such thing as knowledge in the abstract; when we speak of someone having certain knowledge we mean that the person has certain behavioral potentials. This led to prohibitions against discussing mental structures and a claim that an objective science should only talk about behavior. Here we see a basically correct observation being carried to unfortunate extremes. Behaviorism can be separated into a methodological and a theoretical position:

(1) **Methodological.** Behavioral data is the major data for deciding among theories of knowledge. Different theories that imply no difference for the behavior (including verbal) of the system might as well be regarded as notational variants.

(2) **Theoretical.** The terms of a theory should be behavioral. Since only external behavior counts, a theory should not make reference to underlying mental structures.

**The fundamental error in behaviorism comes from extending the methodological prescription to the theoretical prohibition.** [emphasis added] Given that they were prohibited from theorizing about mental structure it is not surprising that the behaviorist theories tended to take strong empiricist stands and claim all knowledge arose directly from experience. A methodology that denied the existence of a mind denied the possibility of a contribution of the mind to knowledge.

[...]

The behaviorist learning theories of the first half-century, while they were rigorous in their choice of data, were fundamentally sloppy in their theorizing. They never really showed that the mechanisms of their theories could be put together to account for the complexities of human behavior. The advent of more computationally oriented theories in the 1950s provide the basis for exploring the issues of what could actually be computed in these frameworks. It became clear that there were serious inadequacies. Chomsky's criticism of Skinner's account of language was the most dramatic instance of such analysis, but there were many others. The learning theorists had insisted that they could account for behavior with theories whose only terms were objectively observable stimuli and responses. It became apparent that one needed to make reference to non-observable mechanisms to account for human behavior. (Anderson, 1989, pp. 315-316)

### 3 A more detailed plan for the course (tentative, subject to change)

#### 3.1 1st part: overview and formal prerequisites

Please note that this part of the course (hopefully, only the first third of the course) will go **fast**. We just want to refresh formal tools, fix the technical vocabulary, and outline main classes of accounts / formal strategies. If this is the first time you're getting acquainted with dynamic semantics or ACT-R, you should be **extremely** proactive at this stage – you should read and explore on your own, and probably dedicate 15+ hours of actual work per week to this class.

We list the overview and prerequisites for DRT / dynamic semantics and for ACT-R separately, but we will most likely do them both at the same time. That is, each meeting in the first part of the course will be more or less evenly split between the two.

The reason for this is that both sides should be more or less equally salient in our minds by the time we get to the second part of the course, when we're going to read and evaluate papers that try to bridge the formal semantics / cognitive architecture divide (or that at least have the potential to bridge that divide). This will also help with the final papers, which should similarly try to integrate the two sides in some form or another.

The literature on incremental interpretation, underspecified representations and related issues in semantics, cognitive science, psycholinguistics, and natural language processing / understanding is enormous. We will only be able to cover a little bit of it, hopefully enough of the fundamentals and of the wider world out there to put us on a productive path towards novel research at the interface of formal semantics and cognitive architectures.

##### 3.1.1 Overview and formal prerequisites on the DRT / dynamic semantics side

- Kamp and Reyle (1993), chapters 1, 2, and 5: the dynamic semantics of propositional connectives, quantification over and anaphora to individuals, quantification over and anaphora to times, events and states
- Dynamic Predicate Logic (DPL) and Compositional DRT (CDRT) (we will do only some of this): Groenendijk and Stokhof (1991), Muskens (1995), Muskens (1996)
- Presuppositions and dynamic semantics (we will do only some of this): Karttunen (1974), Heim (1983), van der Sandt (1992), Krahmer (1998)

##### 3.1.2 Overview and formal prerequisites on the ACT-R side

- Anderson and Lebiere (1998), chapters 1, 2, 3, and 4
- Lewis and Vasishth (2005), Lewis et al. (2006)
- The ACT-R implementation we will use (Python ACT-R): Stewart (2007), Stewart and West (2007)

#### 3.2 2nd part: bringing DRT/dyn. sem. and ACT-R/cognitive architectures together

There is an enormous amount of work on incremental interpretation and language comprehension in the psycholinguistic literature, the formal syntax & parsing literature, and the natural language processing / understanding literature. We will not be able to touch on a lot of that work. The selection of papers below is by no means exhaustive or even representative of all these different

strands of work. The papers marked as  $[fyi]$  will be discussed in class only after the other ones – time permitting.

- Chater et al. (1995)
- Milward and Cooper (1994)
- Vermeulen (1994)
- Poesio (1994)
- $[fyi]$  Bunt (2007)
- $[fyi]$  Hough et al. (2015)
- $[fyi]$  Sag and Wasow (2011)
- $[fyi]$  Budiu and Anderson (2004)
- Vasishth et al. (2008)
- Johnson-Laird (2004)
- Johnson-Laird et al. (1989)
- Dotlačil and Brasoveanu (2015)
- Hemforth and Konieczny (2006)
- Chemla and Bott (2013)
- Oaksford and Chater (2007), chapter 5 (conditionals)
- Oaksford and Chater (2007), chapter 7 (syllogisms)
- Pickering et al. (2006)
- Bott (2008)

### 3.3 Weekly schedule

At first, roughly half of each weekly session will be dedicated to DRT / dynamic semantics, and half to ACT-R. Once the introductory / prerequisites part is over, we will just work through the ‘bridging-the-divide’ papers more or less in the order in which they are listed above.

## 4 Course Requirements

Each registered participant will be required to lead in-class discussions of the readings in the dropbox folder. We will rotate this responsibility between the registered participants throughout the entire course (so you will have to lead several discussions). Reading and discussing each paper is the collective responsibility of the entire group, but the leader is responsible for starting the conversation and keeping it streamlined, concise and productive. The leader is also responsible for writing up a brief report summarizing the main points of the paper that was discussed, and the main points of the conversation we had in class about the paper – as soon as the class is over.

The report should include specific references (quotes, page numbers etc.) to the paper that was discussed. This written report will be posted online as part of our seminar log.

For particularly involved papers, we might want the discussion leader to prepare a handout or slides or an *actually running* computational model (with the code properly documented). We will discuss this ahead of time.

We will generally try to discuss 2, maybe 3, papers/chapters in every class, particularly in the second part of the course. It is possible and acceptable to start the 3rd discussion / paper at the end of one class and finish it up at the beginning of the next class.

You will also be required to write a final paper. The format of the paper should strictly follow the *Sinn und Bedeutung* (SuB) guidelines available here:

<http://www.uni-goettingen.de/en/proceedings/501839.html>

You should discuss the topic and basic structure of your paper with the instructor by the 8th week of classes.

## References

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