Logic Through a Lens

To find a theory of quantum gravity, we may have to view reality through a new filter—sacrificing conventional notions of truth and logic along the way.

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by SCOTT DODD

Collaboration: Christopher Isham & Andreas Döring — September 12, 2008

"It's a bit like a romantic relationship," says Christopher Isham, describing his collaboration with Andreas Döring. If that's so, then it's fitting that the courtship started out like so many others in the Internet age—with an e-mail.

In September 2004, Isham was already a prominent name in theoretical physics, researching deep conceptual questions at Imperial College in London. He was wrestling with some of the most profound mysteries of modern physics, including the quest for a theory that unifies general relativity with quantum mechanics. His work caught the attention of Döring, then still a PhD student at the Johann Wolfgang Goethe-University in Frankfurt, Germany.

Specifically, Isham and a few like-minded colleagues were attempting to use *topos theory*, a well-developed mathematical apparatus that had rarely been used in physics, to build a quantum theory of the universe. Isham's ideas were "quite a rare combination," Döring recalls. The student told his wife that he thought it would be cool to work with Isham one day.

Döring's first e-mail was typical of a tentative young suitor—he expressed his admiration and asked for a "date." Or rather, he asked Isham if there was a chance that he could come to Imperial and work with him.

Isham remembers liking Döring right from the start. "I was very impressed with him, both as a person and a researcher," he says. "He's obviously very bright, but he's also a nice person. I put a lot of stock in a person's personality."

TOUCHSTONE OF REALITY
Christopher Isham (left) and Andreas Döring (right)

Döring has the same recollection of their first meeting, which took place in London in late 2004, shortly after that first e-mail exchange. "It became clear very quickly that we had a lot of common research interests and also that we got along with each other very well," he says.

> It's a bit like a romantic relationship.
> – *Christopher Isham*

The young scientist came to London and started working at Imperial a year later, in December 2005. The two began meeting weekly, and a collaboration into topos theory was underway.

Dynamic Duo

Isham and Döring now get together about once a week for intense three- to four-hour brainstorming sessions. In the early days of their collaboration, they would meet at Imperial; but Isham suffers from a neurological disease and needs a cane to walk, so he prefers to work from his home in London when possible. It's near the college, so it's easy for Döring to swing by.

Their meetings start at a leisurely pace, and their typical routine is built as much around friendship as it is around work. They begin with tea or coffee and discuss the latest news or political scandal. They then settle into the main room of Isham's apartment, which comes complete with an easel and flipchart paper to cover in formulas.

Once they're done chatting, they launch into their latest work. Often, they've both done calculations or worked on the mathematical concepts on their own during the week, so they

BENDING THE TRUTH
Notions of truth and logic depend on which topos you look through
(Image © *Stepan Popov*)

have notes to compare and results to contemplate. "We tend to look at different aspects of the same problem," Isham says. This is one of the things that makes their collaboration effective—they each bring a different perspective.

Döring and Isham's dynamic partnership has even inspired a movie. In 2007, filmmaker Ilian Metev shot a documentary of the partners at work, called *The Physicist*. "What attracted me to their work was a certain creative, almost electrifying energy with which their dialogue of ideas would relentlessly grow," Metev says.

It's clear how much the two like each other. "I hugely enjoy working with Chris," Döring says. "He really is one of the nicest and most interesting persons I ever met."

"If you work with someone you like personally, it produces new ideas," Isham says. "It's a lot of fun."

Fun may be an important component of the partnership, but what they are seeking is quite serious: an end to the dilemma that has plagued their field for much of the last century.

The two most successful theories of modern physics—general relativity, which explains the interactions of cosmic bodies, and quantum mechanics, which defines interactions at the subatomic level—have both proven successful at their separate ends of the universe, the very large and the very small.

Unfortunately, unlike Isham and Döring, the two theories don't mesh.

A unified theory, the so-called Holy Grail of modern physics, would either meld the two together or replace them with something that works at both extremes. Physicists hope to find the answer that eluded Einstein and other intellectual giants of the 20th century.

> We need to change mathematics itself...the whole whack, completely.
>
> – *Christopher Isham*

For more than a dozen years now, Isham has been convinced that topos theory might provide the answer. Don't confuse one type of theory with another, though. Unlike general relativity or quantum mechanics, topos theory isn't a theory about how the universe works. Instead, it helps Isham and his allies think about the world using a completely different form of logic—and even different conceptions of truth.

"What Andreas and I have been arguing is that we need to change mathematics itself to solve this problem" Isham says. "I don't mean to find a different branch of mathematics. I mean actually change mathematics, the whole whack, completely."

True or False?

Reconstructing the rules of logic sounds mind-bending—and it is. But quantum theory wreaks havoc with logic at the best of times. For example, it suggests that the universe isn't the solid construct it seems but actually an array of possibilities collapsed into a single reality by the act of observation. So maybe mind-bending concepts are exactly what's called for.

According to quantum mechanics, you cannot ask what the properties of a quantum particle are before it is measured. Prior to observation, the particle exists in a superposition of multiple contradictory states. There's no simple yes/no or true/false answer to questions about the state of the particle.

Topos theory may be able to incorporate this murky quantum logic. It underlies the laws of mathematics and logic that we use, and is more fundamental than either, the physicists argue. Each topos describes a different "mathematical universe," with its own mathematical constructions and logic. And each topos can be used as a different lens through which to view the world, depending on requirements.

Isham and colleagues have identified a topos in which quantum theory appears to make logical sense—as long as you embrace a new type of logic, in which "true" and "false" are no longer your only options. There are now multiple shades in between. A different topos recreates classical reality with its firm "yes" and "no" answers. Isham and Döring believe that every physical system, from atomic particles to the universe as a whole, can be viewed through different topoi.

"In a sense, using a topos *is* changing the whole of mathematics," says Döring. "One chooses a 'mathematical universe' in which to argue."

CHRISTOPHER ISHAM
Imperial College London

The work has won fans. "It's really quite wonderful," says John Baez, a physicist at the University of California, Riverside.

Flights of Fancy

So how do you keep grounded, when you spend your days rewriting reality? It helps that Isham's background was originally in electrical engineering. Baez recalls visiting the two collaborators at Isham's London home in 2007 to learn about their topos work. "I was surprised, at the end of our talk, when [Isham] showed me into a room with a huge rack of computers hooked up to a bank of about eight video monitors."

It turned out to be Isham's homemade flight simulator. "He's the kind of guy who loves nothing more than a soldering iron in his hand," says Baez.

While Isham's engineering background gave him the expertise to make his own flight simulator, it also reminds him not to get lost in flights of fancy when exploring advanced mathematical concepts. "It's very easy to get seduced," Isham says. "The mathematics is very intriguing, but we have to keep in mind that we're working on theoretical physics."

Staying focused on the ultimate purpose of your intellectual endeavor is one of the many lessons that mathematician Döring has learned from working with Isham, who often reminds him to "think like a physicist."

"I do regard Chris as my mentor, and he surely helped me a lot to develop my style of research, scientific thinking and arguing," he says.

Döring also values the fact that Isham has never pressured him to pursue a particular line of research and does not interfere with his way of writing papers and giving talks. "In the actual scientific work, Chris treated me as a peer from the start, which may sound surprising for a mentor, but that is how it worked."

Nobel Lessons

Isham's skill as a mentor was influenced by one of his own early collaborations at Imperial with Abdus Salam, who won the 1979 Nobel Prize in physics. "He was quite a character, but I learned a lot," Isham says. Salam taught Isham to be his own man, rather than just a sidekick, and Isham now encourages Döring to speak up in the same way.

Another lesson that Döring says he learned from Isham also goes back to his mentor's work with Salam: There is no such thing as a failure. "If something in your theory does not work out as expected, then you should take this as a sign that something interesting lies behind this unexpected behavior," says Döring. "This way of thinking is very useful when exploring new mathematical structures and their relation to physics."

Döring is now getting ready to take the lessons and experience he gained from working with Isham and strike out as an independent researcher. He's been offered a five-year postdoctoral research fellowship at the Perimeter Institute for Theoretical Physics in Waterloo, Canada.

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> – *Andreas Döring*

That means their weekly meetings in London are drawing to an end. "I strongly hope to keep up the collaboration with Chris in some form, even though the style will surely change," Döring says.

In other words, it's not a breakup. It's the beginning of a long-distance relationship.

ANDREAS DÖRING
Imperial College London