

Bob Coecke

Chief Scientist @ Quantinuum

Forbes

Jun 8, 2021, 09:04am EDT | 49,374 views

Honeywell Quantum Solutions And Cambridge Quantum Computing Merge With Go-Public In Mind

Paul Smith-Goodson Contributor



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Cloud

Analyst-in-residence, Quantum Computing



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Bob Coecke

Head of Compositional intelligence Team



Colleagues @ Oxford University, 2008

Colleagues @ Oxford University, 2008

- ...knew **grammar mathematics**:



$$n \cdot {}^{-1}n \cdot s \cdot n^{-1} \cdot n \leq 1 \cdot s \cdot 1 \leq s$$

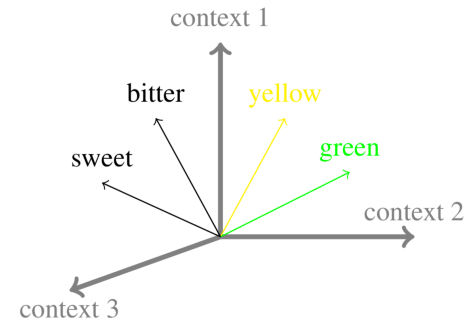
Colleagues @ Oxford University, 2008

- ...knew **grammar mathematics**:



$$n \cdot {}^{-1}n \cdot s \cdot n^{-1} \cdot n \leq 1 \cdot s \cdot 1 \leq s$$

- ...knew **meaning mathematics**:



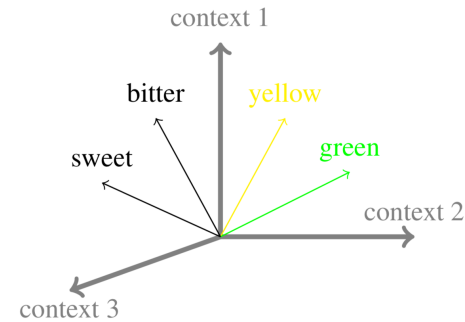
Colleagues @ Oxford University, 2008

- ...knew **grammar mathematics**:



$$n \cdot {}^{-1}n \cdot s \cdot n^{-1} \cdot n \leq 1 \cdot s \cdot 1 \leq s$$

- ...knew **meaning mathematics**:



How combine grammar and meaning?

A new model of language



arXiv.org > cs > arXiv:1003.4394

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Computer Science > Computation and Language

[Submitted on 23 Mar 2010]

Mathematical Foundations for a Compositional Distributional Model of Meaning

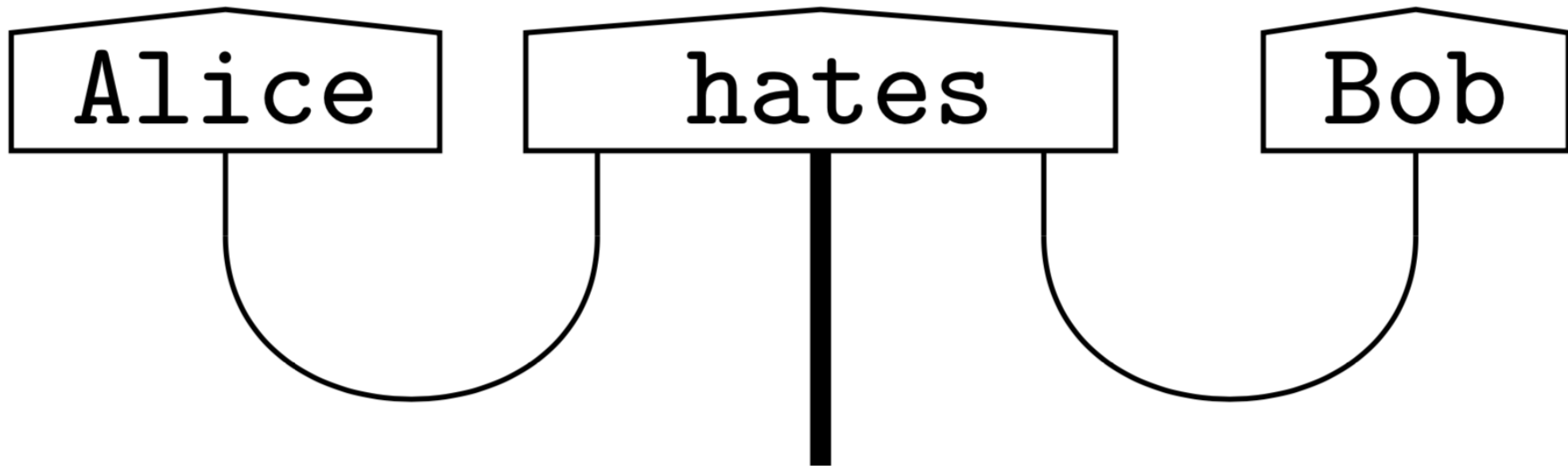
Bob Coecke, Mehrnoosh Sadrzadeh, Stephen Clark

We propose a mathematical framework for a unification of the distributional theory of meaning in terms of vector space models, and a compositional theory for grammatical types, for which we rely on the algebra of Pregroups, introduced by Lambek. This mathematical framework enables us to compute the meaning of a well-typed sentence from the meanings of its constituents. Concretely, the type reductions of Pregroups are 'lifted' to morphisms in a category, a procedure that transforms meanings of constituents into a meaning of the (well-typed) whole. Importantly, meanings of whole sentences live in a single space, independent of the grammatical structure of the sentence. Hence the inner-product can be used to compare meanings of arbitrary sentences, as it is for comparing the meanings of words in the distributional model. The mathematical structure we employ admits a purely diagrammatic calculus which exposes how the information flows between the words in a sentence in order to make up the meaning of the whole sentence. A variation of our 'categorical model' which involves constraining the scalars of the vector spaces to the semiring of Booleans results in a Montague-style Boolean-valued semantics.

Comments: to appear

Subjects: **Computation and Language (cs.CL)**; Logic in Computer Science (cs.LO); Category Theory (math.CT)

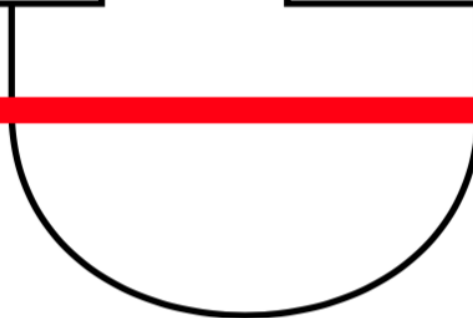
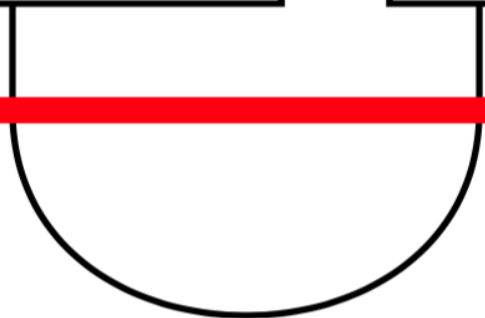
Journal reference: Lambek Festschrift, special issue of Linguistic Analysis, 2010.



Alice

hates

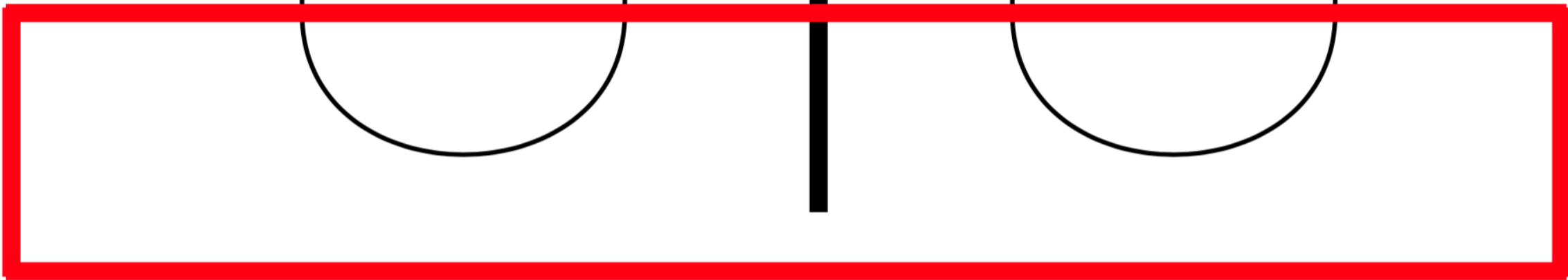
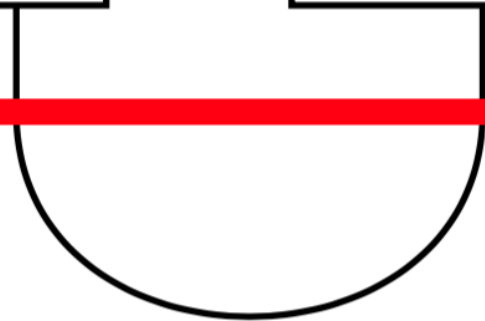
Bob

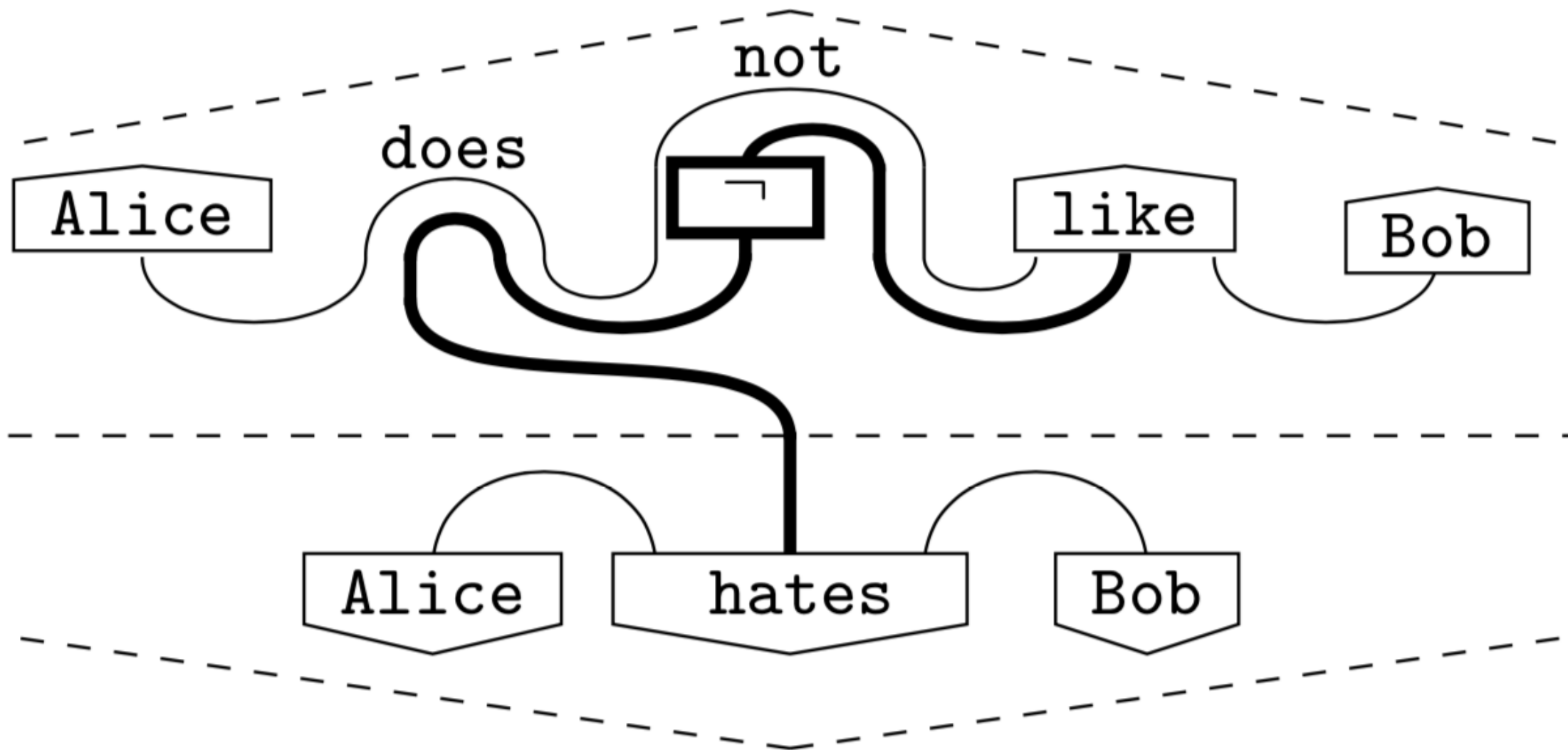


Alice

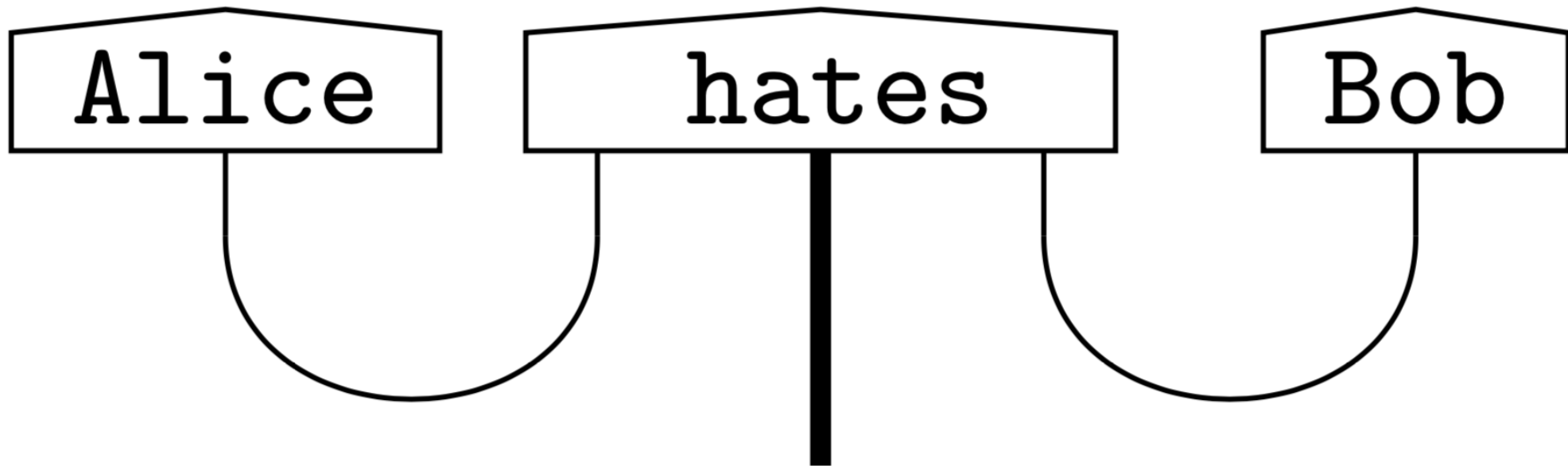
hates

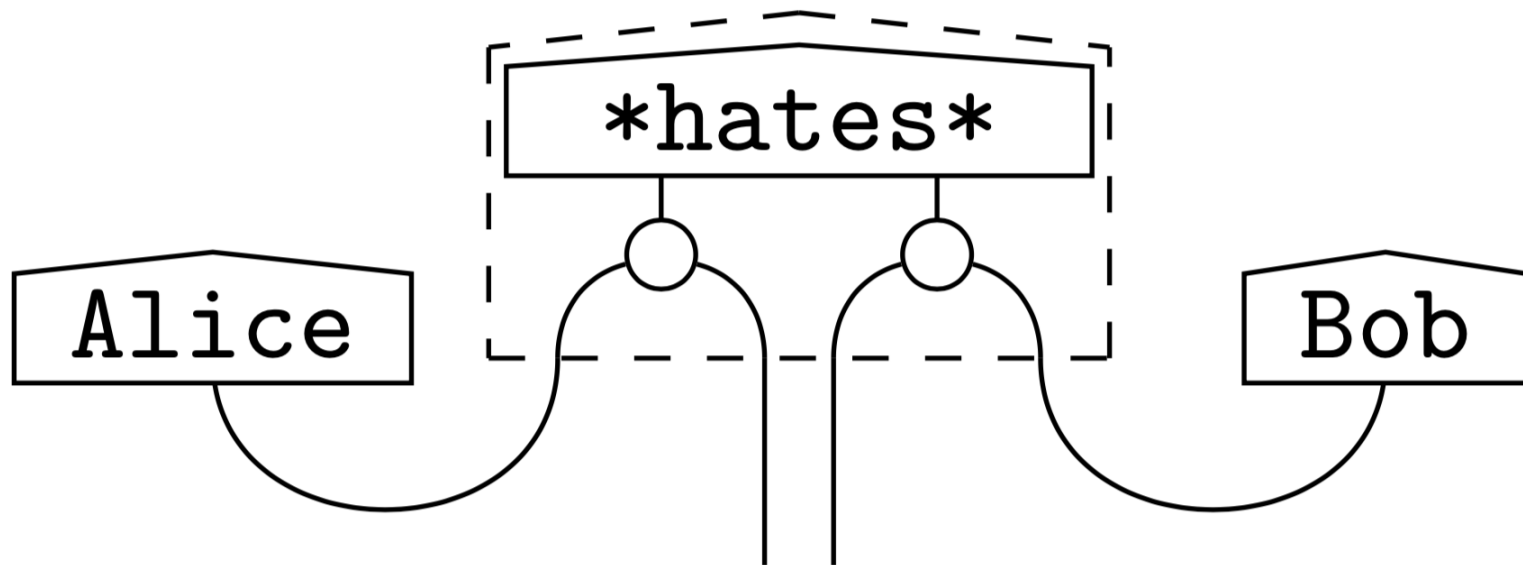
Bob

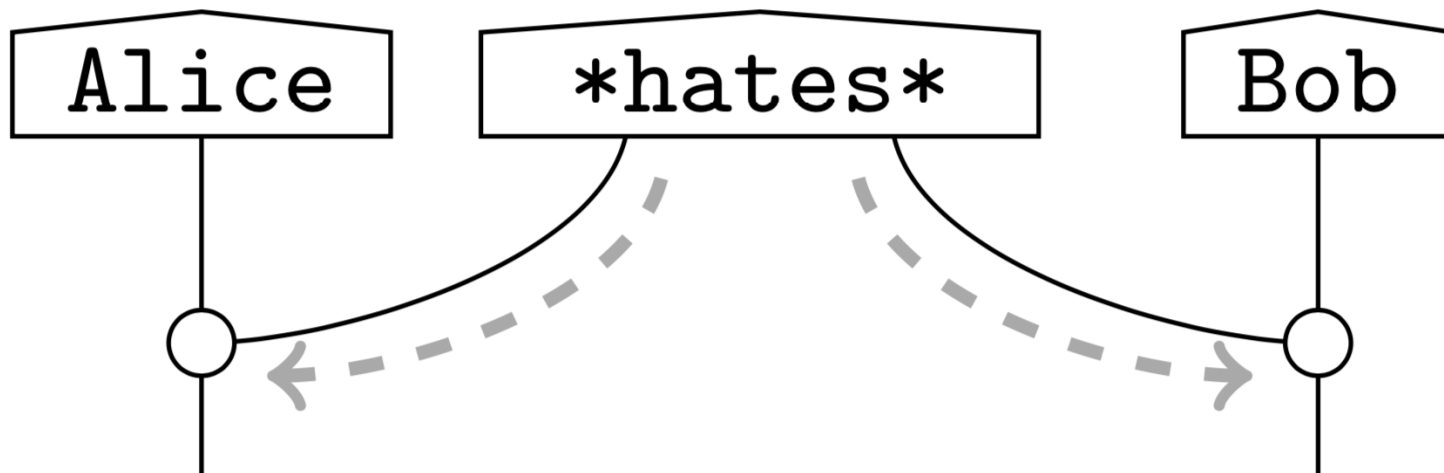


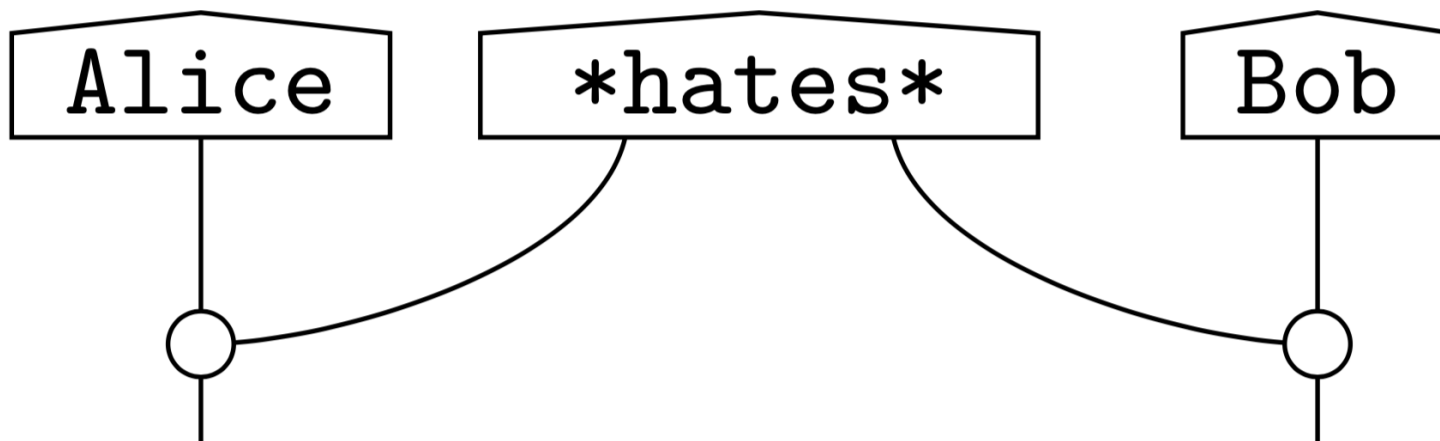


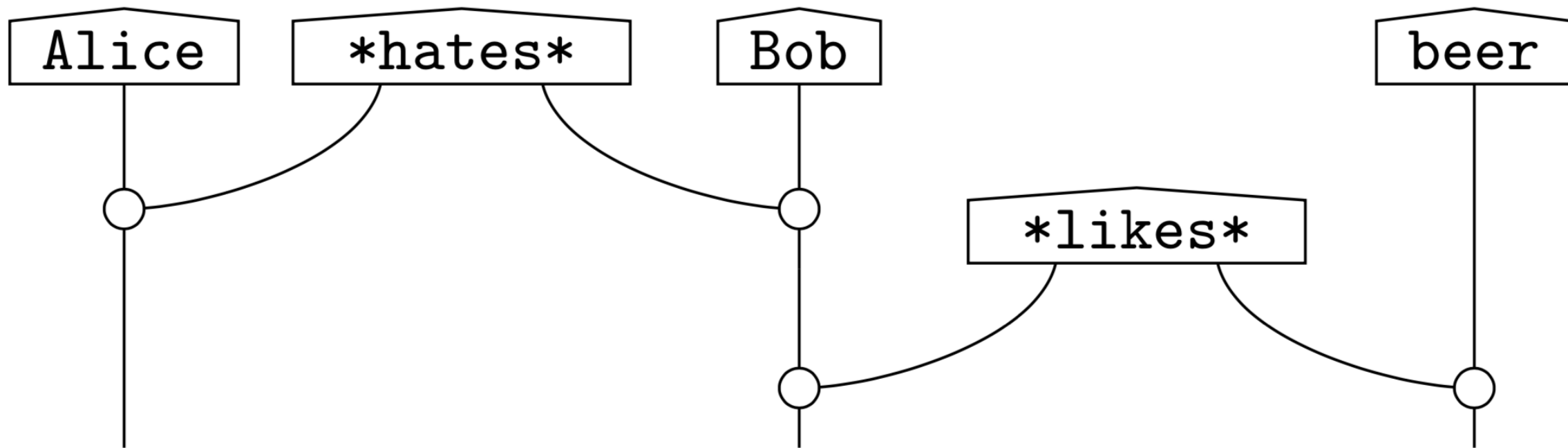
text circuits: a new theory of language













arXiv.org > cs > arXiv:1904.03478

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Computer Science > Computation and Language

[Submitted on 6 Apr 2019 ([v1](#)), last revised 28 Feb 2020 (this version, v2)]

The Mathematics of Text Structure

Bob Coecke

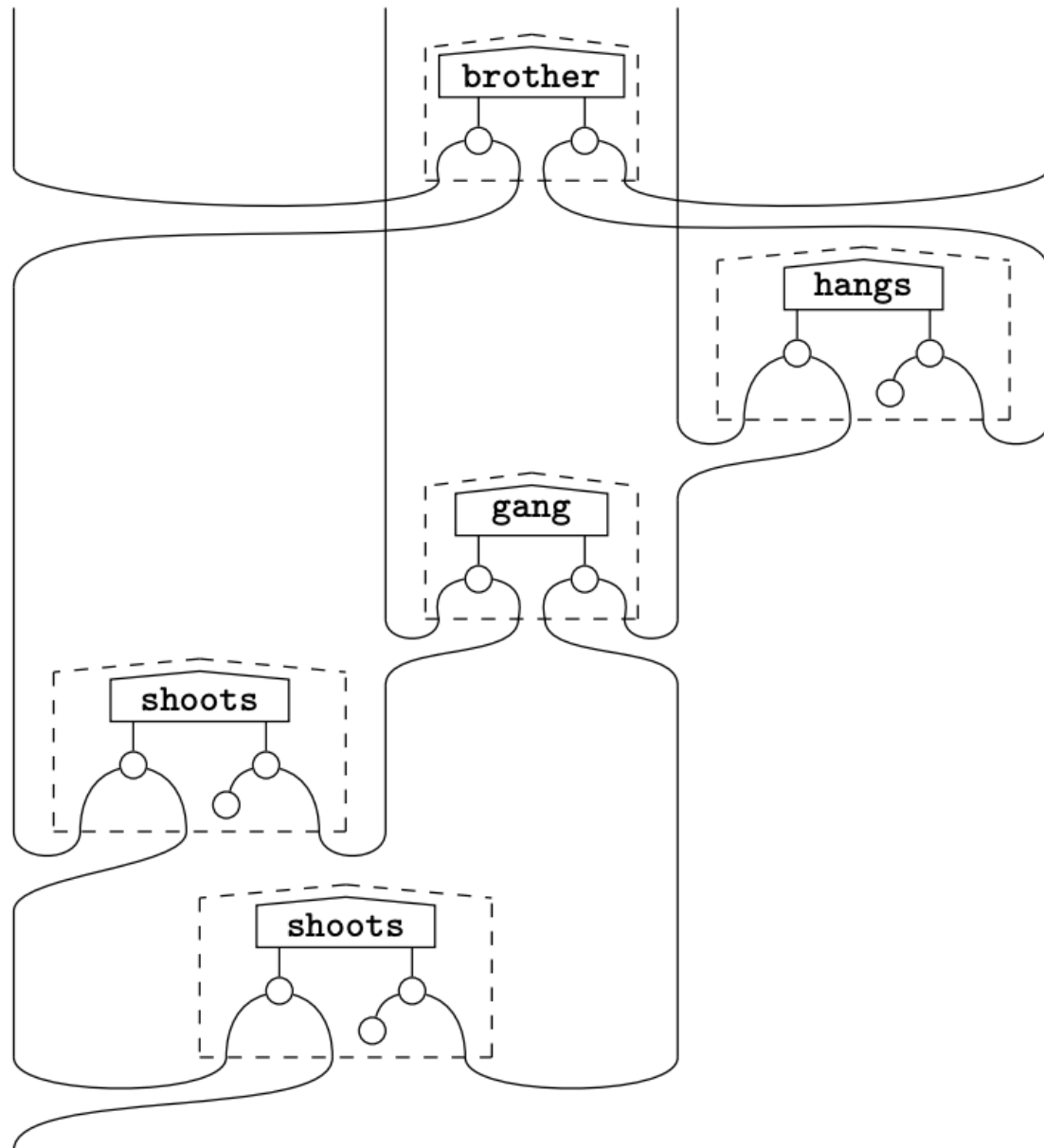
In previous work we gave a mathematical foundation, referred to as DisCoCat, for how words interact in a sentence in order to produce the meaning of that sentence. To do so, we exploited the perfect structural match of grammar and categories of meaning spaces. Here, we give a mathematical foundation, referred to as DisCoCirc, for how sentences interact in texts in order to produce the meaning of that text. First we revisit DisCoCat. While in DisCoCat all meanings are fixed as states (i.e. have no input), in DisCoCirc word meanings correspond to a type, or system, and the states of this system can evolve. Sentences are gates within a circuit which update the variable meanings of those words. Like in DisCoCat, word meanings can live in a variety of spaces e.g. propositional, vectorial, or cognitive. The compositional structure are string diagrams representing information flows, and an entire text yields a single string diagram in which word meanings lift to the meaning of an entire text. While the developments in this paper are independent of a physical embodiment (cf. classical vs. quantum computing), both the compositional formalism and suggested meaning model are highly quantum-inspired, and implementation on a quantum computer would come with a range of benefits. We also praise Jim Lambek for his role in mathematical linguistics in general, and the development of the DisCo program more specifically.

Harmonica

Snaky

Frank

Claudio



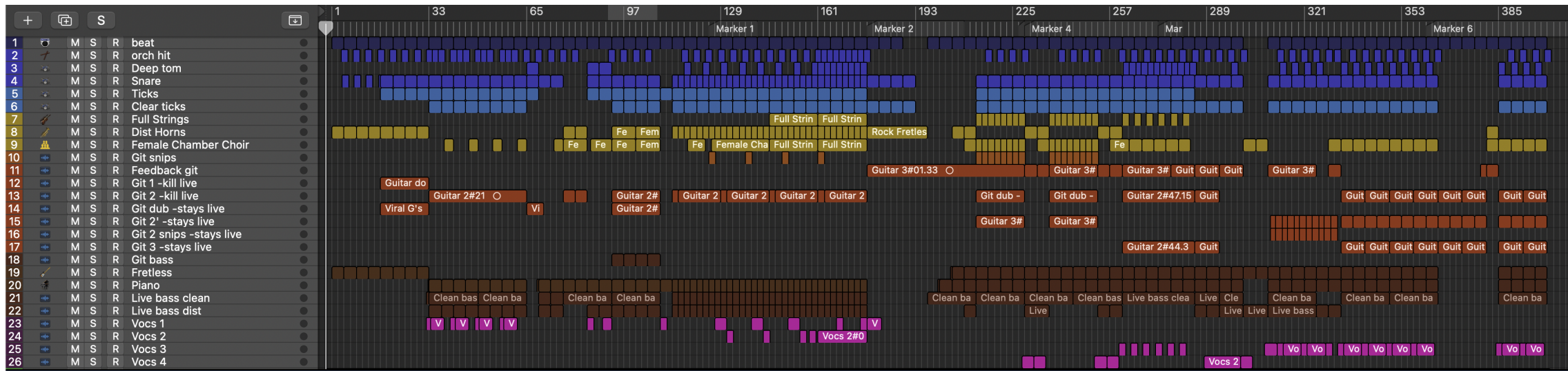
Harmonica

Snaky

Frank

Claudio





space-time as meaning

Spacetime in language:

- Prepositions in, next to, after, on, with...

Spacetime in language:

- Prepositions in, next to, after, on, with...
- Many other words meanings e.g. chasing...

Spacetime in language:

- Prepositions in, next to, after, on, with...
- Many other words meanings e.g. chasing...
- Used for referencing e.g. pointing

Spacetime in language:

- Prepositions in, next to, after, on, with...
- Many other words meanings e.g. chasing...
- Used for referencing e.g. pointing, and where we exist!

Spacetime in language:

- Prepositions **in, next to, after, on, with...**
- Many other words meanings e.g. **chasing...**
- Used for referencing e.g. **pointing**, and **where we exist!**



- **The origin of language?**



arXiv.org > cs > arXiv:2109.06554

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Computer Science > Computation and Language

[Submitted on 14 Sep 2021 ([v1](#)), last revised 16 Sep 2021 (this version, v2)]

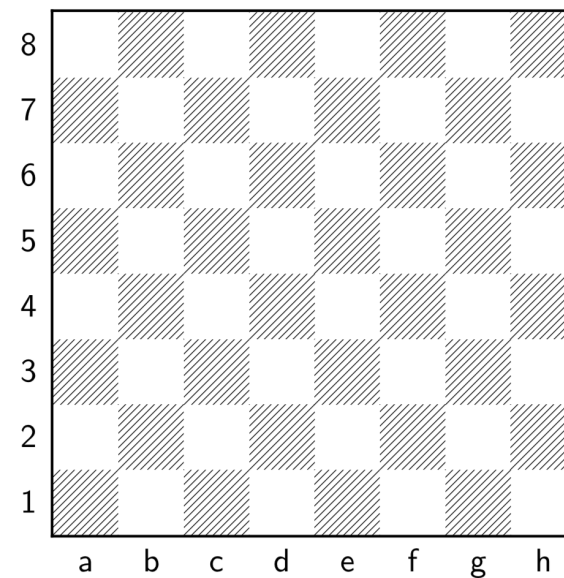
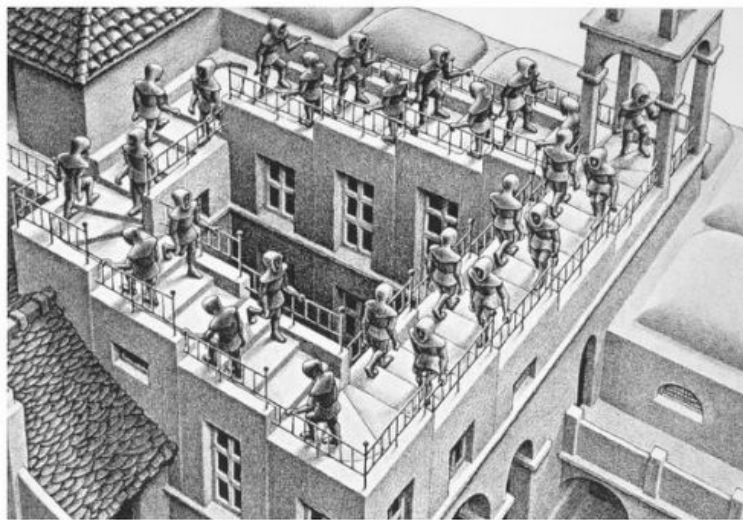
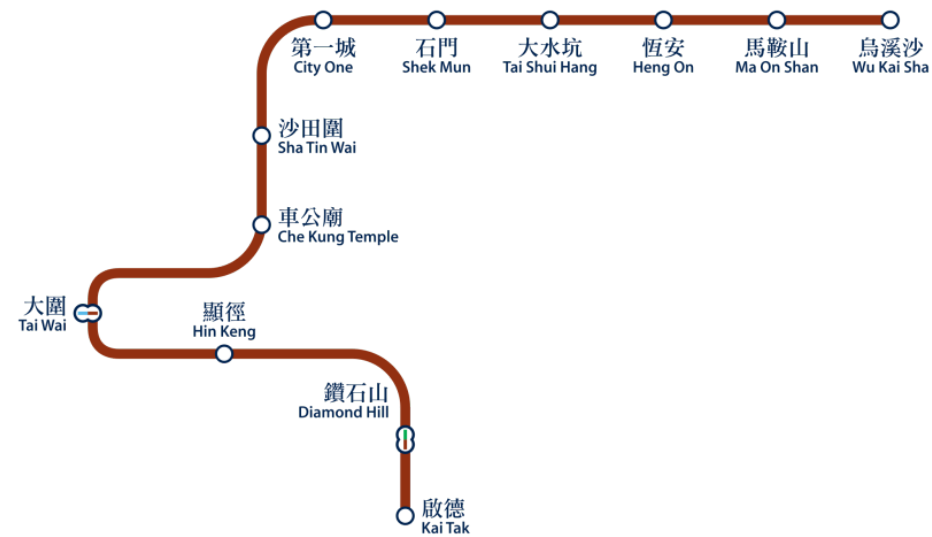
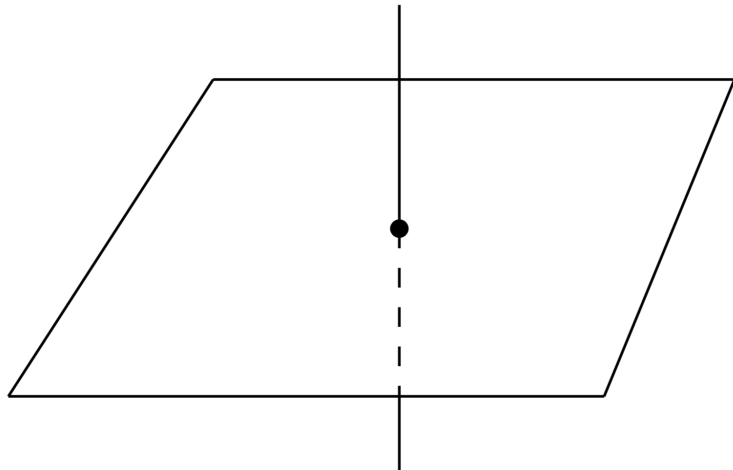
Talking Space: inference from spatial linguistic meanings

Vincent Wang-Mascianica, Bob Coecke

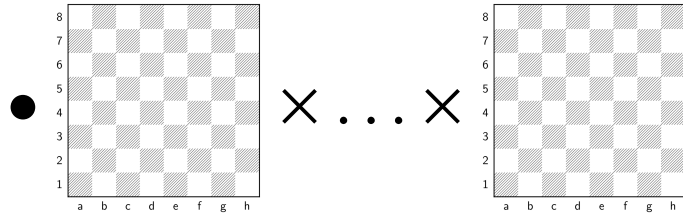
This paper concerns the intersection of natural language and the physical space around us in which we live, that we observe and/or imagine things within. Many important features of language have spatial connotations, for example, many prepositions (like in, next to, after, on, etc.) are fundamentally spatial. Space is also a key factor of the meanings of many words/phrases/sentences/text, and space is a, if not the key, context for referencing (e.g. pointing) and embodiment.

We propose a mechanism for how space and linguistic structure can be made to interact in a matching compositional fashion. Examples include Cartesian space, subway stations, chesspieces on a chess-board, and Penrose's staircase. The starting point for our construction is the DisCoCat model of compositional natural language meaning, which we relax to accommodate physical space. We address the issue of having multiple agents/objects in a space, including the case that each agent has different capabilities with respect to that space, e.g., the specific moves each chesspiece can make, or the different velocities one may be able to reach.

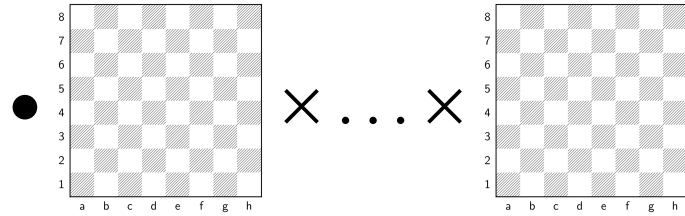
Once our model is in place, we show how inferences drawing from the structure of physical space can be made. We also how how linguistic model of space can interact with other such models related to our senses and/or embodiment, such as the conceptual spaces of colour, taste and smell, resulting in a rich compositional model of meaning that is close to human experience and embodiment in the world.



Monoidal subcategory of **Rel**:

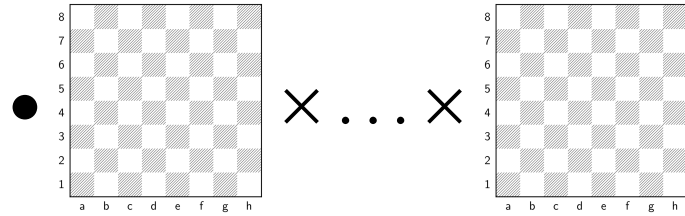


Monoidal subcategory of **Rel**:



- “spatial relations” $R \subseteq X \times \dots \times X$

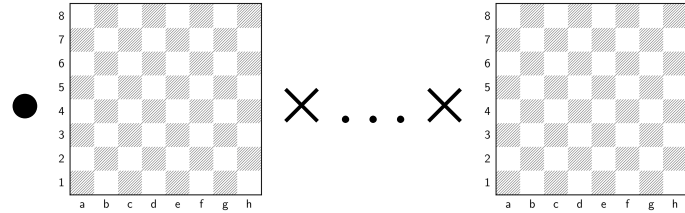
Monoidal subcategory of **Rel**:



- “spatial relations” $R \subseteq X \times \dots \times X$

- $S \circ R := \{(x, z) \mid \exists x' : R(x, y), S(y, z)\}$ & $S \times R := \{((x, y), (z, u)) \mid R(x, y), S(z, u)\}$

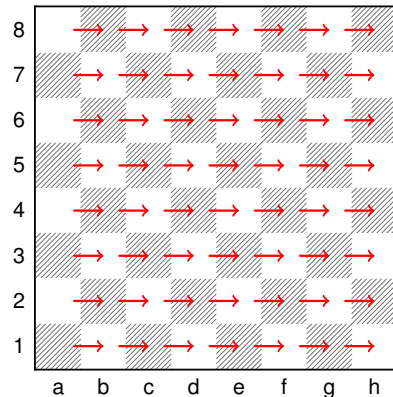
Monoidal subcategory of **Rel**:



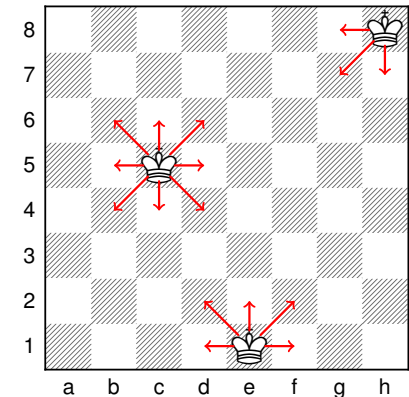
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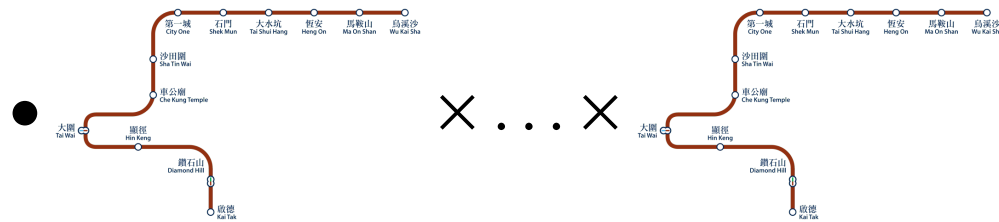
move right :=



king's moves :=



Monoidal subcategory of **Rel**:



• “spatial relations” $R \subseteq X \times \dots \times X$

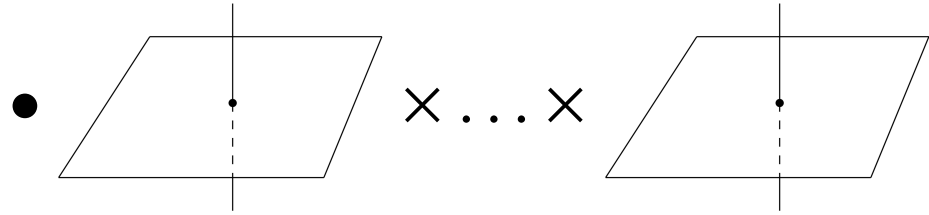
$$\bullet S \circ R := \{(x, z) \mid \exists x' : R(x, y), S(y, z)\} \quad \& \quad S \times R := \{((x, y), (z, u)) \mid R(x, y), S(z, u)\}$$

• next stop := {(Kai Tak, D. H.), (D. H., Hin Keng), ...}

• in-between := {(Kai Tak, D. H., Hin Keng), ...}

• my station := {Wu Kai Sha}

Monoidal subcategory of **Rel**:



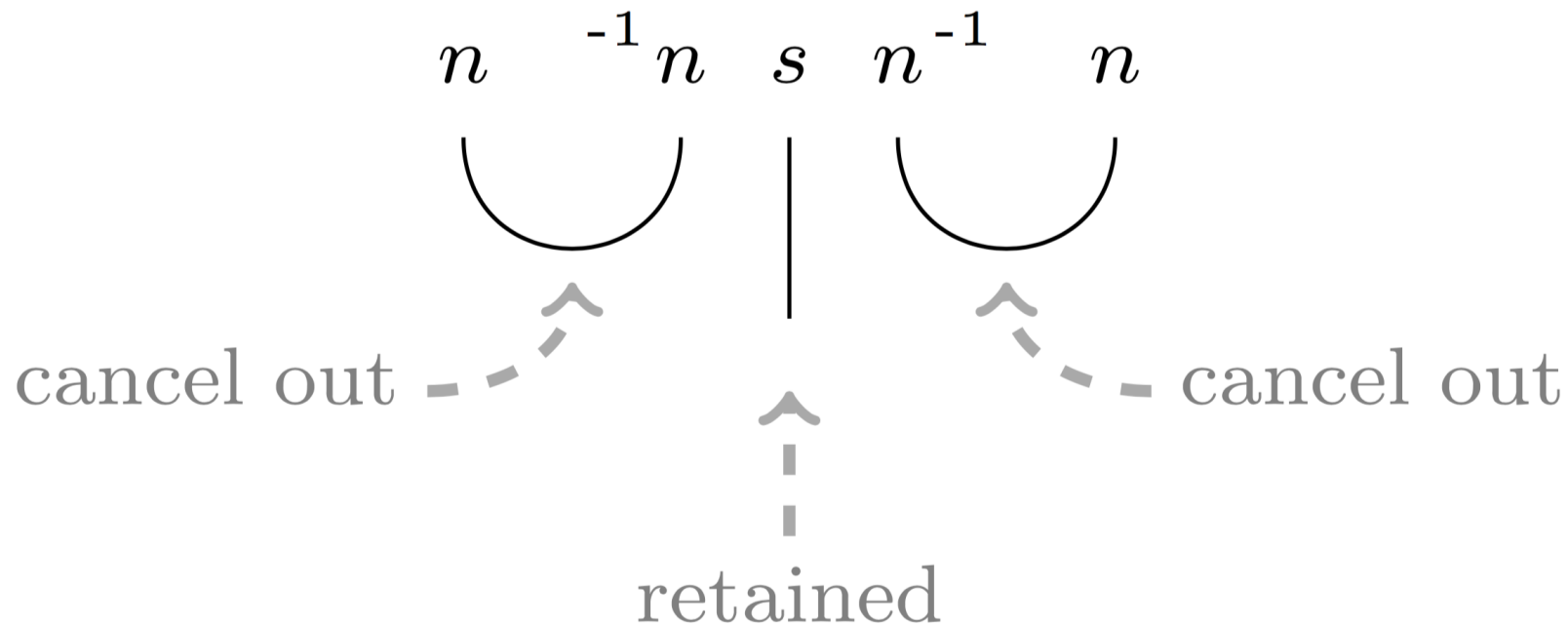
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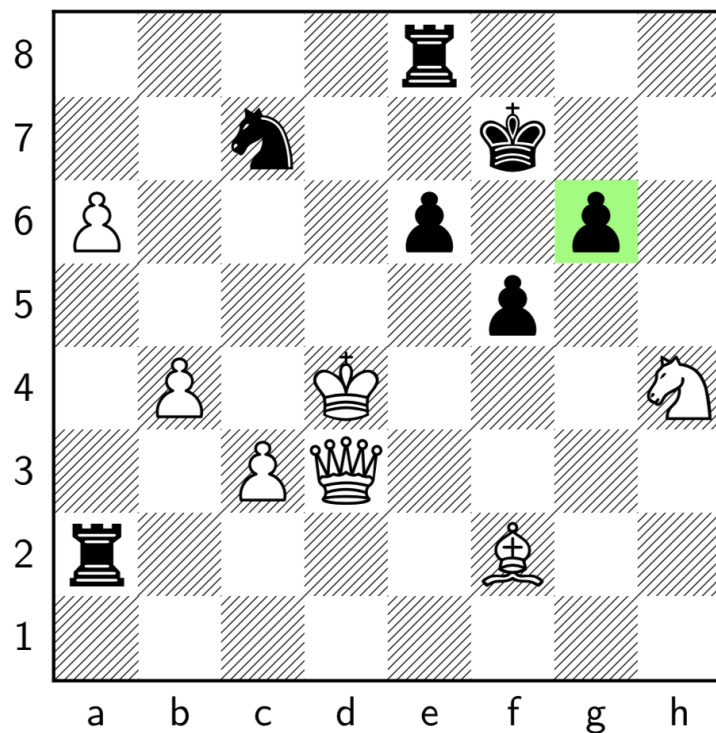
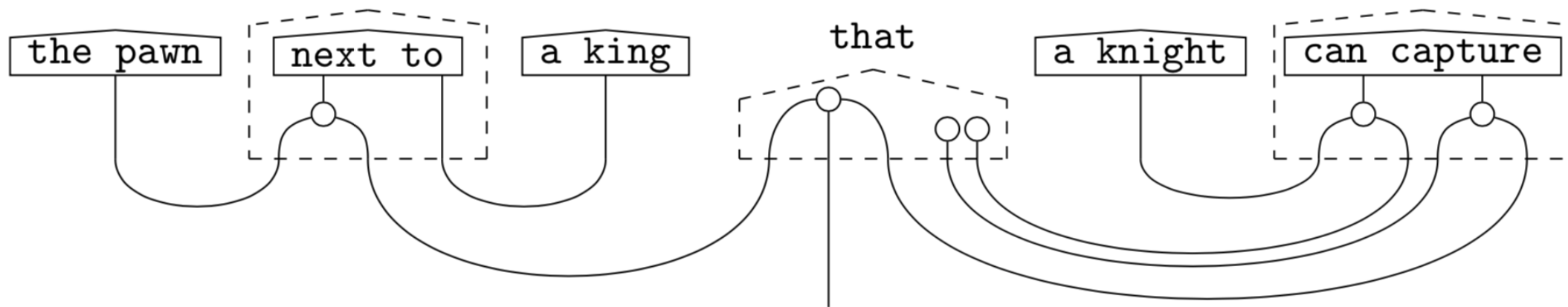
- $\text{higher than} := \{((x, y, z), (x', y', z')) \mid z > z'\}$

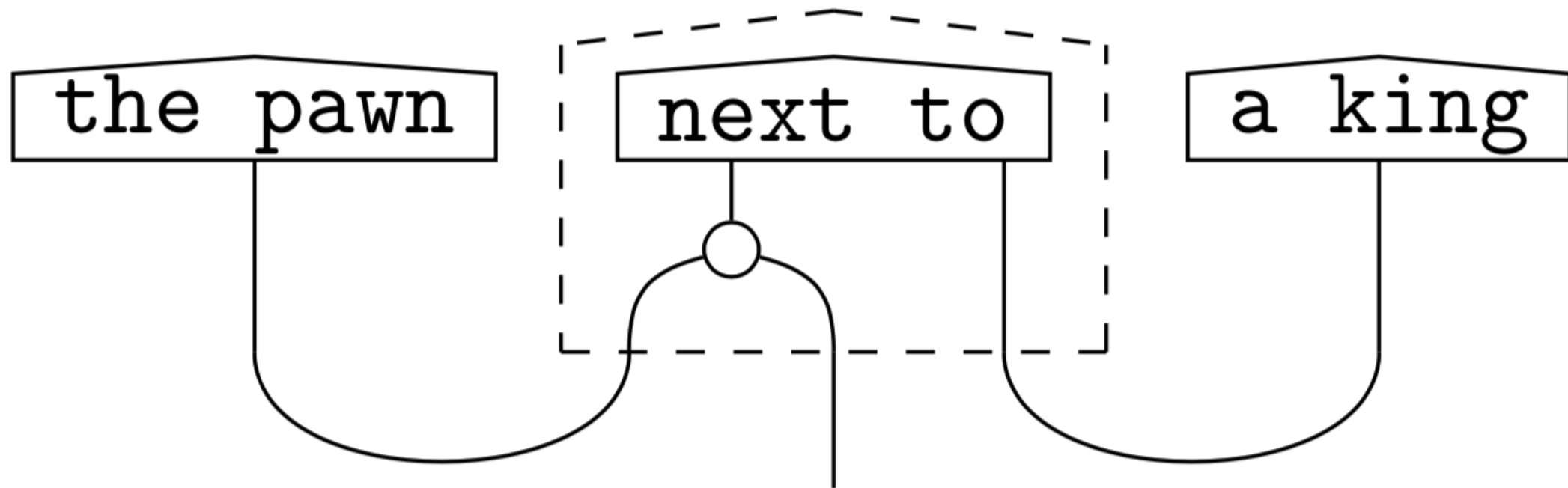
- $\text{above} := \{((x, y, z), (x', y', z')) \mid x = x', y = y', z > z'\}$

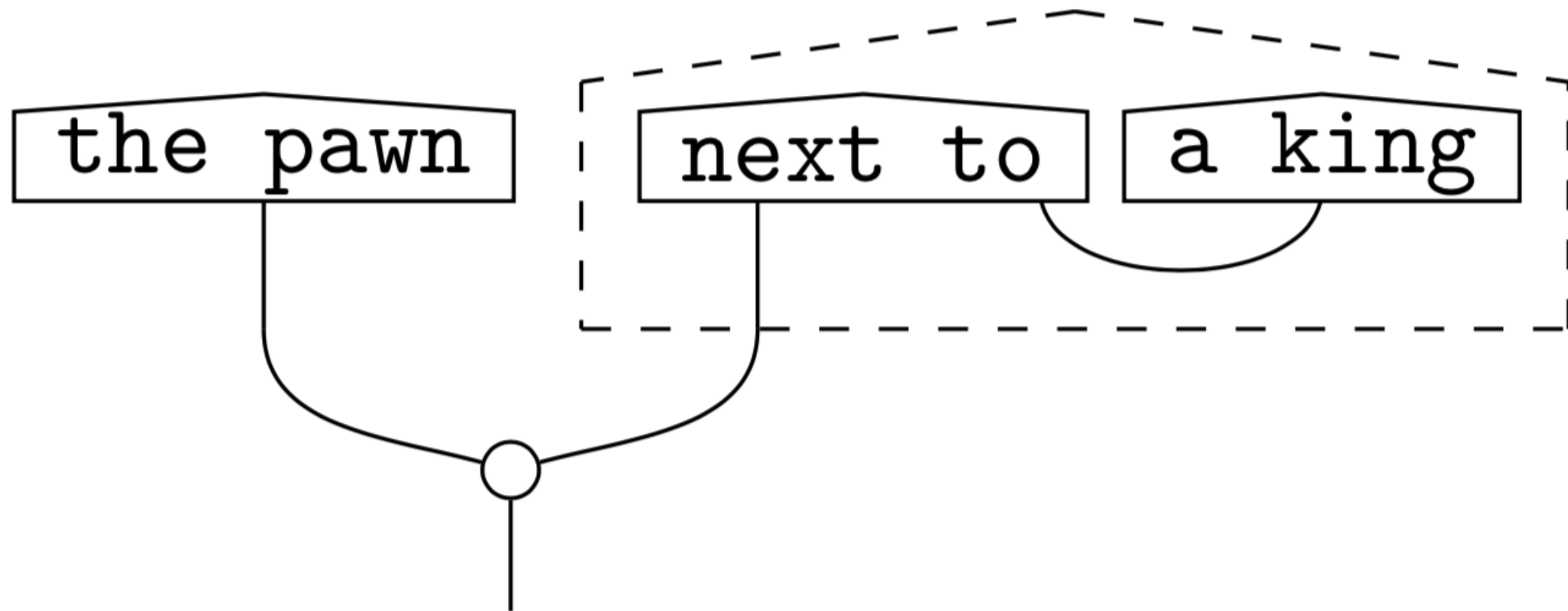
- $\text{chases}_{\delta t > 0} := \{((x, y, z, t), (x, y, z, t')) \mid t = t' + \delta t\}$

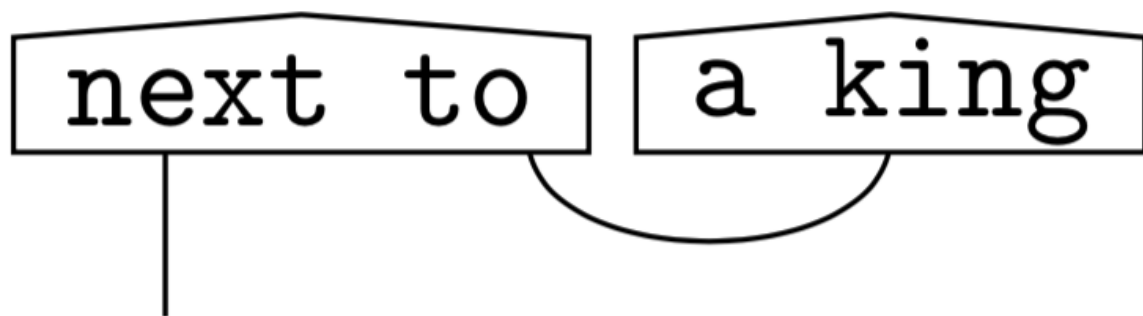


$$\left\{((x, x), *) \mid x \in X\right\} \times \left\{(y, y) \mid y \in Y\right\} \times \left\{((x, x), *) \mid x \in X\right\}$$

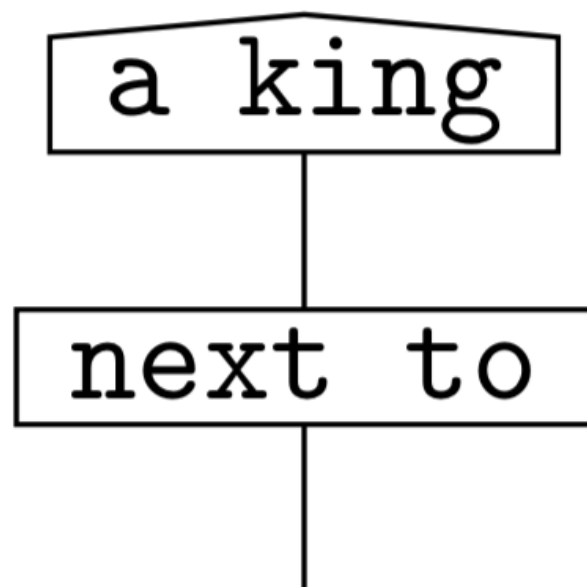


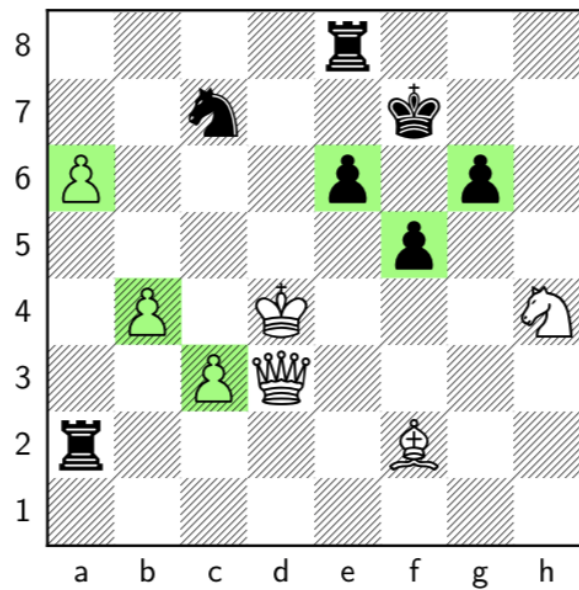




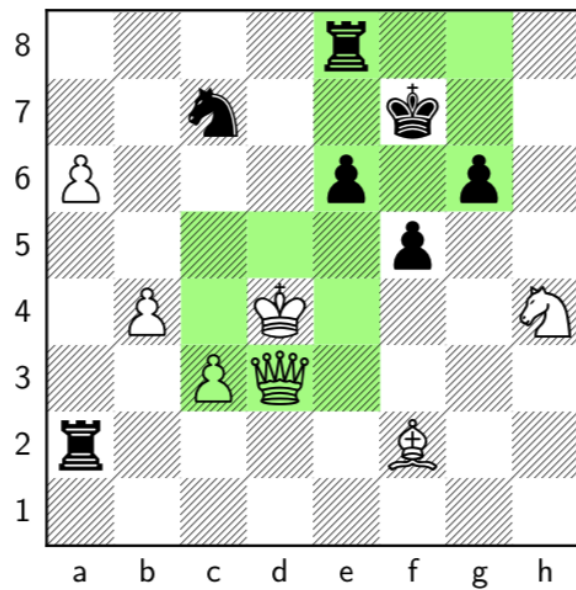


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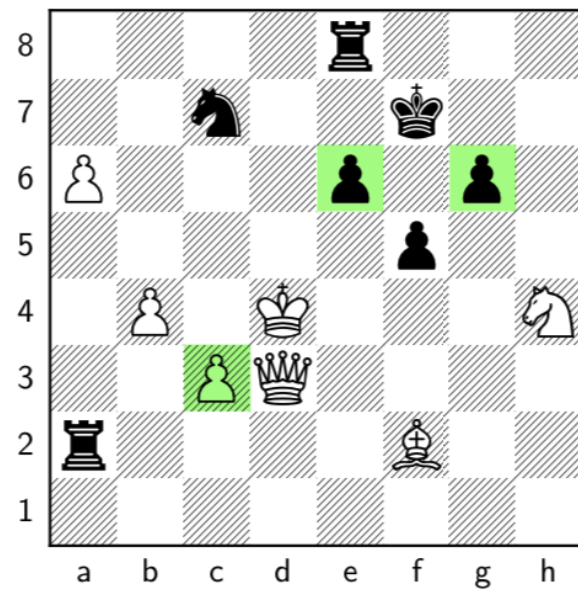


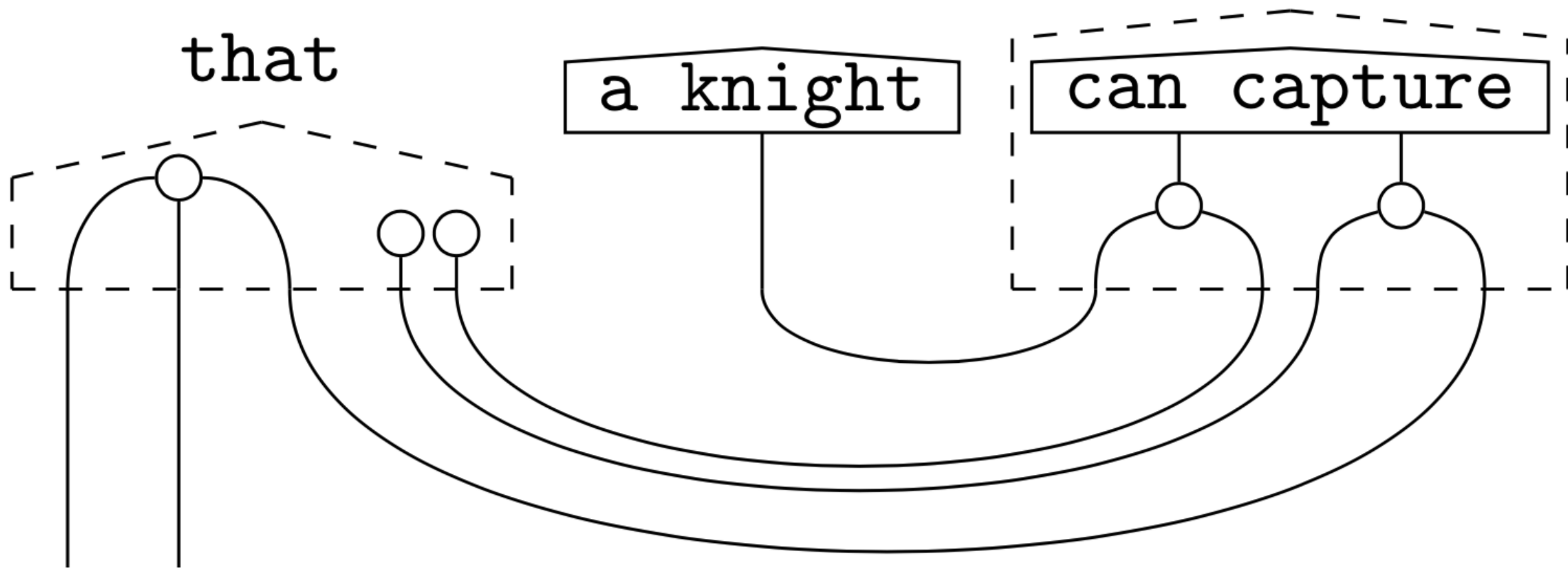


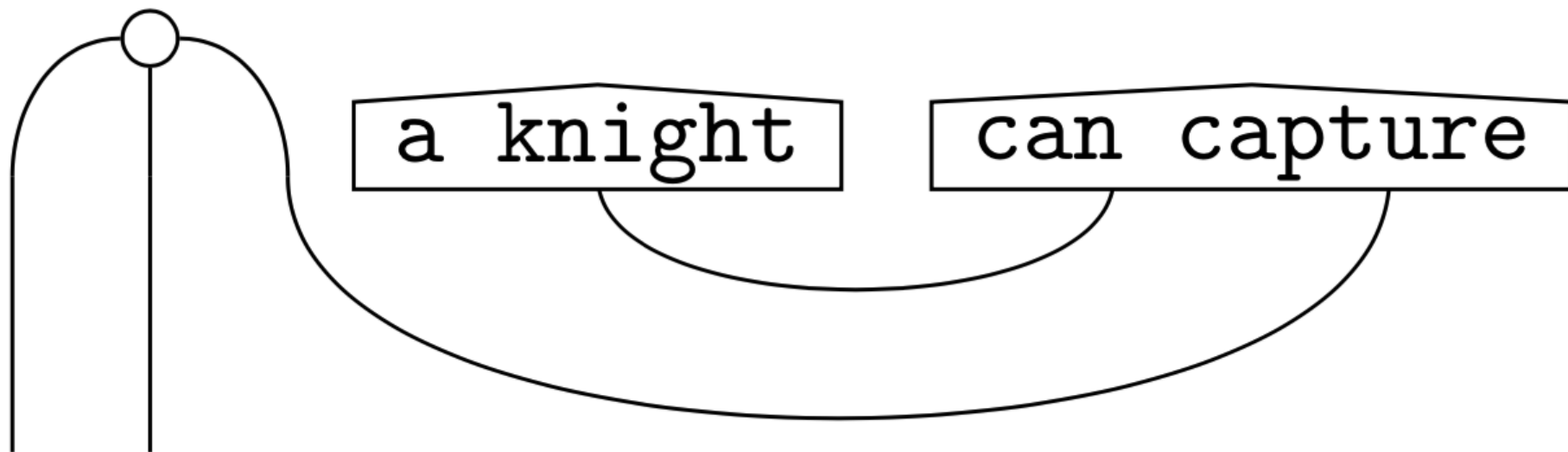
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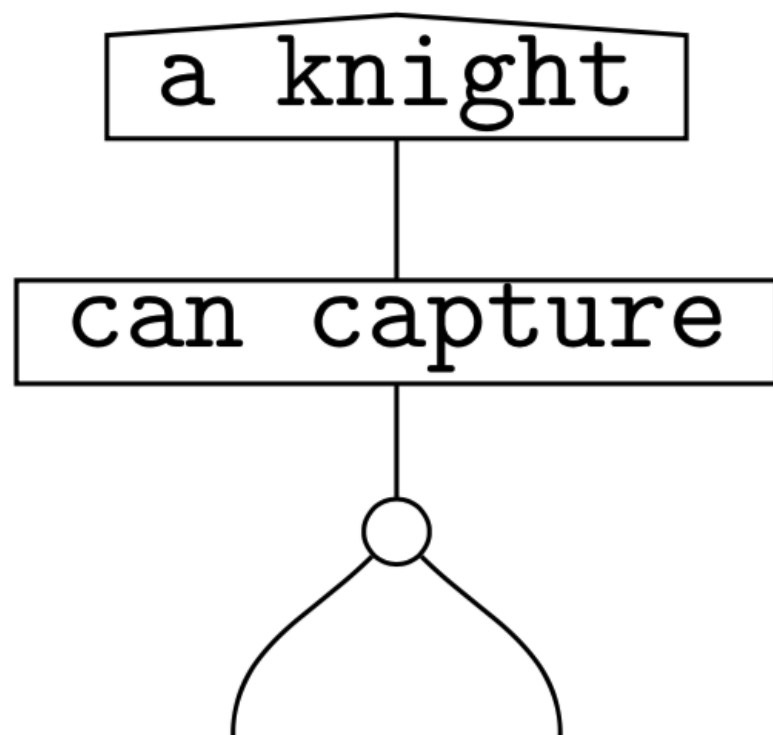


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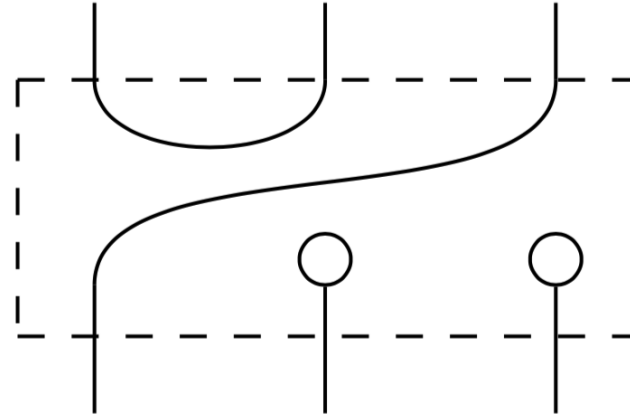




$\text{chessboard} := (\text{a-h} \times 1-8) \times \{\text{♙'s moves}, \text{♖'s moves}, \dots, \text{♔'s moves}\}$

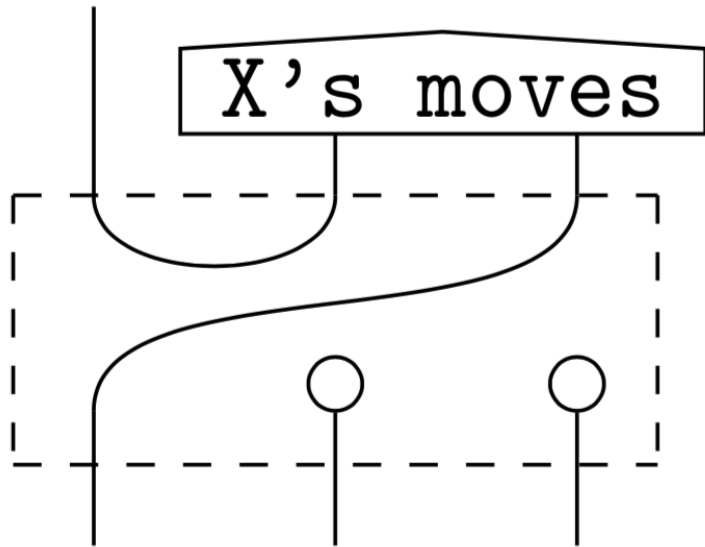
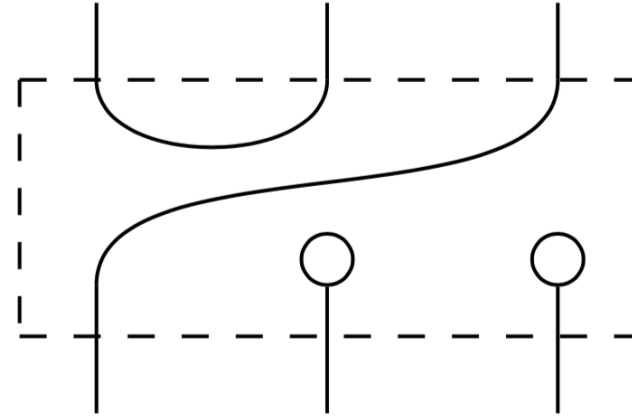
chessboard := (a-h \times 1-8) \times {♙'s moves, ♖'s moves, ..., ♔'s moves}

can capture :=



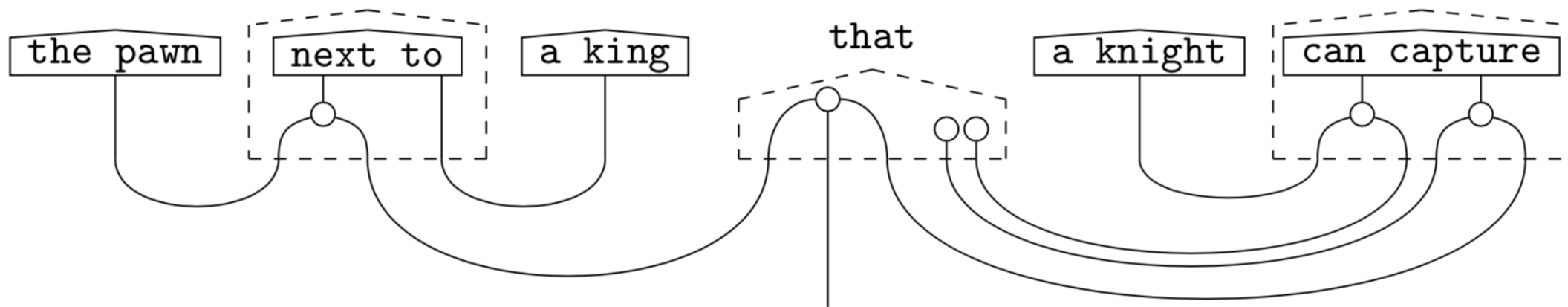
chessboard $:= (a-h \times 1-8) \times \{\text{♙}'\text{'s moves}, \text{♜}'\text{'s moves}, \dots, \text{♔}'\text{'s moves}\}$

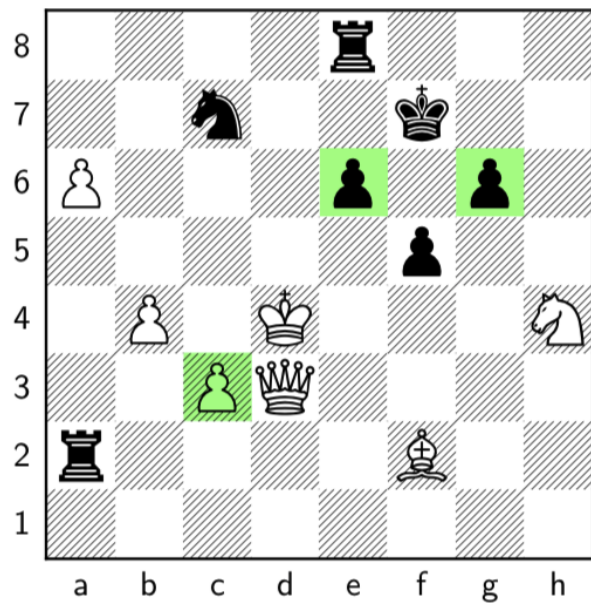
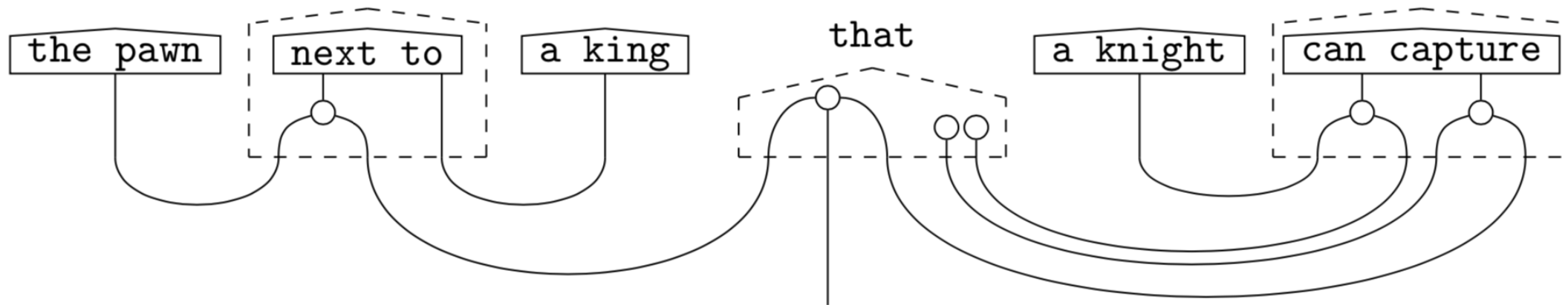
can capture $:=$



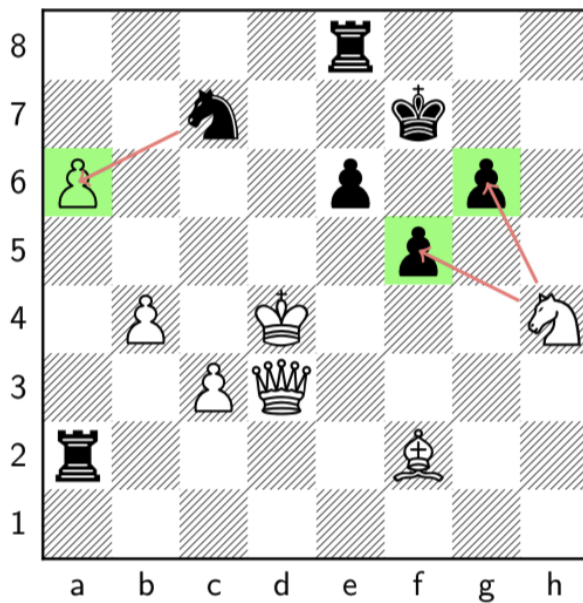
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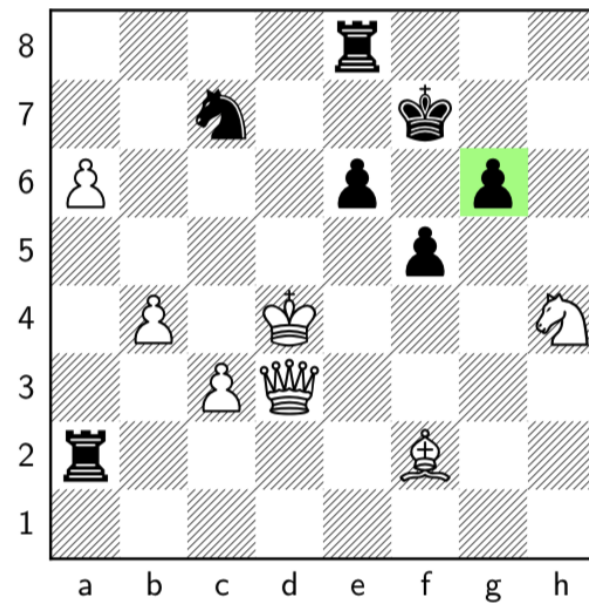


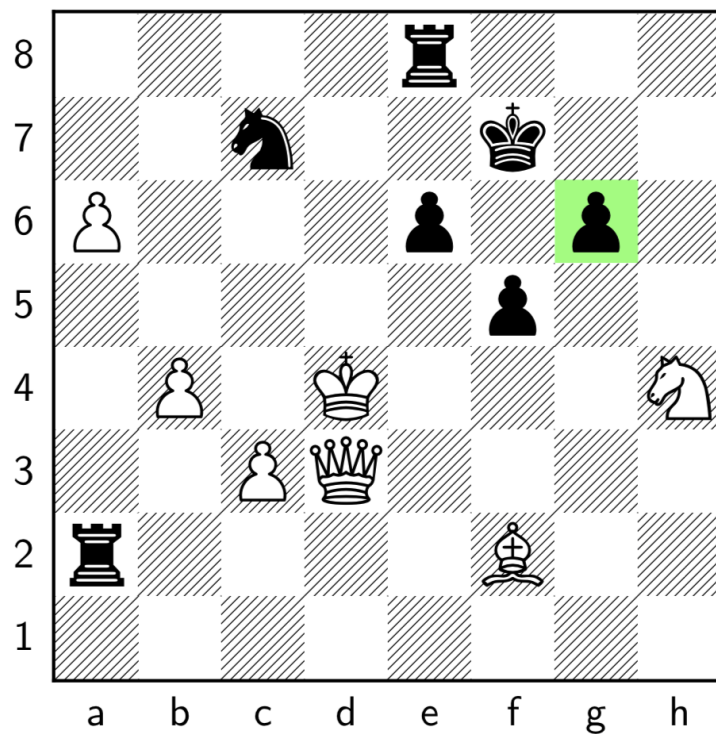
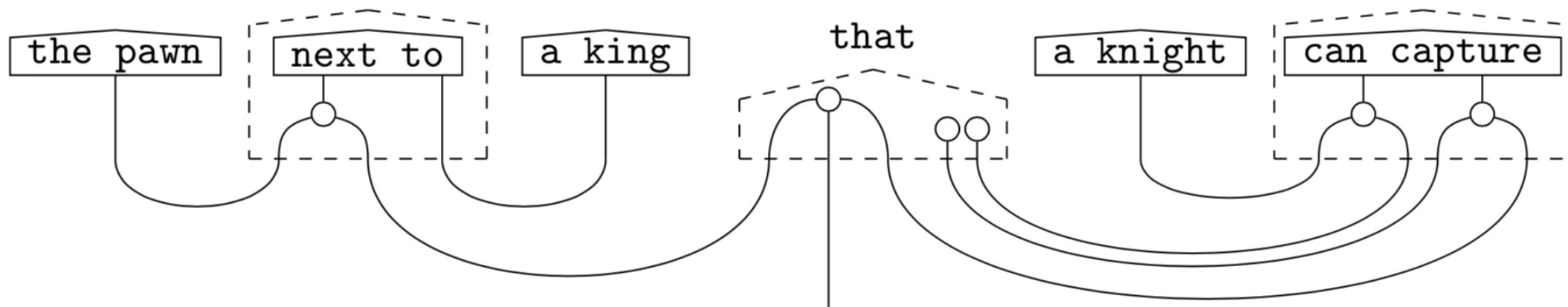


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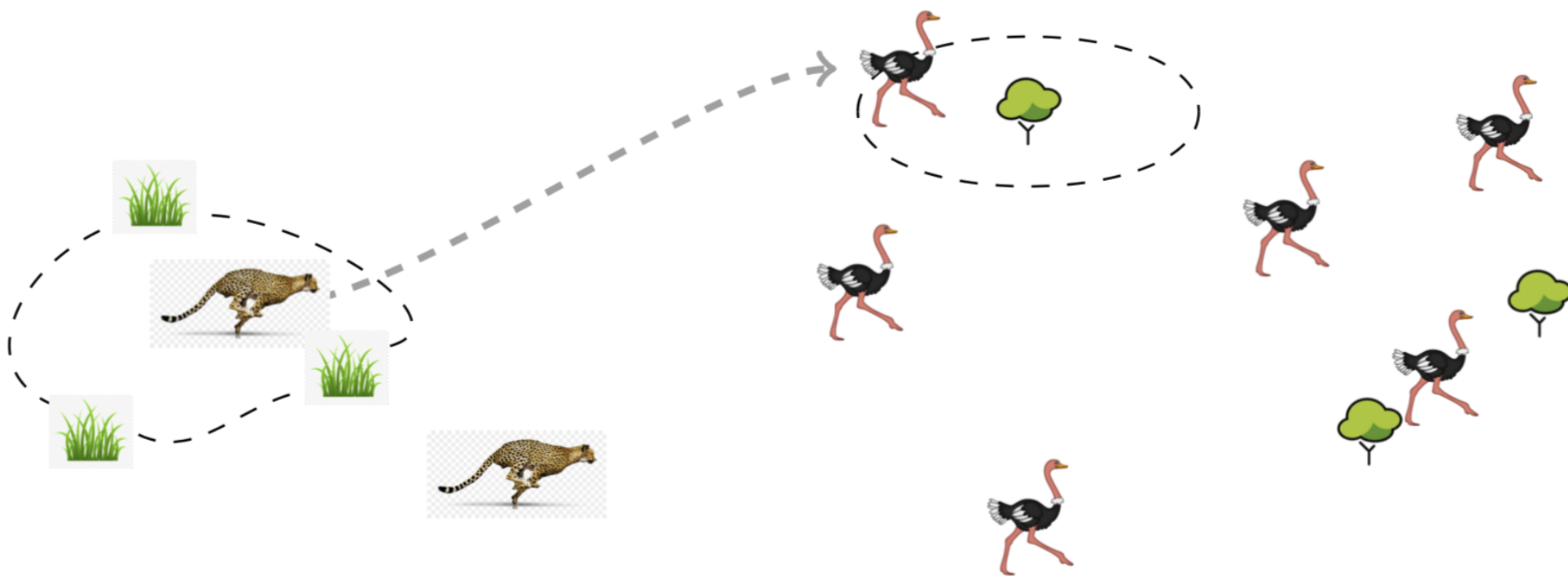
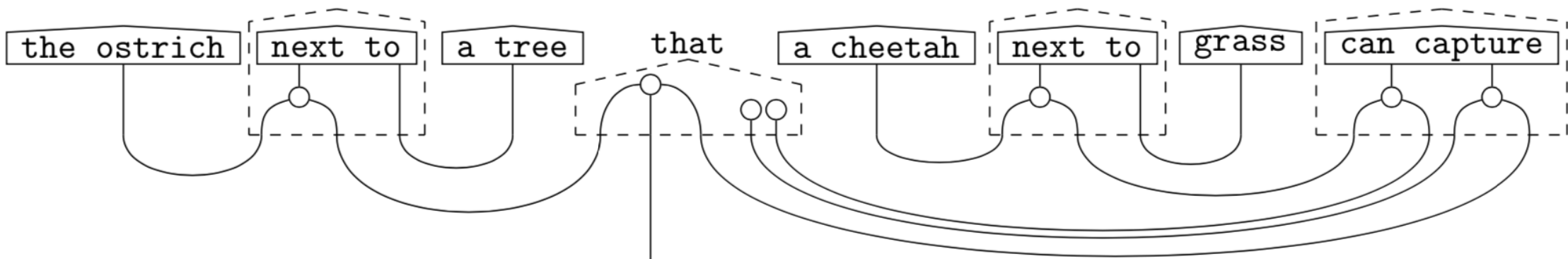
knight

pawn

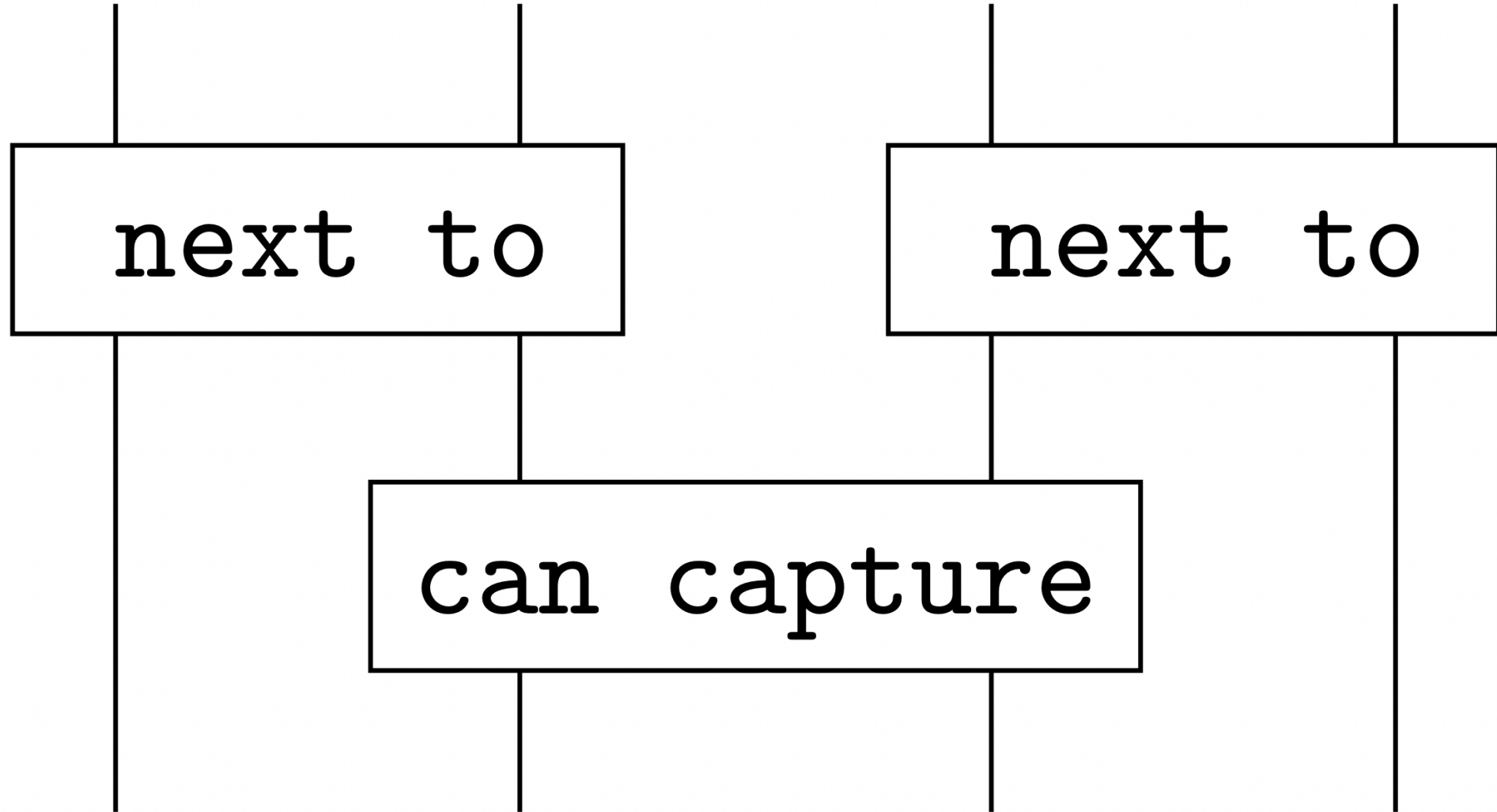
king

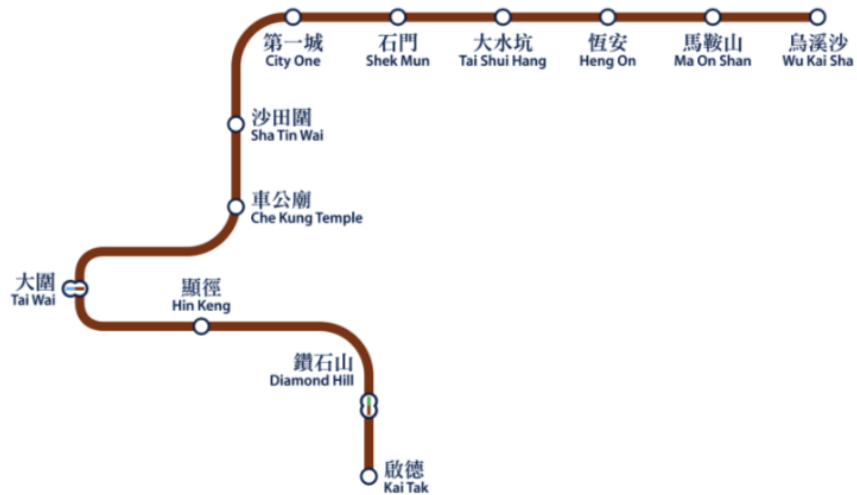
next to

can capture



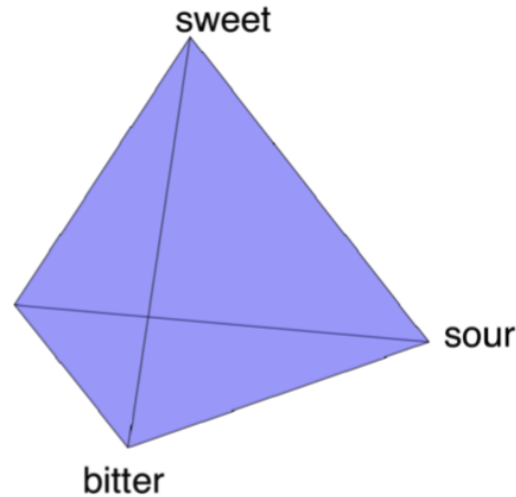
grass cheetah ostrich tree





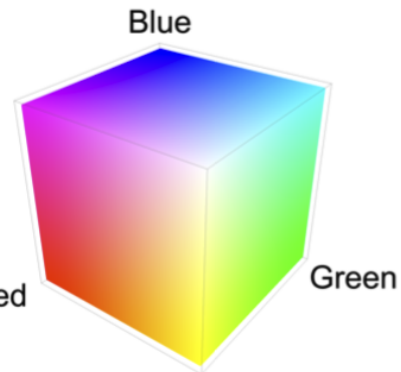
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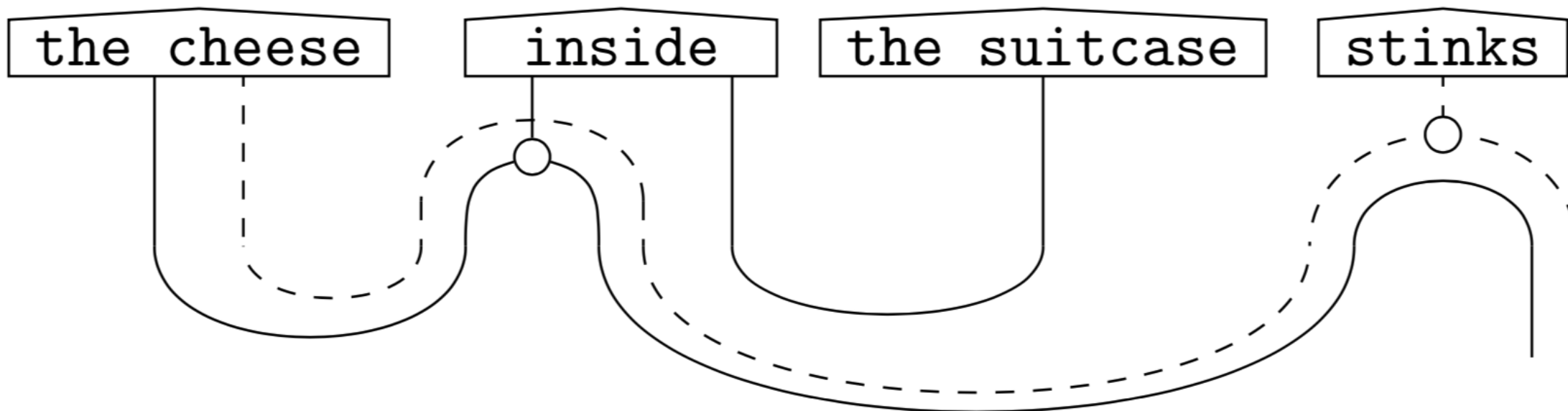
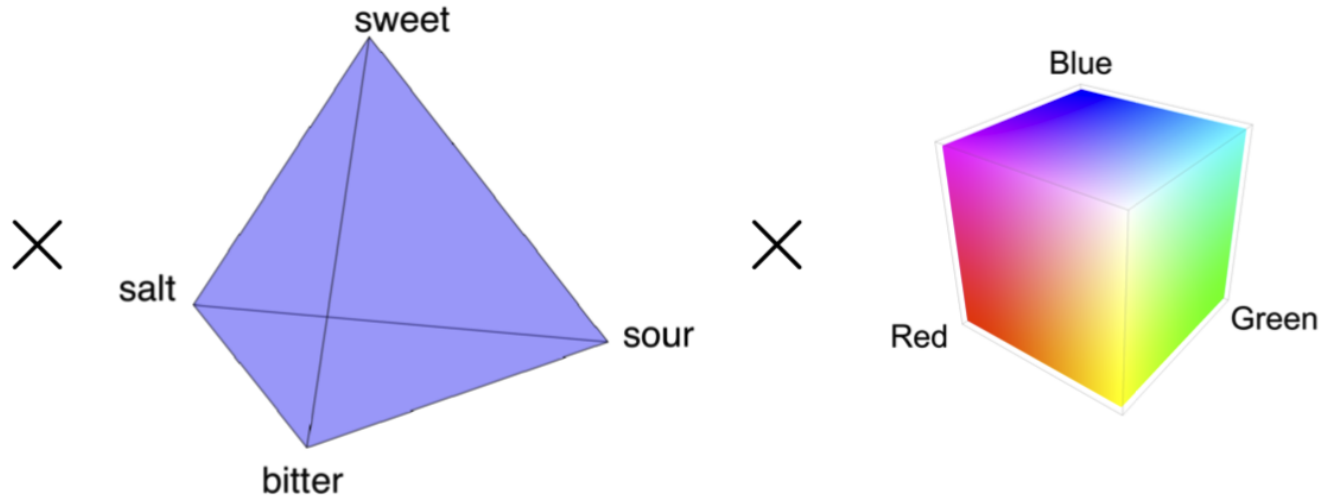
salt



×

Red





cheese

suitcase

inside

stinks



Distilling Text into Circuits

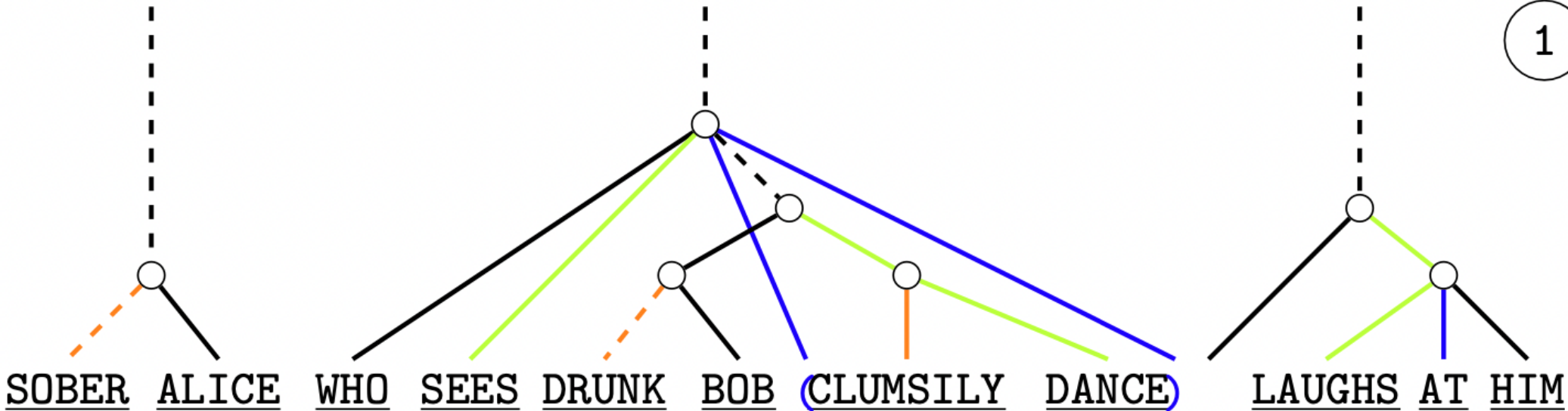
Vincent Wang-Maścianica^{†‡}, Jonathon Liu[†] and Bob Coecke[†]

[†]Cambridge Quantum, Compositional Intelligence Team, Oxford

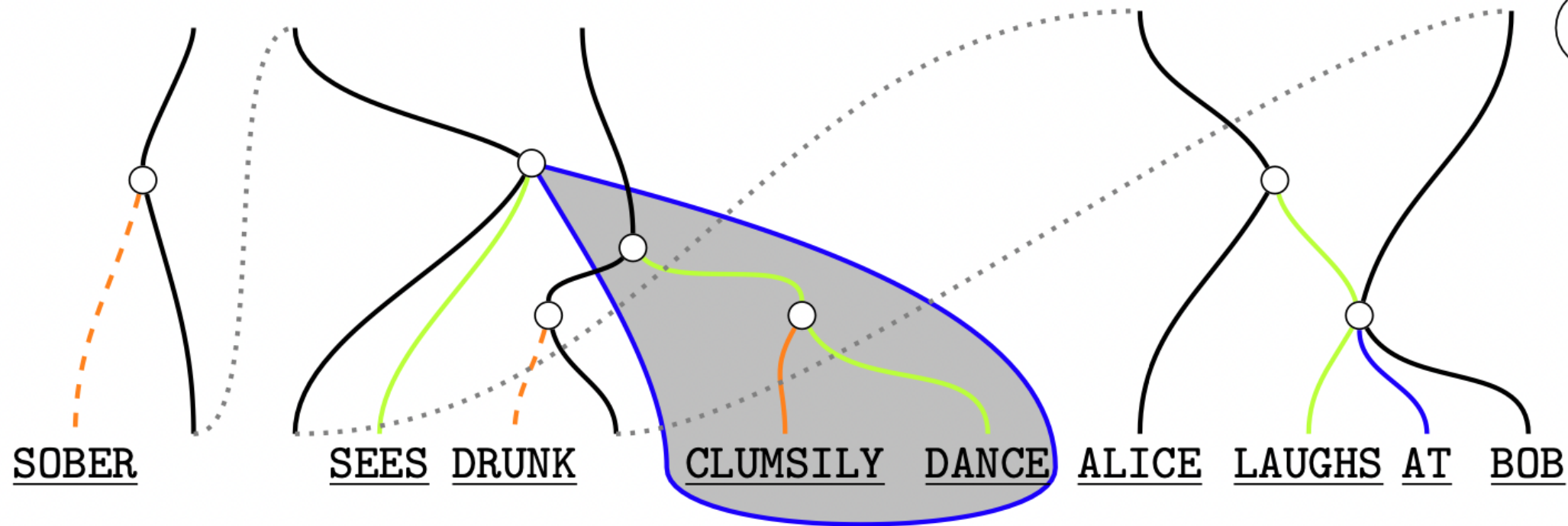
[‡]Oxford University, Department of Computer Science

February 23, 2022

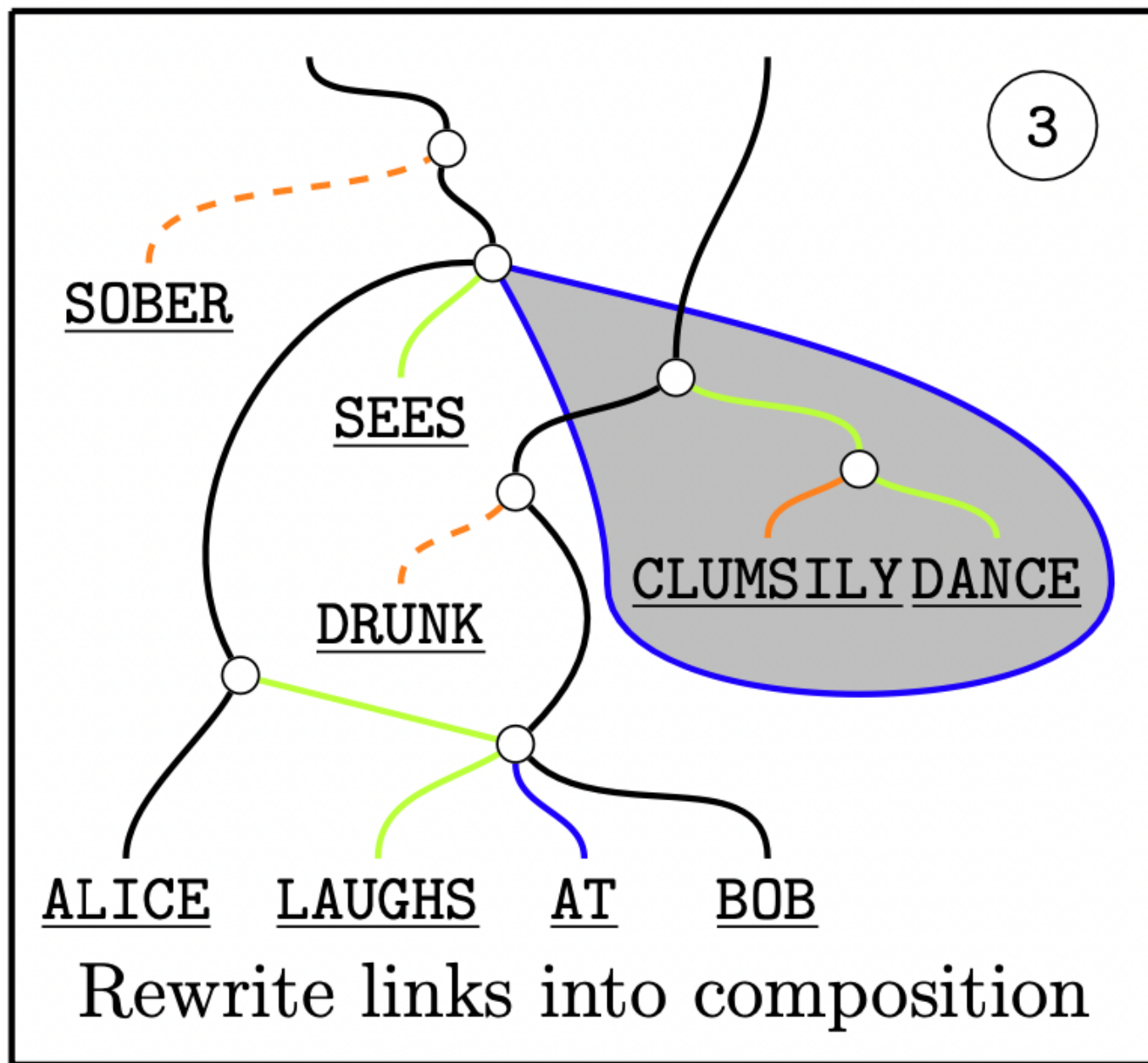
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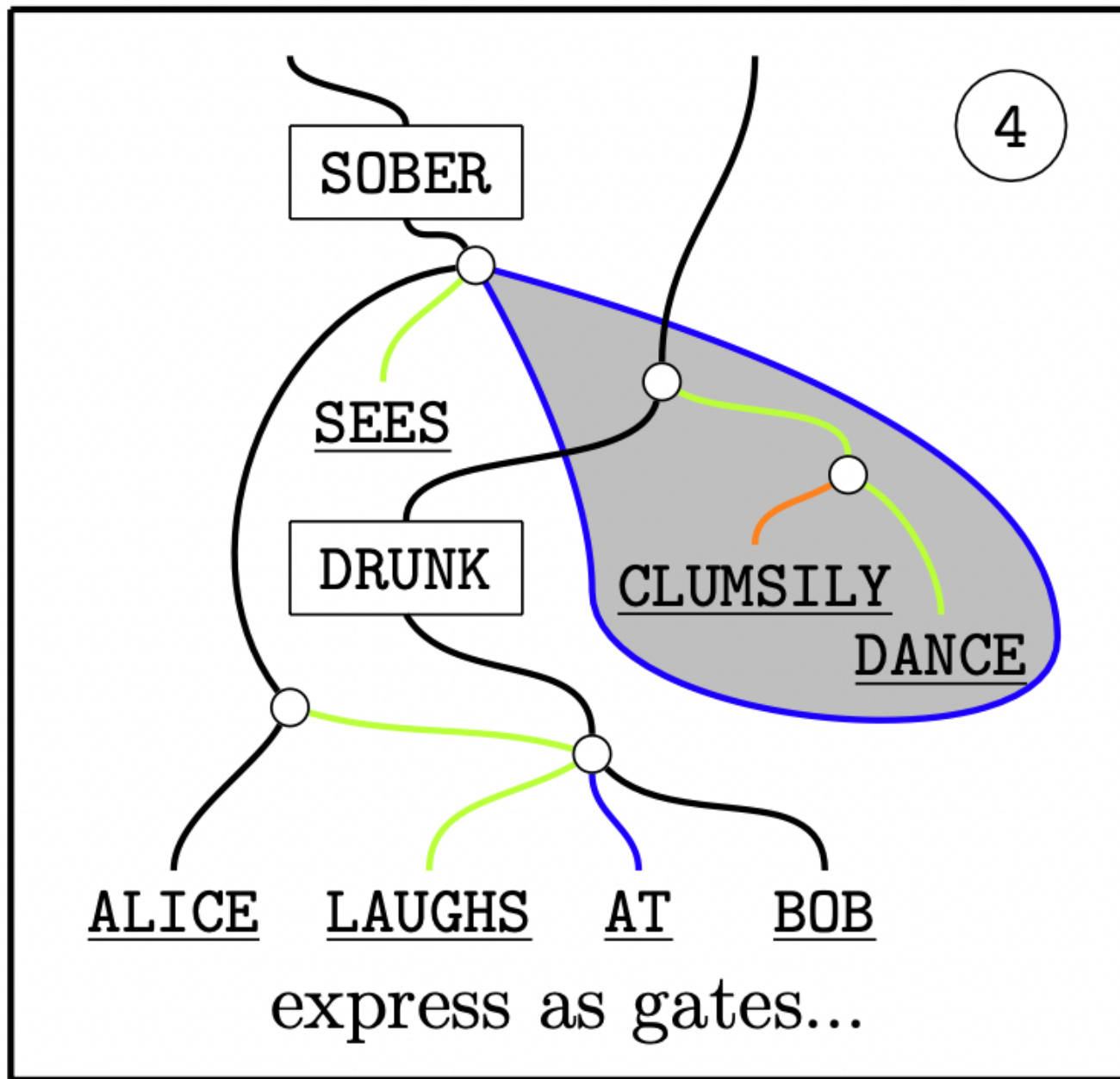


Text with hybrid grammar

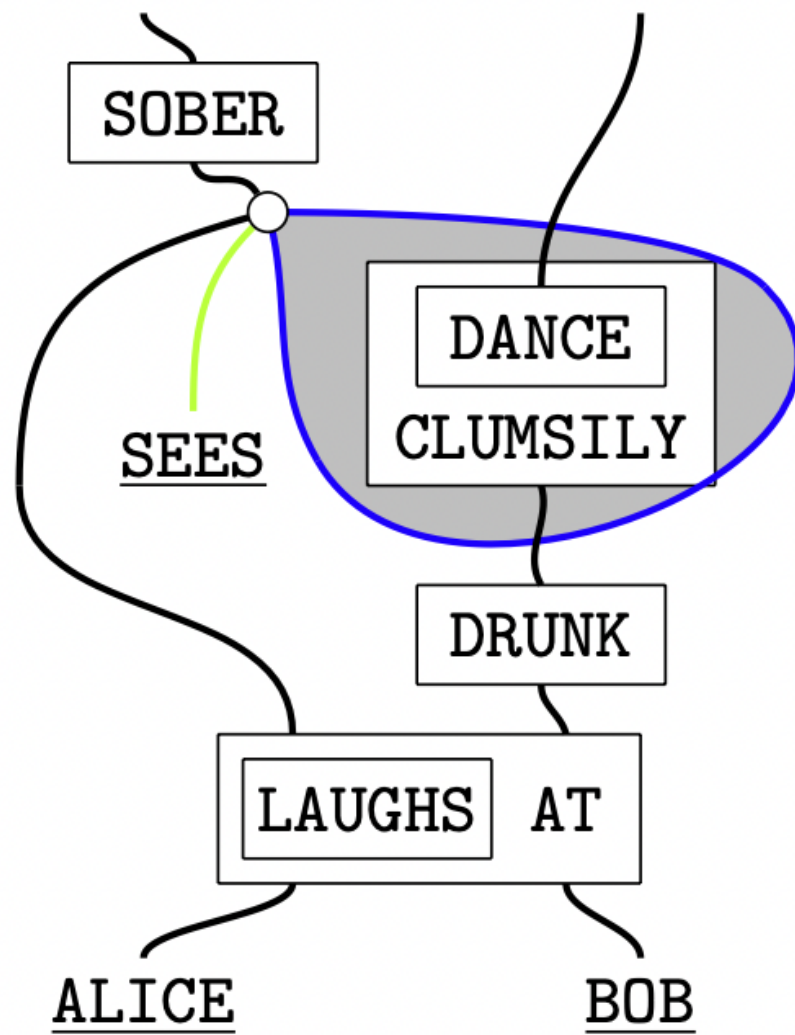


The same data, as a text diagram





5



...and boxes...

6

ALICE

BOB

SOBER

SEES

DANCE

CLUMSILY

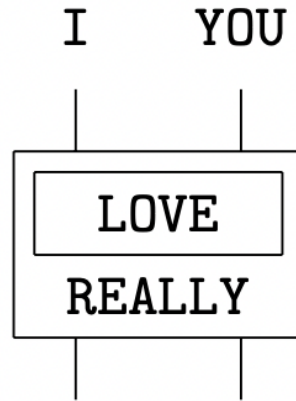
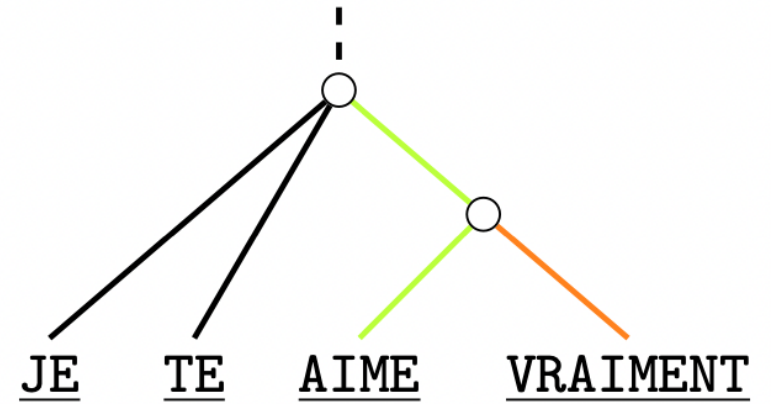
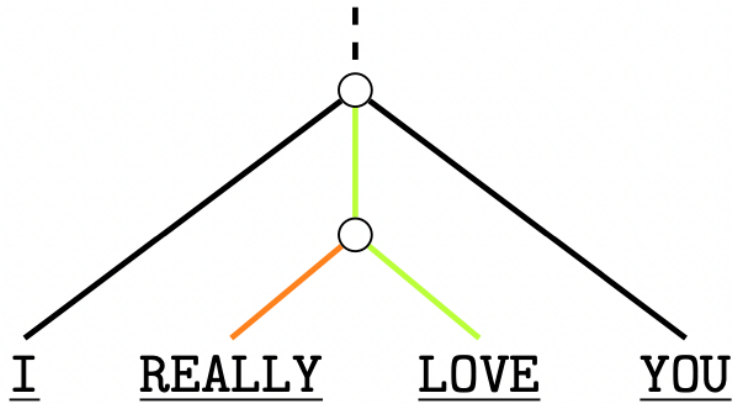
DRUNK

LAUGHS

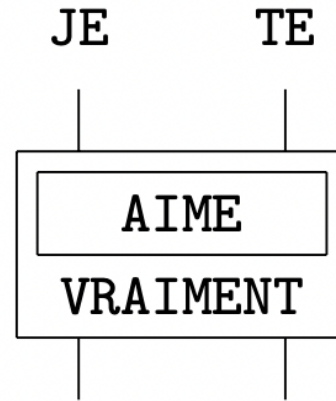
AT

...to get a circuit

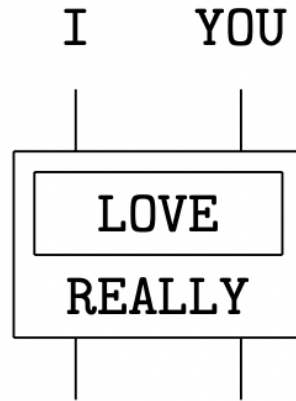
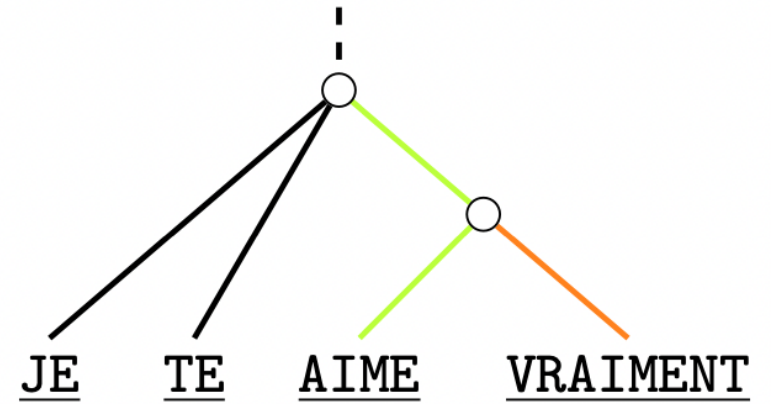
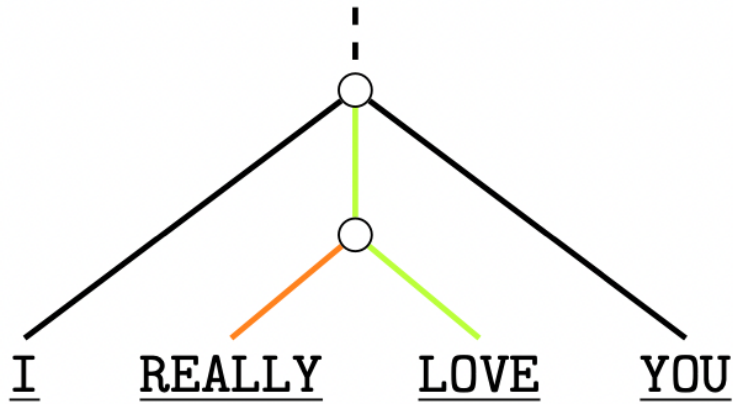
Different languages become the same!



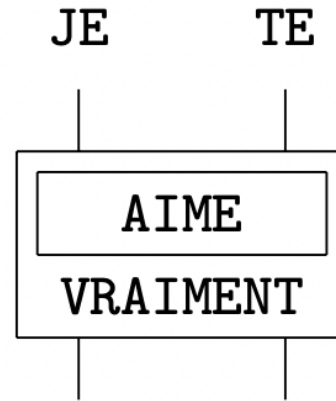
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Different languages become the same!

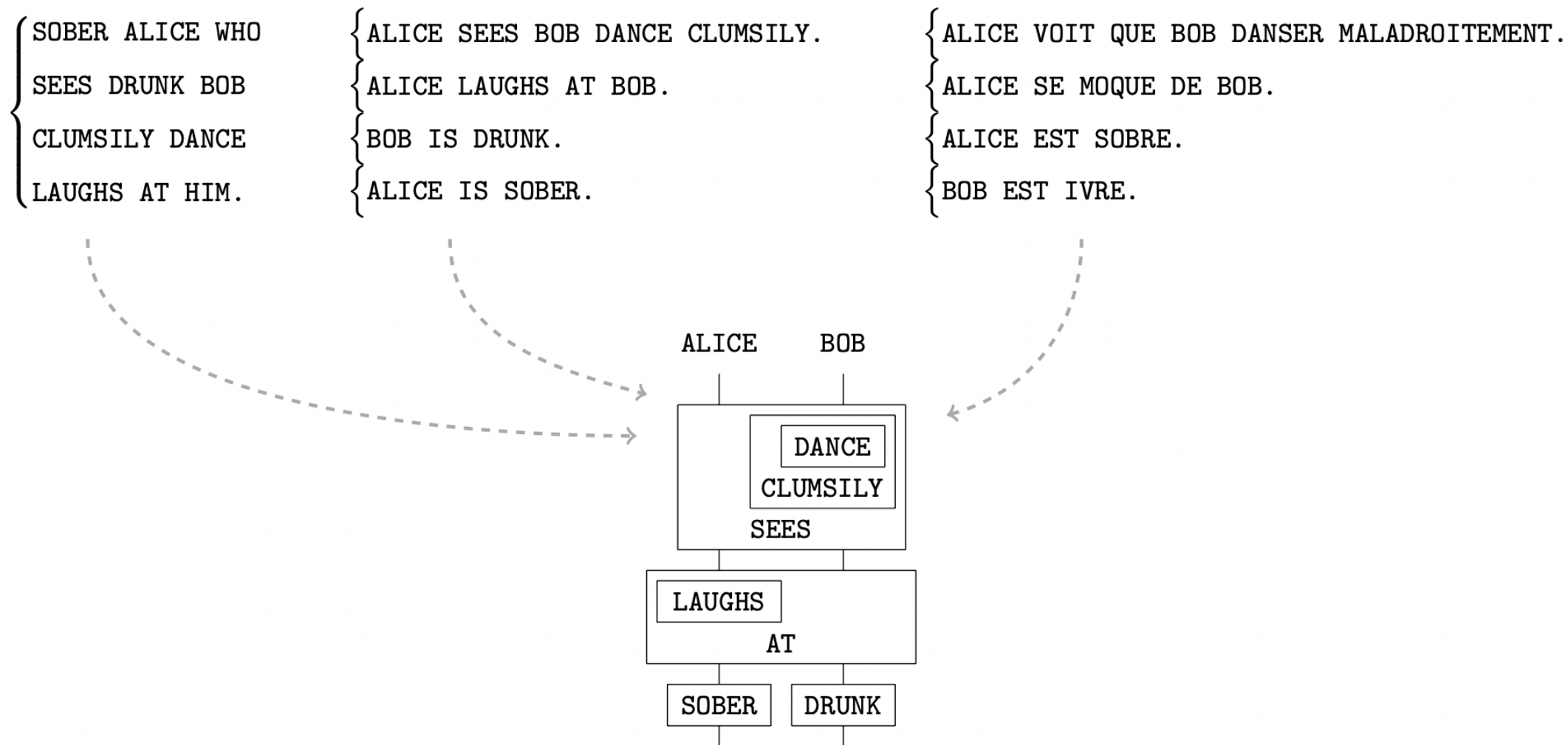


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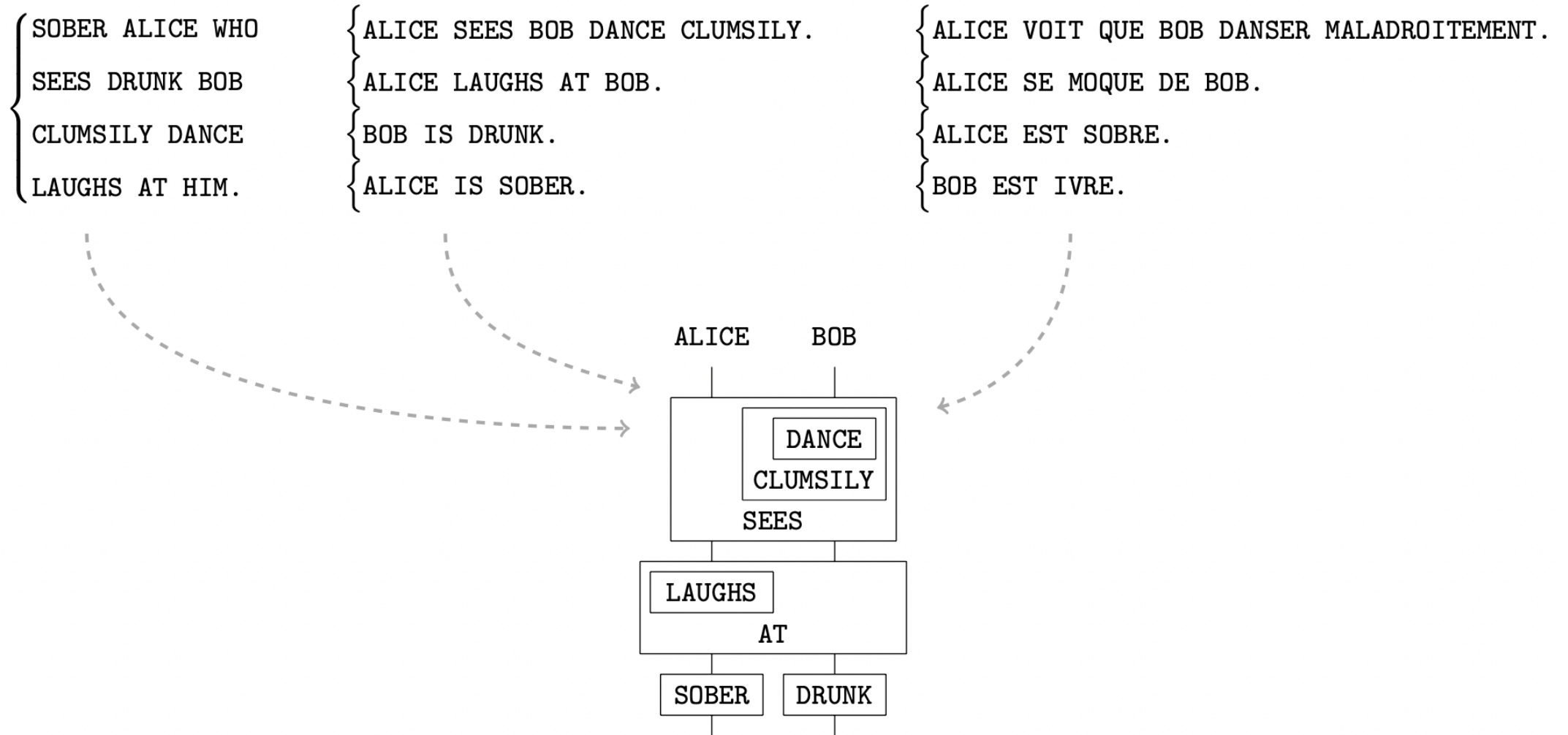


word order-conventions vanish

Different styles become the same!



Different styles become the same!



fancy writing show-off vanishes



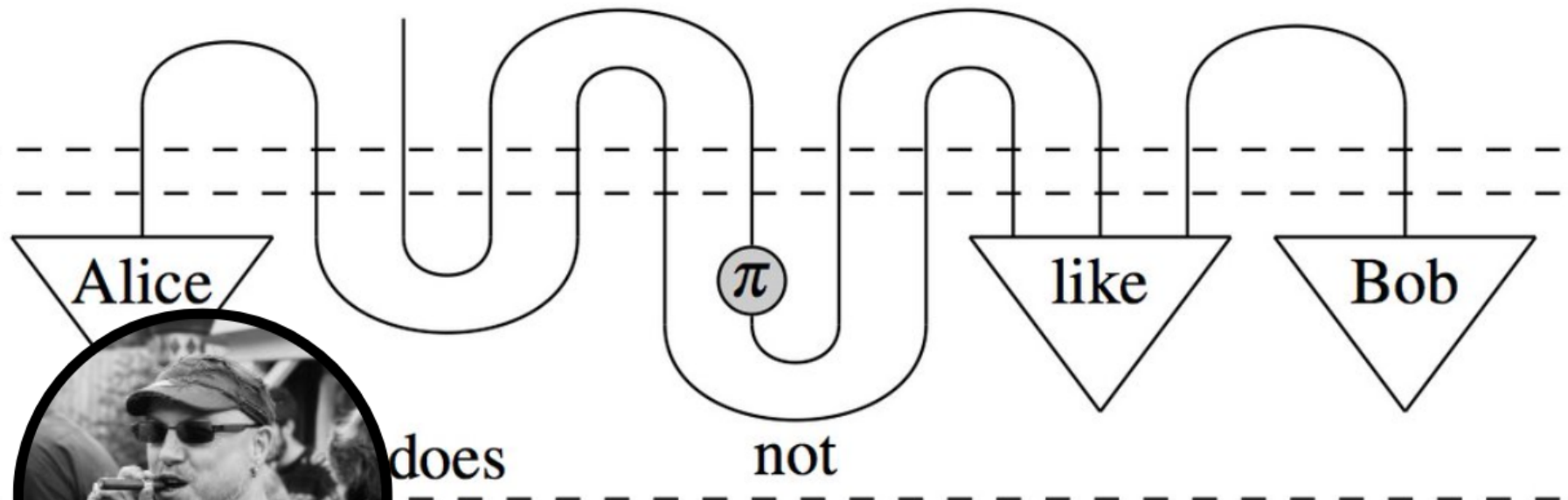
bOb cOeCke

@coecke

Chief Scientist @ CQ/Quantinuum

Ex Professor @ Oxford University (CS)

Emeritus Professor @ Wolfson College (Ox)



Edit profile