1 Outline

- Continuized CCGs generalize scope-taking ("ubiquitous scopal pied piping") using three operations: **lift**, **triv**, and **scope**.
- Main proposal: replacing **lift** and **triv** with options that countenance side effects (Shan 2005). Any side effects regime can be grafted onto a continuized CCG, by replacing **lift** and **triv** with monadic functors.
- Give a general technique for accomplishing this, relate it to the ContT monad transformer (Liang et al. 1995). Offers a type-theoretic way to track effects, integrate them into a well-developed CCG framework for scope-taking.
- Dynamic semantics is (Shan 2001):[1]
  - State: ability to manipulate the discourse context, i.e. create discourse referents.
  - Nondeterminism: analogizes indefinites to referential expressions. Treats indefinites as referring expressions, though ones which refer indeterminately.
- Corollary: there is no need to settle on a single ("the") grammar. Different and quite varied side effects regimes can be modularly grafted onto a simple applicative ("pure") core. Lexical entries that would seem incongruous in a flat-footed standard perspective integrate seamlessly in a single grammar.
- 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.
- The standard continuations-based perspective of Barker 2002, Shan & Barker 2006, Barker & Shan 2014 is an instantiation of a more general perspective.
- Standard dynamic techniques (DPL, DMG) not reducible to monads.

2 Adding side effects to k

- Standard continuized grammar:
  - **lift**: $\lambda k.\, k\, x$
  - **triv**: $\lambda x.\, x$
  - **scope**: $\lambda k.\, m\, (\lambda f.\, n\, (\lambda x.\, k\, (f\, x)))$

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.

- Type-theoretic details here
- Adding side effects (Wadler 1994, 1995, Shan 2002):
  - Replace **lift** with $\star$
  - Replace **triv** with η
  - **scope** stays the same
- Two type constructors:
  - Bipartite Cont:
  - Unary Monadic:

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: treating nondeterminism and state modification as side effects, within a functional programming setting for side effects.
- 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).

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

2 Fn. about SetT

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
- Modular treatment of binding.

$$\begin{aligned} \text{Previous}: &\quad \textbf{bind}\, m := \lambda k.\, m\, (\lambda x.\, k\, x\, x) \\ \text{Proposal}: &\quad \textbf{bind}\, m := \lambda k.\, m\, (\lambda x s.\, k\, x\, \widehat{s x}) \end{aligned}$$

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

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

4 Examples

- Some upshots: no dynamic conjunction, completely standard model theory (cf. de Groote 2006). "Contexts of evaluation" are constructed on the fly.

de Groote 2001 Charlow 2014 Bumford to appear

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