Recent developments in Computational Semantics

Markus Egg and Valia Kordoni

Universität des Saarlandes

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Underspecification formalisms 1

- ultimate goal: efficient and non-disjunctive representation of structural ambiguities

  (1) *Every woman loves a man*

- first motivation: efficiency
  - for complex expressions, generating and enumerating the readings would be too long-winded
  - example: the number of readings of a sentence with n quantifiers is the Catalan number for n
  - one of the formulae for Catalan numbers: $\frac{(2n)!}{n!(n+1)!}$
  - much less than factorials, but...
  - the first ten Catalan numbers (for $1 \leq n \leq 10$) are: 1, 2, 5, 14, 42, 132, 429, 1430, 4862, 16796

Underspecification formalisms 2

- second motivation: getting rid of disjunction
- even if one were willing to enumerate all the readings of an ambiguous expression, there is an incumbent problem with its negation
- assume that the interpretation of an ambiguous expression is the disjunction of their readings
- e.g., for (1), the readings are abbreviated as $\exists\forall$ and $\forall\exists$, then its interpretation were $\forall\exists \vee \exists\forall$
- intuitively, the negation of (1) is $\neg\forall\exists \vee \neg\exists\forall$
  - in words: one of the readings is negated
  - formally, this is a disjunction of negated readings
- example: *Max didn't run*

Underspecification formalisms 3

- but due to the interpretation of (1) as $\forall\exists \vee \exists\forall$, its negation is predicted to be $\neg(\forall\exists \vee \exists\forall) = \neg\forall\exists \wedge \neg\exists\forall$ (De Morgan)
  - in words: all of the readings are negated
  - formally, this is a negation of a disjunction of readings
- therefore, we model the meaning of ambiguous expressions as a set of readings, and their assertion, as a disjunction of the elements of this set
  - meaning of (1): $\{\forall\exists, \exists\forall\}$
  - meaning of the negation of (1): $\{\neg\forall\exists, \neg\exists\forall\}$

Underspecification formalisms 4

- efficiency and getting rid of disjunctions can be captured in two ways:
  - describing the elements of the set by a property that singles them out
    - i.e., there are meta-level descriptions that denote object-level semantic representations
    - often, the described representations are expressions of the λ-calculus
  - giving an underlying representation plus an algorithm with which to derive all elements of this set
    - this algorithm can be nondeterministic or deterministic

Minimal Recursion Semantics (MRS): intuitions 1

- basic idea: represent nested semantic structures as a set of relations, without losing dependencies between these relations (in particular, scope)
- relations are semantic atoms ('elementary predications'), which usually correspond to morphemes/words
  - advantage 1: facilitates further processing (e.g., in Machine Translation)
  - advantage 2: allows for straightforward semantic underspecification
- example: translate *the beginning of spring* into *Frühlingsanfang*

(2) the beginning of spring arrived

(3) $\mathbf{the}'_x(\mathbf{beginning}'(x) \wedge \mathbf{the}_y(\mathbf{spring}'(y), \mathbf{of}(x,y)), \mathbf{arrive}'(x))$

(4) $\mathbf{the}_y(\mathbf{spring}'(y), \mathbf{the}'_x(\mathbf{beginning}'(x) \wedge \mathbf{of}(x,y), \mathbf{arrive}'(x)))$

- the equivalence problem like in in(3) and (4) is in general undecidable

MRS: intuitions 2

- first attempt: drop scope

  (5) $\mathbf{the}'(x), \mathbf{beginning}'(x), \mathbf{of}(x,y), \mathbf{the}(y), \mathbf{spring}'(y), \mathbf{arrive}'(x)$

- but: this loses important differences

  (6) Every old horse is white

  (7) Every white horse is old

  (8) $\mathbf{every}'(x), \mathbf{old}'(x), \mathbf{horse}'(x), \mathbf{white}'(x)$

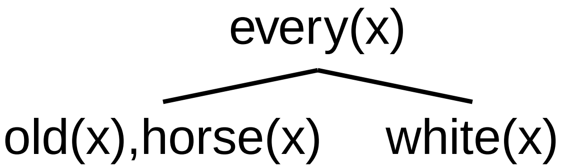
- consequence: We need a means of addressing relations themselves, in order to distinguish restriction and scope
- to this end, relations have a unique address, called ‘handle’ or ’label’
- conjunction of relations is expressed by identifying their handles

MRS: intuitions 3

- now the semantics of (6) and (7) is different:
  - for (6):

(9) $h_0 : \mathbf{every}'(x, h_1, h_2), h_1 : \mathbf{old}'(x), h_1 : \mathbf{horse}'(x), h_2 : \mathbf{white}'(x)$

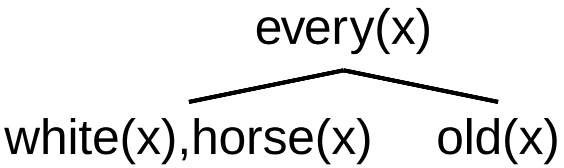
(10)



  - for (7):

(11) $h_0 : \mathbf{every}'(x, h_1, h_2), h_2 : \mathbf{old}'(x), h_1 : \mathbf{horse}'(x), h_1 : \mathbf{white}'(x)$

(12)



MRS: intuitions 4

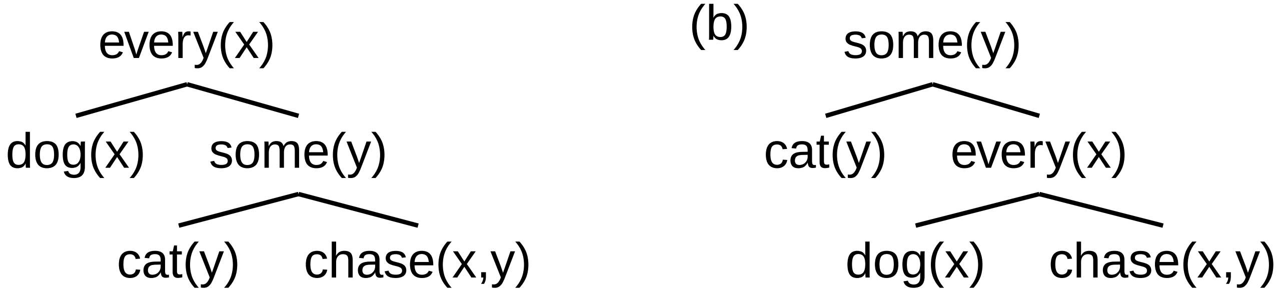
- underspecification is now easy to express: leave open handle arguments of quantifiers for scope:

(13) Every dog chases some cat

(14) $h_1 : \mathbf{every}'(x, h_2, h_n), h_2 : \mathbf{dog}'(x), h_3 : \mathbf{some}'(y, h_4, h_m), h_4 : \mathbf{cat}'(y), h_5 : \mathbf{chase}'(x, y)$

- first solution: $n = 3, m = 5$; wide scope of the universal quantifier
- second solution: $n = 5, m = 1$; wide scope of the existential quantifier

(15) (a) (b)



- this presupposes ‘treeness’ of the solutions

MRS: advanced scope issues 1

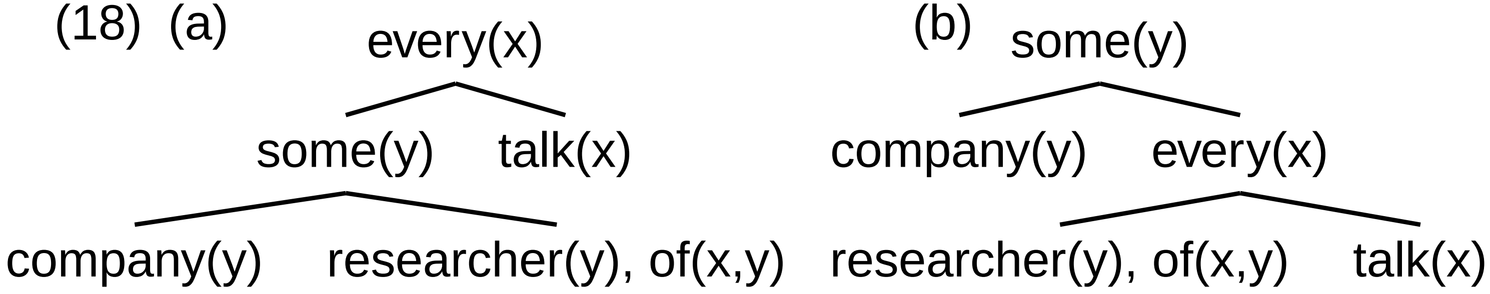
- additional problem: nested quantifiers
- handles arguments of quantifiers for restrictions must be left open, too

(16) Every researcher of some company talks

(17) $h_1 : \mathbf{every}'(x, h_i, h_j), h_2 : \mathbf{researcher}'(x), h_2 : \mathbf{of}'(x, y), h_3 :$
$\mathbf{some}'(y, h_n, h_m), h_4 : \mathbf{company}'(y), h_5 : \mathbf{talk}'(x)$

- first solution: $i = 3, j = 5, n = 4, m = 2$; wide scope of $\mathbf{every}'$
- second solution: $i = 2, j = 5, n = 4, m = 1$; wide scope of $\mathbf{some}'$

(18) (a)



every(x)

some(y) talk(x)

company(y) researcher(y), of(x,y)

(b)

some(y)

company(y) every(x)

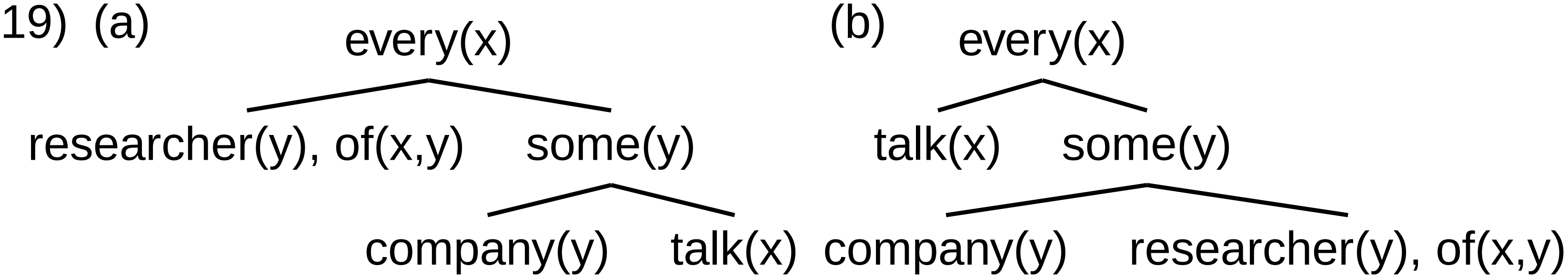
researcher(y), of(x,y) talk(x)

MRS: advanced scope issues 2

- but what about other, unwanted solutions?
- type 1: $i = 2, j = 3, n = 4, m = 5$ (unbound variables)
- type 2: $i = 5, j = 3, n = 4, m = 2$ (scope and restriction of $\mathbf{every}'$ exchanged)

  ‘every talker is a researcher of some company or other’

(19) (a) (b)



- consequence 1: all solutions must respect variable binding
- consequence 2: additional constraints on scope relations

  (qeq constraints)

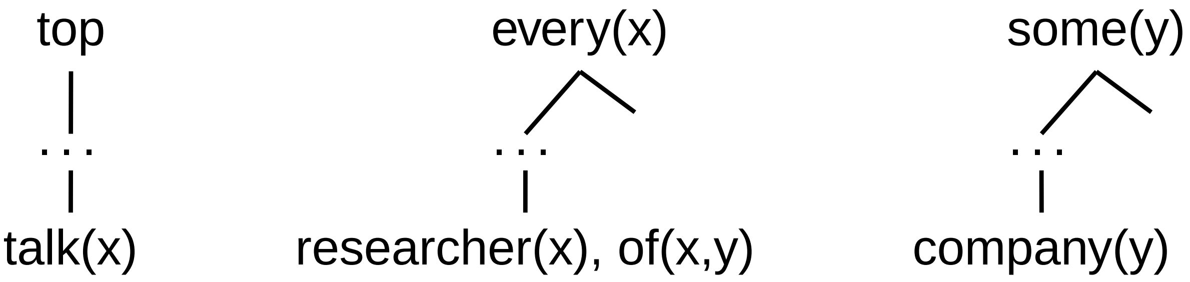
MRS: qeq constraints

- definition: $h_1 =_q h_2$ iff $h_1 = h_2$ or h_1 is the address of a relation with a handle argument h_3, and $h_3 =_q h_2$

  (20) Every researcher of some company talks

  - set of relations: $\{h_1 : \textbf{every}'(x, h_i, h_j), h_2 : \textbf{researcher}'(x), h_2 : \textbf{of}'(x, y), h_3 : \textbf{some}'(y, h_n, h_m), h_4 : \textbf{company}'(y), h_5 : \textbf{talk}'(x)\}$
  - the top handle h_0: handle of the highest relation (whatever that may be)
  - set of qeq constraints: $\{h_0 =_q h_5, h_i =_q h_2, h_n =_q h_4\}$
  - resulting partial description:

(21)



MRS: formal definition 1

- elementary predications have four arguments:

  an ‘address’ handle, a relation, a list of (zero or more) variable arguments of the relation, a list of (zero or more) scopal (handle) arguments of the relation
- example *every*: $h_1 : \text{every}(x, h_2, h_3)$
- example *man*: $h_4 : \text{man}(x)$
- a MRS structure is a 4-tuple with a global top handle, a local top handle, a set of elementary predications, and a set of handle constraints
- example *Every researcher talks*: $\langle h_0, h_2, \{h_3 : \mathbf{every}'(x, h_4, h_5), h_6 : \mathbf{researcher}'(x), h_7 : \mathbf{talk}'(x)\}, \{h_0 =_q h_7, h_4 =_q h_6\}\rangle$
- in MRS structures for scope-bearing NPs, the local top is not identical to the handle of one of the relations, for other expressions, it is

MRS: formal definition 2

- fully specified MRS structures are called scope-resolved
- they are derived from underspecified ones by adding information monotonically, by equating handles
- all handle arguments and the global top handle are equated with a handle from a relation
- fully specified MRS structures have a tree structure (a connected graph with one root node, no node has more than one parent)
- they respect all handle constraints and restrictions from variable binding
- an underspecified MRS structure may be compatible with more than one scope-resolved MRS
- then each scope-resolved MRS models a reading of the linguistic expression whose semantics is given by the underspecified MRS structure

MRS: formal definition 3

- example *Every dog chases some cat*
- the underspecified MRS structure, which results from semantic construction:

(22) $\langle h_0, h_1, \{h_2 : \mathbf{every}'(x, h_3, h_4), h_5 : \mathbf{dog}'(x), h_6 : \mathbf{some}'(y, h_7, h_8), h_9 :$
$\mathbf{cat}'(y), h_{10} : \mathbf{chase}'(x, y)\}, \{h_0 =_q h_{10}, h_3 =_q h_5, h_7 =_q h_9\}\rangle$

- a fully specified MRS structure for one of the readings (wide scope for *some cat*):

(23) $\langle h_1, h_1, \{h_8 : \mathbf{every}'(x, h_3, h_4), h_3 : \mathbf{dog}'(x), h_1 : \mathbf{some}'(y, h_7, h_8), h_7 :$
$\mathbf{cat}'(y), h_4 : \mathbf{chase}'(x, y)\}, \{\ldots\}\rangle$

Semantic construction in MRS 1

- constituents inherit all relations and qeq relations of their immediate constituents
- rules of the syntax-semantics interface specify further qeq relations or equate handle values
- specific values from within the set of relations must be visible to the interface:
  - a distinguished relation, whose handle is given as L[ocal]TOP
  - a distinguished argument of one of the relations (often, of the distinguished relation), whose value is given as INDEX
  - the top handle, given in G[lobal]TOP

Semantic construction in MRS 2

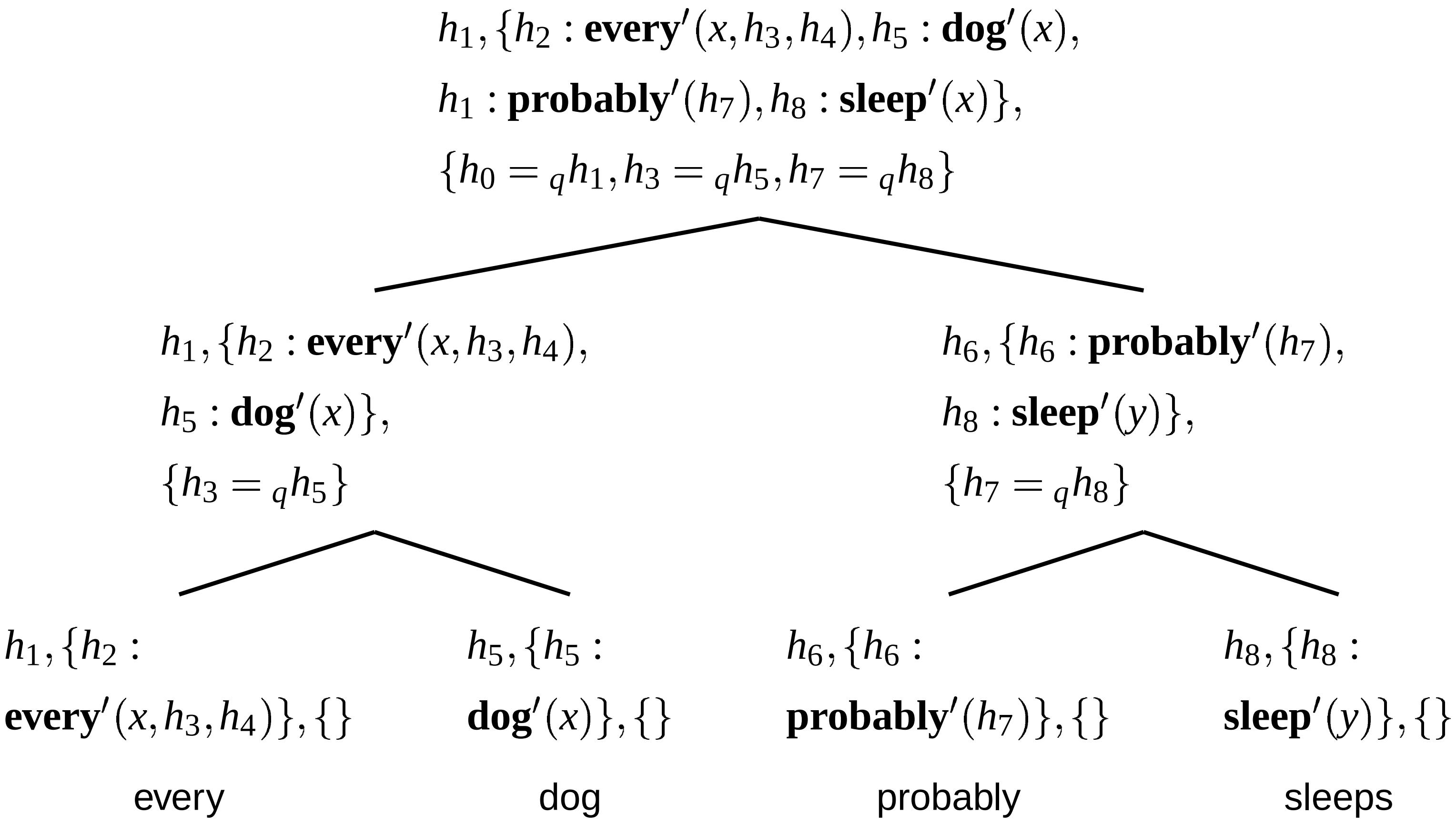
- there are two kinds of combination
  - ‘intersective’ combination:
    - the LTOP value of a constituent is equal to the LTOP values of its immediate constituents
    - this rule is also used to combine NP arguments with their verbs
  - ‘scopal’ combination:
    - the scope-bearing immediate constituent’s LTOP percolates to the whole constituent
    - the handle-valued argument of this LTOP relation is put into a qeq relation with the other immediate constituent’s LTOP value
    - for quantifiers, this applies to the handle-valued argument for the restriction, the one for the scope is always open

Semantic construction in MRS 3

- further conditions on semantic construction
  - the root condition stipulates that the global top is qeq the eventual local top of the whole phrase
  - the GTOP value of a constituent is always equal to the GTOP values of its immediate constituents
- lexical entries for scope-bearing quantifiers do not equate the LTOP value with the handle of one of the relations
  - example *every*: $\langle h_0, h_1, \{h_2 : \mathbf{every}'(x, h_3, h_4)\}, \{\}\rangle$
- problem: semantic construction for NPs from determiner and $\overline{\text{N}}$ semantics
- all other lexical entries do
  - example *man*: $\langle h_0, h_1, \{h_1 : \mathbf{man}'(x)\}, \{\}\rangle$
  - example *probably*: $\langle h_0, h_1, \{h_1 : \mathbf{probably}'(h_2)\}, \{\}\rangle$

Semantic construction in MRS 4

- example: *Every dog probably sleeps*



$$h_1, \{h_2 : \textbf{every}'(x, h_3, h_4), h_5 : \textbf{dog}'(x),$$
$$h_1 : \textbf{probably}'(h_7), h_8 : \textbf{sleep}'(x)\},$$
$$\{h_0 =_q h_1, h_3 =_q h_5, h_7 =_q h_8\}$$

$$h_1, \{h_2 : \textbf{every}'(x, h_3, h_4),$$
$$h_5 : \textbf{dog}'(x)\},$$
$$\{h_3 =_q h_5\}$$

$$h_6, \{h_6 : \textbf{probably}'(h_7),$$
$$h_8 : \textbf{sleep}'(y)\},$$
$$\{h_7 =_q h_8\}$$

$h_1, \{h_2 :$ $\textbf{every}'(x, h_3, h_4)\}, \{\}$

$h_5, \{h_5 :$ $\textbf{dog}'(x)\}, \{\}$

$h_6, \{h_6 :$ $\textbf{probably}'(h_7)\}, \{\}$

$h_8, \{h_8 :$ $\textbf{sleep}'(y)\}, \{\}$

every

dog

probably

sleeps

  - global top values are omitted here

MRS in typed feature structures 1

- values addressed in the interface are singled out in a CONT feature (HOOK)
- compare (24) and its feature structure equivalent:

(24) $h_0, h_1, \{h_2 : \mathbf{every}'(x, h_3, h_4), h_5 : \mathbf{dog}'(x), h_1 : \mathbf{probably}'(h_7), h_8 : \mathbf{sleep}'(x)\}, \{h_0 =_q h_1, h_3 =_q h_5, h_7 =_q h_8\}$

(25)

$$\begin{bmatrix} \text{HOOK} & \begin{bmatrix} \textbf{hook} & \\ \text{GTOP} & \boxed{0}\,\textbf{handle} \\ \text{LTOP} & \boxed{1}\,\textbf{handle} \end{bmatrix} \\ \text{RELS} & \left\langle \begin{bmatrix} \textbf{every\_rel} & \\ \text{HANDLE} & \boxed{2} \\ \text{ARG} & \boxed{11}\,\textbf{ref\_ind} \\ \text{RESTR} & \boxed{3}\,\textbf{handle} \\ \text{BODY} & \boxed{4}\,\textbf{handle} \end{bmatrix}, \begin{bmatrix} \textbf{dog\_rel} & \\ \text{HANDLE} & \boxed{5}\,\textbf{handle} \\ \text{ARG} & \boxed{11} \end{bmatrix}, \begin{bmatrix} \textbf{probably\_rel} & \\ \text{HANDLE} & \boxed{1} \\ \text{ARG} & \boxed{7}\,\textbf{handle} \end{bmatrix}, \begin{bmatrix} \textbf{sleep\_rel} & \\ \text{HANDLE} & \boxed{8}\,\textbf{handle} \\ \text{ARG} & \boxed{11} \end{bmatrix} \right\rangle \\ \text{HCONS} & \left\langle \begin{bmatrix} \textbf{qeq} & \\ \text{HARG} & \boxed{0} \\ \text{LARG} & \boxed{1} \end{bmatrix}, \begin{bmatrix} \textbf{qeq} & \\ \text{HARG} & \boxed{3} \\ \text{LARG} & \boxed{5} \end{bmatrix}, \begin{bmatrix} \textbf{qeq} & \\ \text{HARG} & \boxed{7} \\ \text{LARG} & \boxed{8} \end{bmatrix} \right\rangle \end{bmatrix}$$

MRS in typed feature structures 2

- the HOOK value is passed on from the semantic head of a phrase to its parent
- the rules of the syntax-semantics interface are encoded as feature structures, e.g., for scopal composition:

$$\begin{bmatrix}
\text{CONT} & \begin{bmatrix} \text{HOOK} & \boxed{1}\begin{bmatrix}\text{GTOP} & \boxed{0}\end{bmatrix} \\ \text{RELS} & \boxed{2}+\boxed{3} \\ \text{HCONS} & \boxed{4}+\boxed{5}\end{bmatrix} \\
\text{DTR1}|\text{CONT} & \begin{bmatrix} \text{HOOK} & \boxed{1}\begin{bmatrix}\text{LTOP} & \boxed{7}\end{bmatrix} \\ \text{RELS} & \boxed{2}\left\langle \ldots \begin{bmatrix}\text{HANDLE} & \boxed{7} \\ \text{ARG} & \boxed{8}\end{bmatrix} \ldots \right\rangle \\ \text{HCONS} & \boxed{4}\left\langle \ldots \begin{bmatrix}\textbf{qeq} & \\ \text{HANDLE} & \boxed{8}\\ \text{ARG} & \boxed{9}\end{bmatrix}\ldots\right\rangle \end{bmatrix}\\
\text{DTR2}|\text{CONT} & \begin{bmatrix}\text{HOOK} & \begin{bmatrix}\text{GTOP} & \boxed{0}\\ \text{LTOP} & \boxed{9}\end{bmatrix}\\ \text{RELS} & \boxed{3}\\ \text{HCONS} & \boxed{5}\end{bmatrix}
\end{bmatrix}$$

MRS: background 1

- MRS was developed first as a practical tool for handling the semantics in the HPSG grammar which was part of the Verbmobil Machine Translation system (Wahlster 2000)
- the formal specification and interpretation of MRS was left somewhat implicit at first
- compare the first MRS description in Copestake et al. (1995) to the final MRS paper (Copestake et al. 2001)
- for formal specifications of MRS-type formalisms, see Egg (1998) and Copestake et al. (2001)

MRS: background 2

- MRS is used in the English Resource Grammar (ERG), a broad-coverage HPSG-based grammar of English
- ERG is developed at the Linguistic Grammars Online (LinGO) Lab of CSLI Stanford
- it is developed in the grammar engineering environment Linguistic Knowledge Building (LKB; Copestake 2002)
- see also the web page of LKB: `http://www-csli.stanford.edu/ aac/lkb.html`