QUANTUM LINGUISTICS Leap forward for artificial intelligence

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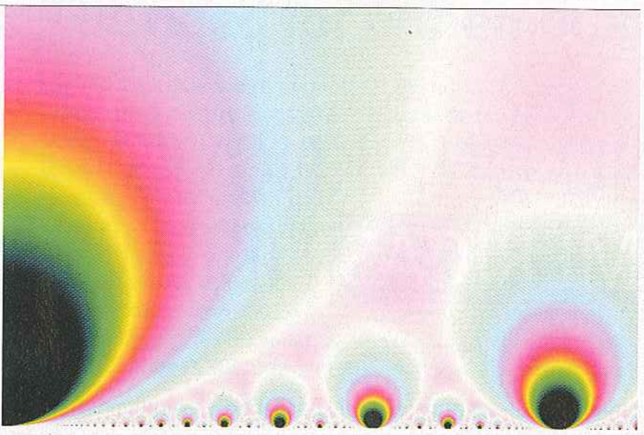

FRANK A. FARRIS

Coming next week...

Universe in reverse
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Microbe matrix
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Quantum links let computers read

Jacob Aron

AS YOU read this article, your brain not only takes in individual words, but also combines them to extract the meaning of each sentence. It is a feat any competent reader takes for granted, but it's beyond even the most sophisticated of today's computer programs. Now their abilities may be about to leap ahead, thanks to a form of graphical mathematics borrowed from quantum mechanics.

"It's important for people like Google," says physicist Bob Coecke at the University of Oxford, who is pioneering the new approach to linguistics. At the moment computers "only understand sentences as a bag of different words without any structure".

Coecke's approach, aired at a recent workshop in Oxford, is based on category theory, a branch of mathematics that allows different objects within a collection, or category, to be linked. This makes it easy to express a problem in one area of mathematics as a problem in another, but for many years was viewed even by its creators as "general abstract nonsense".

That changed when Coecke and his colleague Samson Abramsky used a graphical form of category to formulate some problems in quantum mechanics in a way that can be understood more intuitively. It provided a way to link quantum objects, written as vectors, to each other. That's useful for representing quantum teleportation, say, when information passes instantaneously between certain locations via a specific route.

"A graphical approach developed for quantum mechanics combines words and grammar"

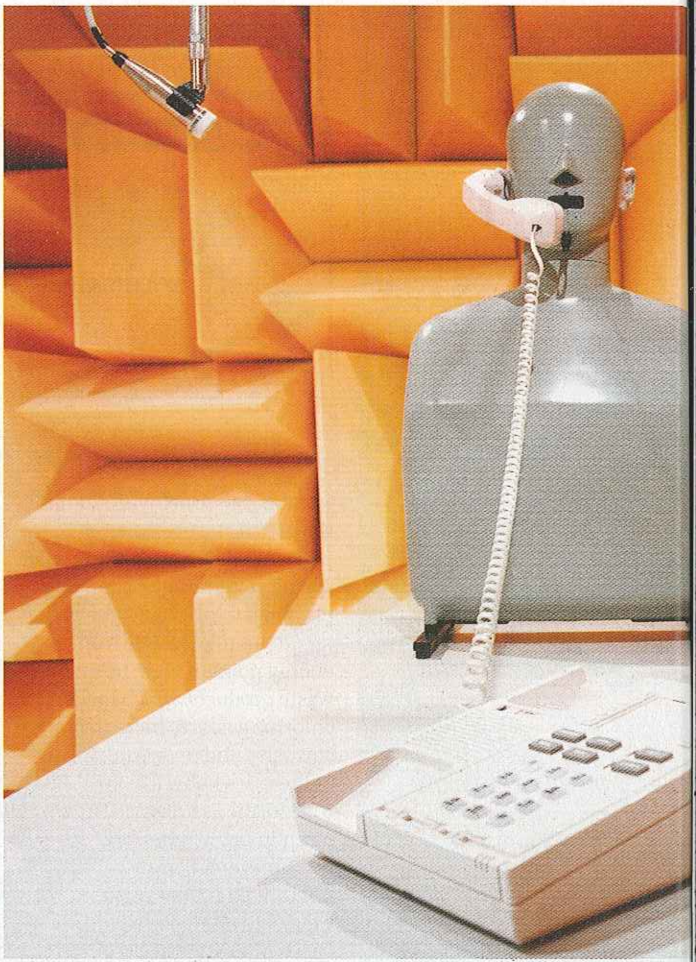
Coecke likens traditional approaches to such problems to watching television at a pixel level. "Rather than seeing the image, you get it in terms of 0s and 1s," he says. "It wouldn't mean anything to you." By translating quantum mechanical processes into pictures, higher-level structures become apparent.

More recently, Coecke, together with Mehrnoosh Sadrzadeh, also at Oxford, and Stephen Clark, now at the University of Cambridge, realised this graphical mathematics might also be useful in computational linguistics. The field aims to create a universal "theory of meaning" in which language and grammar are encoded in a set of mathematical rules.

Computers could, in principle, use the rules to make sense of language. In practice, most existing models of human language focus either on the meaning of individual words, allowing search engines to work out the general context of a web page, or on the rules of grammar, but not both.

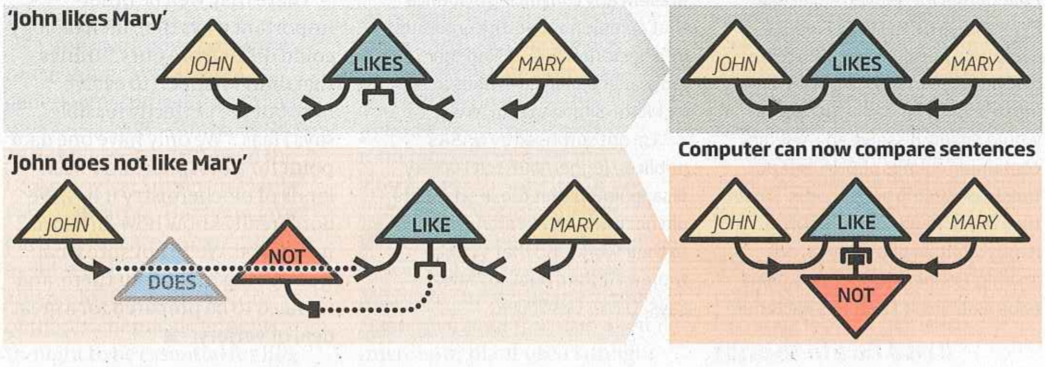
To produce a model that uses the rules of grammar to encode the meaning of sentences, Coecke and his colleagues had to combine the existing model types. To do this, they adopted the graphical approach Coecke had developed for use in quantum mechanics.

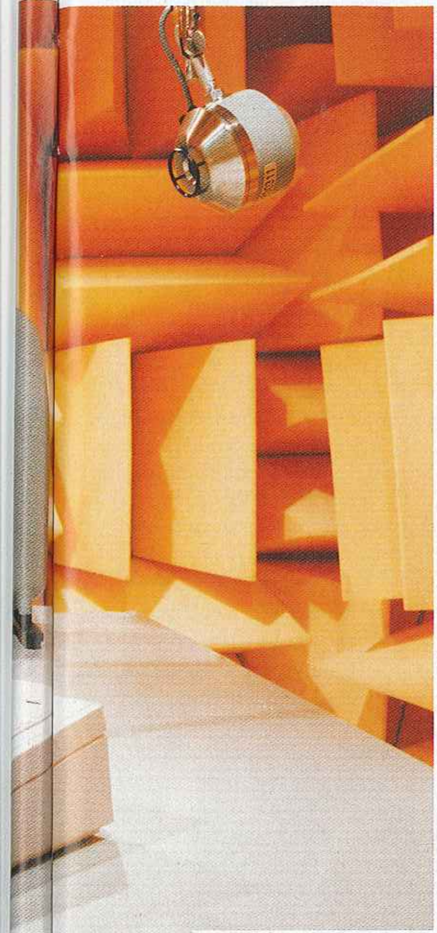
Existing models for word meanings define words as vectors in a high-dimensional space, in which each dimension represents some key attribute. So the vector for "dog" might include the vectors for "eat", "sleep" and "run". "Cat" might be generated by a combination of similar words



Making sense of sentences

An algorithm based on graphical links that embody grammatical rules can extract meaning from a string of words





LOUIE PSIHOYOS/SCIENCE FACTION/CORBIS

Ask me anything you like

to "dog", but "banker" would be built from quite different words, such as "money" and "work". Defining words in this way allows a dictionary to be represented as a "neighbourhood" of words, with the distances between residents in the high-dimensional space defined by their vectors. The vector representations of "dog" and "cat" would ensure that these words live much closer to each other than either does to "banker".

Now Coecke's team has created a similar neighbourhood for sentences. To create a vector for a sentence, Coecke has devised an algorithm to connect individual words, using the graphical links that were developed to model the flow of quantum information. In this case, the links embody basic grammatical rules, such as the way the word "likes" can be linked to "John" or "Mary", and the different way it can be linked to the word "not" (see diagram).

The team has already shown that the method allows the two sentences "John likes Mary" and "John does not like Mary" to be represented as vectors and placed at the appropriate location. That's no small feat: while anyone who can read English knows that these sentences are directly opposite, to a computer this isn't obvious. The work will be published in the journal *Linguistic Analysis*.

Most sentences have more nuanced relationships than these two examples. The next stage of Coecke's work allows more complex sentences to be represented as vectors, with the vectors that represent verbs taking into account the meaning of their subject and object nouns. This ensures that "dogs chase cats" gets assigned a vector placing it closer in sentence space to "dogs pursue kittens" than to "cats chase dogs". This work will be presented next month at the International Conference on Computational Semantics.

The team plans to train the new system on a billion pieces of text, starting with formal, carefully written legal or medical documents which should be relatively easy to parse. From there they will work their way up to more challenging extracts such as ambiguous sentences or sloppily written pages on the web.

It is not yet clear whether the insights gained so far can deal with all the nuances of language. Sebastian Pado, who studies computational linguistics at Heidelberg University in Germany, says that Coecke's team needs to show its method working on text from the real world, rather than specially prepared examples. Coecke agrees: "We have shown many proof-of-concept examples which have been crafted by hand, but to really convince the whole world this is the way to do things, you need a huge experiment." ■

Solar sails could be steered by light alone

LIGHT has been used to generate aerodynamic-like lift for the first time. The technique, which takes advantage of the fact that light bends, or refracts, when moving from one medium to another, could be used to create solar-sail spacecraft steered using light alone.

Photons create pressure when they bounce off objects. Solar sails are made from highly reflective materials to maximise this push, but the effect does not allow the sails to be easily steered. "It's well known you can use a light source to push on something, but the steering mechanisms are still up for grabs," says Grover Swartzlander of the Rochester Institute of Technology in New York state.

To manoeuvre future sails, Swartzlander believes the photons should not rebound off the material's surface but pass through it. As they enter and exit the sail, he says, the photons would change direction by an amount dictated by the shape of the material's surface and its refractive index – how much it causes light to bend. The angles of the incoming and outgoing light would control the direction of the sail's movement (see diagram).

Swartzlander and his colleagues demonstrated the effect in the lab using plastic rods shaped like half-cylinders, each a fraction of the size of a human hair. They put the rods in water, then shined laser light at them from below. The rods floated due to the pressure from the light, as any object of similar mass would. But, crucially, they also drifted sideways – a sign that they had been "steered" by refracted light (*Nature Photonics*, DOI: 10.1038/nphoton.2010.266).

The fact that the rods' asymmetrical shape affected their movement makes them the optical equivalent of aeroplane wings, say the team. Wings soar because air moves faster over their top sides, reducing the pressure above. The relatively high pressure below pushes upwards, providing lift.

"It's well known you can use light to push a solar sail, but the steering mechanism is up for grabs"

A future solar sail could be fully controlled with two perpendicular arrays of half-cylinders, says Swartzlander. But Dean Alhorn, a NASA solar sail engineer, says sunlight may be too weak for this to work in practice. Kate McAlpine ■

Floating on light

The shape and internal properties of a tiny plastic 'lightfoil' cause laser light to bend. The angles of the photons as they leave the lightfoil helps determine the direction in which the object moves