Quotation and effects in natural language

Three applications

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Computational Linguistics
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Outline

➤ Past: Mixed quotation

Present: Quantifier scope
- Quotation for programming: code generation
- Control for programming: let insertion
- Control for linguistics: quantification
- Quotation for linguistics: inverse scope

Future: Rational metaprogramming
Anaphora as state

Apparently, the idea of meeting participants making their own reservations at the hotel does not work well for them.
Mixed quotation

“Bachelor” has eight letters.
Mixed quotation

“Bachelor” has eight letters.

Direct
Quine said, “Quotation has a certain anomalous feature”.

Indirect
Quine said that quotation has a certain anomalous feature.

Mixed
Quine said that quotation “has a certain anomalous feature”.
Mixed quotation

“Bachelor” has eight letters.

Direct
Quine said, “Quotation has a certain anomalous feature”.

Indirect
Quine said that quotation has a certain anomalous feature.

Mixed
Quine said that quotation “has a certain anomalous feature”.
Bush said he has an “eclectic” reading list.
Bush said the enemy “misunderestimates me”.

Anaphora in quotation

The professor said she requires “every student in my class who lives on campus” to bring their homework to her office.

Professor to journalist:

I require every student in my class who lives on campus to drop their work into this box.

Run with state?
Anaphora in quotation

The professor said she requires “every student in my class who lives on campus” to bring their homework to her office.

Professor to journalist:

I require every student in my class who lives on campus to drop their work into this box.

Run with state?

* The professor told every student in her class who lives on campus to “bring their homework to my office”.

Professor to John:

Please bring your Lordship’s homework to my office.

Professor to Mary:

Please bring your Ladyship’s homework to my office.

No cross-stage persistence?
Past: Mixed quotation

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Future: Rational metaprogramming
Staging power

let rec power1 x = function
  | 0 -> 1
  | n -> x * power1 x (pred n)
▶ val power1: int -> int -> int = <fun>

let test1 = power1 2 11
▶ val test1: int = 2048
Staging power

let rec power1 x = function
  | 0 -> 1
  | n -> x * power1 x (pred n)
▶ val power1: int -> int -> int = <fun>

let test1 = power1 2 11
▶ val test1: int = 2048

let rec power2 x = function
  | 0 -> 〈1〉
  | n -> 〈~x * ~(power2 x (pred n))〉
▶ val power2: ('a,int)code->int->('a,int)code = <fun>

let test2 = 〈fun x -> ~(power2 〈x〉 11)〉
▶ val test2: ('a,int->int)code = 〈fun x -> x*(x*(x*(x*(x*(x*(x*(x*(x*(x*(x*1))))))))))〉
Interpreting English

John loves Mary
▶ -: bool = true

John loves himself
▶ -: bool = false

Someone loves John
▶ -: bool = true
Interpreting English

John loves Mary
▶ -: bool = true

John loves himself
▶ -: bool = false

Someone loves John
▶ -: bool = true

John loves Mary
▶ -: (‘a,bool) code = ⟨love Mary John⟩

John loves himself
▶ -: (‘a,bool) code = ⟨love John John⟩

Someone loves John
▶ -: (‘a,bool) code = ⟨List.exists people (love John)⟩
The need to insert let

let square3 x =  x *  x

let rec power3 x = function
  | 0 ->  1
  | 1 -> x
  | n when n mod 2 = 0 -> power3 (square3 x) (n/2)
  | n -> power3 (square3 x) (n/2)  *  x

let test3 = power3 2 11
▶ val test3: int = 2048
The need to insert let

let square4 x = 〈~x * ~x〉

let rec power4 x = function
  | 0    -> 〈1〉
  | 1    -> x
  | n when n mod 2 = 0 -> power4 (square4 x) (n/2)
  | n    -> 〈(~(power4 (square4 x) (n/2))) * ~x〉

let test4 = 〈fun x -> ~(power4 〈x〉 11)〉
▶ val test4: ('a, int -> int) code
  = 〈fun x -> (((x*x)*(x*x))*((x*x)*(x*x)))*(x*x)*x〉
Inserting let in continuation-passing (or monadic) style

let square4 x = ⟨ ~x * ~x ⟩
Inserting let in continuation-passing (or monadic) style

let square5 x k = (let r = ~x * ~x in ~(k <r>))
Inserting let in continuation-passing (or monadic) style

let square5 x k = <let r = ~x * ~x in ~(k <r>))>

let rec power5 x k = function
  | 0 -> k <1>
  | 1 -> k x
  | n when n mod 2 = 0
    -> square5 x (fun s -> power5 s k (n/2))
  | n -> square5 x (fun s -> power5 s (fun r ->
                       k <~r * ~x>)
                     (n/2))

let test5 = <fun x -> ~(power5 <x> (fun r -> r) 11)>
▶ val test5: ('a, int -> int) code
   = <fun x -> let r1 = x * x in
                let r2 = r1 * r1 in
                let r3 = r2 * r2 in (r3 * r1) * x>
Inserting let in direct style

let square6 x = shift (fun k -> \<let r = ~x * ~x in ~ (k \r)>)

let rec power6 x = function
  | 0 -> \<1>
  | 1 -> x
  | n when n mod 2 = 0 -> power6 (square6 x) (n/2)
  | n -> ~(power6 (square6 x) (n/2)) * ~x

let test6 = \<fun x -> ~ (reset (fun () -> power6 \x \11))> ▶

val test6 : ('a, int -> int) code
= \<fun x -> let r1 = x * x in
             let r2 = r1 * r1 in
             let r3 = r2 * r2 in (r3 * r1) * x>
Outline

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Future: Rational metaprogramming
Shifting gears

type person = John | Mary
let people = [John; Mary]
let love (x: person) (y: person) = x != y
let f $ x = f x
let x $ f = f x

John $ (love $ Mary)

*John loves Mary.*
In-situ quantification

let forall (f: person -> bool) = List.for_all f people
let exists (f: person -> bool) = List.exists f people

Someone loves John.

reset (fun () => )

\[
\text{shift exists } \text{someone} \quad \text{love} \quad \text{loves} \quad \text{John} \quad \text{John}
\]
In-situ quantification

let forall (f: person -> bool) = List.for_all f people
let exists (f: person -> bool) = List.exists f people

Mary loves everyone.

reset (fun () -> )

Mary

Mary

love

loves

shift forall
everyone
In-situ quantification

let forall (f: person -> bool) = List.for_all f people
let exists (f: person -> bool) = List.exists f people

Someone loves everyone.

reset (fun () -> )

\$

shift exists

someone

$ 

shift loves

everyone

shiftforall
Scope ambiguity

Someone loves everyone.
Someone loves everyone.

Children... There's a time and a place for everything
Scope ambiguity

Someone loves everyone.

Children...
There’s a time and a place for everything, and it’s called college.
Scope ambiguity

Someone loves everyone.

Children... There’s a time and a place for everything, and it’s called college.

Require left-to-right evaluation for other side effects:
* His mother loves everyone.
* What did who buy?
* Anyone loves no one.
Inverse scope as quotation

Someone loves everyone.

reset (fun () -> )

shift exists

someone

love

loves

shift for all

everyone
Inverse scope as quotation

“Someone loves everyone”.

reset (fun () -> !( ) )

reset (fun () -> )

$ $

shift exists someone

love loves

shift forall everyone
Inverse scope as quotation

“Someone loves” everyone.

reset (fun () -> !( ) )

reset (fun () -> )

$ $

\text{shift exists someone}

\text{loves}

\sim (\text{let } v = \text{ in } \langle v \rangle )

\text{shift forall everyone}
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Future: Rational metaprogramming
Isn’t it getting chilly in here?
Isn’t it getting chilly in here?

A hotel cleaner enters a room and starts to clean it. A female guest emerges from the shower. The cleaner says “Excuse me sir” and exits.
Rational metaprogramming

To model the beliefs, desires, and intentions of agents who have beliefs about each other’s intentions, about each other’s desires about each other’s beliefs, and so on,
Rational metaprogramming

To model the beliefs, desires, and intentions of agents who have beliefs about each other’s intentions, about each other’s desires about each other’s beliefs, and so on, we model

- intentions to perform actions as programs.
- beliefs as probability distributions.
  (weighted nondeterminism $\rightarrow$ stochastic programs)
- desires as utility functions.
  (rational choice $\rightarrow$ rational programs)
To model the beliefs, desires, and intentions of agents who have beliefs about each other’s intentions, about each other’s desires about each other’s beliefs, and so on, we model

- **intentions** to perform actions as *programs*.
- **beliefs** as probability distributions.
  *(weighted nondeterminism → stochastic programs)*
- **desires** as utility functions.
  *(rational choice → rational programs)*

One agent’s model of another is a probability distribution over *(quoted)* rational programs.

We need a modal type system and efficient self-interpretation.
Summary

Quotation goes well with effects (state, control, nondeterminism), so that code does not have to be generated in lexical order.

But we want a type system that prevents scope extrusion.

Multigrained theories of quotation: the less intensional a theory, the more cross-stage persistence it allows?

Levels of quotation are not quite levels of control operators.
Reckless let insertion

```ml
let test6 = \x -> ~(reset (fun () ->
  power6 \x\n11))

val test6 : ('a, int -> int) code
  = \x -> let r1 = x * x in
    let r2 = r1 * r1 in
    let r3 = r2 * r2 in (r3 * r1) * x
```

Reckless let insertion

let test6 = \( \langle \text{fun } x \to \sim \text{(reset (fun () -> power6 } \langle x \rangle 11) \rangle \rangle \)
▶ val test6: (’a, int -> int) code
  = \langle \text{fun } x \to \text{let } r1 = x \times x \text{ in let } r2 = r1 \times r1 \text{ in let } r3 = r2 \times r2 \text{ in (r3 \times r1) \times x} \rangle

let test7a = \langle \text{fun } x \to \sim \text{(reset (fun () -> \langle let y = x + 1 \text{ in } \sim \text{(power6 } \langle y \rangle 11) \rangle \rangle) \rangle \rangle \rangle
▶ val test7a: (’a, int -> int) code
  = \langle \text{fun } x \to \text{let } r1 = y \times y \text{ in let } r2 = r1 \times r1 \text{ in let } r3 = r2 \times r2 \text{ in let } y = x + 1 \text{ in (r3 \times r1) \times y} \rangle
Reckless let insertion

```ocaml
let test6 = <fun x -> ~(reset (fun () ->
    power6 <x> 11))>
▶ val test6: ('a, int -> int) code
  = <fun x -> let r1 = x * x in
    let r2 = r1 * r1 in
    let r3 = r2 * r2 in (r3 * r1) * x>

let test7b = <fun x -> ~(reset (fun () ->
    <let y=x+1 in ~(reset (fun () -> power6 <y> 11))>)>)
▶ val test7b: ('a, int -> int) code
  = <fun x -> let y = x + 1 in
    let r1 = y * y in
    let r2 = r1 * r1 in
    let r3 = r2 * r2 in (r3 * r1) * y>
```