Anaphora and Ellipsis in Lambek Calculus with a Relevant Modality: Syntax and Semantics

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Today's Goal

How to turn the piece of language

"John sleeps. He snores."

into a vector?

My bigger goal

Making distributional-compositional models of discourse

Anaphora and Ellipsis

Coreference

When two lexically distinct items have the same meaning.

- Ontological coreference:
  - *'Stefan Löfven'* = *'Prime minister of Sweden'*
  - *'Fock Space'* = *'Tensor Algebra'*
- Contextual coreference: *'He'* = *'John'* in *"John sleeps. He snores."*

Contextual coreference refers mainly to **anaphora** and **ellipsis**

Anaphora and Ellipsis

Anaphora (and cataphora) are words which receive their meaning from previously mentioned words

eg. "***John*** *sleeps.* ***He*** *snores.*"

Ellipsis is a type of coreference where the meaning of a whole phrase is used by a later mentioned word

eg. "*John* ***plays guitar****. Mary* ***does too****.*"

See [Coecke et al, 2018] for nice model of discourse and probabilistic anaphora resolution!

Anaphora and Ellipsis

Combining anaphora and ellipsis can lead to multiple possible meanings, depending on which coreference you resolve first.

"***John likes his*** *code*. ***Bill does too***."

Resolving anaphora ('*his*') first yields the **strict** meaning

"*John* ***likes John's*** *code. Bill* ***likes John's*** *code.*"

Resolving the ellipsis ('*does too*') first yields the **sloppy** reading:

"*John* ***likes John's*** *code. Bill* ***likes Bill's*** *code.*"

Anaphora and Ellipsis
via
Type Logical Grammars

Anaphora & Ellipsis via TLGs

[Jäger 1998, 2006] proposes method to analyse anaphora and ellipsis in type logical grammars (TLGs)

Given a discourse where a is being referred to by b:

(eg. $a =$ *John* and $b =$ *He* in "***John*** *sleeps.* ***He*** *snores.*")

1. Copy the meaning of a
2. Move one of the copies of a to b
3. Identify b with a

Anaphora, Ellipsis and TLGs

1. Copy a
2. Move a copy to b
3. Identify

John *sleeps.* ***He*** *snores.*

Anaphora, Ellipsis and TLGs

1. Copy a
2. Move a copy to b
3. Identify

John

John *sleeps.* ***He*** *snores.*

Anaphora, Ellipsis and TLGs

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John

John *sleeps.* ***He*** *snores.*

Anaphora, Ellipsis and TLGs

1. Copy a
2. Move a copy to b
3. Identify

John sleeps. ***John*** *snores.*

$!\mathbf{L}^*$ - Definition

First defined in [Kanovich et al, 2016] in a sequent calculus presentation

Fix a fixed set of atoms At, and define **formulas** of $!\mathbf{L}^*$ as:

$$\phi ::= \varnothing \mid \phi \in At \mid \phi, \phi \mid \phi / \phi \mid \phi \backslash \phi \mid !\phi$$

Sequents of $!\mathbf{L}^*$ written $\Gamma \longrightarrow A$ meaning "Γ reduces to A"

Sequents are built using **rules** of $!\mathbf{L}^*$ (next slide…)

Rules of $!\mathbf{L}^*$

$$\frac{}{A \to A}$$

$$\frac{\Gamma \to A \quad \Delta_1, B, \Delta_2 \to C}{\Delta_1, B/A, \Gamma, \Delta_2 \to C}\ (/L) \qquad \frac{\Gamma, A \to B}{\Gamma \to B/A}\ (/R)$$

$$\frac{\Gamma \to A \quad \Delta_1, B, \Delta_2 \to C}{\Delta_1, \Gamma, A\backslash B, \Delta_2 \to C}\ (\backslash L) \qquad \frac{A, \Gamma \to B}{\Gamma \to A\backslash B}\ (\backslash R)$$

Rules of $!\mathbf{L}^*$

$$\frac{\Delta_1, !A, \Gamma, \Delta_2 \to C}{\Delta_1, \Gamma, !A, \Delta_2 \to C}\,(perm_1) \qquad \frac{\Delta_1, \Gamma, !A, \Delta_2 \to C}{\Delta_1, !A, \Gamma, \Delta_2 \to C}\,(perm_2)$$

$$\frac{\Delta_1, !A, !A, \Delta_2 \to C}{\Delta_1, !A, \Delta_2 \to C}\,(contr)$$

$$\frac{\Gamma_1, A, \Gamma_2 \to C}{\Gamma_1, !A, \Gamma_2 \to C}\,(!L) \qquad \frac{!A_1, \ldots, !A_n \to B}{!A_1, \ldots, !A_n \to !B}\,(!R)$$

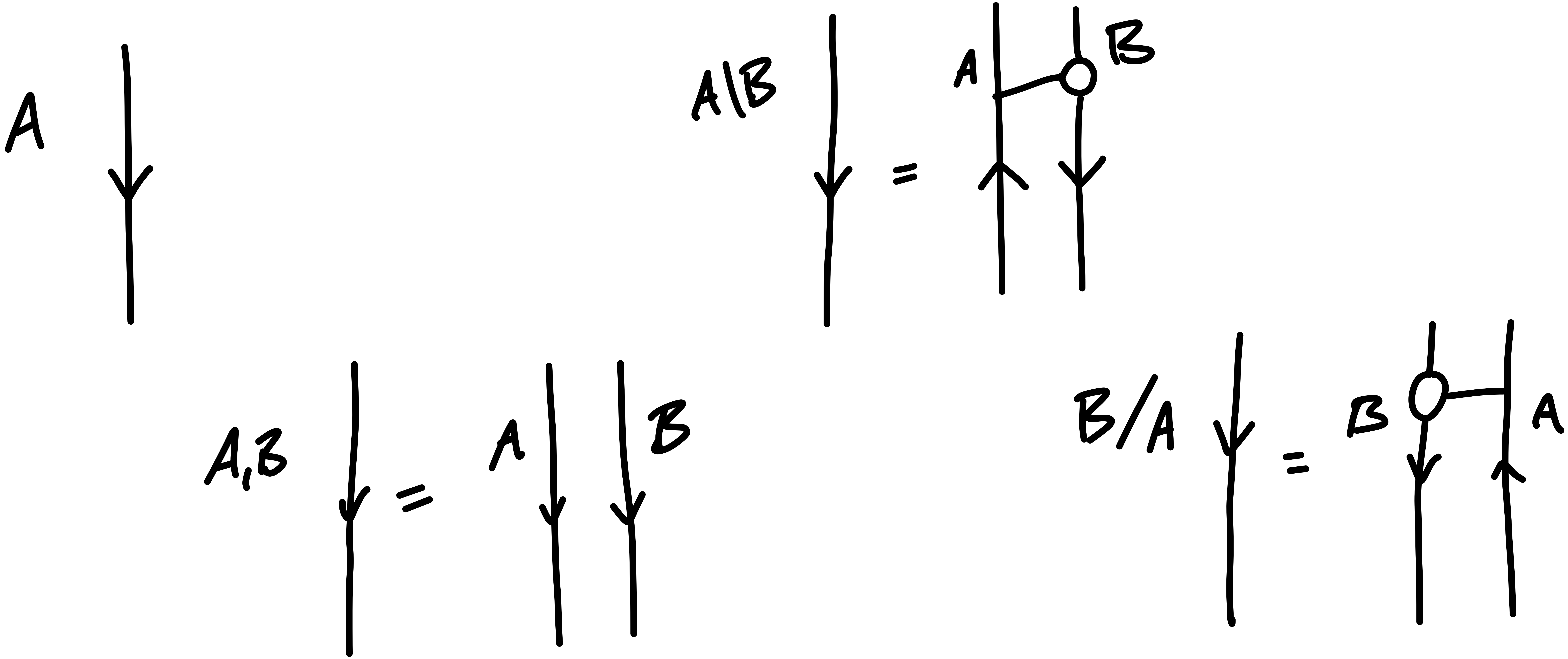
Categorical Presentation of $\mathbf{!L*}$

Define a category $\mathscr{C}(\mathbf{!L*})$ where $\mathbf{!L*}$-formulas are objects, and derivable sequents $\Gamma \longrightarrow A$ are morphisms

$\mathscr{C}(\mathbf{!L*})$ is a **monoidal biclosed category** with

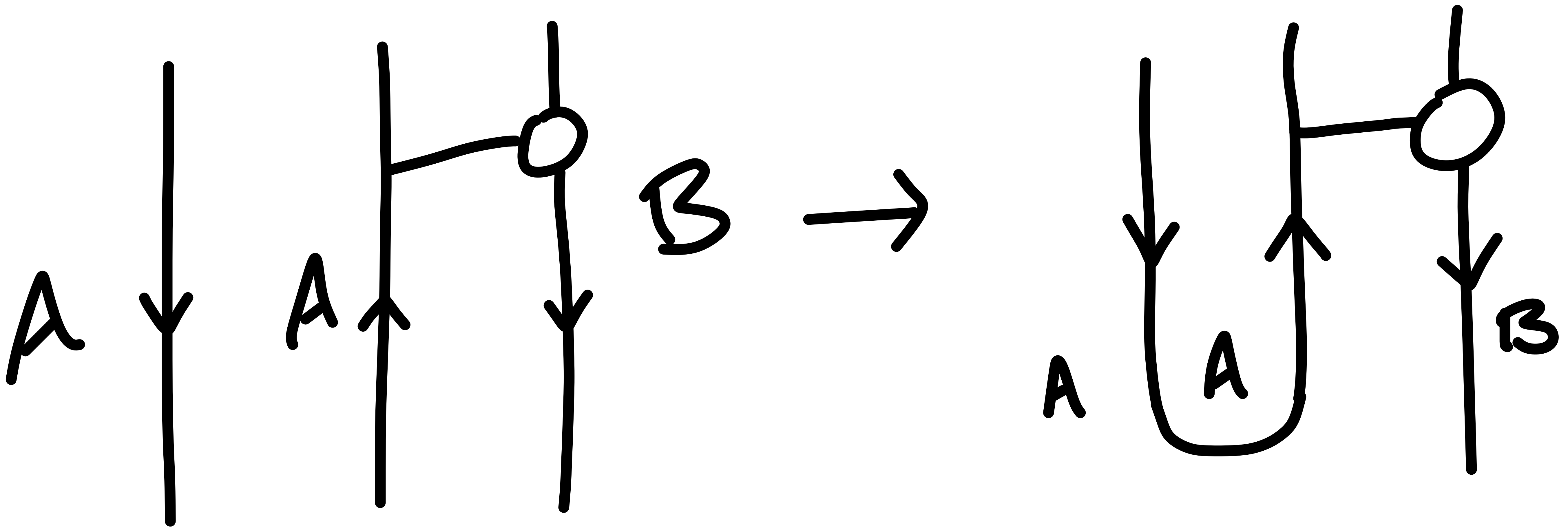
- a monoidal comonad, $!$
- copying transformation $\Delta : \ ! \to \ ! \otimes \ !$
- Permutation isomorphism $\sigma : \ ! \otimes 1 \cong 1 \otimes \ !$

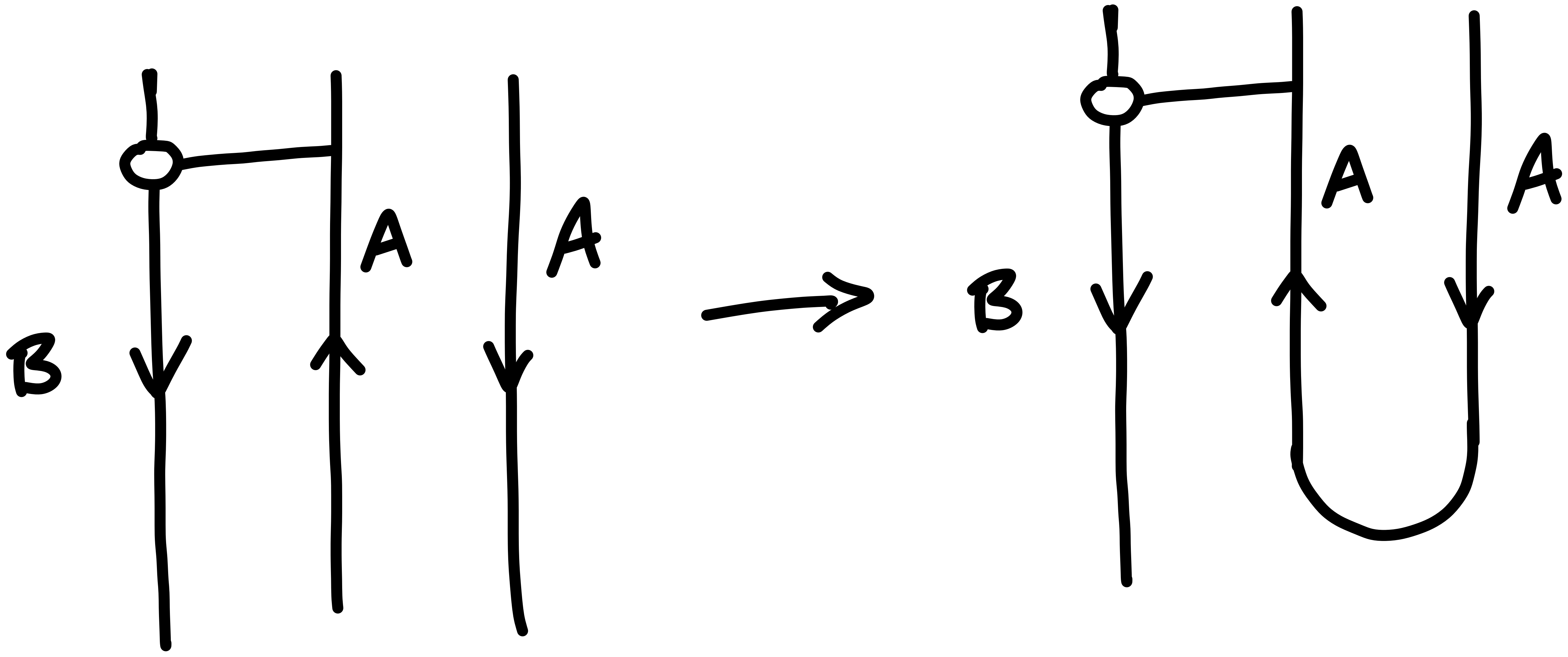
$!\mathbf{L}^*$ Categorically



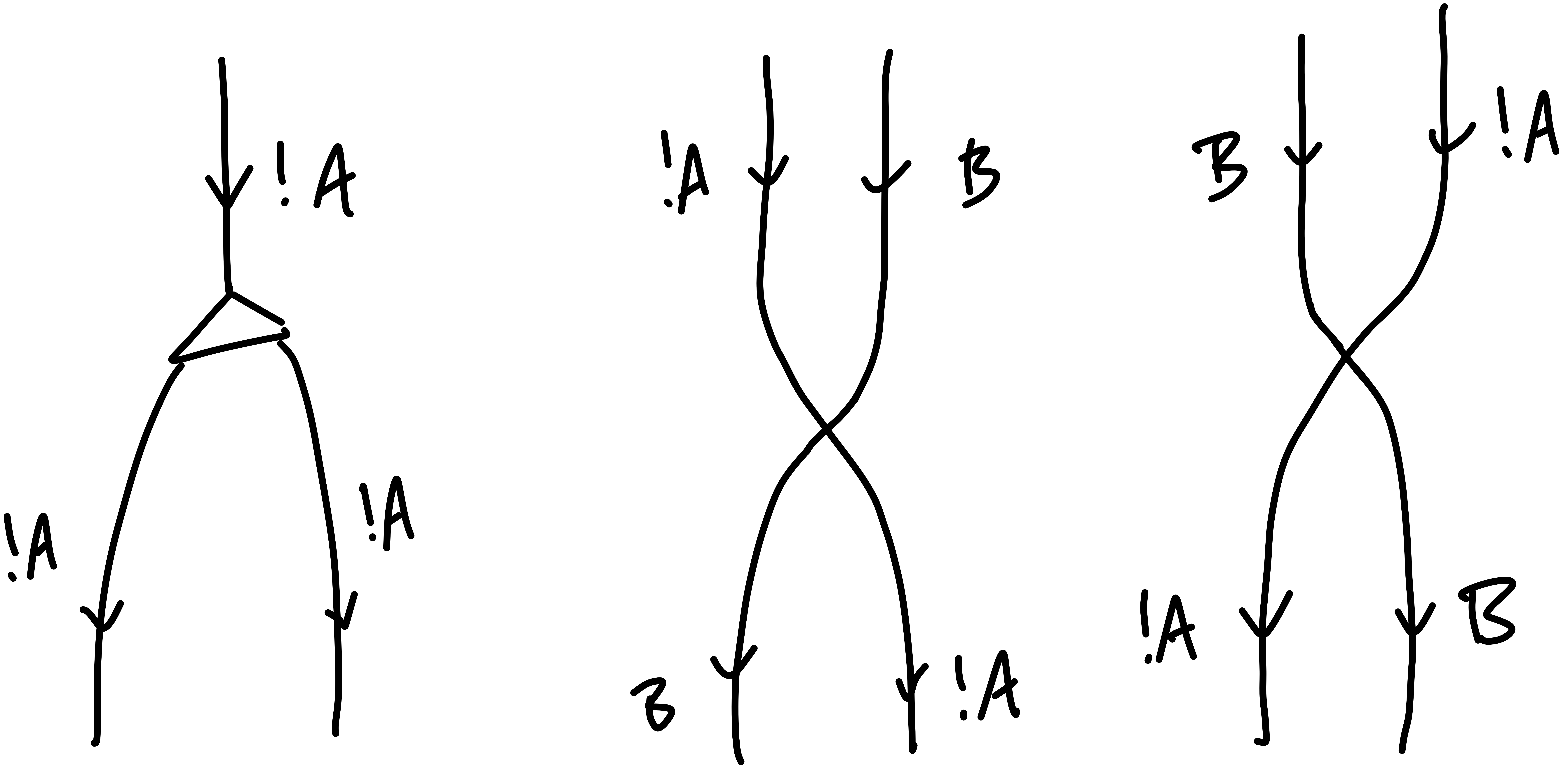
[Baez & Stay , 2009]

!L* Categorically

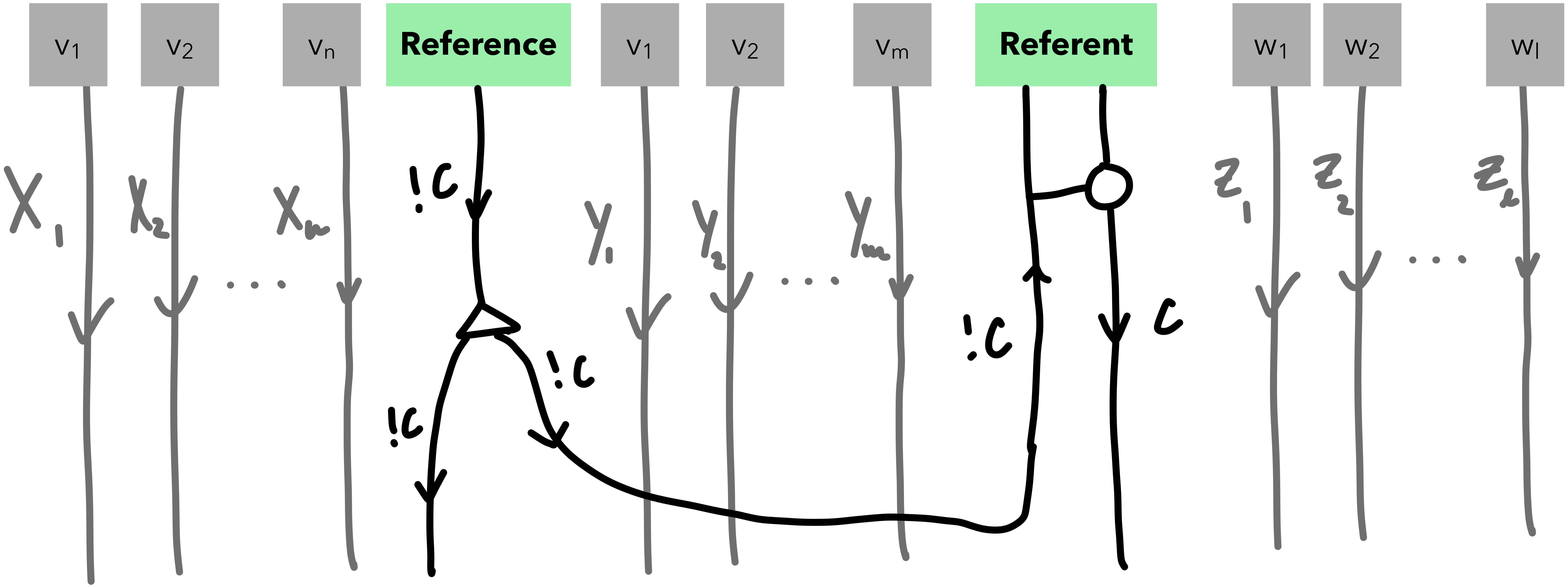




!L* Categorically



Anaphora/Ellipsis Resolution in $\mathscr{C}(!\mathbf{L}^*)$



Vector Space Semantics of

$!\mathbf{L}^*$

Vector Space Semantics of $!\mathbf{L}*$

Recall vector space semantics (VSS) from ACT2020 [McP. et al, 2020], as strong monoidal biclosed functors

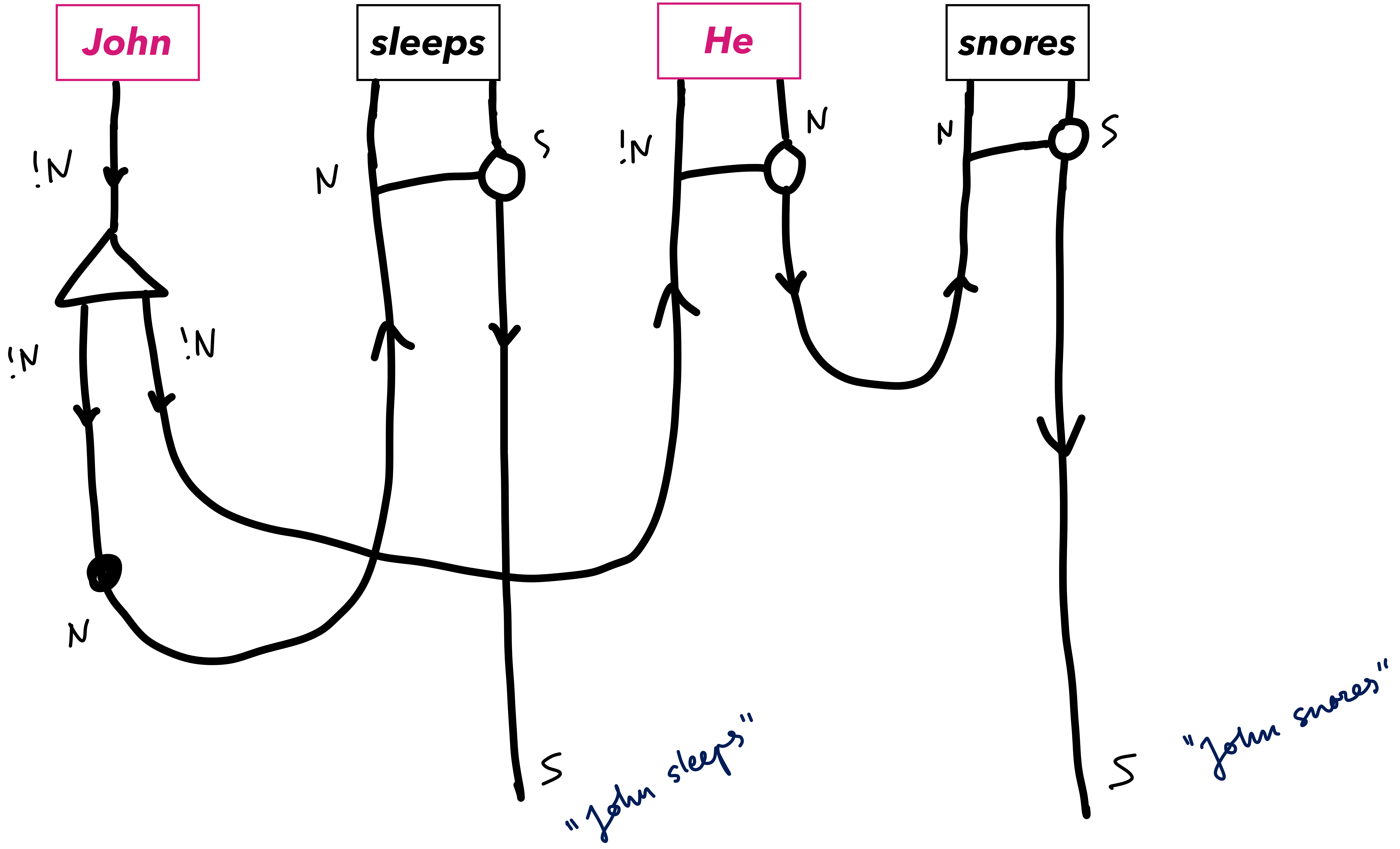
$$F : \mathscr{C}(!\mathbf{L}*) \to \mathbf{fdVect}$$

Thus, every diagram in $\mathscr{C}(!\mathbf{L}*)$ allows us to produce vector representations of anaphora and ellipsis.

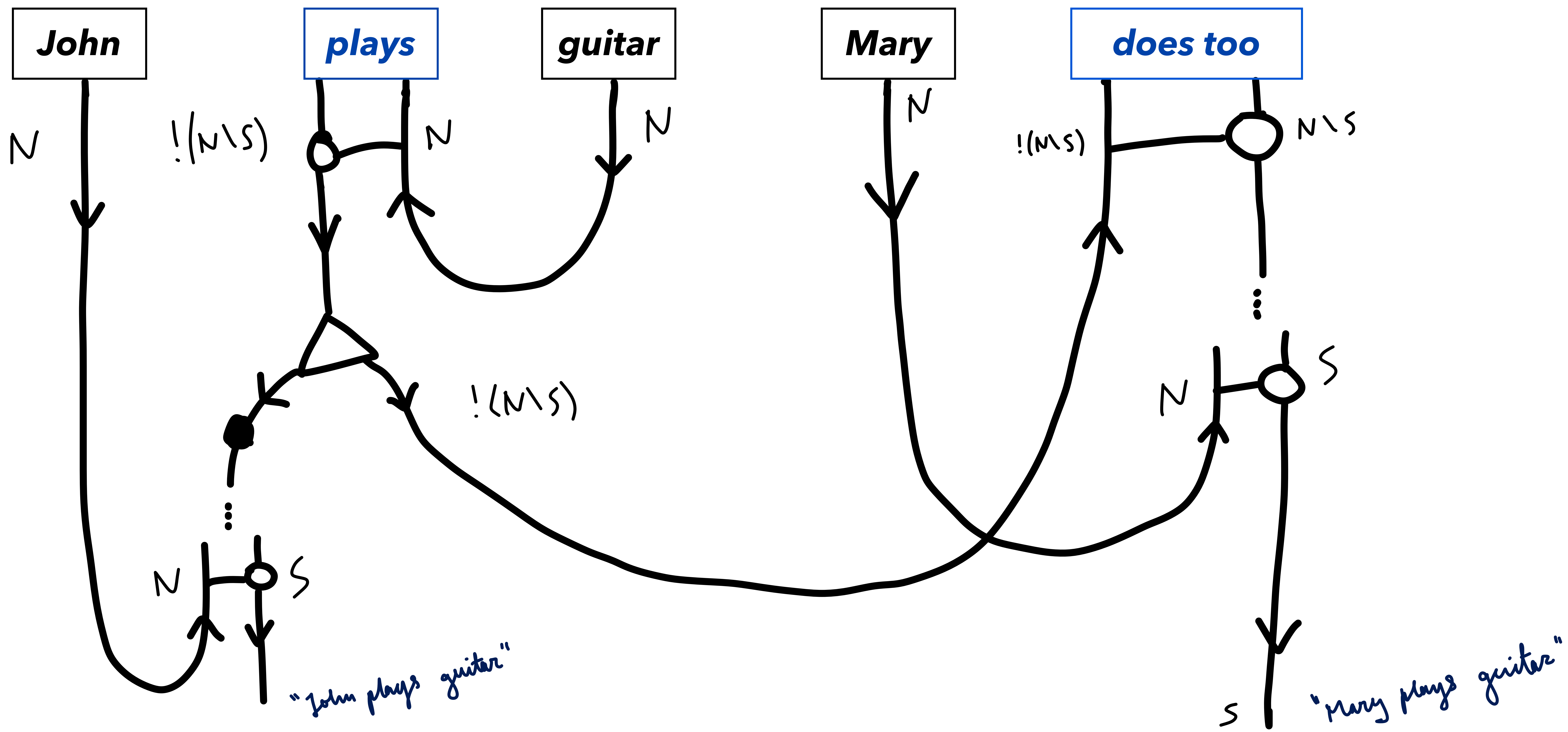
Mapping ! to fermionic Fock space or identity comonad.

Examples

Example: Anaphora



Example: Ellipsis

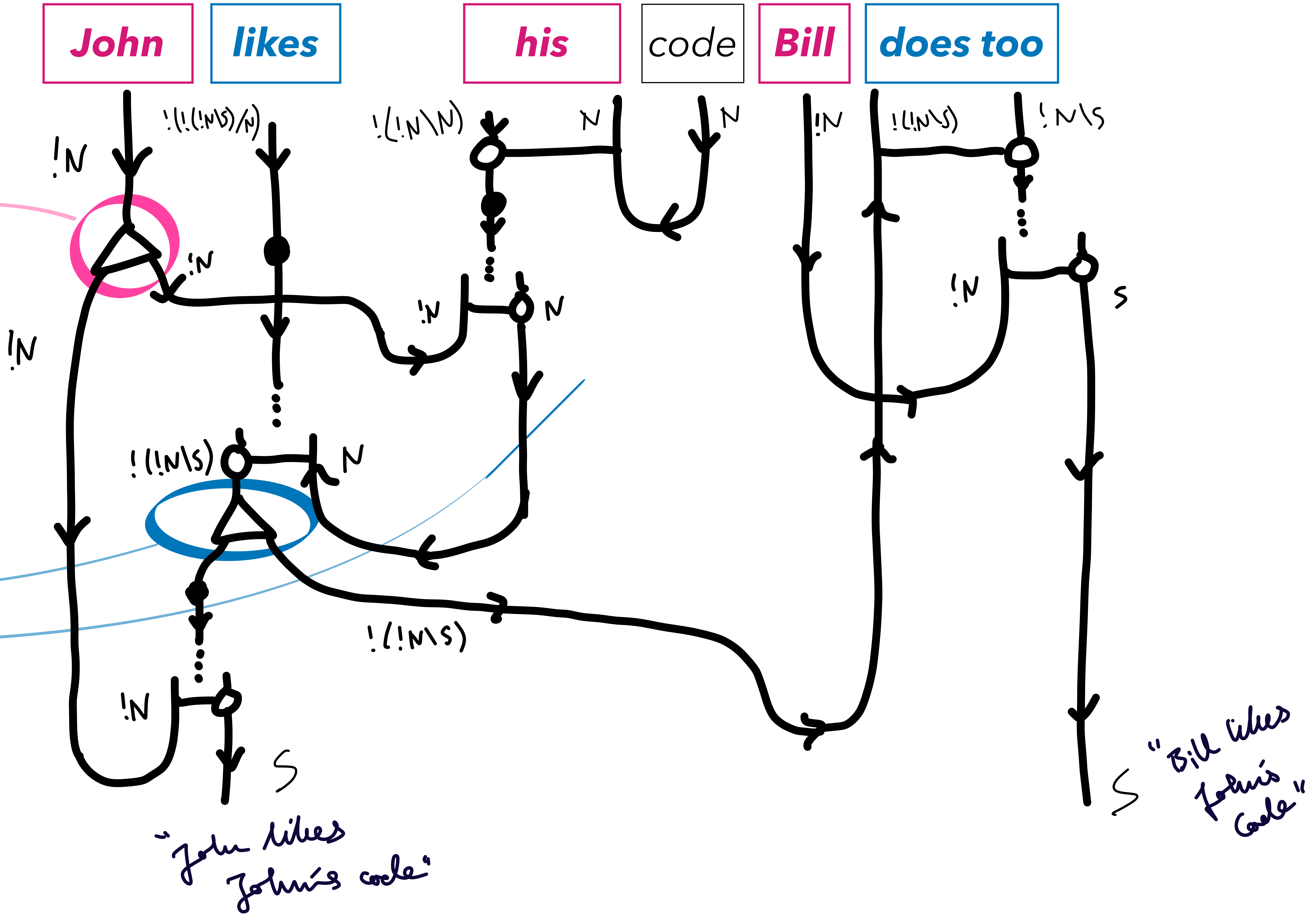


Example: Strict and Sloppy

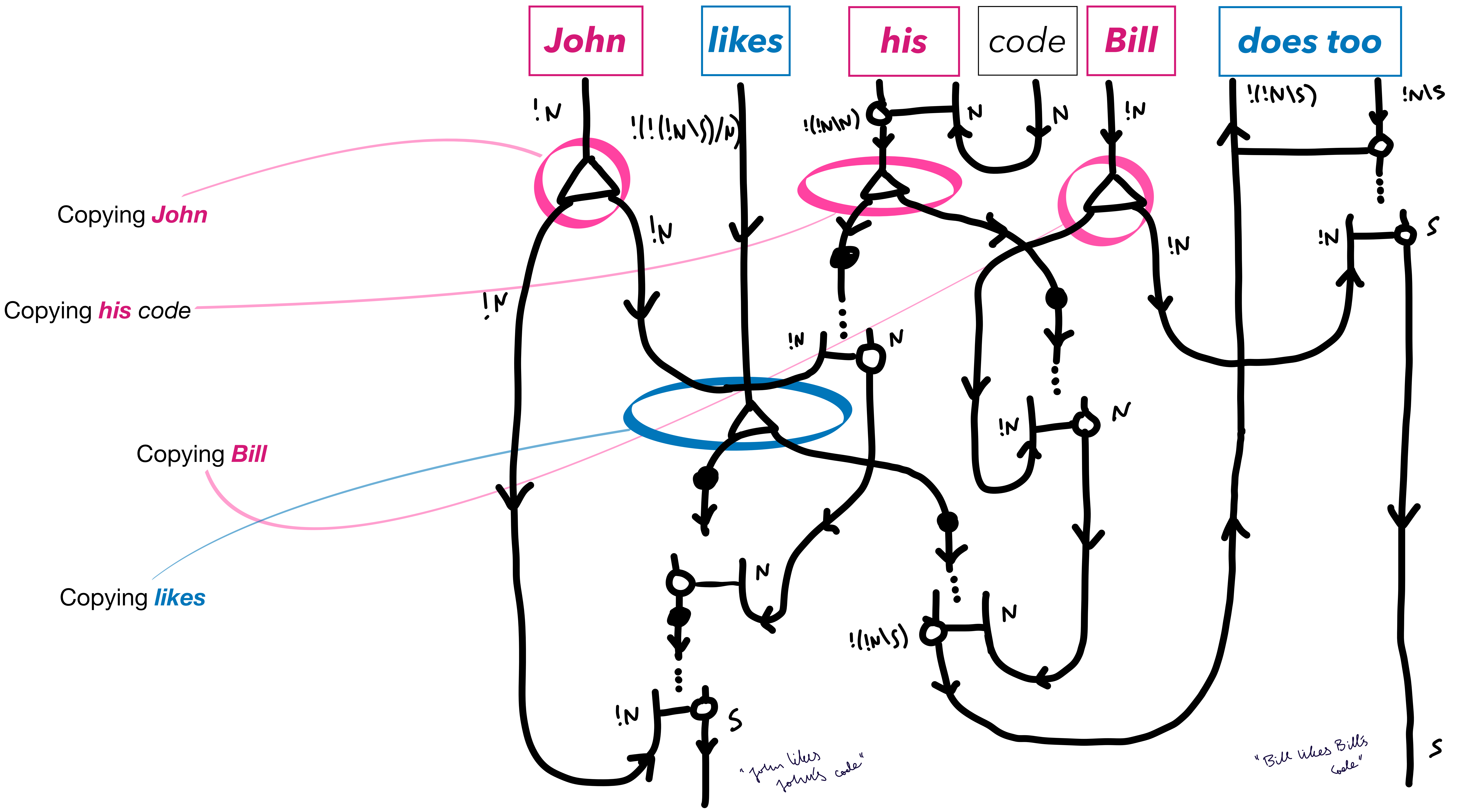
Copying *John*

Copying *likes John's code*

Identifying *does too* and *likes John's code*



Example: Strict and Sloppy



Empirical Validation

The Task

Applied VSS to disambiguation task from [Wijnholds & Sadrzadeh 2019]

The goal is disambiguating elliptical sentences of the form

"*Man draws sword and artist does too*"

Where the ambiguous verb (*draw*) has two meanings: '*depict*' and '*pull*'

(General sentence format: "*S V's O and S* does too*")

The Results

Tested over 400 such sentences, and correlated with human annotations.

$v \longmapsto$		$v \otimes v$	$\mathbf{1} \otimes v$	$v \otimes \mathbf{1}$	$v \otimes \mathbf{k} + \mathbf{k} \otimes v$
		full	basis copy(a)	basis copy(b)	**k**-extension
word2vec		0.44	0.34	0.42	0.44
fasttext		0.43	0.36	0.41	0.43
baselines					
verb only	0.24				
additive	0.31				
BERT phrase	0.36				
inter-annotator agreement	0.58				

Spearman's ρ correlations, upper bound is inter-annotator agreement

Outlook

VSS for **decidable calculus** with similar properties to $\mathbf{!L^*}$

Find **complete models** of $\mathbf{!L^*}$

Apply plausibility model to solve **Winograd Schema Challenge**

Study compatibility of our model of anaphora and ellipsis with **DisCoCirc**

Many thanks!

Any questions?

References

[Kanovich et al, 2016] *Max Kanovich, Stepan Kuznetsov, and Andre Scedrov. Undecidability of the Lambek calculus with a relevant modality*

[Coecke et al, 2018] Bob Coecke, Giovanni de Felice, Dan Marsden, and Alexis Toumi. *Towards compositional distributional discourse analysis*

[Jäger, 1998] Gerhard Jäger. *A multi-modal analysis of anaphora and ellipsis*

[Jäger, 2006] Gerhard Jäger. *Anaphora and type logical grammar*

[Baez & Stay, 2009] John Baez and Michael Stay. *Physics, topology, logic, and computation: A rosetta stone*

[McP. et al, 2020] McPheat, Lachlan, Mehrnoosh Sadrzadeh, Hadi Wazni, and Gijs Wijnholds. *Categorical vector space semantics for lambek calculus with a relevant modality*