Title: From quantum to cognition in pictures.

Date: Aug 02, 2018 11:30 AM

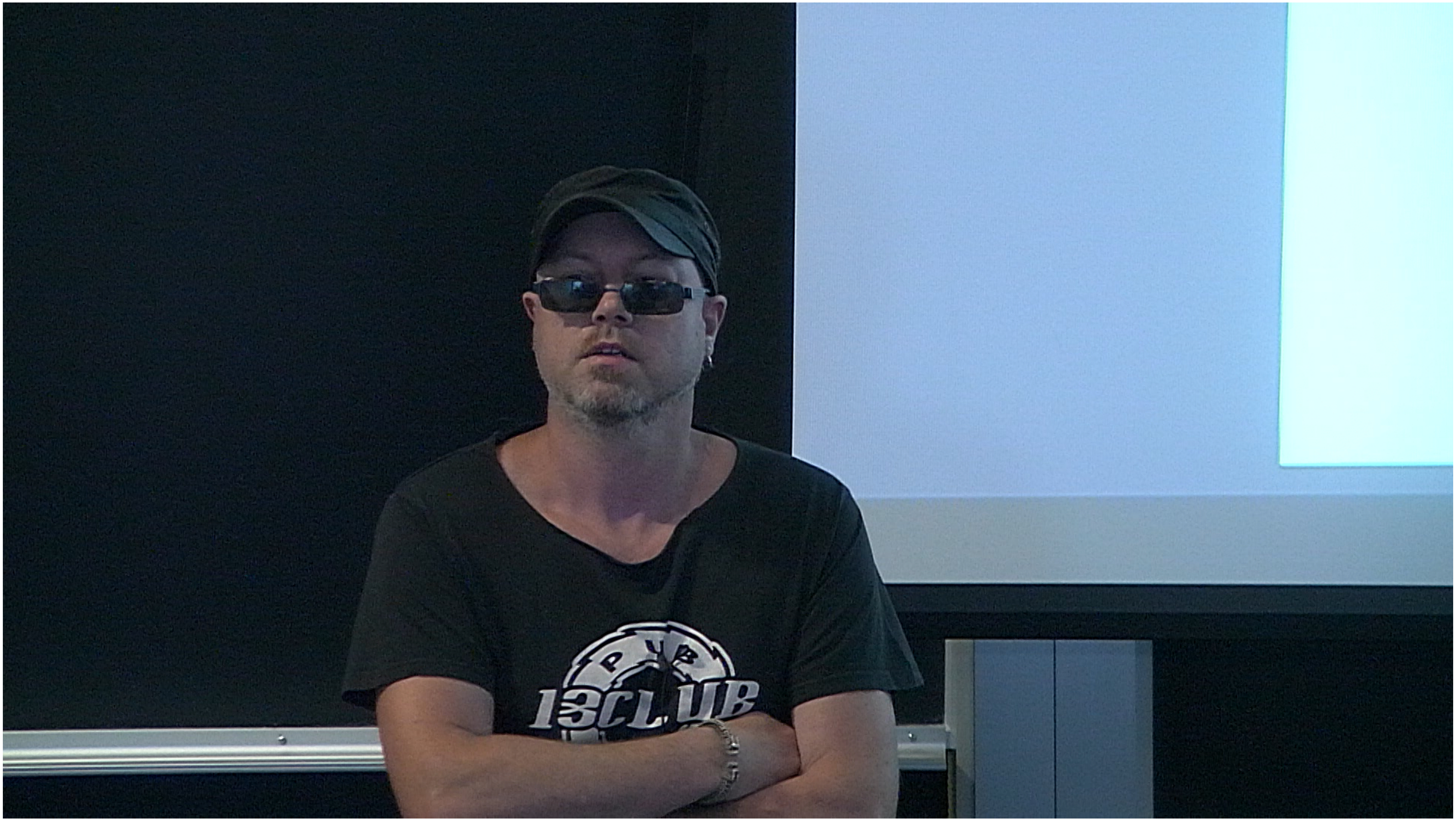
URL: http://pirsa.org/18080034

Abstract: For well over a decade, we developed an entirely pictorial (and formally rigorous!) presentation of quantum theory [*]. At the present, experiments are being setup aimed at establishing the age at which children could effectively learn quantum theory in this manner. Meanwhile, the pictorial language has also been successful in the study of natural language, and very recently we have started to apply it to model cognition, where we employ GPT-alike models. We present the key ingredients of the pictorial language language as well as their interpretation across disciplines.

[*] B. Coecke & A. Kissinger (2017) Picturing Quantum Processes. A first course on quantum theory and diagrammatic reasoning. Cambridge University Press.

every QF conference needs a crackpot

Page 1 of 89


PUB
13CLUB

QUANTUM LINGUISTICS Leap forward for artificial intelligence

NewScientist

WEEKLY 11 December 2010

FQXI ARTICLE September 29, 2013

Video Article: The Quantum Linguist

Bob Coecke has developed a new visual language that could be used to spell out a theory of quantum gravity—and help us understand human speech.

by Sophie Hebden

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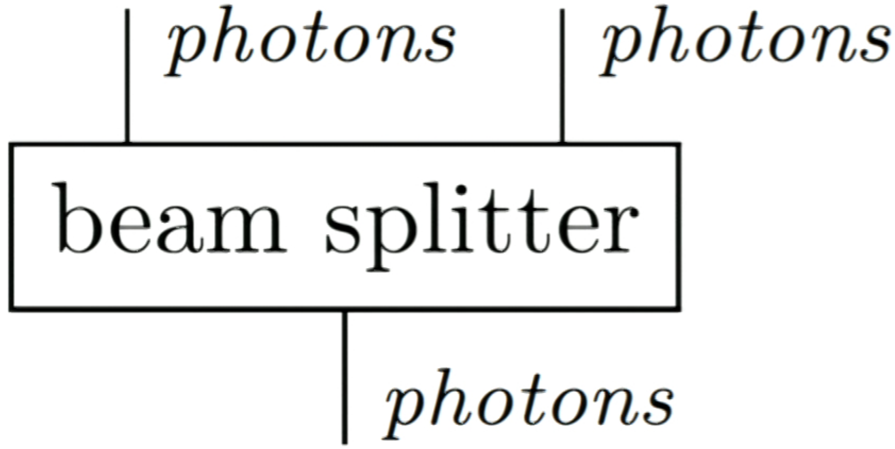
Quantum Mechanical Words and Mathematical Organisms

By Joselle Kehoe | May 16, 2013 | 10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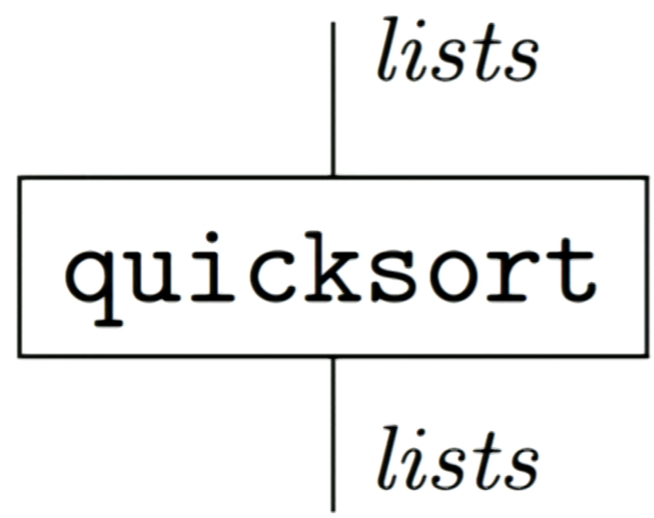
photons
beam splitter
photons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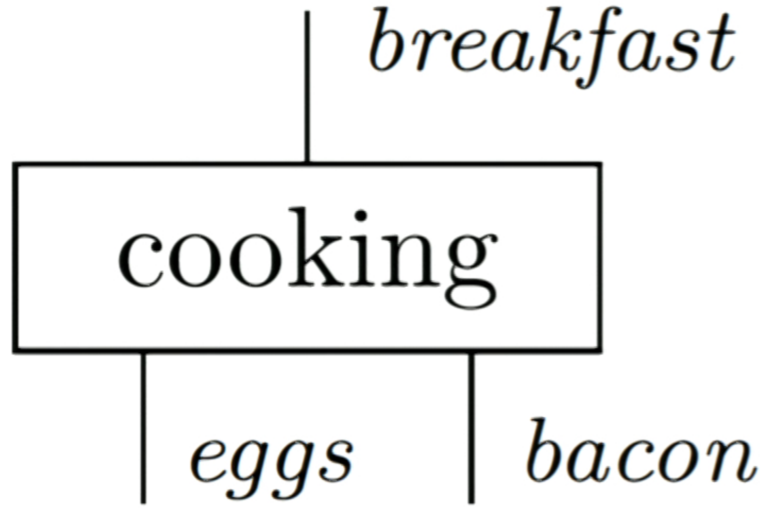
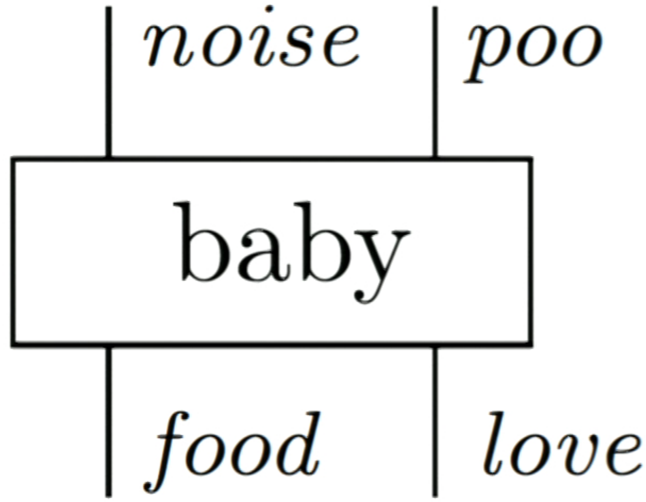
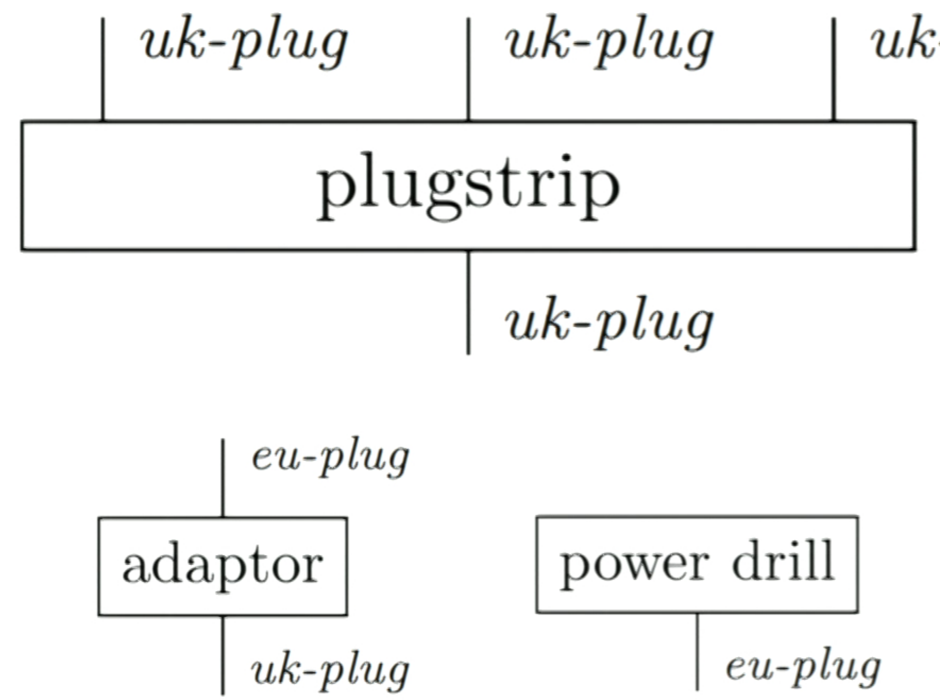
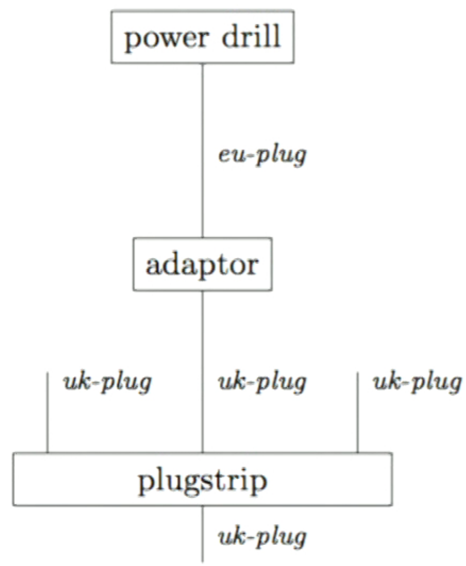
quicksort
lists


breakfast
cooking
eggs
bacon


noise
poo
baby
food
love


uk-plug
uk-plug
uk-plug
plugstrip
uk-plug
eu-plug
adaptor
uk-plug
power drill
eu-plug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eu-plug
adaptor
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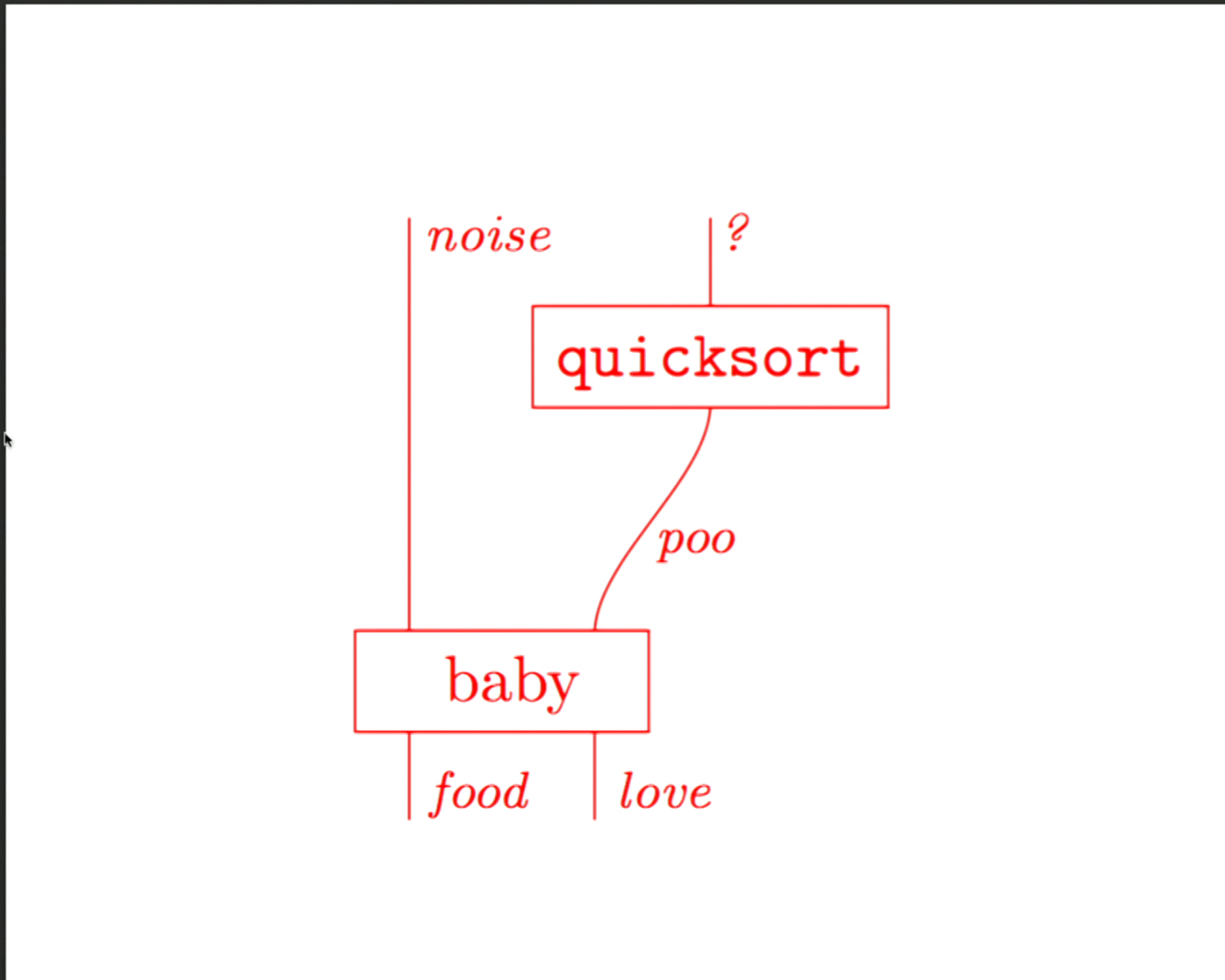
uk-plug
uk-plug
plugstrip
uk-plug

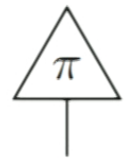
:=



noise
?
quicksort
poo
baby
food
love

State :=

Test :=

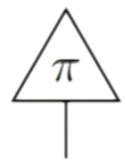


Number :=

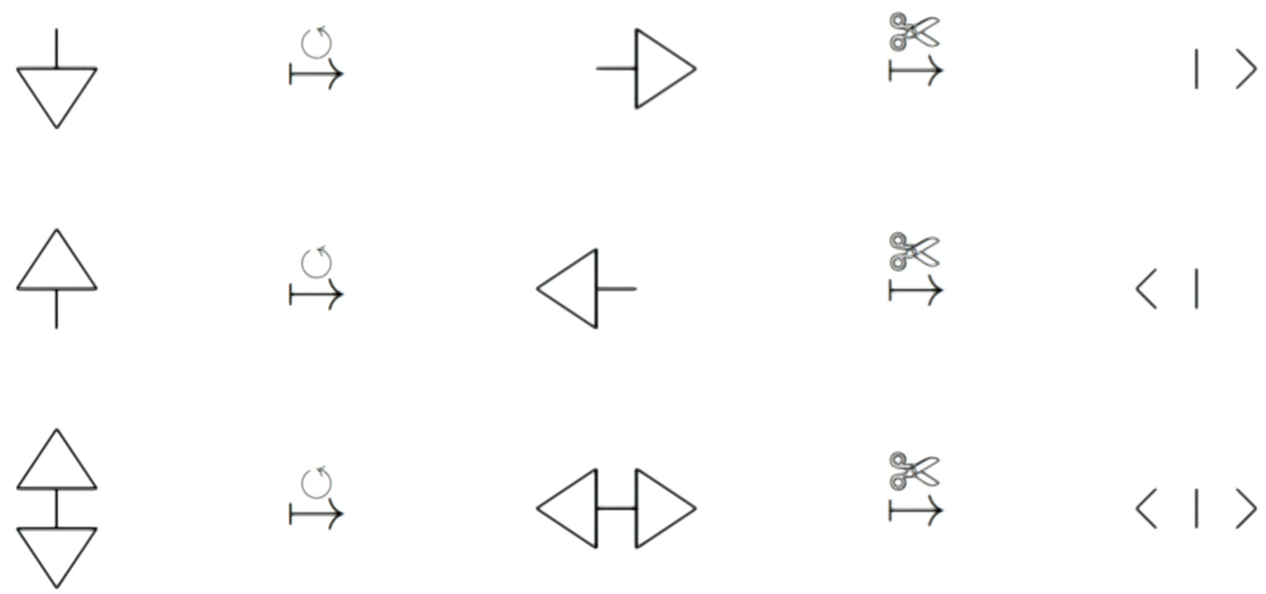
Number :

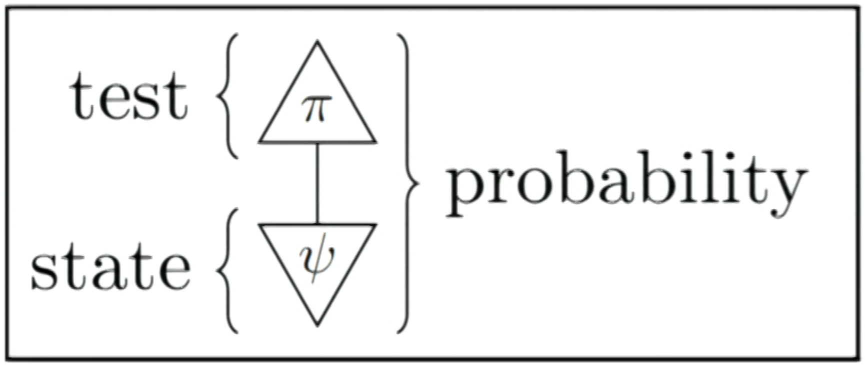
State :=

Test :=



Number :=

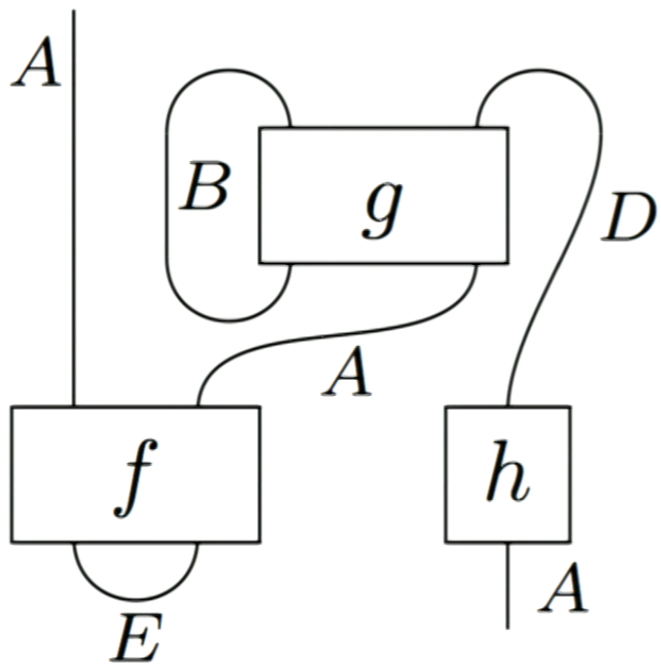



test
π
state
ψ
probability

quantum wires and boxes

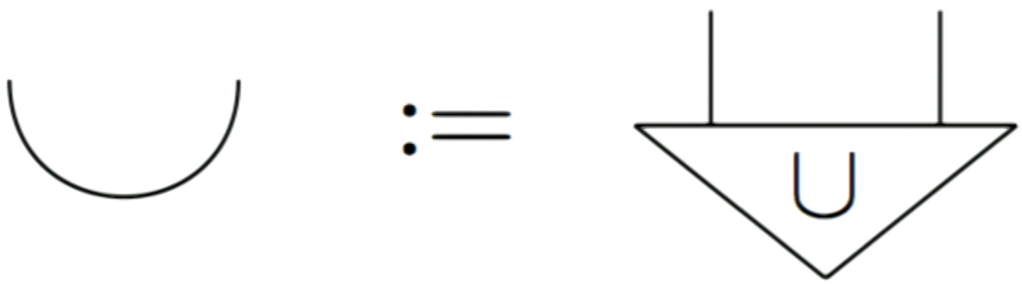
When two systems, of which we know the states by their respective representatives, enter into temporary physical interaction due to known forces between them, and when after a time of mutual influence the systems separate again, then they can no longer be described in the same way as before, viz. by endowing each of them with a representative of its own. ***I would not call that one but rather the characteristic trait of quantum mechanics****, the one that enforces its entire departure from classical lines of thought.*

— Erwin Schrödinger, 1935.

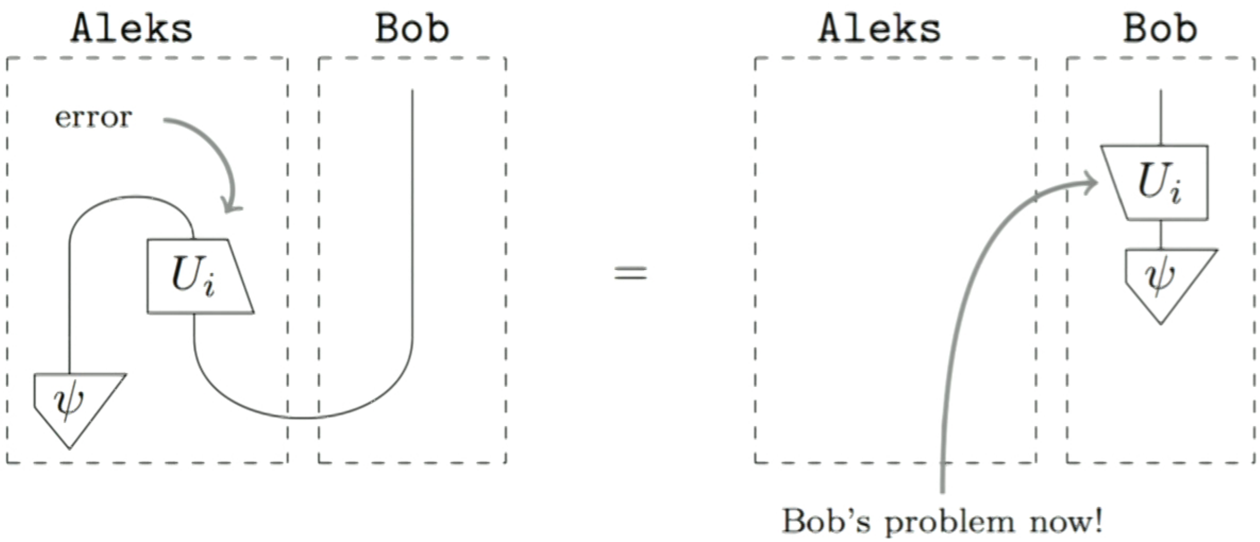


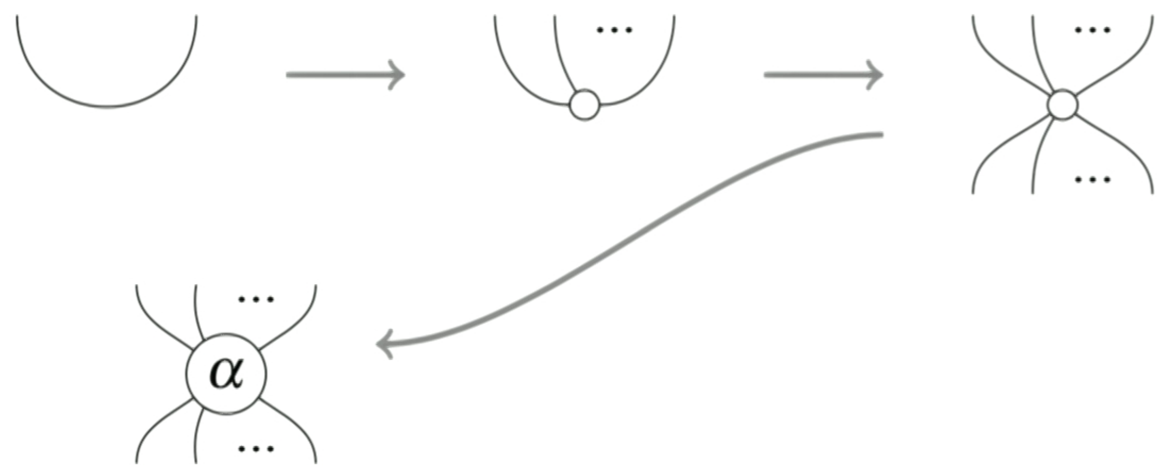
A
B
g
D
A
f
h
A
E

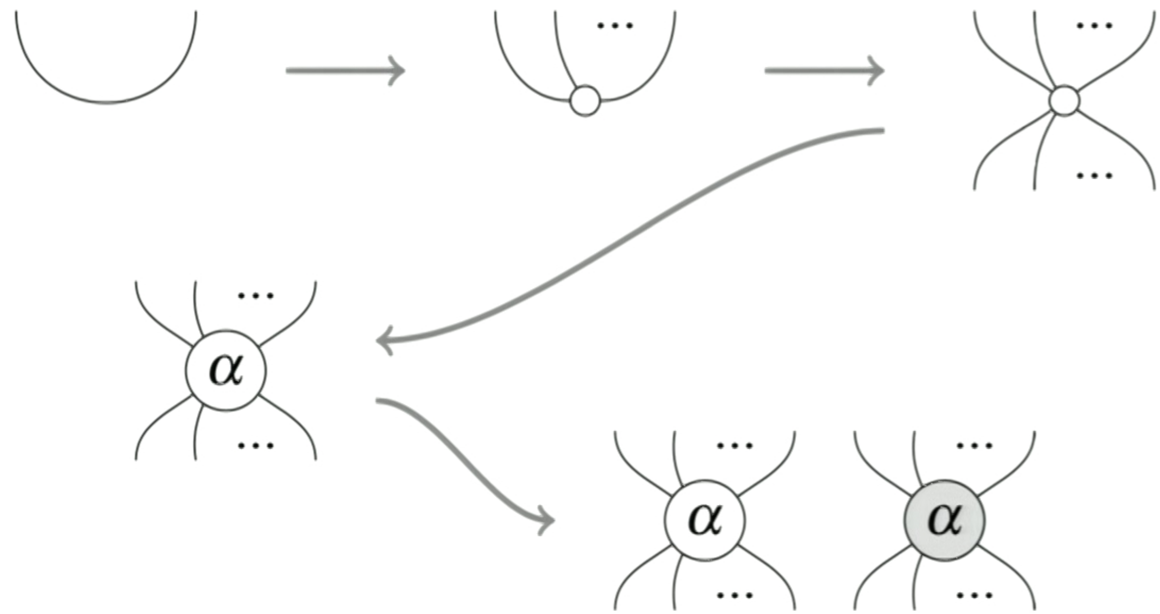
– entanglement –



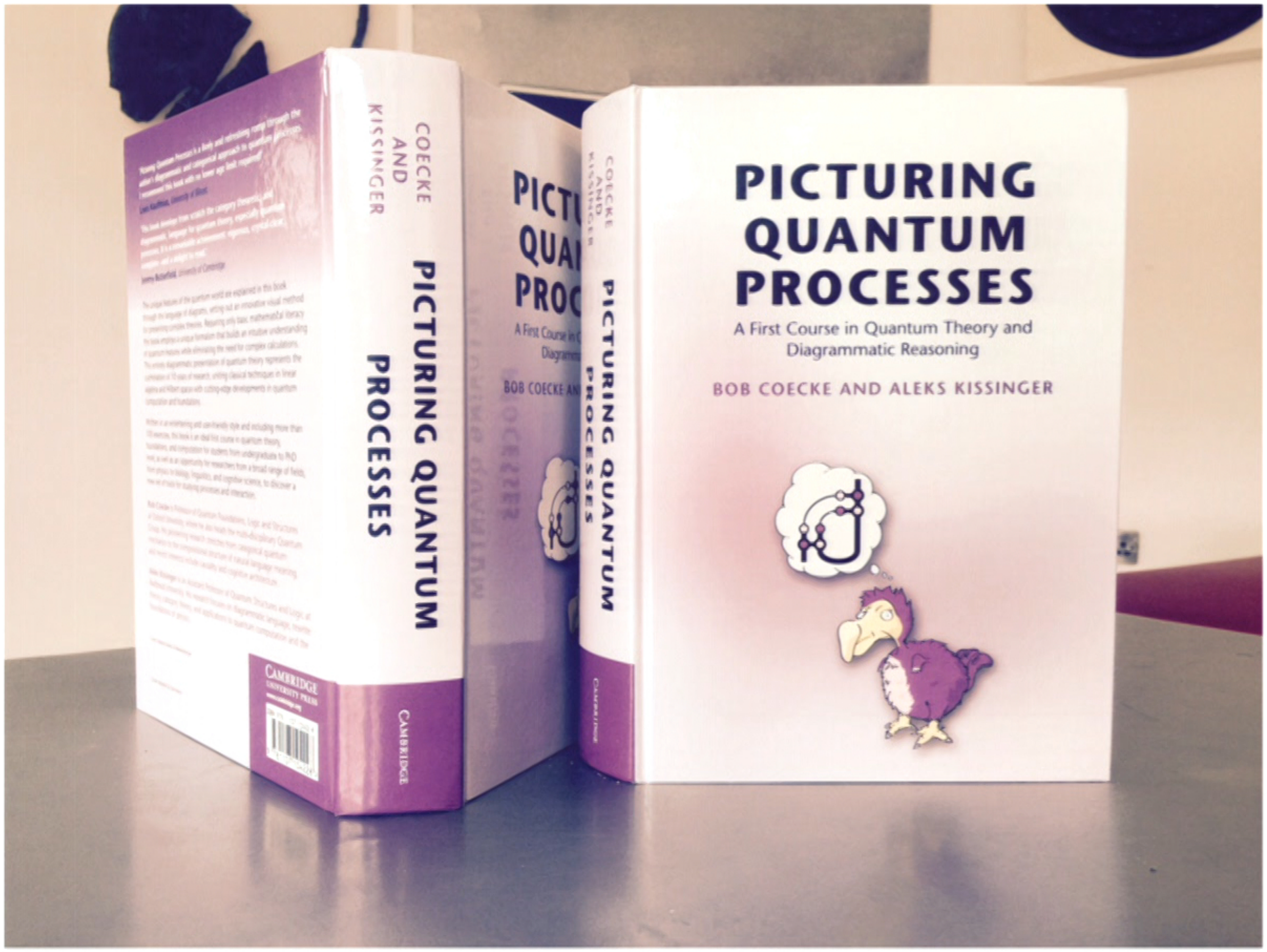
– quantum teleportation –

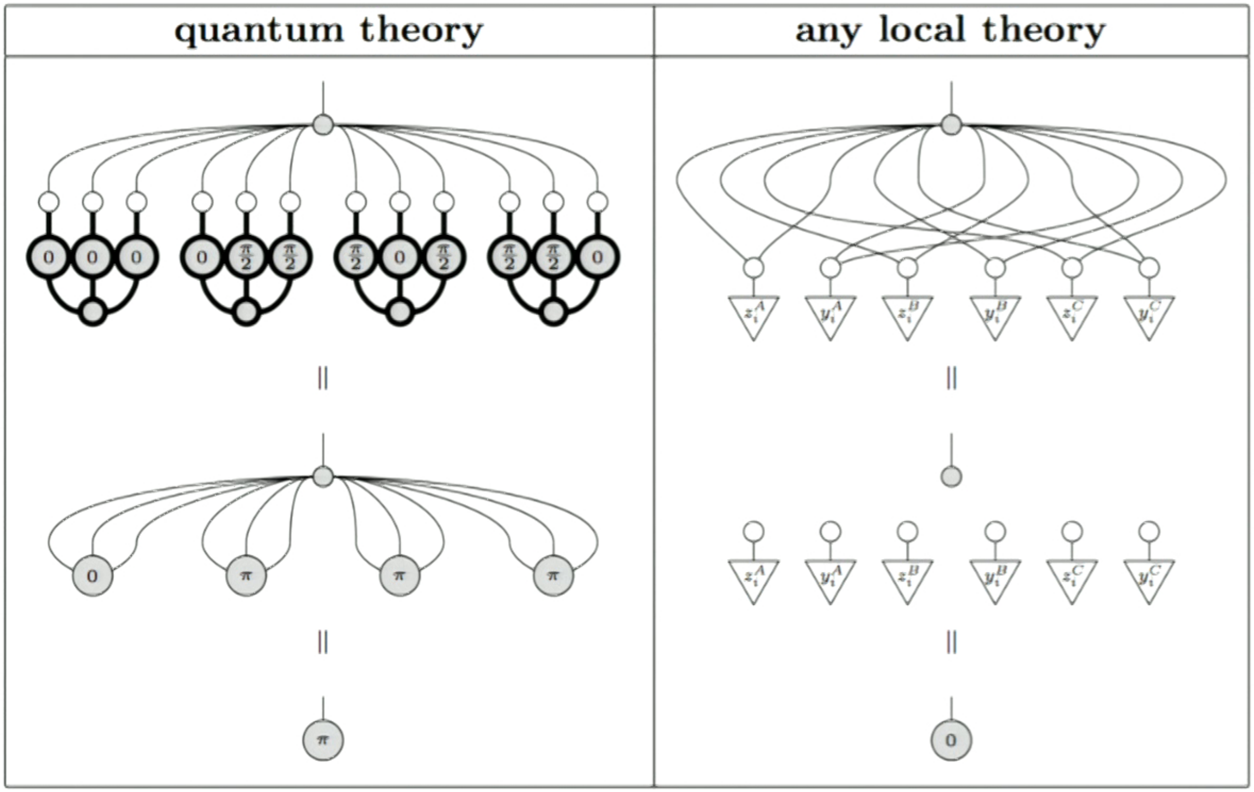



α



α
α
α


PICTURING QUANTUM PROCESSES
A First Course in Quantum Theory and Diagrammatic Reasoning
BOB COECKE AND ALEKS KISSINGER
COECKE AND KISSINGER
PICTURING QUANTUM PROCESSES
CAMBRIDGE



quantum theory
any local theory

– completeness –

Peter Selinger (2008) Any equational statement is provable for string diagrams if and only if it is provable for Hilbert spaces and linear maps.

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Miriam Backens (2012) ... stabiliser restriction of **ZX-calculus**...

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Amar Hadzihasanovic (2015) ... Z/W (with some restriction)...

– *completeness* –

Peter Selinger (2008) Any equational statement is provable for string diagrams if and only if it is provable for Hilbert spaces and linear maps.

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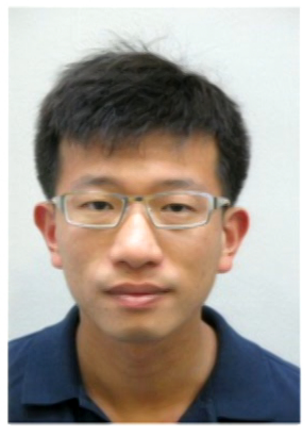
Amar Hadzihasanovic (2015) ... Z/W (with some restriction)...

E. Jeandel, S. Perdrix & R. Vilmart (2017) ... Clifford +T...

Amar Hadzihasanovic (2017) ... Z/W (no restriction)...

Kang Feng Ng and Quanlong Wang (2017) ... everything...



– completeness –

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Miriam Backens (2012) ... stabiliser restriction of **ZX-calculus**...

Amar Hadzihasanovic (2015) ... Z/W (with some restriction)...

E. Jeandel, S. Perdrix & R. Vilmart (2017) ... Clifford +T...

Amar Hadzihasanovic (2017) ... Z/W (no restriction)...

Kang Feng Ng and Quanlong Wang (2017) ... everything...

E. Jeandel, S. Perdrix & R. Vilmart (2018) ... everything, better...

Kang Feng Ng and Quanlong Wang (2018) ... everything, even better...

– completeness –

Peter Selinger (2008) Any equational statement is provable for string diagrams if and only if it is provable for Hilbert spaces and linear maps.

Miriam Backens (2012) ... stabiliser restriction of **ZX-calculus**...

Amar Hadzihasanovic (2015) ... Z/W (with some restriction)...

E. Jeandel, S. Perdrix & R. Vilmart (2017) ... Clifford +T...

Amar Hadzihasanovic (2017) ... Z/W (no restriction)...

Kang Feng Ng and Quanlong Wang (2017) ... everything...

E. Jeandel, S. Perdrix & R. Vilmart (2018) ... everything, better...

Kang Feng Ng and Quanlong Wang (2018) ... everything, even better...

E. Jeandel, S. Perdrix & R. Vilmart (yesterday) ... everything, even^2 better...

Kang Feng Ng and Quanlong Wang (4 hours ago) ... everything, even^3 better...

E. Jeandel, S. Perdrix & R. Vilmart (17.4 mins ago) ... everything, even^4 better...

Kang Feng Ng and Quanlong Wang (3.4 secs ago) ... everything, even^5 better...

– industry –

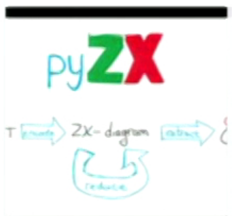
Cambridge Quantum Computing

RCHAIN COOPERATIVE

Will Zeng
2 hrs ·

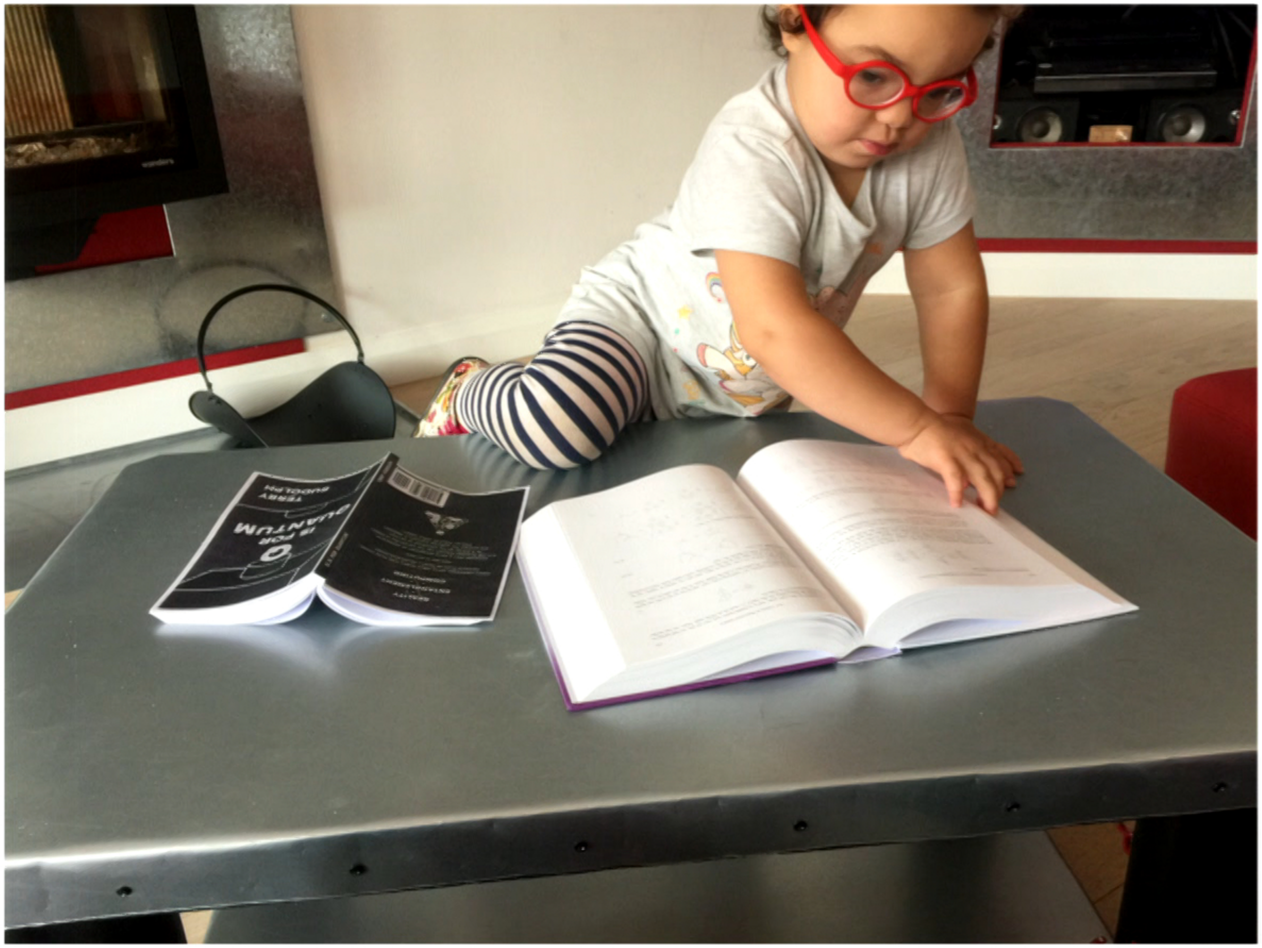
Excited to share that the next http://unitary.fund grant has been made to to Aleks Kissinger and John van de Wetering to support pyZX https://github.com/Quantomatic/pyzx, an optimizing quantum circuit compiler based on a diagrammatic semantics. Congrats!

https://www.youtube.com/watch?v=iC-KVdB8pf0

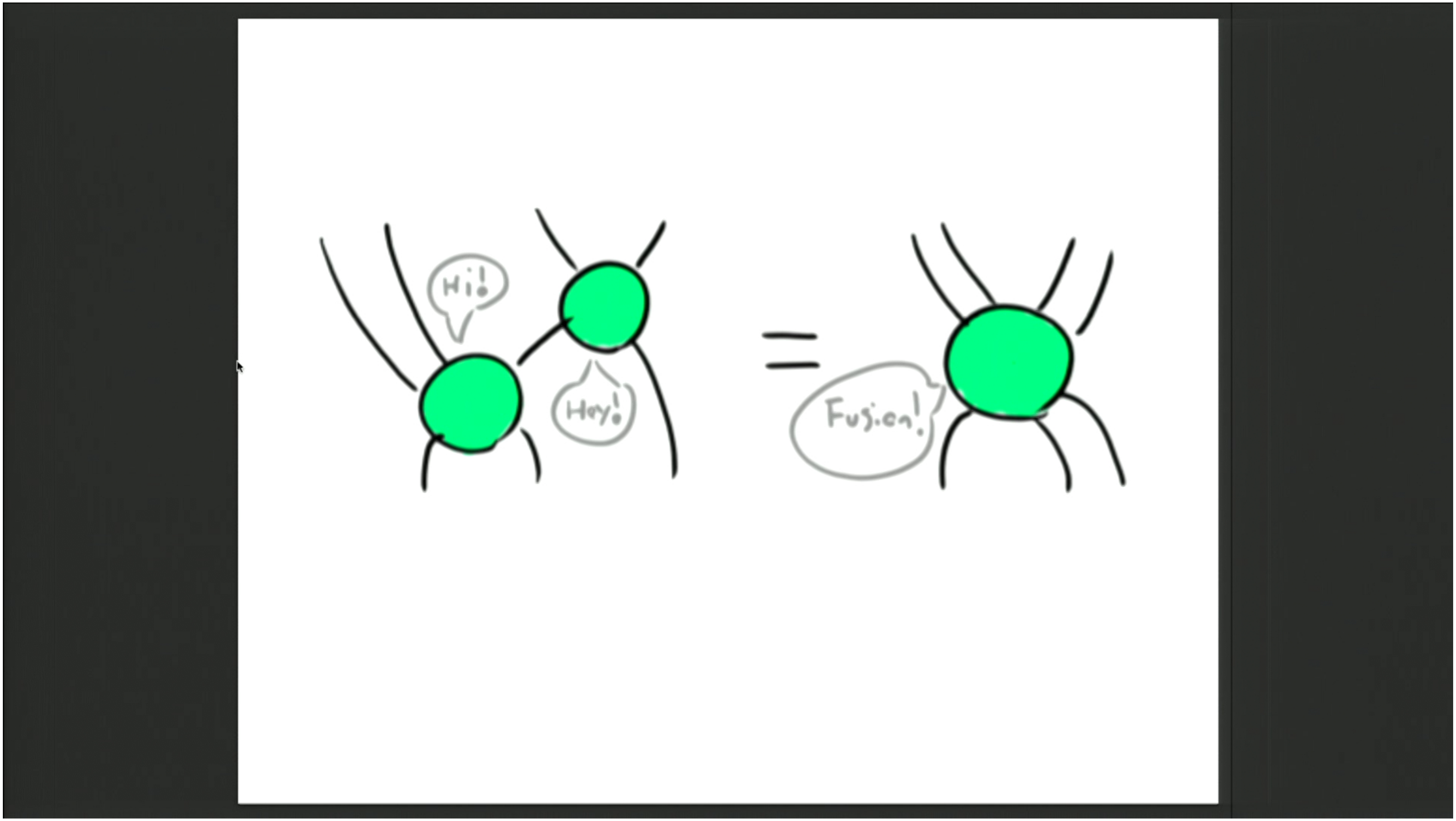


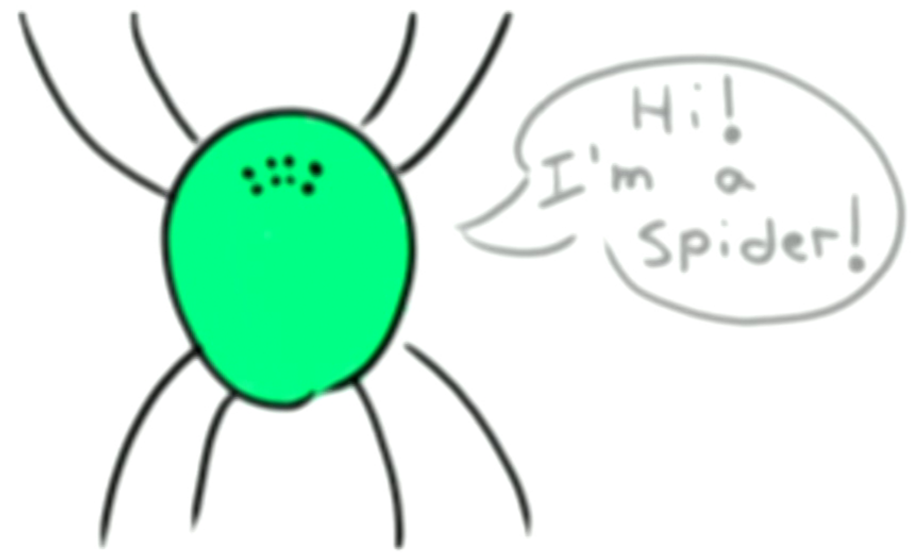
YOUTUBE.COM
pyZX
pyZX, a new tool for quantum circuit optimisation using the ZX calculus.

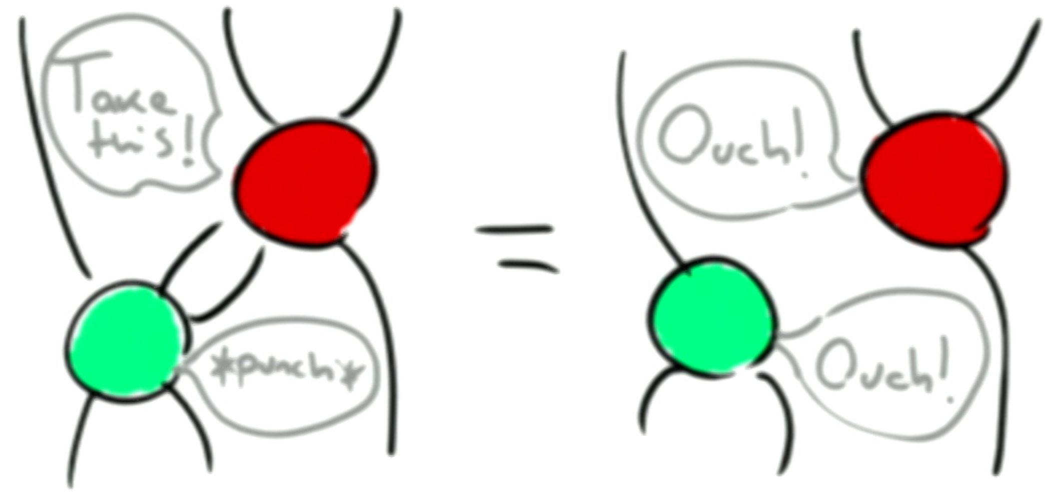
Any age restrictions?

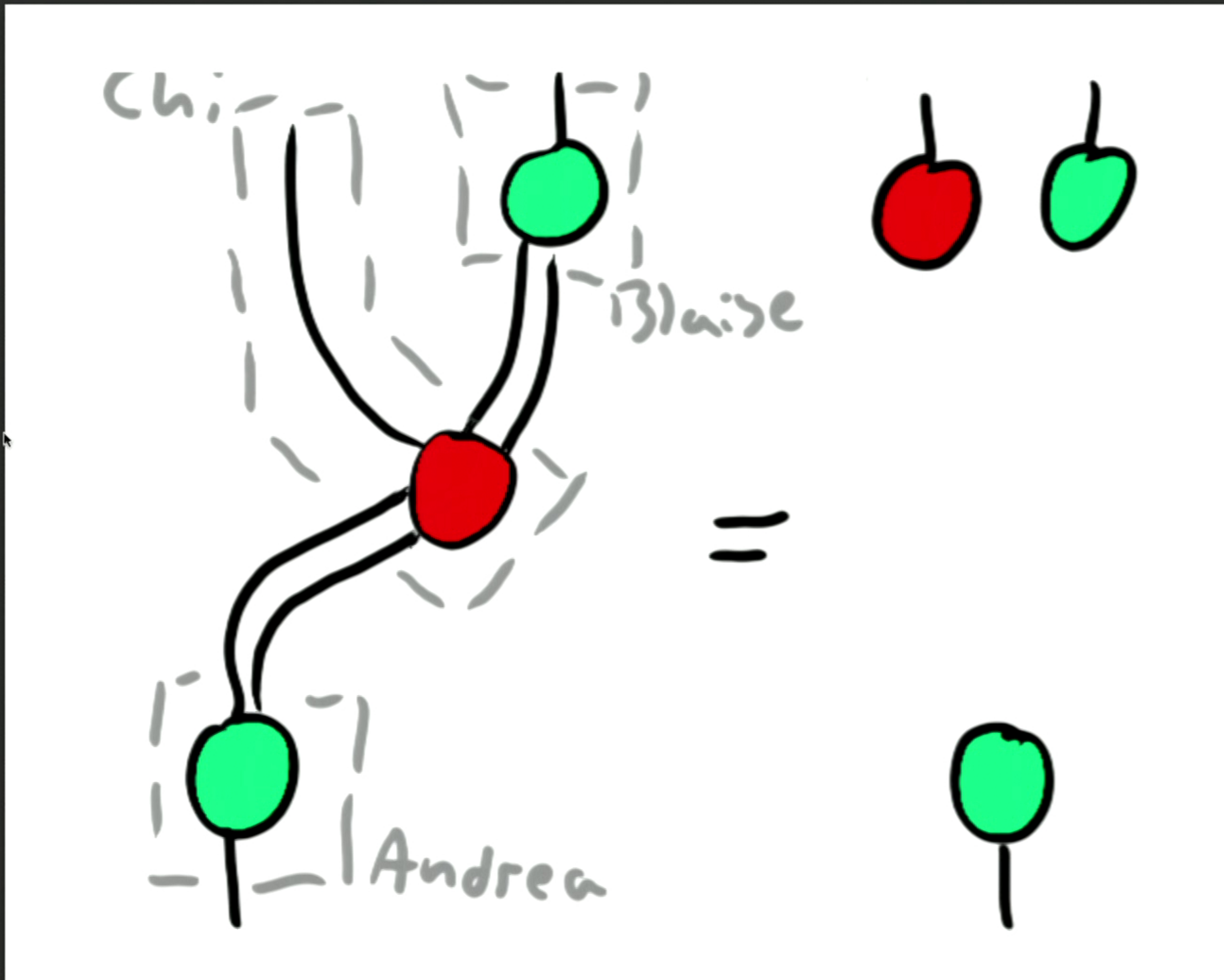


KIDS OUTPERFORM OXFORD STUDENTS AND DISCOVER QUANTUM FEATURES THAT TOOK TOP SCIENTISTS 60y

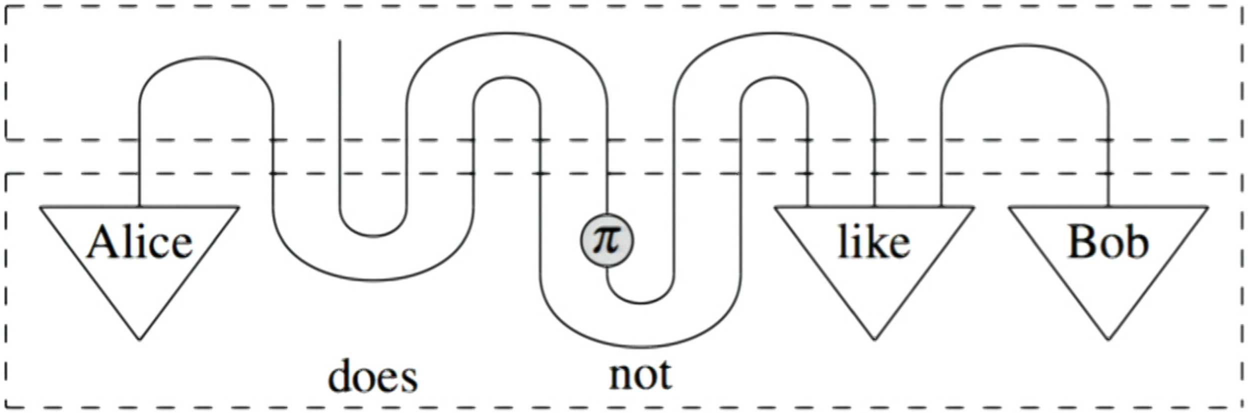

Hi!
Hey!
=
Fusion!


Hi!
I'm a
Spider!

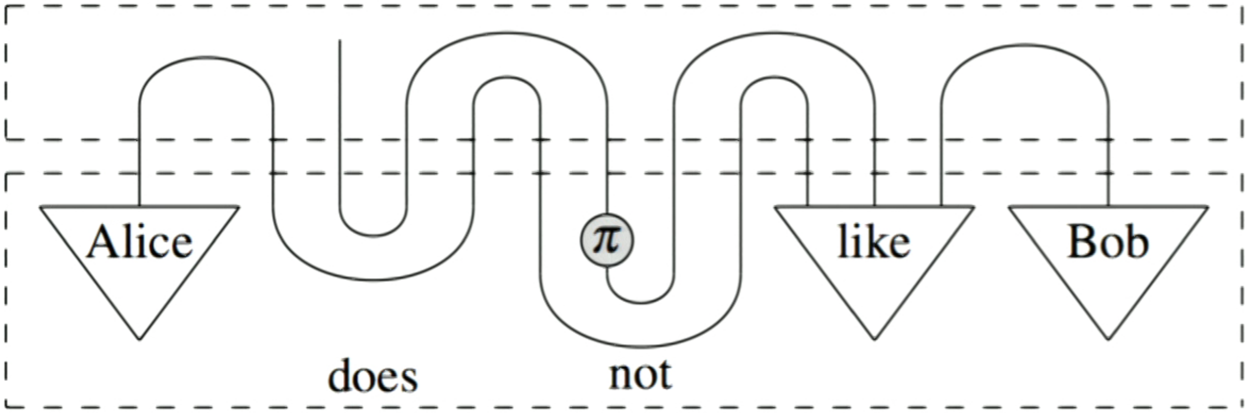

Take this!
punch
=
Ouch!
Ouch!


Chi
Blaise
Andrea
=

we have dictionaries for words



B. Coecke, M. Sadrzadeh & S. Clark (2010) *Mathematical foundations for a compositional distributional model of meaning*. Lambek Festschr. arXiv:1003.4394



- Bottom part: word meanings
- Top part: grammar

B. Coecke, M. Sadrzadeh & S. Clark (2010) *Mathematical foundations for a compositional distributional model of meaning*. Lambek Festschr. arXiv:1003.4394

Mathematics of grammar:

Lambek's Residuated monoids (1950's):

$$b \leq a \multimap c \Leftrightarrow a \cdot b \leq c \Leftrightarrow a \leq c \multimapinv b$$

so in particular,

$$a \cdot (a \multimap 1) \leq 1 \leq a \multimap (a \cdot 1)$$

$$(1 \multimapinv b) \cdot b \leq 1 \leq (1 \cdot b) \multimapinv b$$

Lambek's Pregroups (2000's):

$$a \cdot {}^{-1}a \leq 1 \leq {}^{-1}a \cdot a$$

$$b^{-1} \cdot b \leq 1 \leq b \cdot b^{-1}$$

Mathematics of grammar:

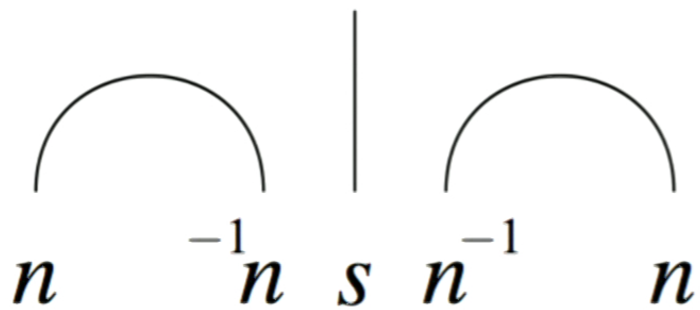
For noun type n, verb type is ${}^{-1}n \cdot s \cdot n^{-1}$, so:

Mathematics of grammar:

For noun type n, verb type is ${}^{-1}n \cdot s \cdot n^{-1}$, so:

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

As a diagram:



Mathematics of grammar:

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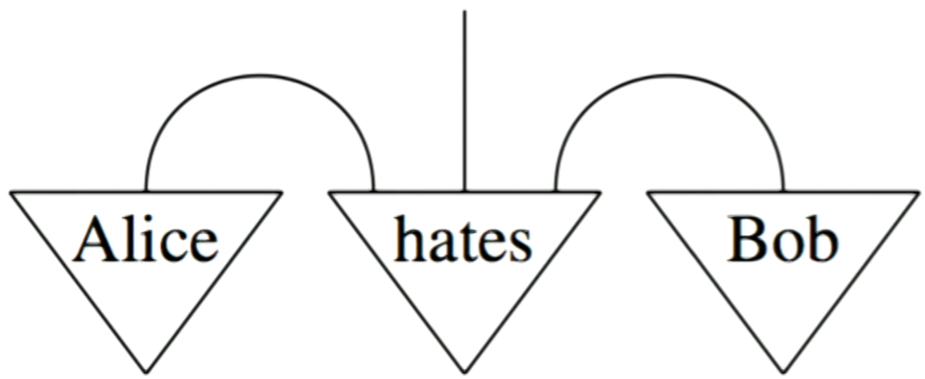
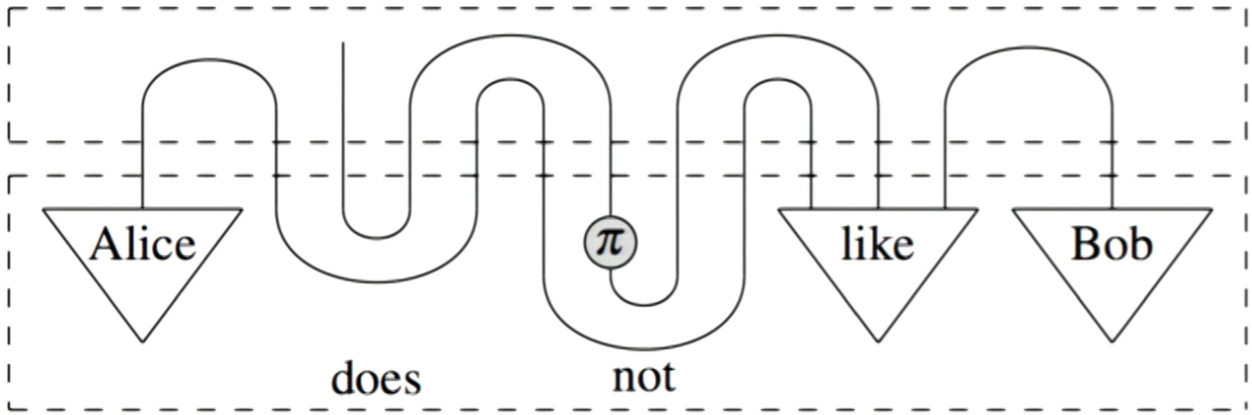
$$n \cdot {}^{-1}n \cdot s \cdot n^{-1} \cdot n \leq 1 \cdot s \cdot 1 \leq s$$

As a diagram:

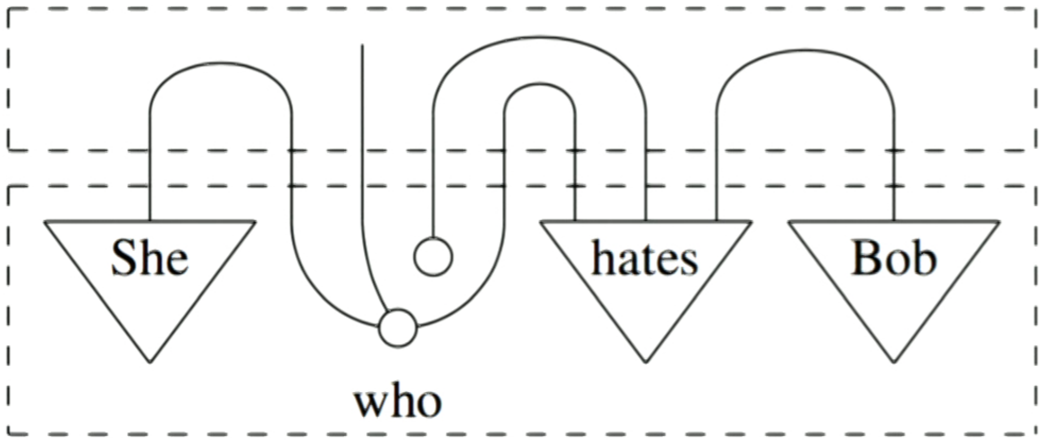


Logical meanings:



B. Coecke, M. Sadrzadeh & S. Clark (2010) *Mathematical foundations for a compositional distributional model of meaning*. Lambek Festschr. arXiv:1003.4394

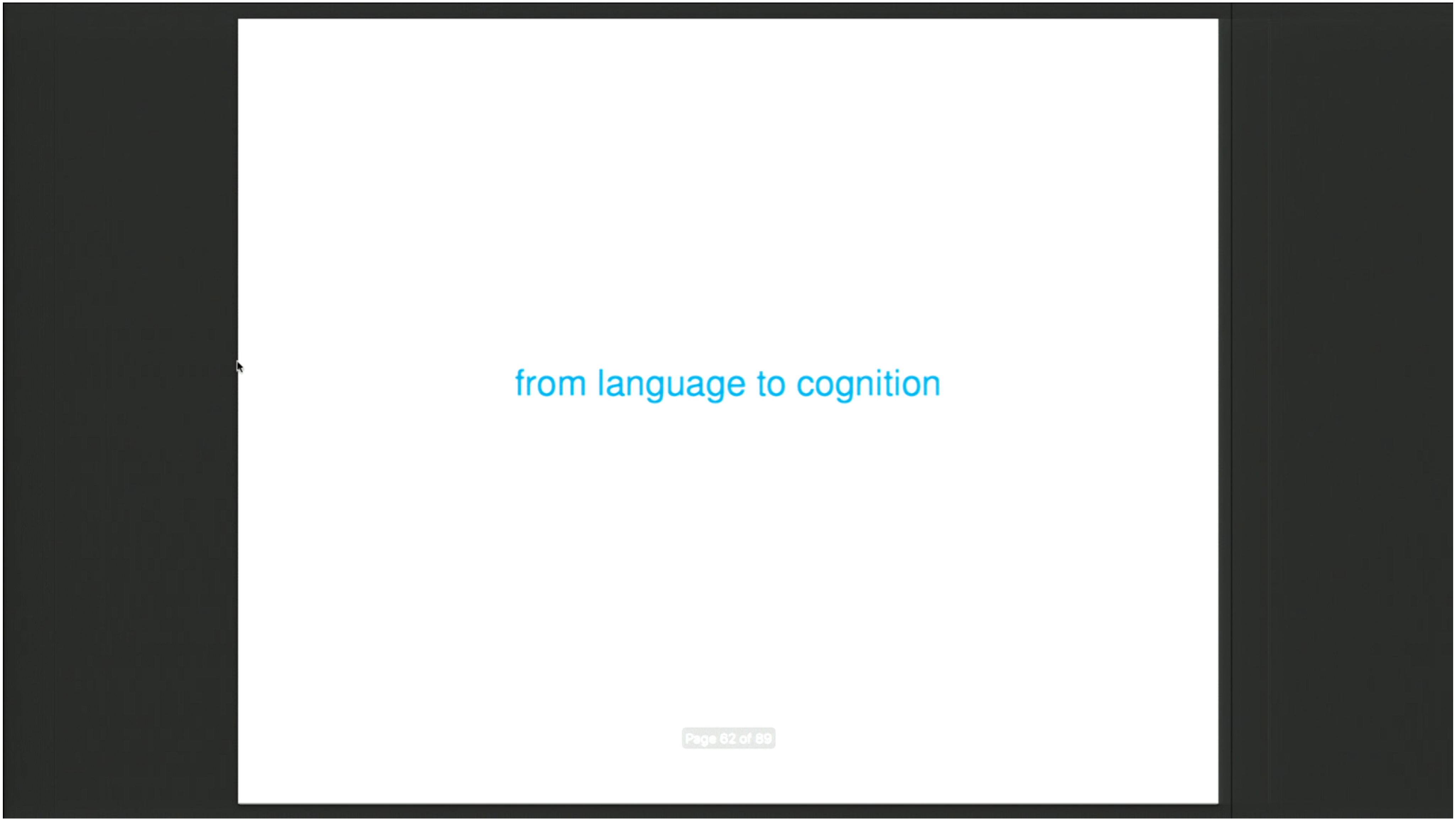
Logical meanings:



M. Sadrzadeh, B. Coecke & S. Clark (2013–2014) *The Frobenius anatomy of word meaning I & II*. Journal of Logic and Computation. arXiv:1404.5278

$\rho_{queen} :=$

R. Piedeleu, D. Kartsaklis, B. Coecke & M. Sadrzadeh (2015) *Open system categorical quantum semantics in NLP. CalCo. arXiv:1502.00831*


from language to cognition
Page 62 of 89

Algorithm for NLP-meaning composition:

1. Perform grammatical type reduction:

$$(\textit{word type } 1)\ldots(\textit{word type } n) \ \rightsquigarrow \ \textit{sentence type}$$

2. Interpret diagrammatic type reduction as NLP-map:

$f ::$  $\mapsto \left(\sum_i \langle ii|\right) \otimes \mathrm{id} \otimes \left(\sum_i \langle ii|\right)$

3. Apply this map to tensor of word NLP-states:

$$f\left(\overrightarrow{v}_1 \otimes \ldots \otimes \overrightarrow{v}_n\right)$$

Page 63 of 89

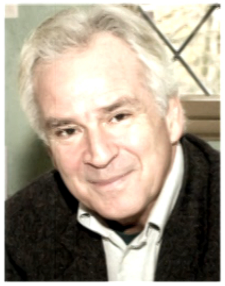
Books by famous developmental psychologist:

- P. Gärdenfors (2004) Conceptual Spaces: The Geometry of Thought. MIT.
- P. Gärdenfors (2014) The Geometry of Meaning. MIT.

books by famous developmental psychologist:

- P. Gärdenfors (2004) Conceptual Spaces: The Geometry of Thought. MIT.
- P. Gärdenfors (2014) The Geometry of Meaning. MIT.

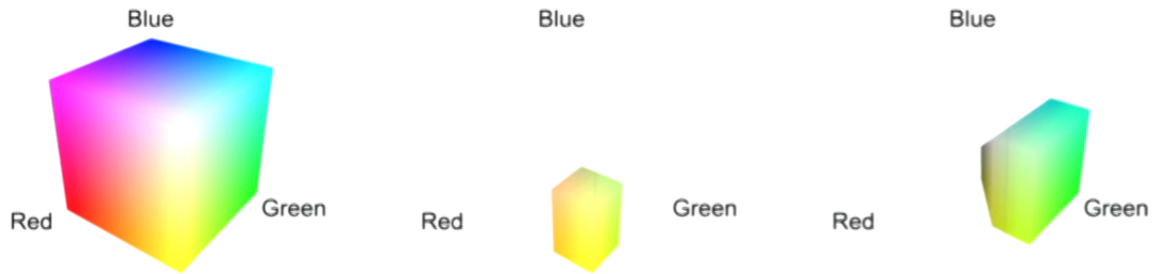
we made it compositional:



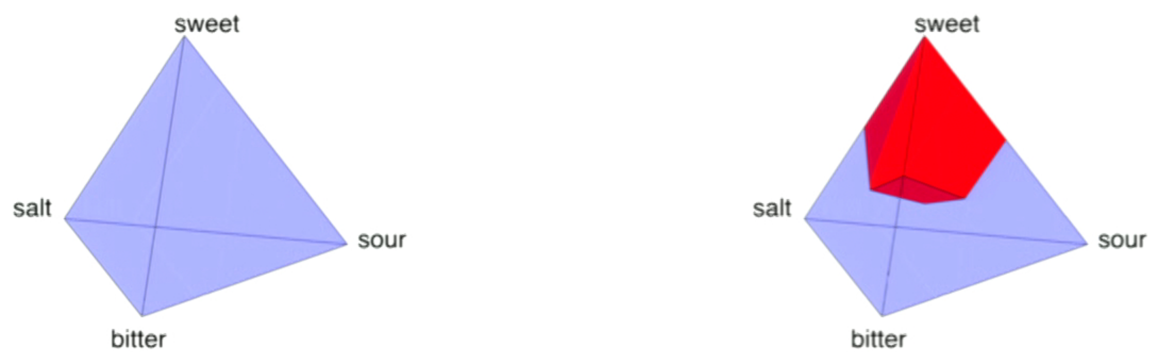
$\hookrightarrow$ **ConvRel**

J. Bolt, B. Coecke, F. Genovese, M. Lewis, D. Marsden & R. Piedeleu (2017) *Interacting Conceptual Spaces I: Grammatical Composition of Concepts.* arXiv:1703.08314

– conceptual spaces –



(a) The RGB colour cube (b) Property p_{yellow} (c) Property p_{green}



(a) The taste tetrahedron (b) The property p_{sweet}

convex algebra := set A and 'mixing' function:

$$\alpha : D(A) \to A$$

$$\alpha(|a\rangle) = a \qquad \alpha\left(\sum\nolimits_{ij} p_i q_{ij} |a_{ij}\rangle\right) = \alpha\left(\sum\nolimits_i p_i \left|\alpha\left(\sum\nolimits_j q_{ij} |a_{ij}\rangle\right)\right\rangle\right)$$

convex relation := relation that 'commutes with mixtures':

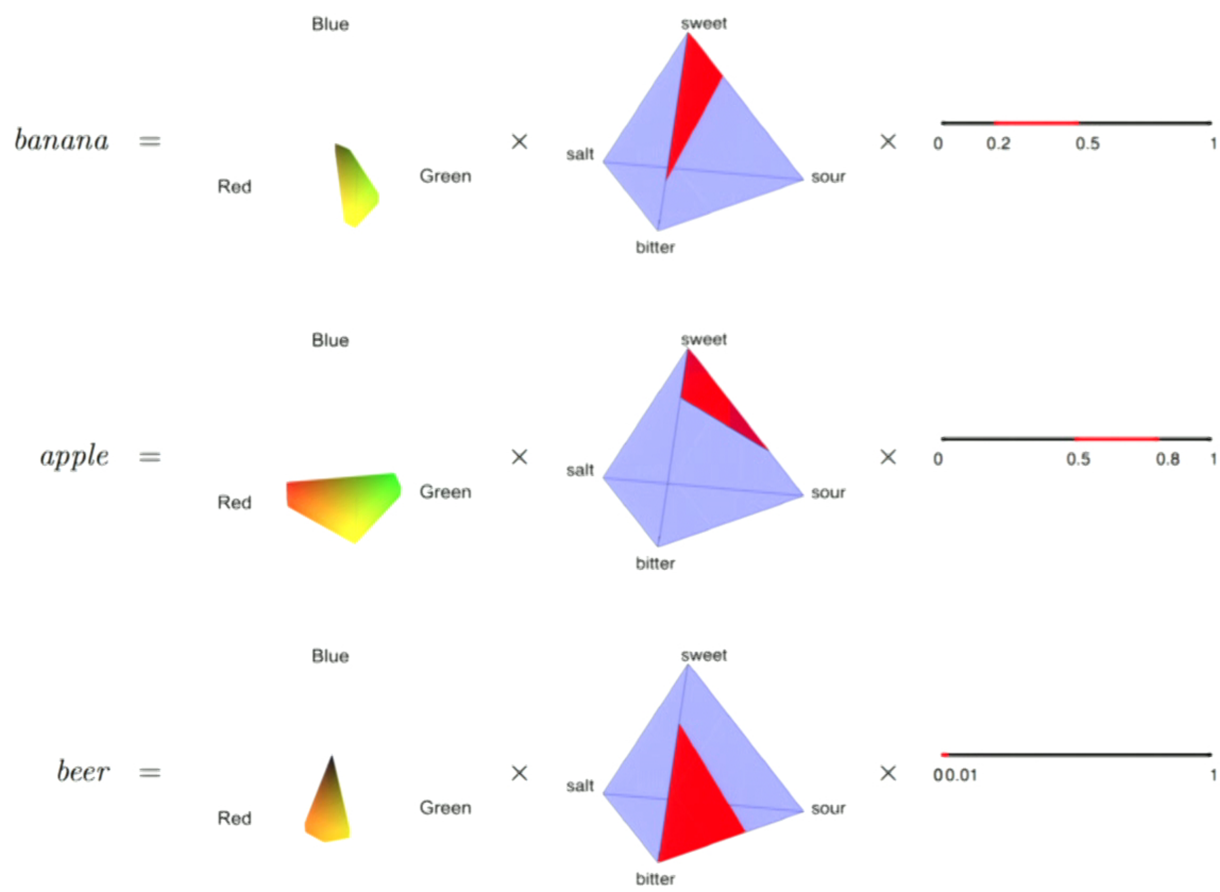
$$\forall i : R(a_i, b_i) \implies R\left(\alpha\left(\sum_i p_i |a_i\rangle\right), \alpha\left(\sum_i p_i |b_i\rangle\right)\right)$$

ConvRel := compact closed category of these

relavant structures:

- tensor := (non-cartesian) cartesian product
- cups := also like in Rel
- spiders := like ONB ones in Rel

– naively –


banana =
Blue
Red
Green
×
sweet
salt
sour
bitter
×
0
0.2
0.5
1
apple =
Blue
Red
Green
×
sweet
salt
sour
bitter
×
0
0.5
0.8
1
beer =
Blue
Red
Green
×
sweet
salt
sour
bitter
×
00.01
1

– more profoundly –

$$banana$$
$$:= |green\rangle|bitter\rangle|hard\rangle + |yellow\rangle|sweet\rangle|soft\rangle$$

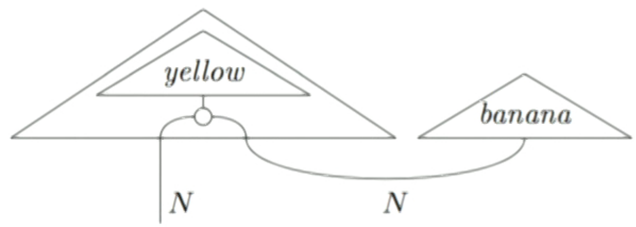
– more profoundly –

$$\begin{aligned} & banana \\ := & |green\rangle|bitter\rangle|hard\rangle + |yellow\rangle|sweet\rangle|soft\rangle \end{aligned}$$

$$\begin{aligned} & green\ banana \\ = & bitter\ banana \\ = & hard\ banana \\ := & |green\rangle|bitter\rangle|hard\rangle \end{aligned}$$

$$\begin{aligned} & yellow\ banana \\ = & sweet\ banana \\ = & soft\ banana \\ := & |yellow\rangle|bitter\rangle|hard\rangle \end{aligned}$$

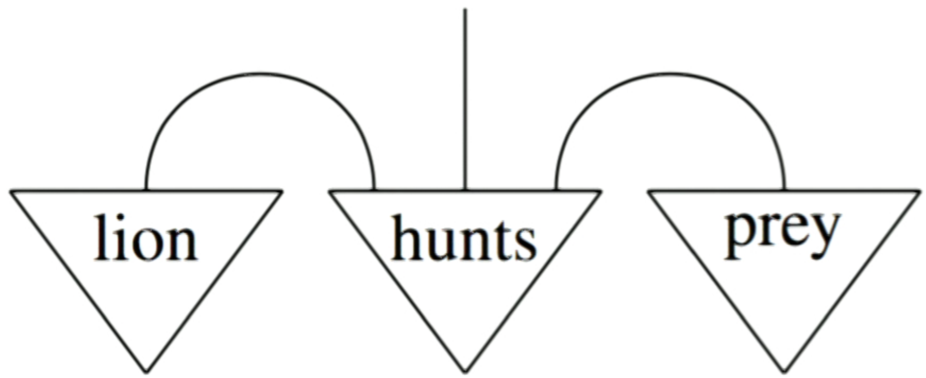
Phrase example:



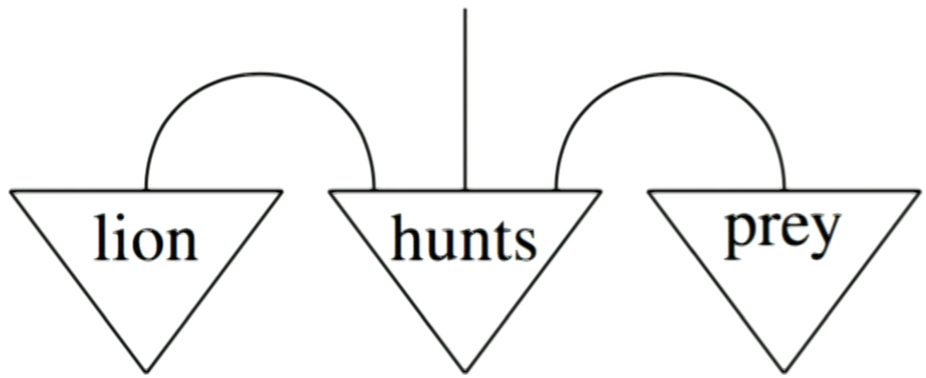
MEANING $\otimes$ GRAMMAR (i.e. are intertwined)

- Ambiguous grammar depending on meaning.
- Order of adjectives “large red” vs. “red large”
- 3D(+1) spatial connotation of prepositions like:
  “on (the table)”, “next to (her)”, “after (the game)” etc.

Transitive verb sentence:



Transitive verb sentence:



A lion understand grammar, since is very aware of:

- action of hunting
- him/her being hunter
- wants to get a prey

– visual perception –

$$Sentences \mapsto MovieClips$$

– visual perception –

$$MovieClips \mapsto Language$$

Origin of grammar?

quantum → diagrams → language → cognition

Bob Coecke & Eric Oliver Paquette (2009) *Categories for the practising physicist.* arXiv:0905.3010

Clark-Coecke-Grefenstette-Pulman-Sadrzadeh (2013) *A quantum teleportation inspired algorithm produces sentence meaning from word meaning and grammatical structure.* arXiv:1305.0556

Bob Coecke (2013) *An alternative Gospel of structure: order, composition, processes.* arXiv:1307.4038

Bob Coecke (2016) *From quantum foundations via natural language meaning to a theory of everything.* arXiv:1602.07618