1 Overview

- Any side effects regime can be grafted onto a continuized CCG. Give a general technique for accomplishing this, relate it to the ContT monad transformer (Liang et al. 1995).
- Yields two combinators. Type-theoretic way to track effects (Shan 2005).
- Dynamic semantics is (Shan 2001):[1]
  - State: ability to manipulate the discourse context, i.e. create discourse referents.
  - Nondeterminism: indefinites are
- No need to settle on "the" grammar. Functional application can live in its bones, and side effects can be grafted on, modularly. Lexical entries that would from a more flat-footed perspective seem completely incongruous can play together nicely.
- The perspective Barker 2002, Shan & Barker 2006, Barker & Shan 2014 is in a sense an instantiation of this general perspective, where the underlying monad is the $\mathsf{Identity}$ monad.
- Monads as a natural way to extend a continuations-based grammar with tools for dynamic binding and exceptional scope. In the end: you have functional application, plus the functors from whichever monads are implicated in a given language.
- Other techniques (DPL, DMG) not reducible to monads.

2 Adding side effects to k

- Normal continuized grammar:
  - Lift
  - Lower
  - Continuized functional application
- Adding side effects (Wadler 1994, 1995, Shan 2002):
  - Replace Lift with $\star$
  - Replace Lower with η
  - Keep continuized functional application
- Two type constructors:
  - Bipartite Cont:
  - Unary Monadic:

1 NB: does not characterize all varieties of dynamic semantics. Dynamic treatments following Groenendijk & Stokhof 1990 (e.g. Zimmermann 1991, Dekker 1993, Szabolcsi 2003, de Groote 2006) provide a way for indefinites to extend their binding domain but do not treat indefinites as nondeterministic analogs of proper names.

3 Finding the dynamic monad

- The meat of PLA (Dekker 1994): sentences are relations on stacks. Non-empty relations correspond to truth. Non-functional pairs in the relation correspond to nondeterminism introduced by indefinites (and perhaps disjunction).

$$[\![\text{a linguist}]\!] = \lambda k s . \bigcup_{x \in \mathsf{ling}} k\, x\, \widehat{sx}$$

- A different perspective on this.
- Monad for nondeterminism:

Definition 1 (The Set monad).

$$\begin{aligned} \mathsf{M}\,a &::= a \to t \\ \eta\, x &:= \{x\} \\ m \star k &:= \bigcup_{x \in m} k\, x \end{aligned}$$

- Monad for state (generalization of monad for environment-sensitivity):

Definition 2 (The State monad).

$$\begin{aligned} \mathsf{M}\,a &::= s \to a \times s \\ \eta\, x &:= \lambda s . \langle x, s \rangle \\ m \star k &:= \lambda s . k\,(m\,s)_0\,(m\,s)_1 \end{aligned}$$

- Use StateT to stitch the two together[2]

Definition 3 (The StateT monad transformer).

$$\begin{aligned} \mathsf{M}\,a &::= s \to \mathsf{L}\,(a \times s) \\ \eta\, x &:= \lambda s . \eta_{\mathsf{L}}\,\langle x, s \rangle \\ m \star k &:= \lambda s . m\, s \star_{\mathsf{L}} \lambda \pi . k\, \pi_0\, \pi_1 \end{aligned}$$

Definition 4 (The State_Set monad).

$$\begin{aligned} \mathsf{M}\,a &::= s \to (a \times s) \to t \\ \eta\, x &:= \lambda s . \{\langle x, s \rangle\} \\ m \star k &:= \lambda s . \bigcup_{\pi \in m s} k\, \pi_0\, \pi_1 \end{aligned}$$

- Static lexicon, dynamic lexicon
- Binding, totally modularized

$$\begin{aligned} &BarkerShan: && \mathbf{bind}\, m := \lambda k . m\,(\lambda x . k\, x\, x) \\ &Now: && \mathbf{bind}\, m := \lambda k . m\,(\lambda x s . k\, x\, \widehat{sx}) \end{aligned}$$

- Summing up: three combinators for "order-insensitive" (i.e. continuized combination). **unit**, **run**, **bind**

	$\mathbf{lift}\, m$	$M\, \mathbf{triv}$	$\mathbf{bind}\, M$
Previous	$\lambda k . k\, m$	$M\,(\lambda x . x)$	$\lambda k . m\,(\lambda x . k\, x\, x)$
Proposal	$\lambda k . m \star k$	$M\, \eta$	$\lambda k . m\,(\lambda x s . k\, x\, \widehat{sx})$

2 Fn. about SetT

4 Examples

- Interesting properties: no dynamic conjunction, completely standard model theory (cf. de Groote 2006).

de Groote 2001 Charlow 2014 Bumford to appear

References

Barker, Chris. 2002. Continuations and the Nature of Quantification. *Natural Language Semantics* 10(3). 211–242. http://dx.doi.org/10.1023/A:1022183511876.

Barker, Chris & Chung-chieh Shan. 2014. *Continuations and Natural Language*. Oxford: Oxford University Press.

Bumford, Dylan. to appear. Incremental quantication and the dynamics of pair-list phenomena. *Semantics & Pragmatics* 8(9).

Charlow, Simon. 2014. *On the semantics of exceptional scope*: New York University Ph.D. thesis.

Dekker, Paul. 1993. *Transsentential meditations: ups and downs in dynamic semantics*: University of Amsterdam Ph.D. thesis.

Dekker, Paul. 1994. Predicate Logic with Anaphora. In Mandy Harvey & Lynn Santelmann (eds.), *Proceedings of Semantics and Linguistic Theory 4*, 79–95. Ithaca, NY: Cornell University.

Groenendijk, Jeroen & Martin Stokhof. 1990. Dynamic Montague Grammar. In Laszlo Kalman & Laszlo Polos (eds.), *Proceedings of the Second Symposium on Logic and Language*, 3–48. Budapest: Eötvös Loránd University Press.

de Groote, Philippe. 2001. Type raising, continuations, and classical logic. In Robert van Rooy & Martin Stokhof (eds.), *Proceedings of the Thirteenth Amsterdam Colloquium*, 97–101. University of Amsterdam.

de Groote, Philippe. 2006. Towards a Montagovian account of dynamics. In Masayuki Gibson & Jonathan Howell (eds.), *Proceedings of Semantics and Linguistic Theory 16*, 1–16. Ithaca, NY: Cornell University.

Liang, Sheng, Paul Hudak & Mark Jones. 1995. Monad Transformers and Modular Interpreters. In *22nd ACM Symposium on Principles of Programming Languages (POPL '95)*, 333–343. ACM Press.

Shan, Chung-chieh. 2001. A Variable-Free Dynamic Semantics. In Robert van Rooy & Martin Stokhof (eds.), *Proceedings of the Thirteenth Amsterdam Colloquium*, University of Amsterdam.

Shan, Chung-chieh. 2002. Monads for natural language semantics. In Kristina Striegnitz (ed.), *Proceedings of the ESSLLI 2001 Student Session*, 285–298.

Shan, Chung-chieh. 2005. *Linguistic Side Effects*: Harvard University Ph.D. thesis.

Shan, Chung-chieh & Chris Barker. 2006. Explaining Crossover and Superiority as Left-to-right Evaluation. *Linguistics and Philosophy* 29(1). 91–134. http://dx.doi.org/10.1007/s10988-005-6580-7.

Szabolcsi, Anna. 2003. Binding on the Fly: Cross-Sentential Anaphora in Variable-Free Semantics. In Geert-Jan M. Kruijff & Richard T. Oehrle (eds.), *Resource-Sensitivity, Binding and Anaphora*, 215–227. Dordrecht: Kluwer Academic Publishers.

Wadler, Philip. 1994. Monads and composable continuations. *Lisp and Symbolic Computation* 7(1). 39–56. http://dx.doi.org/10.1007/BF01019944.

Wadler, Philip. 1995. Monads for functional programming. In Johan Jeuring & Erik Meijer (eds.), *Advanced Functional Programming*, vol. 925 Lecture Notes in Computer Science, 24–52. Springer Berlin Heidelberg. http://dx.doi.org/10.1007/3-540-59451-5_2.

Zimmermann, Thomas Ede. 1991. Dynamic logic and case quantification. In Martin Stokhof, Jeroen Groenendijk & David Beaver (eds.), *Quantification and Anaphora I* (DYANA Deliverable R2.2.A), 191–195.