Verifying novel cryptography

Forging a forward path

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High Integrity Software Conference, 17th October 2023

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- The National Institute of Standards and Technology in the US has been holding an open process for the past 6 or 7 years with the aim of developing, selecting, and standardising a range of suitable candidates.

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- The National Institute of Standards and Technology in the US has been holding an open process for the past 6 or 7 years with the aim of developing, selecting, and standardising a range of suitable candidates.
- The entries for this process constitute novel cryptography: even though some involve old ideas, they are new proposals when taken as a whole.

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State of NIST Post-Quantum Cryptography Standardization

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Not every example of novel cryptography will be found in a submission to a government agency's standardization efforts... but it is a good example of the sort of thing we mean: and we can definitely ask questions like "is the NIST approach to calling for proposals and evaluating them effective"?

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What is verification?

Definition

The term *verification* and the act of *verifying* is here used in a slightly imprecise sense, to mean any (computer-aided) *production of evidence that a system meets the requirements it is designed to meet*.

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The paradox of computer-aided cryptographu.

There is a healthy community of practitioners of "computer-aided cryptography" — the within-discipline term for "develop[ing] and appl[ying] formal, machine-checkable approaches to the design, analysis, and implementation of cryptography" [BBB+21], which broadly includes what we are calling verification here (and the terms are sometimes imprecisely used synonymously).

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I find this paradox very interesting, and one way or another have been picking at it throughout my PhD.

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The state-of-the-art: overview

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And the implementation is performant. It's a tremendous achievement, in my view. It also took nearly three years of work from more experts in the field than I can count on one hand and perhaps on two. They make a very persuasive case for the value of their work, but undoubtedly it has great costs in time and resources.

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But what does this mean? What should we take from this? The authors make no major attempt at linking any of their efforts to an assurance case for Kyber, or to Kyber's specific design to the extent it can now be changed.

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Does this tell us *anything* about the implementations of Kyber that will actually be deployed in practice?

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But I think better is possible, and desirable.

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This extends even to the draft standards themselves.

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By reason about, I mean: we want the claims of provable security to be meaningful.

By evaluate, I am talking about, for example, the way that submissions to the NIST process are evaluated against the 'Call for Proposals'. If one is going to pose a requirements document that some novel cryptography must meet, then the submission must include a clear explanation of how each required criteria is addressed, in a structured way that leaves no room for ambiguity.

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In particular, if you have a structured reasoning framework, it is a lot easier to work out how to integrate the results of formal verification into this framework. Without it, it can be nebulous — too often, I see people gesture towards the idea of formal proof with no indication as to what it supports, or what meaning it should have in context.

Bridging worlds

We have the cryptography world, and we have the high-integrity software world. It is desirable in and of itself to bridge the two, but also it has the advantage of making it easier to connect the former to the 'computer-aided cryptography/formal verification' world. These worlds, empirically, are not currently that strongly linked in terms of the work of the latter finding practical use.

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To reiterate: empirically just means 'looking at the revealed preferences derived from people's behaviour'.

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The observation I make is that this is no less true of formal verification. If a formal proof is to be regarded as a form of evidence for the security of an implementation or design, that evidence has meaning only alongside the claims it justifies and the argument which links them to a web of justified belief.

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Claims, argument, evidence: a reasoning framework

After some time thinking about this problem — in the context of trying different methods of formal verification on a particular post-quantum proposal in order to evaluate the merits of various approaches — I came to the Claims, Argument, Evidence reasoning and communication framework pioneered by Adelard, now part of the NCC group.

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Verification artifacts are often presented as both evidence and argument. However, often, the actual explanation of the link between "this verification has been performed" and a particular claim is missing or obscured. It isn't unheard of to see a talismanic approach to verification — "oh, we should do some formal verification here, that will increase confidence in the scheme" — with no explanation as to how or why this will occur.

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Dangling assurance cases

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The case for a particular piece of novel cryptography is an answer to this dangling case — an assertion that there is a specific fufillment of the problem it poses. In this perspective, a good scheme is precisely one which wholly justifies its fufillment of unjustified claims, and resolves satisfactorily any potential defeaters.

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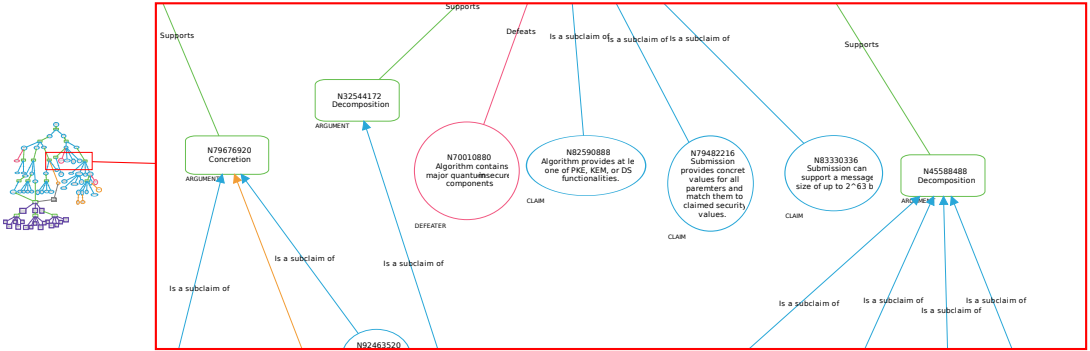
Example: Analysing the NIST Call for Proposals



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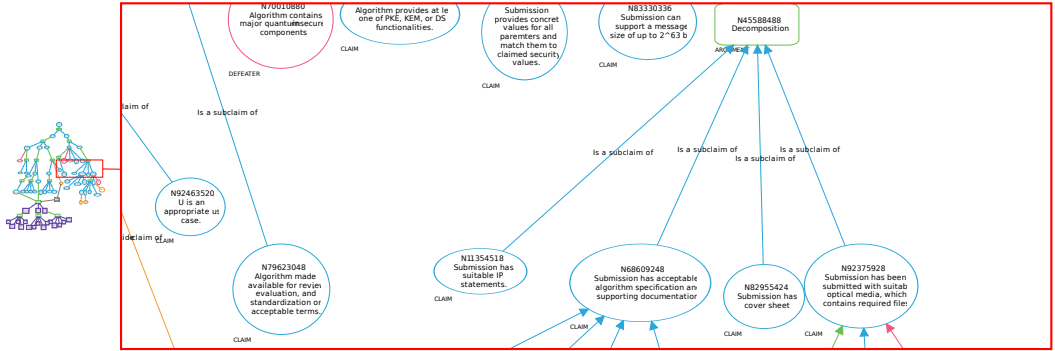

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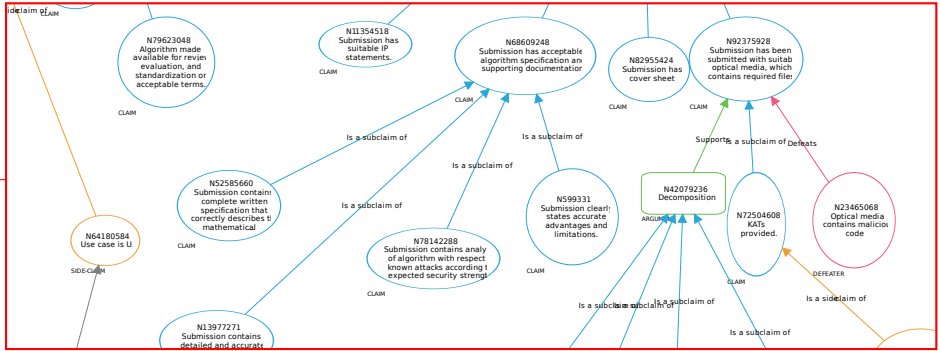

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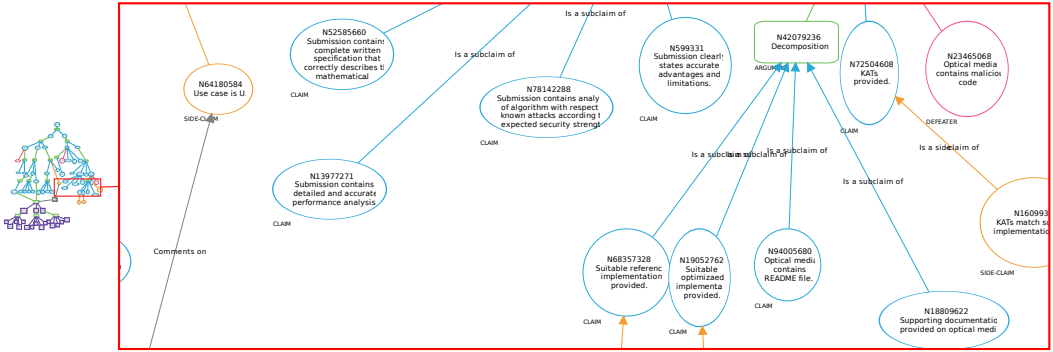

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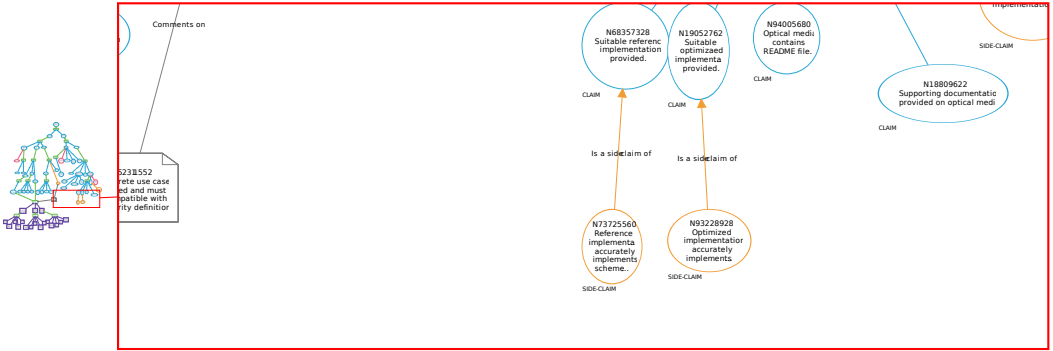

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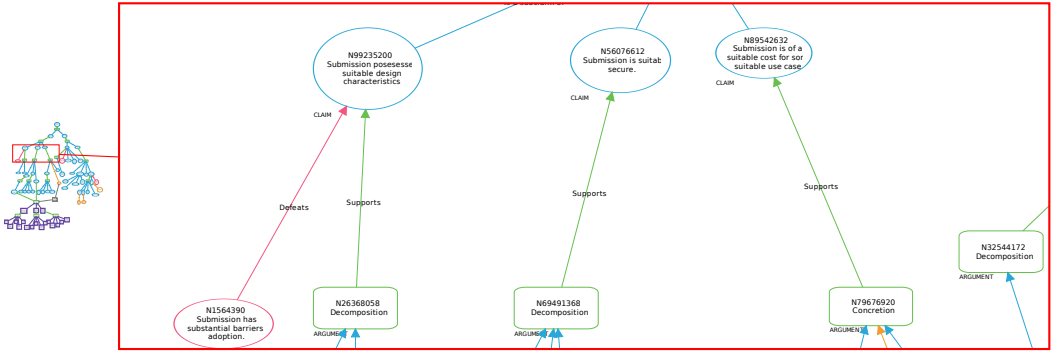

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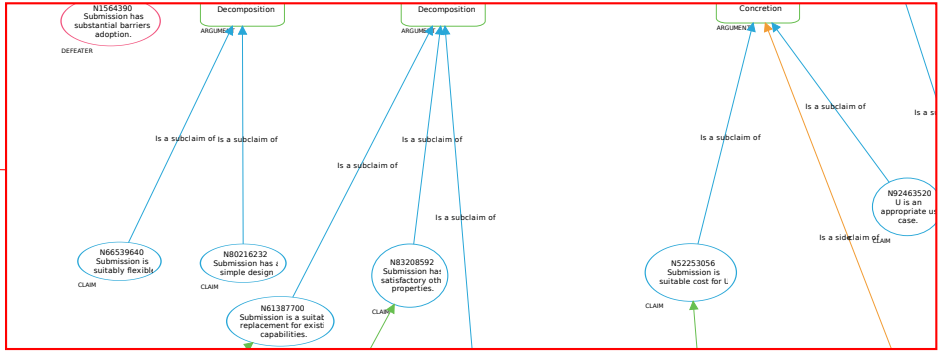

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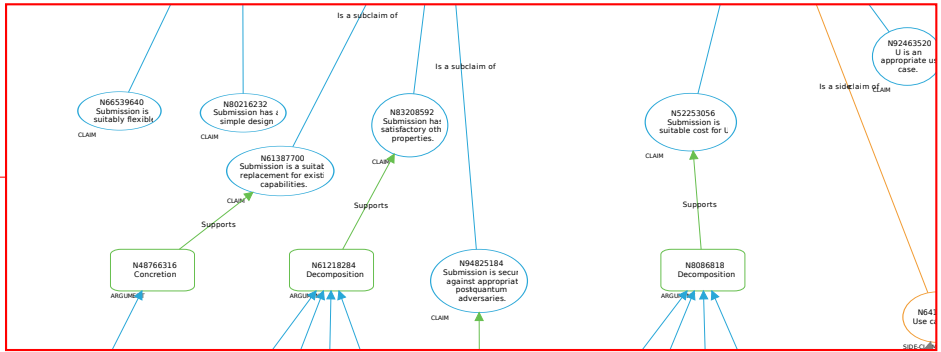

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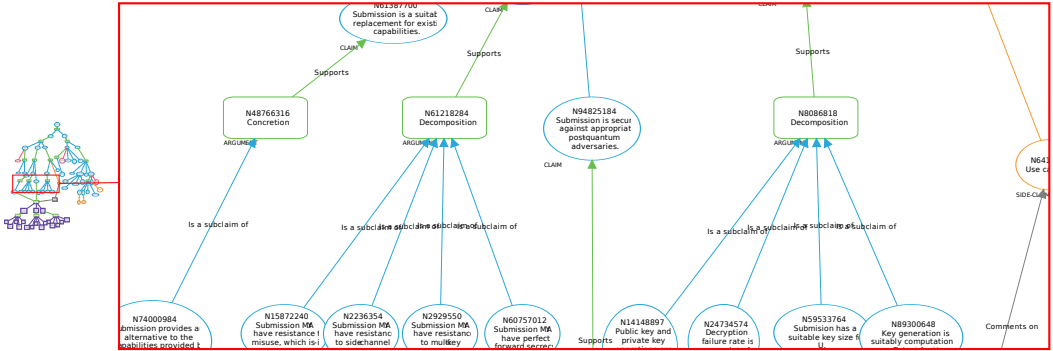

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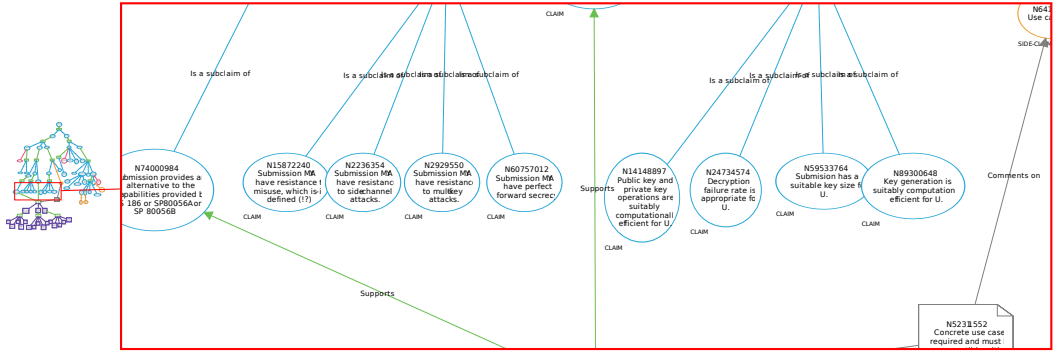

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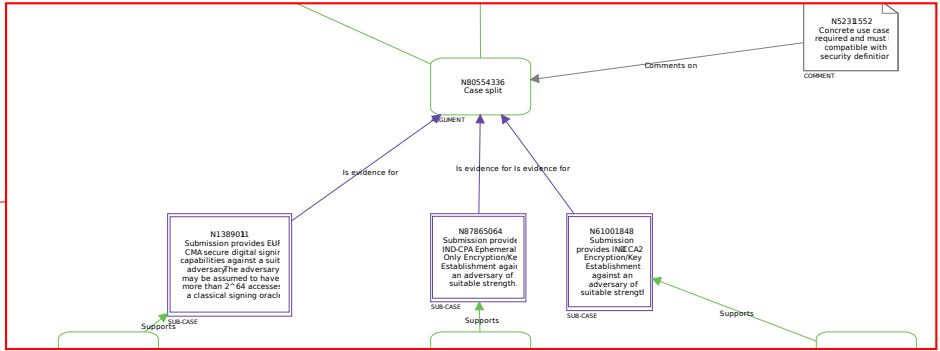

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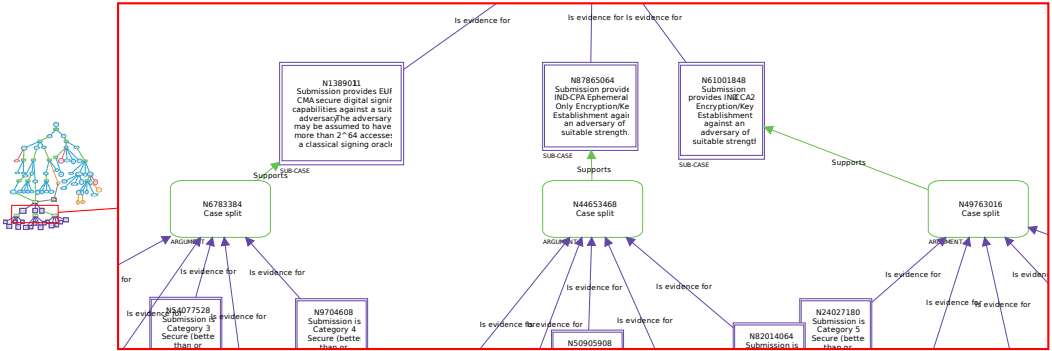

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I argue "If you build it, they will come" — if the expectations and standards are clear, then people will adapt to them. I think a rules-based, principle-based, evidence-based approach to novel cryptography assurance cases is sensible and possible — but someone needs to light the way.

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CAE Tooling & Thoughts

I have used Adelard's ACSE a little. Seems good — but I note that academics are often resistant to the use of proprietary software — and academics are often the people creating novel cryptography.

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Security arguments in cryptography often use arguments of the form 'P. If not-Q then not-P. Thus, Q.' (The so-called proof by contrapositive.) This argument is often fairly non-constructive in its form: secretly it uses, I think, the law of the excluded middle.

A little about me

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Just to give you some context about where I'm coming from in all this: I'm near the end of a PhD at Royal Holloway's Centre for Cyber Security in the Everyday. I have two supervisors: Dr Rachel Player within the college handles the cryptography end of things, and Dr Martin Brain of City University has been my route into the verification community.

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I've spent my PhD approaching the verification of different aspects (mainly functional correctness) of Classic McEliece with different tools. I'm now writing up case studies and drawing conclusions into my thesis, which was the motivation of the thought that sparked this talk.

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The future

I'm considering submitting something on this to the upcoming NIST conference if I can get my thoughts together in time. I'm interested to hear more about any prior work which anyone is aware of using CAE arguments in a cryptographic context.

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I can be contacted on `wren.robson@gmail.com` if you have further comment on anything I've talked about today.

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