BACK TO THE DRAWING BOARD

The Myth of Data-Driven NLU and How to go Forward (Again)

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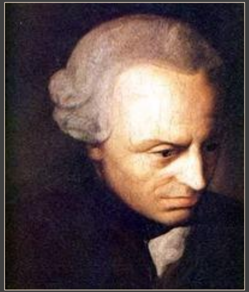

Immanue

Richard

Jerry Hol

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SRI International
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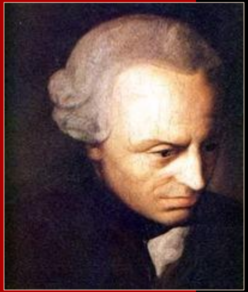
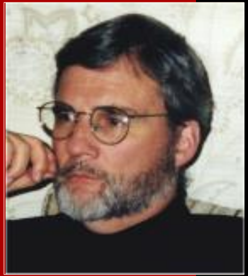


Immanuel Kant

Every thing in nature, in the inanimate as well as in the animate world, happens according to some rules, though we do not always know them ...

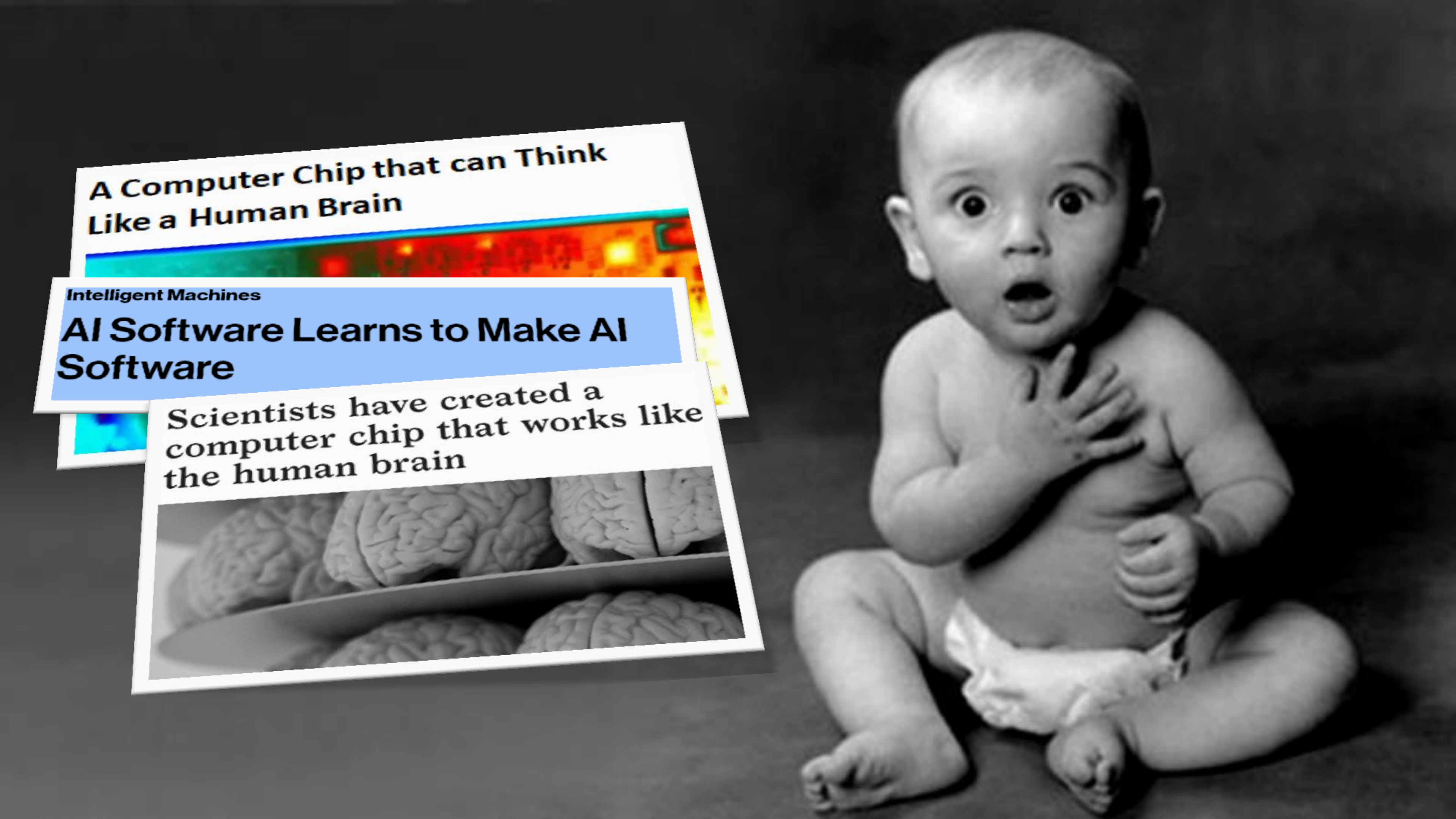
Richard Montague

I reject the contention that an important theoretical difference exists between formal and natural languages ...



Jerry Hobbs

One can assume a theory of the world that is isomorphic to the way we talk about it ... in this case, semantics becomes very nearly trivial


A Computer Chip that can Think
Like a Human Brain
Intelligent Machines
AI Software Learns to Make AI
Software
Scientists have created a
computer chip that works like
the human brain

about the resurgence of
and the currently dominant
paradigm in ‘AI’ …

the availability of huge amounts data, coupled with advances in computer hardware and distributed computing resulted in some advances in certain types of (data-centric) problems (image, speech, fraud detection, text categorization, etc.)

But …

many problems in AI require **understanding** that is beyond discovering patterns in data

Identifying an adult female in an image might be a data-centric problem

Identifying an adult female in an image might be a data-centric problem

However, picking up the photo with the teacher and the photo with the mother requires information that is not in the data

where's the musical band?

where’s the musical band?

Musician?

a person who plays a musical instrument?

So what is at issue here?

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The issue here is that there are no musicians, teachers, lawyers, or even mothers! What exists, ontologically (metaphysically), are humans, and the above concepts are logical concepts that are, sometimes, true of a certain human

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The issue here is that there are no musicians, teachers, lawyers, or even mothers! What exists, ontologically (metaphysically), are humans, and the above concepts are logical concepts that are, sometimes, true of a certain human

Data-driven (quantitative) approaches can only reason with (detect, infer, recognize) objects that are of an ontological type, but not logical concepts, that form the majority of objects of (human) thought

ONTOLOGIACL CONCEPTS

human

LOGIACL CONCEPTS

lawyer ?

dancer ?

teacher ?

mother ?

⋮

Can a ‘lawyer’ or a ‘dancer’ be identified by data-analysis only?

failure to distinguish between logical and ontological concepts is not only a flaw in data-driven approaches

logical/formal semantics also failed to provide adequate models for natural language and for exactly the same reason but data-driven approaches are inadequate for natural language understanding for other reasons besides their inability to distinguish between logical and ontological concepts

No Statistical Significance in the Data

(1) *The trophy did not fit in the brown suitcase because **it** was too*

  a. *big*

  b. *small*

(2) *Dr. Spok told Jon that **he** should soon be done*

  a. *writing his thesis*

  b. *reading his thesis*

No Statistical Significance in the Data

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   a. *big*
   b. *small*

(2) *Dr. Spok told Jon that **he** should soon be done*
   a. *writing his thesis*
   b. *reading his thesis*

In a data-driven approach it is not clear how such decisions can be made since the only difference between the sentence-pairs in (1) and (2) are words that co-occur with equal probabilities

No Statistical Significance in the Data

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   a. *big*
   b. *small*

(2) *Dr. Spok told Jon that **he** should soon be done*
   a. *writing his thesis*
   b. *reading his thesis*

How many labeled examples would be required to learn how to resolve such references?

*trophy-fit-in-suitcase-**small***
*trophy-fit-in-suitcase-**big***
*trophy-not-fit-in-suitcase-**small***
*trophy-not-fit-in-suitcase-**big***
*radio-fit-in-purse-**small***
*radio-fit-in-purse-**big***
*radio-not-fit-in-purse-**small***
*radio-not-fit-in-purse-**big***
etc.

It's not even in the data

(1) *Don't worry, Simon is* [as solid as] *a rock.*
(2) *The* [person sitting at the] *corner table wants another beer.*
(3) *Carlos likes to play* [the game] *bridge.*
(4) *Mary enjoyed* [watching] *the movie.*
(5) *Carl owns a* [different] *house on every street in the village.*

challenges in the computational comprehension of ordinary text is often due to quite a bit of missing text – text which is not explicitly stated but is often assumed as shared knowledge among a community of language users

Innate Ontological Structure?

(1) a. *The small brown suitcase was found unattended.*
b. #*The brown small suitcase was found unattended*

(2) a. *Jon bought a beautiful red car.*
b. #*Jon bought a red beautiful car*

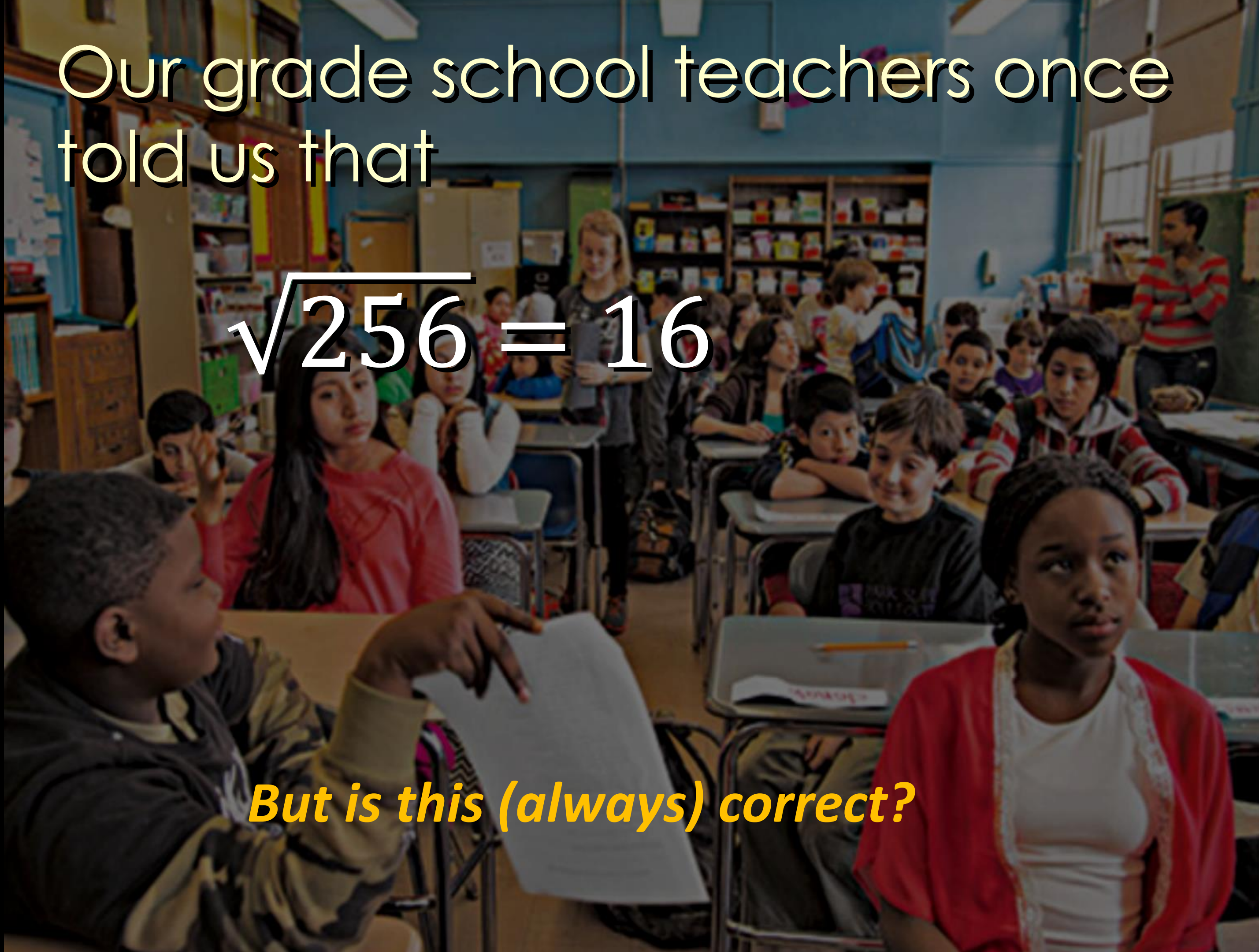
The readings in (1a) and (2a) are clearly preferred over the readings in (1b) and (2b), although there are no structural/syntactic rules that speakers of ordinary language seem to be following. What makes the AORs phenomenon even more intriguing is the fact that these preferences are also consistently made across multiple languages.

Reasoning with data only in NL leads to absurdities

Our grade school teachers once told us that

$$\sqrt{256} = 16$$

But is this (always) correct?



Reasoning with data only in NL leads to absurdities

$$\sqrt{256} = 16\,?$$

Mary taught her little brother that $7 + 9 = 16$

Reasoning with data only in NL leads to absurdities

$\sqrt{256} = 16$?

Mary taught her little brother that $7 + 9 = 16$

If 16 always equals (and is replaceable by) the square root of 256 then we can alter reality and restate the above as

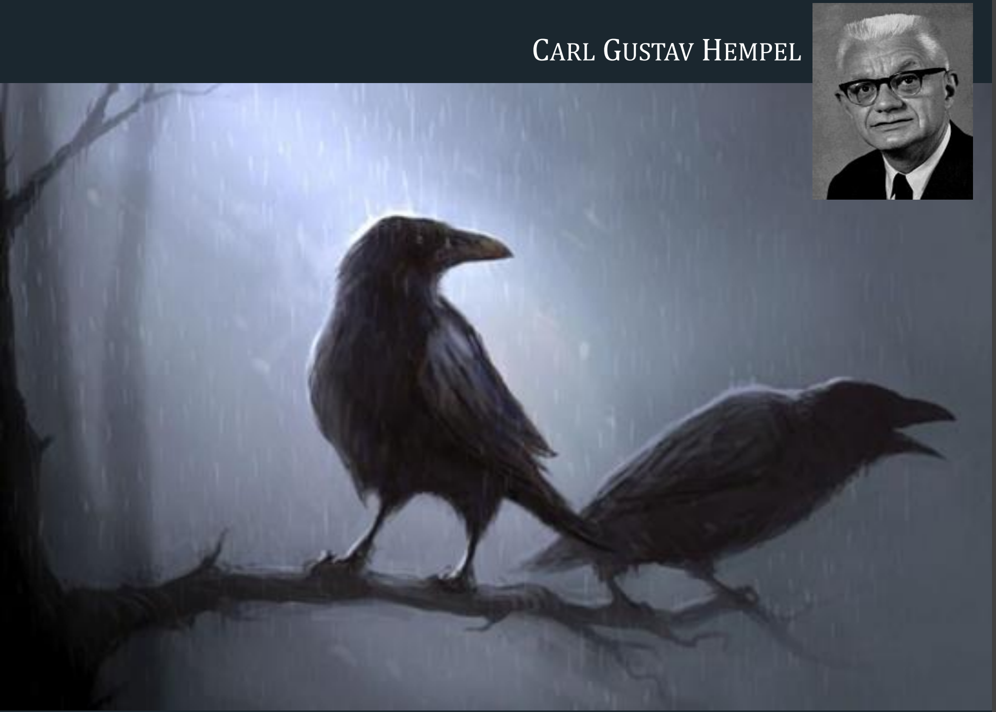
✗ *Mary taught her little brother that $7 + 9 = \sqrt{256}$*

If logical/formal semantics failed, and if data-driven approaches are inadequate, then what?

logical semantics failed us (thus far) because they did not differentiate between logical and ontological concepts

as such, logical semantics were mere symbol manipulation systems adequate for mathematics, but not for natural language what happens when we do not distinguish between ontological and logical concepts?

Carl Gustav Hempel



the paradox of the ravens

what happens when we do not distinguish between ontological and logical concepts?

Consider the following

(H1) *All ravens are black*
(H2) *All non-black things are not ravens*

That is, we have the hypothesis H1 that ‘All ravens are black’. This hypothesis, however, is logically equivalent to the hypothesis H2 that ‘All non-black things are not ravens’.

Consider the following

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That is, we have the hypothesis H1 that 'All ravens are black'. This hypothesis, however, is logically equivalent to the hypothesis H2 that 'All non-black things are not ravens'.

In FOPL, we have:

(1) $(\forall x)(\textsc{raven}(x) \supset \text{BLACK}(x))$
(2) $(\forall x)(\neg\text{BLACK}(x) \supset \neg\text{RAVEN}(x))$

H1

$$(\forall x)(\text{RAVEN}(x) \supset \text{BLACK}(x))$$

Observing black ravens confirms hypothesis H1, namely that ‘All ravens are black’.

H2

$$(\forall x)(\neg\text{BLACK}(x) \supset \neg\text{RAVEN}(x))$$

Observing non-black and non-raven objects confirms hypothesis H2 (that ‘All non-black things are not ravens’).

H1

$$(\forall x)(\text{RAVEN}(x) \supset \text{BLACK}(x))$$

Observing black ravens confirms hypothesis H1, namely that ‘All ravens are black’.

H2

$$(\forall x)(\neg\text{BLACK}(x) \supset \neg\text{RAVEN}(x))$$

Observing non-black and non-raven objects confirms hypothesis H2 (that ‘All non-black things are not ravens’).

and here’s the paradox

H1 is equivalent to H2, and so observing a red apple now confirms the hypothesis that ‘All ravens are black’

and here's the solution

First, let us make our logic strongly-typed:

- in addition to a scope, a variable also has a type.
- the type associated with a variable is the most general type for which the predicate makes sense

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First, let us make our logic strongly-typed:

- in addition to a scope, a variable also has a type.
- the type associated with a variable is the most general type for which the predicate makes sense

(1) $\text{BLACK}(x :: \texttt{physical})$

(2) $\text{IMMINENT}(x :: \texttt{event})$

(3) $\text{SYMPATHETIC}(x :: \texttt{human})$

(4) $\text{HUNGRY}(x :: \texttt{animal})$

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(4) $\text{HUNGRY}(x :: \texttt{animal})$

The predicate IMMINENT is applicable to objects of type **event** (or, it makes sense to say IMMINENT x when x is an **event** or any of its subtypes)

All ravens are black

$\Rightarrow$

1. $(\forall x)(\textsc{raven}(x) \supset \textsc{black}(x))$

the traditional representation in FOPL

All ravens are black

$\Rightarrow$

1. $(\forall x)(\textsc{raven}(x) \supset \textsc{black}(x))$
2. $(\forall x)(\textsc{raven}(x :: \texttt{raven}) \supset \textsc{black}(x :: \texttt{physical}))$

types are associated with variables in the context of the predicates in which they are used

All ravens are black

$\Rightarrow$

1. $(\forall x)(\textsc{raven}(x) \supset \textsc{black}(x))$
2. $(\forall x)(\textsc{raven}(x :: \mathtt{raven}) \supset \textsc{black}(x :: \mathtt{physical}))$
3. $(\forall x)(\textsc{raven}(x :: \mathtt{raven}) \supset \textsc{black}(x :: (\mathtt{physical} \bullet \mathtt{raven})))$

x is associated with more than one type in the same scope, requiring a **type unification**

All ravens are black

$\Rightarrow$

1. $(\forall x)(\textsc{raven}(x) \supset \textsc{black}(x))$
2. $(\forall x)(\textsc{raven}(x :: \mathtt{raven}) \supset \textsc{black}(x :: \mathtt{physical}))$
3. $(\forall x)(\textsc{raven}(x :: \mathtt{raven}) \supset \textsc{black}(x :: (\mathtt{physical} \bullet \mathtt{raven})))$
4. $(\forall x)(\textsc{raven}(x :: \mathtt{raven}) \supset \textsc{black}(x :: \mathtt{raven}))$

since $\mathtt{raven} \sqsubseteq \mathtt{physical}$,
the type unification here is
simple, resulting in $\mathtt{raven}$

All ravens are black

$\Rightarrow$

1. $(\forall x)(\textsc{raven}(x) \supset \textsc{black}(x))$
2. $(\forall x)(\textsc{raven}(x :: \mathtt{raven}) \supset \textsc{black}(x :: \mathtt{physical}))$
3. $(\forall x)(\textsc{raven}(x :: \mathtt{raven}) \supset \textsc{black}(x :: (\mathtt{physical} \bullet \mathtt{raven})))$
4. $(\forall x)(\textsc{raven}(x :: \mathtt{raven}) \supset \textsc{black}(x :: \mathtt{raven}))$
5. $(\forall x :: \mathtt{raven})(\mathtt{true} \supset \textsc{black}(x))$

(i) since x is now associated with one type throughout its scope, the type can be moved to where x was introduced; and (ii) the predicate $\textsc{raven}(x :: \mathtt{raven})$ is replaced by $\mathtt{true}$

All ravens are black

$\Rightarrow$

1. $(\forall x)(\text{RAVEN}(x) \supset \text{BLACK}(x))$
2. $(\forall x)(\text{RAVEN}(x :: \mathbf{raven}) \supset \text{BLACK}(x :: \mathbf{physical}))$
3. $(\forall x)(\text{RAVEN}(x :: \mathbf{raven}) \supset \text{BLACK}(x :: (\mathbf{physical} \bullet \mathbf{raven})))$
4. $(\forall x)(\text{RAVEN}(x :: \mathbf{raven}) \supset \text{BLACK}(x :: \mathbf{raven}))$
5. $(\forall x :: \mathbf{raven})(\mathbf{true} \supset \text{BLACK}(x))$
6. $(\forall x :: \mathbf{raven})(\text{BLACK}(x))$

$$\boxed{\textit{All ravens are black} \Rightarrow (\forall x :: \mathbf{raven})(\text{BLACK}(x))}$$

ontological concept

logical concept

$All\ non\text{-}black\ things\ are\ not\ ravens$

$\Rightarrow$

$$1. \quad (\forall x)(\neg\textsc{black}(x) \supset \neg\textsc{raven}(x))$$

the traditional representation in FOPL

All non-black things are not ravens

$\Rightarrow$

1. $(\forall x)(\neg\mathrm{BLACK}(x) \supset \neg\mathrm{RAVEN}(x))$
2. $(\forall x)(\neg\mathrm{BLACK}(x :: \mathtt{physical}) \supset \neg\mathrm{RAVEN}(x :: \mathtt{raven}))$

types are associated with
variables in the context of
the predicates in which
they are used

All non-black things are not ravens

$\Rightarrow$

1. $(\forall x)(\neg\text{BLACK}(x) \supset \neg\text{RAVEN}(x))$
2. $(\forall x)(\neg\text{BLACK}(x :: \mathtt{physical}) \supset \neg\text{RAVEN}(x :: \mathtt{raven}))$
3. $(\forall x)(\neg\text{BLACK}(x :: (\mathtt{physical} \bullet \mathtt{raven})) \supset \neg\text{RAVEN}(x :: \mathtt{raven}))$

x is associated with more than one type in the same scope, requiring a **type unification**

All non-black things are not ravens

$\Rightarrow$

1. $(\forall x)(\neg\mathrm{BLACK}(x) \supset \neg\mathrm{RAVEN}(x))$
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All non-black things are not ravens

$\Rightarrow$

1. $(\forall x)(\neg\text{BLACK}(x) \supset \neg\text{RAVEN}(x))$
2. $(\forall x)(\neg\text{BLACK}(x :: \mathtt{physical}) \supset \neg\text{RAVEN}(x :: \mathtt{raven}))$
3. $(\forall x)(\neg\text{BLACK}(x :: (\mathtt{physical} \bullet \mathtt{raven})) \supset \neg\text{RAVEN}(x :: \mathtt{raven}))$
4. $(\forall x)(\neg\text{BLACK}(x :: \mathtt{raven}) \supset \neg\text{RAVEN}(x :: \mathtt{raven}))$
5. $(\forall x :: \mathtt{raven})(\neg\text{BLACK}(x) \supset \neg\mathtt{true})$

(i) since x is now associated with one type throughout its scope, the type can be moved to where x was introduced; and (ii) the predicate $\text{RAVEN}(x :: \mathtt{raven})$ is replaced by $\mathtt{true}$

All non-black things are not ravens

$\Rightarrow$

1. $(\forall x)(\neg\text{BLACK}(x) \supset \neg\text{RAVEN}(x))$
2. $(\forall x)(\neg\text{BLACK}(x :: \mathtt{physical}) \supset \neg\text{RAVEN}(x :: \mathtt{raven}))$
3. $(\forall x)(\neg\text{BLACK}(x :: (\mathtt{physical} \bullet \mathtt{raven})) \supset \neg\text{RAVEN}(x :: \mathtt{raven}))$
4. $(\forall x)(\neg\text{BLACK}(x :: \mathtt{raven}) \supset \neg\text{RAVEN}(x :: \mathtt{raven}))$
5. $(\forall x :: \mathtt{raven})(\neg\text{BLACK}(x) \supset \neg\mathbf{true})$
6. $(\forall x :: \mathtt{raven})(\text{BLACK}(x))$

simplifying we get (6) – we used the facts:

$(P \supset Q) = (\neg P \vee Q)$

$\neg\mathbf{true} = \mathbf{false}$

$(P \vee \mathbf{false}) = P$

All non-black things are not ravens

$\Rightarrow$

1. $(\forall x)(\neg \mathrm{BLACK}(x) \supset \neg \mathrm{RAVEN}(x))$
2. $(\forall x)(\neg \mathrm{BLACK}(x :: \mathtt{physical}) \supset \neg \mathrm{RAVEN}(x :: \mathtt{raven}))$
3. $(\forall x)(\neg \mathrm{BLACK}(x :: (\mathtt{physical} \bullet \mathtt{raven})) \supset \neg \mathrm{RAVEN}(x :: \mathtt{raven}))$
4. $(\forall x)(\neg \mathrm{BLACK}(x :: \mathtt{raven}) \supset \neg \mathrm{RAVEN}(x :: \mathtt{raven}))$
5. $(\forall x :: \mathtt{raven})(\neg \mathrm{BLACK}(x) \supset \neg \mathbf{true})$
6. $(\forall x :: \mathtt{raven})(\mathrm{BLACK}(x))$

$$\boxed{\textit{All non-black things are not ravens} \Rightarrow (\forall x :: \mathtt{raven})(\mathrm{BLACK}(x))}$$

ontological concept

logical concept

what paradox of the ravens?

$$\textit{All ravens are black} \Rightarrow (\forall x :: \texttt{raven})(\textsc{black}(x))$$

$$\textit{All non-black things are not ravens} \Rightarrow (\forall x :: \texttt{raven})(\textsc{black}(x))$$

It seems that making a clear distinction between logical and ontological concepts shows that the problem was in the representation and there is no so-called ‘paradox of the ravens’

logical
vs.
ontological
concepts

let's put the typed ontologic to use

$$[\![\textit{Sheba is a thief}]\!]$$
$$\Rightarrow (\exists^1 Sheba :: \texttt{thing})(\textsc{thief}(Sheba :: \texttt{human}))$$

let's put the typed ontologic to use

$$[\![\mathit{Sheba\ is\ a\ thief}]\!]$$
$$\Rightarrow (\exists^1 \mathit{Sheba} :: \mathtt{thing})(\mathrm{THIEF}(\mathit{Sheba} :: \mathtt{human}))$$

Type unification is required

$$(\mathit{Sheba} :: (\mathtt{thing} \bullet \mathtt{human})) \rightarrow (\mathit{Sheba} :: \mathtt{human})$$

let's put the typed ontologic to use

$$[\![\mathit{Sheba\ is\ a\ thief}]\!]$$
$$\Rightarrow (\exists^1 Sheba :: \texttt{thing})(\text{THIEF}(Sheba :: \texttt{human}))$$

Type unification is required

$$(Sheba :: (\texttt{thing} \bullet \texttt{human})) \rightarrow (Sheba :: \texttt{human})$$

Final representation (we now know Sheba must be a human)

$$[\![\mathit{Sheba\ is\ a\ thief}]\!] \Rightarrow (\exists^1 Sheba :: \texttt{human})(\text{THIEF}(Sheba))$$

let's put the typed ontologic to use

$$[\![\textit{Sara owns a black cat}]\!]$$
$$\Rightarrow (\exists^1 Sara :: \texttt{thing})(\exists c :: \texttt{cat})(\text{BLACK}(c :: \texttt{physical}) \wedge \text{OWN}(Sara :: \texttt{human},\ c :: \texttt{entity}))$$

Two type unifications are required

$$(Sara :: (\texttt{thing} \bullet \texttt{human})) \rightarrow (Sara :: \texttt{human})$$

$$(c :: ((\texttt{physical} \bullet \texttt{entity}) \bullet \texttt{cat}))$$
$$\rightarrow (c :: (\texttt{physical} \bullet \texttt{cat}))$$
$$\rightarrow (c :: \texttt{cat})$$

Final representation

$$[\![\textit{Sara owns a black cat}]\!]$$
$$\Rightarrow (\exists^1 Sara :: \texttt{human})(\exists c :: \texttt{cat})(\text{BLACK}(c) \wedge \text{OWN}(Sara,\ c))$$

let's put the typed ontologic to use

$$[\![Sara\ is\ a\ beautiful\ dancer]\!]$$

How is it that 'beautiful' could be meant to describe Sara or her dancing?

let's put the typed ontologic to use

$$\llbracket \textit{Sara is a beautiful dancer} \rrbracket$$

$$\Rightarrow (\exists^1 Sara :: \texttt{thing})(\exists a :: \texttt{activity})$$
$$(\text{DANCING}(a) \wedge \text{AGENT}(a :: \texttt{activity}, Sara :: \texttt{human})$$
$$\wedge (\text{BEAUTIFUL}(a :: \texttt{entity})$$
$$\vee \text{BEAUTIFUL}(Sara :: \texttt{entity})))$$

Two type unifications are required

$$(Sara :: ((\texttt{thing} \bullet \texttt{human}) \bullet \texttt{entity}))$$
$$\rightarrow (Sara :: (\texttt{human} \bullet \texttt{entity}))$$
$$\rightarrow (Sara :: \texttt{human})$$

$$(a :: (\texttt{activity} \bullet \texttt{entity}))$$
$$\rightarrow (a :: \texttt{activity})$$

let‘s put the typed ontologic to use

Final interpretation

$$
\begin{aligned}
&[\![\textit{Sara is a beautiful dancer}]\!] \\
&\Rightarrow (\exists^1 Sara :: \mathtt{human})(\exists a :: \mathtt{activity}) \\
&\qquad (\textsc{dancing}(a) \wedge \textsc{agent}(a, Sara) \\
&\qquad\qquad \wedge (\textsc{beautiful}(a) \vee \textsc{beautiful}(Sara)))
\end{aligned}
$$

Since ‘beautiful’ can be said of activities as well as humans, the sentence remains ambiguous. But how about ‘Sara is a tall dancer’ ?

let's put the typed ontologic to use

$$[\![\textit{Sara is a tall dancer}]\!]$$

$$\begin{aligned}\Rightarrow & (\exists^1 Sara :: \texttt{thing})(\exists a :: \texttt{activity}) \\ & \quad (\textsc{dancing}(a) \wedge \textsc{agent}(a :: \texttt{activity}, Sara :: \texttt{human}) \\ & \qquad \wedge (\textsc{tall}(a :: \texttt{physical}) \vee \textsc{tall}(Sara :: \texttt{physical})))\end{aligned}$$

Two type unifications are required

$$\begin{aligned}& (Sara :: ((\texttt{thing} \bullet \texttt{human}) \bullet \texttt{physical})) \\ \rightarrow & (Sara :: (\texttt{human} \bullet \texttt{physical})) \\ \rightarrow & (Sara :: \texttt{human})\end{aligned}$$

$$\begin{aligned}& \textsc{tall}(a :: (\texttt{phsycial} \bullet \texttt{activity})) \\ \rightarrow & \textsc{tall}(a :: \bot) \\ \rightarrow & \bot\end{aligned}$$

let‘s put the typed ontologic to use

Since $((\text{A} \vee \bot) = \text{A})$ we finally get

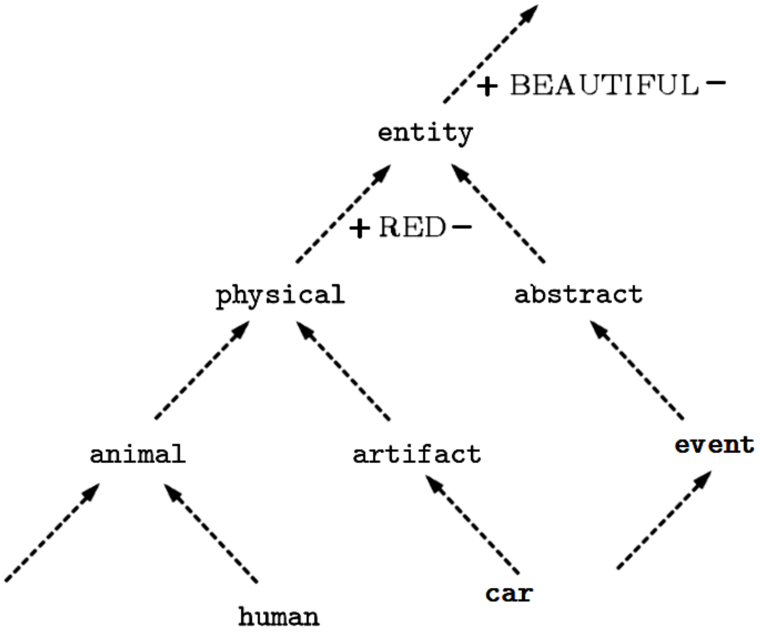
$$
\begin{aligned}
&[\![\mathit{Sara\ is\ a\ tall\ dancer}]\!] \\
&\Rightarrow (\exists^1 \mathit{Sara} :: \mathtt{human})(\exists a :: \mathtt{activity}) \\
&\quad\ (\textsc{dancing}(a) \wedge \textsc{agent}(a, \mathit{Sara}) \wedge \textsc{tall}(\mathit{Sara}))
\end{aligned}
$$

Unlike the case of ‘Sara is a beautiful dancer’, in this case type unification rejected the possibility of a ‘tall dancing’

Adjective-ordering restrictions

John owns a beautiful red car
John owns a red beautiful car

a. $\mathrm{BEAUTIFUL}(\mathrm{RED}(x :: \texttt{physical}) :: \texttt{entity})$
b. $\mathrm{RED}(\mathrm{BEAUTIFUL}(x :: \texttt{entity}) :: \texttt{physical})$



Adjective-ordering restrictions

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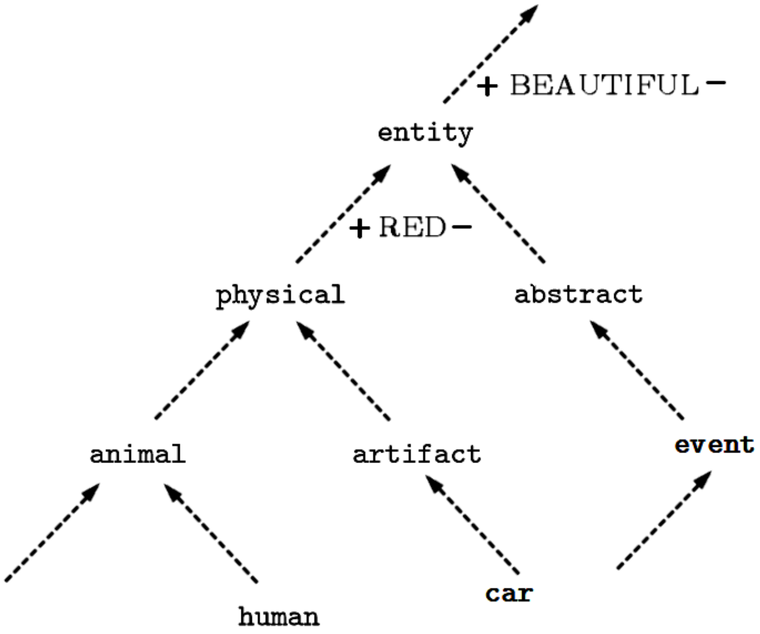
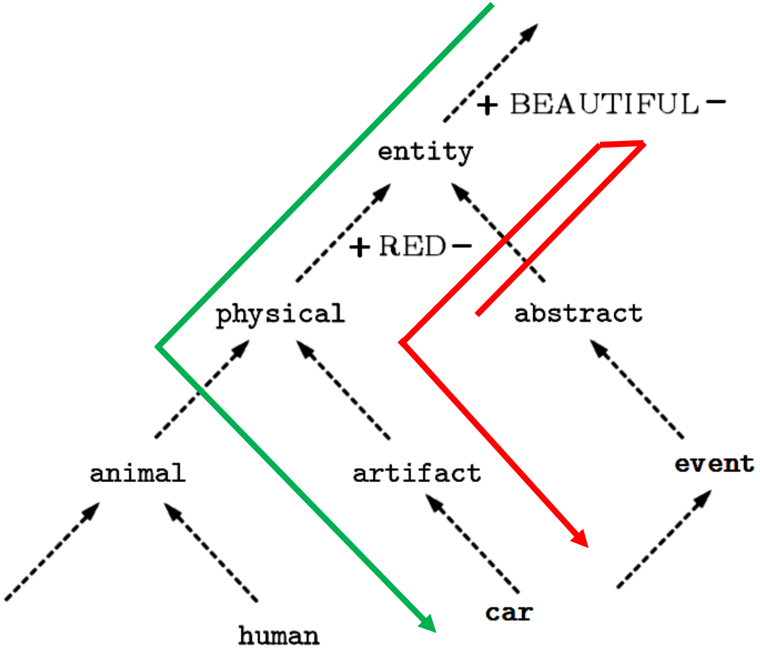


Downcasting is undecidable so (a) is acceptable but (b) is not

Adjective-ordering restrictions

John owns a beautiful red car
John owns a red beautiful car

a. $\mathrm{BEAUTIFUL}(\mathrm{RED}(x :: \mathtt{physical}) :: \mathtt{entity})$ ✓
b. $\mathrm{RED}(\mathrm{BEAUTIFUL}(x :: \mathtt{entity}) :: \mathtt{physical})$ ✗



The second order requires us to go up, and then down again!

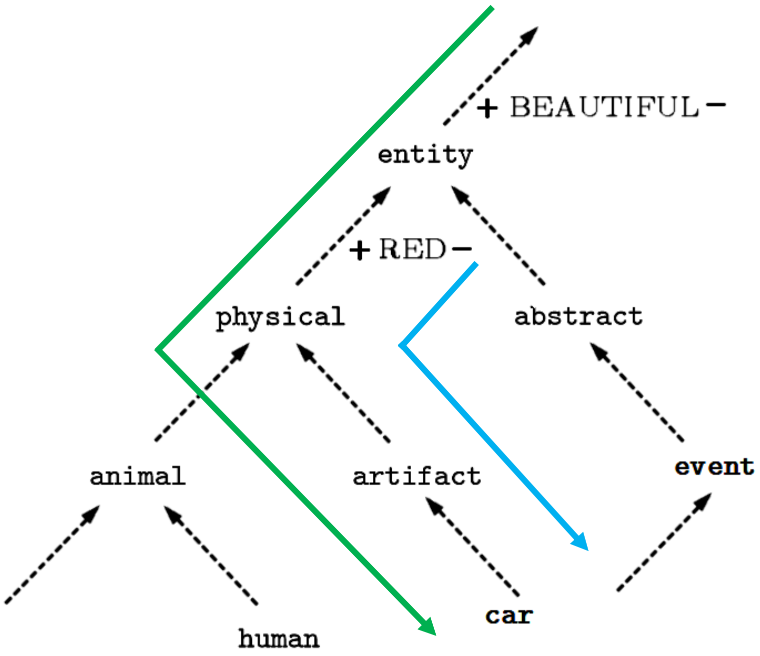
Adjective-ordering restrictions

John owns a red and beautiful car

$\Rightarrow$

(*John owns a red car*)

and (*John owns a beautiful car*)



We can, though we rarely do, say two separate statements!

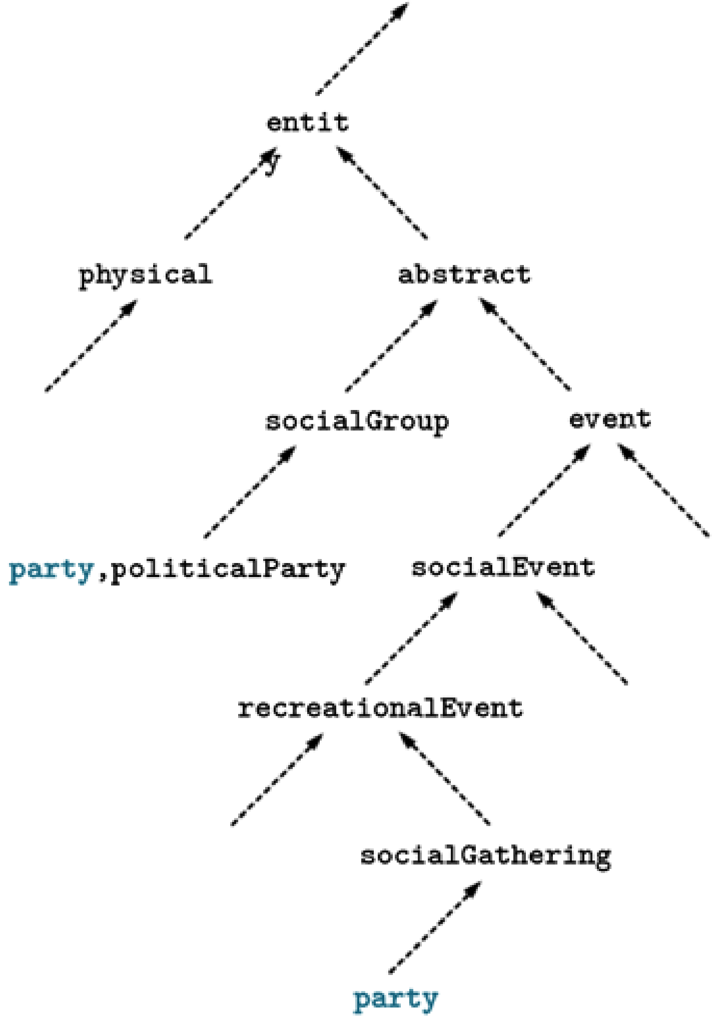
Lexical disambiguation

$[\![\textit{The party was cancelled}]\!]$

$$\Rightarrow (\exists^1 p :: \{\texttt{politicalParty},\texttt{socialGroup},\texttt{socialEvent},\ldots\})$$
$$(\exists a :: \texttt{activity})(\textsc{cancellation}(a)$$
$$\wedge\ \textsc{object}(a, p :: \texttt{event}))$$

Type unifications relevant to 'party'

$$(p :: \{(\texttt{politicalParty} \bullet \texttt{event}),(\texttt{socialGroup} \bullet \texttt{event}),$$
$$(\texttt{socialEvent} \bullet \texttt{event}),\ldots\}$$
$$\rightarrow (p :: \{\bot,\bot,\texttt{socialEvent}\})$$
$$\rightarrow (p :: \texttt{socialEvent})$$



Type unification will remove the 'political group' meaning of 'party'

Discovering 'missing text' - metonymy

$[\![\textit{the ham sadnwich wants a beer}]\!]$
$\Rightarrow (\exists^1 x :: \mathsf{HamSandwich})(\exists y :: \mathsf{Beer})(\mathrm{WANT}(x :: \mathsf{Human}, y :: \mathsf{Thing}))$

Discovering 'missing text' - metonymy

$[\![$*the ham sadnwich wants a beer*$]\!]$

$\Rightarrow (\exists^1 x :: \mathsf{HamSandwich})(\exists y :: \mathsf{Beer})(\mathrm{WANT}(x :: \mathsf{Human}, y :: \mathsf{Thing}))$

x, introduced as a **HamSandwich** is also considered to be an object of type **Human** in the context of a **WANT** relation

Discovering 'missing text' - metonymy

$[\![\textit{the ham sadnwich wants a beer}]\!]$
$\Rightarrow (\exists^1 x :: \text{HamSandwich})(\exists y :: \text{Beer})(\text{WANT}(x :: \text{Human}, y :: \text{Thing}))$

$$(y :: (\text{Beer} \bullet \text{Thing})) \longrightarrow \text{Beer}$$

$$(x :: (\text{Human} \bullet \text{HamSandwich})) \longrightarrow \mathbf{R} = msr(\text{Human}, \text{Sandwich})$$

The unification of two types
that are not on the same path
is some salient relationship
between the two types

Data-driven approaches to NLU are inadequate for several reasons, most important of which is the fact that understanding ordinary spoken language involves **discovering the missing text** that is not even explicitly stated in the data

Logical/formal semantics treated logical and ontological concepts the same, as a consequence, they were for the most part symbol manipulation systems devoid of any ontological content

Typed logical semantics (embedded with ontological types) seem to suggest very simple solutions to many challenging problems in language understanding

thank you