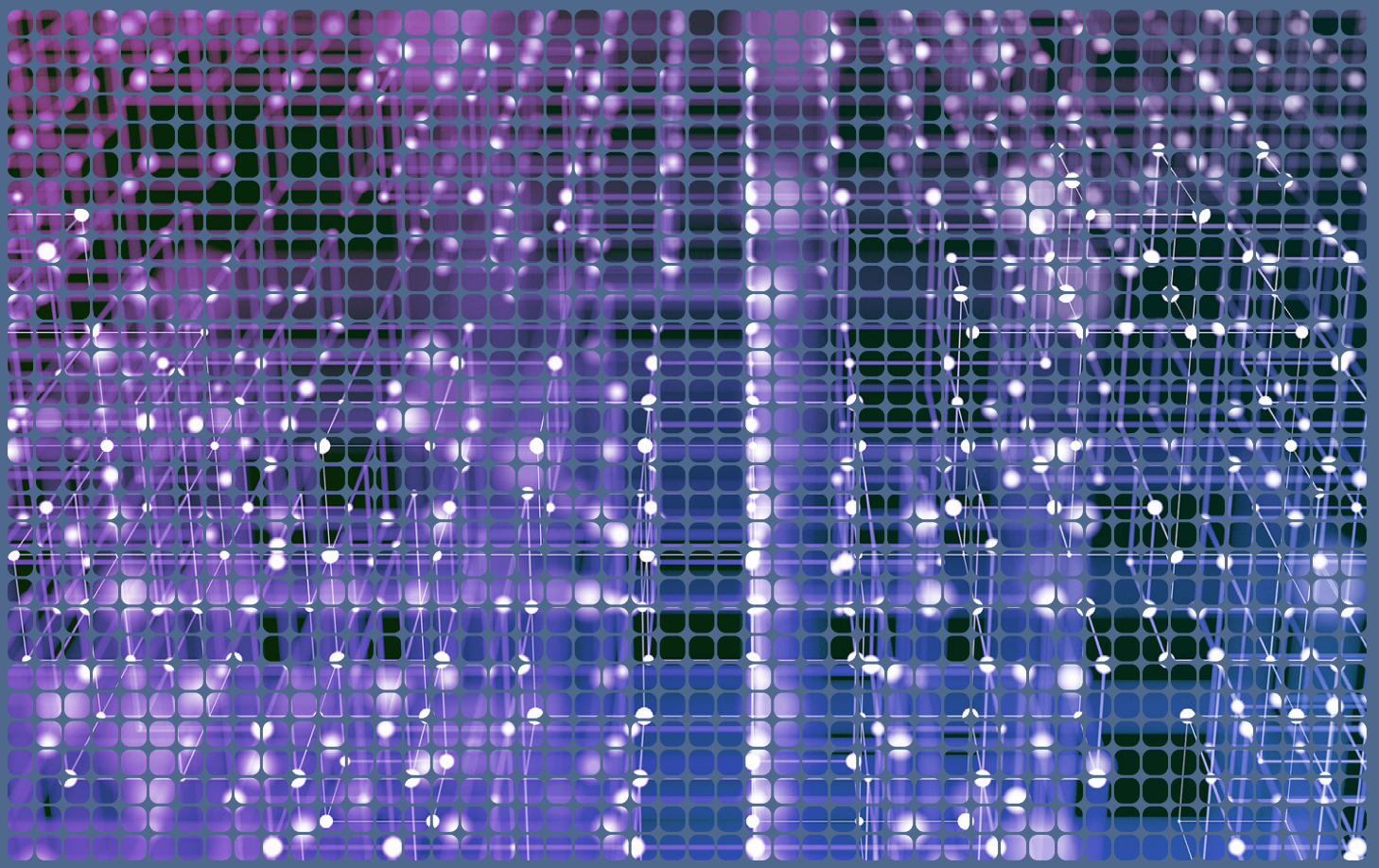

Digital Science Report

Blockchain for Research

Perspectives on a New Paradigm for Scholarly Communication

DR. JORIS VAN ROSSUM

NOVEMBER 2017

DIGITAL science

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Introduction

"Blockchain technology has the potential to solve some of the most prominent issues currently facing scholarly communication."

Blockchain is a revolutionary technology that has the potential to fundamentally change many industries, which include banking, music and the publishing industry. This report will zoom in on the potential of blockchain to transform scholarly communication and research in general. By describing important initiatives in this field, it will highlight how blockchain can touch many critical aspects of scholarly communication, including transparency, trust, reproducibility and credit. Moreover, blockchain could change the role of publishers in the future, and it could have an important role in research beyond scholarly communication. The report shows that blockchain technology has the potential to solve some of the most prominent issues currently facing scholarly communication, such as those around costs, openness, and universal accessibility to scientific information.

What is Blockchain?

This section does not attempt to provide a complete overview of blockchain technology. What follows here is a broad outline, introducing many of the terms used in this report. For further reading suggestions, see the links below this section.

Blockchain is a technology for decentralised, self-regulating data. Through blockchain data can be managed and organised in a revolutionary new way: open, permanent, verified and shared, without the need of a central authority.

The best known application of the technology is the digital payment system Bitcoin[1]. Financial transactions between two parties using its own currency (bitcoins) are conducted in an authorised and encrypted way, using digital signatures, and broadcast to the peer-to-peer network. Transactions made with bitcoins are verified in bundles by 'miners' - members of the general public using their computers to help validate and timestamp transactions. These validated transactions are then added as 'blocks' to the end of a chain of similar blocks at regular intervals (approximately every 10 minutes) and shared on the network. Cryptography is used to ensure that all previous transactions cannot be altered. Through this, a permanent record of transactions is created and kept on every participating node, ensuring that there is no single point of failure nor a single entity controlling the data. Miners receive financial rewards for their work in the form of bitcoins - the right to create a new block depends on who manages to solve a mathematical problem incorporated in the process. This process is designed such that no single miner can be guaranteed to write the next block to the chain, which greatly reduces the opportunity to manipulate the system. Through this, a ledger of all transactions is created that is shared (although information like people's identities are hidden using cryptography), verified and permanent, without the need of a central authority.

Ethereum[2] is another decentralised platform based on blockchain technology that is broader than a financial transaction system. It runs so-called smart contracts: applications that run as programmed without the possibility of fraud, censorship, or any other third-party interference. For example, a smart contract could state that once a person transfers funds related to the purchase of a house, a digital key that gives access to that house is sent. Being on the blockchain, this smart contract cannot be interfered with. Platforms like Ethereum and hyperledger[3] allow developers to build applications on top of a blockchain infrastructure.

Two different parameters affect the different flavours of blockchains that exist: permissionless/permissioned and public/private. Public or private blockchains refer to who can actually use the blockchain - private blockchains restrict access to the chain to certain parties. In permissionless blockchains, any node can perform any actions, including adding blocks to the chain. In permissioned blockchains, certain nodes are granted permission to do specific tasks.

The application of blockchain technology is being explored for managing a variety of digital assets, such as educational and medical records, and affect industries such as publishing, retail & manufacturing, healthcare and government. In light of its potential impact on different industries and sectors, the current state of the blockchain is seen as analogous to the early days of the internet.

"In light of its potential impact on different industries and sectors, the current state of the blockchain is seen as analogous to the early days of the internet."

Further Reading:

https://www.oreilly.com/ideas/understanding-the-blockchain

https://blockgeeks.com/guides/what-is-blockchain-technology

http://usblogs.pwc.com/emerging-technology/a-primer-on-blockchain-infographic/

https://spectrum.ieee.org/computing/networks/blockchains-how-they-work-and-why-theyll-change-the-world#BlockchainDoOtherThings

1. https://bitcoin.org/

2. http://www.ethereum.org

3. https://www.hyperledger.org/

Challenges in Scholarly Communication

Communication is an essential part of research. As a truly collaborative endeavor, research depends on an effective exchange of ideas, hypotheses, data, and results. This exchange has to overcome geographical as well as temporal barriers, allowing researchers to collaborate with colleagues located in different parts of the world, and build on the work of predecessors.

There is a general consensus that this communication in its current form has serious challenges. Scholarly communication is perceived to be suffering from legacy workflows, outdated publishing paradigms, and business interests that are diametric to the interest of science. Often, the word 'crisis' is used to convey the seriousness of the challenges. Conceived problems around scholarly communication exist at a number of different levels and touch different aspects of the process.

Reproducibility

The ability of scientists to reproduce the results of other scientists, is a cornerstone of research. This makes the general consensus that there is a crisis around reproducibility even more distressing. Pressure to publish, selective reporting, poor use of statistics and finicky protocols are seen as factors that contribute to work that is hard to reproduce[1]. Moreover, difficult techniques, poorly described methods and incompletely reported data are reported as aspects that hamper researchers from building on solid work. Problems around reproducibility have received a lot of attention during recent years. For example, in 2011 a project was launched by the Center of Open Science which aimed to replicate 100 different studies that all were published in 2008 in the field of psychology. The results of this reproducibility project, published in 2015, showed that whereas 97% of the original results showed a statistically significant effect, this was reproduced in only 36% of the replication attempts[2]. In a 2016 poll on Nature.com, two-thirds of respondents indicated that current levels of reproducibility are a major problem, with 52% saying that there is a 'significant crisis'[1]. Others stress that the reproducibility crisis is a multifaceted, multi stakeholder problem, with no simple solution being available and no single party being solely responsible[3].

Journals as inflexible and limited vehicles for communication

Research results are primarily published in academic journals, which have a strong tendency to publish positive and novel results. Moreover, researchers themselves are more inclined to report on their successes than on failed experiments. This means that a lot of research that did not lead to positive results remains unpublished, and therefore unknown.

This is problematic in several ways. Negative results, results that falsify instead of confirm a hypothesis, can be just as informative to researchers than results that corroborate a hypothesis. It also causes a waste of resources, with other researchers unaware of this work potentially performing the same experiment[4]. Moreover, as the format of scientific journals has remained largely unchanged for hundreds of years, it is not well adapted to deal with other types of content that play an important role in today's research such as protocols and datasets. Also, the dominant format of electronic journal articles, PDF, is static and restrictive in terms of information displayed.

Peer review

In recent years a lot of attention has been given to fundamental problems associated with the peer review process which lies at the heart of scholarly communication[5,6,7]. The perceived problems are multiple. There is a lack of visibility and recognition for reviewers, with their review work remaining largely unnoticed. Together, the increased number of manuscripts submitted to journals, and a subsequent need for more reviewers, leads to an increasing difficulty in finding suitable reviewers. Additionally, there is a perceived bias against women in the review process[8]. There are also cases of review manipulation, sometimes involving identity fraud which forced publishers to retract articles[9]. Overall, the review process is considered opaque and expensive, slowing down the speed of scientific discovery and progress.

"Science is essentially a non-commercial activity, but ironically the business of scholarly communication is one of the most lucrative industries in the world."

Credit

Science has grown over the centuries from an activity performed predominantly by amateurs to an increasingly international and professional activity largely funded by the public purse. Given this, a growing need has evolved for metrics measuring the impact of researchers, universities and research itelf. Since the invention of the science citation index in the 1960s, measuring the performance of researchers has become ever more prevalent, influential, and also controversial[10]. For example, the dominant use of metrics can lead to a simplified and inaccurate assessment of research. It can also lure researchers into pursuing high rankings first and good research second, and even attempts to game the system. Moreover, as it measures productivity predominantly in terms of journal article output, research effort leading to negative results and non-research but valuable activities (e.g. reviewing articles and grants, sitting on scientific committees, or even micro-contributions such as participation in brainstorms, informal comments) are undervalued. Another problem affecting the proper attribution of credit is the challenge to correctly identify researchers in the research workflow, partly caused by a lack of a widely used standard.

Commercial interests

Research is essentially a non-commercial activity, but ironically the business of scholarly communication is one of the most lucrative industries in the world, dominated by a few large publishing giants[11]. This causes several issues. High prices charged by commercial publishers for subscriptions challenges library budgets, and implies that not all content is made accessible to scientists at institutions. This has led to the success of Sci-Hub, a website with over 62 million papers and articles available for direct download, often infringing the copyright of publishers. Similarly, the social network ResearchGate is used to exchange articles among peers, circumventing publishers. Partly as a reaction to the problems associated with the subscription model, open access, the model whereby payment is shifted from the reader or library to the author granting universal access to the article, has been introduced. But several decades after its introduction, only a minority of articles are open access. Moreover, open access has introduced its own set of problems, such as the incentive of publishers to accept articles potentially leading to less rigorous quality norms, and the appearance of so-called predatory publishers, exploitative publishers that charge publication fees to authors without providing the editorial and publishing services that are associated with legitimate journals.

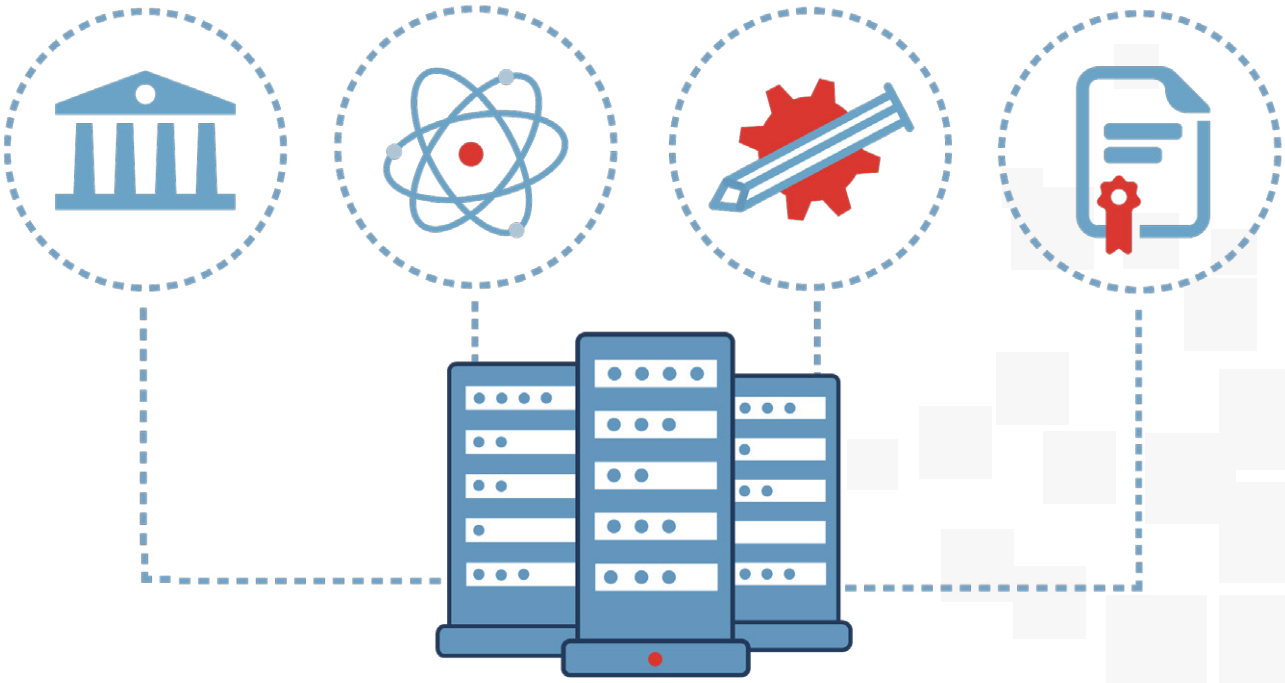
1. *http://www.nature.com/news/reality-check-on-reproducibility-1.19961*
2. *https://digest.bps.org.uk/2015/08/27/this-is-what-happened-when-psychologists-tried-to-replicate-100-previously-published-findings/*
3. *http://circres.ahajournals.org/content/116/1/116*
4. *https://www.elsevier.com/authors-update/story/innovation-in-publishing/why-science-needs-to-publish-negative-results*
5. *https://www.forbes.com/sites/geoffreykabat/2015/11/23/the-crisis-of-peer-review/#7cb8a04a463e*
6. *https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1420798/*
7. *http://www.nature.com/news/let-s-make-peer-review-scientific-1.20194*
8. *https://www.nature.com/news/journals-invite-too-few-women-to-referee-1.21337*
9. *For an example see http://group.springernature.com/gp/group/media/press-releases/retractions-from-springer-and-biomed-central-journals/11002850*
10. *http://www.nature.com/nature/journal/v465/n7300/full/465870a.html?foxtrotcallback=true*
11. *https://www.theguardian.com/science/2017/jun/27/profitable-business-scientific-publishing-bad-for-science*

How the Blockchain Could be Applied: Ideas and Initiatives

The challenges in scholarly communication have inspired many initiatives that attempt to make science more open, transparent, rigorous and effective. In the last few decades, we have witnessed a myriad of efforts that were initiated from all players in the sector, including funders, universities, publishers, researchers, as well as startups. New platforms and journals for alternative publication outputs were launched, alternative metrics were introduced, and more generally, cross-industry groups and discussion forums were formed with the aim of bringing long-lasting improvements in scholarly communications. But despite its well-recognised challenges, scholarly communication has remained surprisingly unchanged over decades, if not over centuries. In spite of its growth and increased institutionalisation, and a successful transition from print to online, scholarly communication is characterised by the same processes and workflows, models, outputs, and metrics, notwithstanding their associated problems. However, a growing number of people believe that the blockchain technology might provide the technology to alter scholarly communication in a fundamental way.

"Adopting a blockchain for research would mean that researchers work in a different way."

Adopting a blockchain for research would mean that researchers work in a different way. Currently, academics use different - and to a large extent disconnected - systems in their research workflow. For example, spreadsheets or lab software are used to capture the results of an experiment. When results are collected, an article is written using a local writing application or on a cloud-based collaborative writing tool. This manuscript is then submitted to a publisher through a submission system. After review and acceptance the manuscript is converted to PDF and HTML, and hosted on a publisher



"Working on a blockchain would mean that whenever researchers create or interact with content in whatever way and at whatever stage, their interaction will be stored in a single platform."

platform, from where it is downloaded. Access to this publisher platform is often facilitated by librarians. Citations are collected in citation databases which are distributed through librarians or via freely accessible databases.

In a 'blockchained' science, this process would look very different. Blockchain allows for decentralised, self-regulating data, creating a shared infrastructure where all transactions are saved and stored (see section 'what is blockchain'). Scientific information in its essence is a large, dynamic body of information and data that is collaboratively created, altered, used and shared which lends itself perfectly to the blockchain technology. Working on a blockchain would mean that whenever researchers create or interact with content in whatever way and at whatever stage, their interaction will be stored in a single platform[1].

A big advantage that the blockchain brings is that it would make the platform decentralised, which means that there is no single owner, although everyone has access to the same information. Moreover, in a blockchain for research, critical aspects of scholarly communication such as trust, credit, universal access and - where required - anonymity, can be realised and safeguarded. Its potential relates to almost all stages in the researcher's workflow.

Research & Data

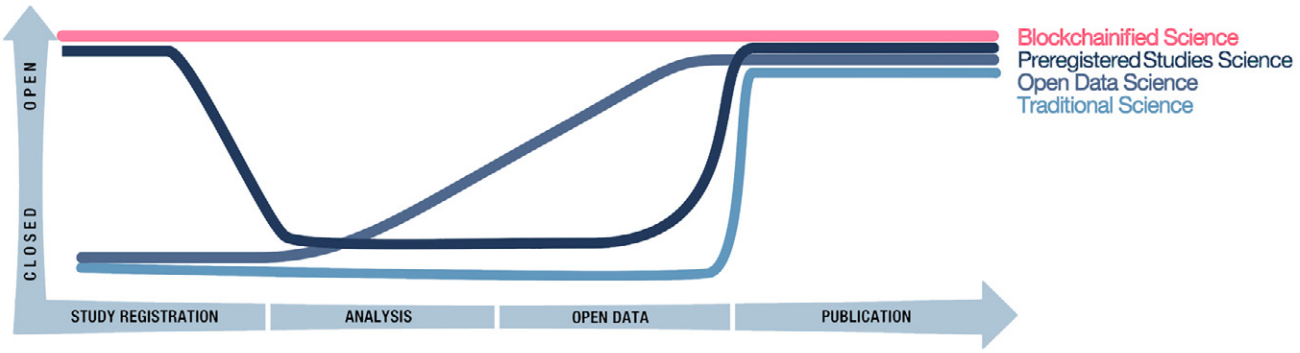
Dr. Soenke Bartling is a German radiologist and founder of Blockchain for Science[2], a think tank based in Berlin. Launched in 2016, its aim is to 'open up science and knowledge creation by means of the blockchain (r)evolution'. Besides meetings, hackathons[3] and stimulating knowledge sharing through its online platform, the organisation also launched and maintains a living document[4] on blockchain and science, collecting ideas on how blockchain could open up science and knowledge creation.

According to Soenke and his group, an open, permissioned blockchain instead of separate, disconnected systems would bring significant advantages on various levels to researchers. It would make larger parts of the research cycle open to self-correction, and could, therefore, be a new potential to addressing the reproducibility and credibility crisis as well as reducing overhead thereby accelerating the scientific process. The team has collected, and proposes, an impressive number of applications of a blockchain for science:

- A blockchain could provide a notarisation function by allowing scientists to post a text or file with ideas, results or simply data. These time-stamped records would allow researchers to claim information or ideas, if needed anonymised. This could potentially replace the function of patent offices.
- Study designs could be registered using the blockchain, which would prevent the arbitrary suppression of research studies in case results do not meet expectations or the retrospective alteration of study designs. Moreover, smart contracts could be used so that research protocols are set in 'blockchain stone' before the data is collected, and the processing and analysis would be automated. This 'smart evidence' would prevent ex post facto hypothesising and could be especially relevant to the healthcare and pharmaceutical industry. Moreover, this could be done while maintaining data autonomy and subject privacy through cryptographic protection.

- Research data could be automatically uploaded, time-stamped and where necessary, encrypted by devices (the intersection of the blockchain with the internet-of-things), which would speed up the research workflow and make it less prone to error. Another advantage of having research data available on the blockchain is that computational power available within the network could be used for processing, statistical analysis and calculations. Having information shared on the blockchain provides the opportunity for a marketplace for research where labs or groups specialise in specific aspects of the research workflow. Some labs will collect the data, others will carry out the statistical analysis etc. It could also accelerate the potential for collaboration.
- The peer review process could greatly improve through the blockchain and data underlying the published results could be made available. This would not only improve reproducibility in general, but also allow reviewers to do their work more thoroughly. Encryption allows reviews to be validated but remain anonymous and stored permanently. Moreover, post-publication review in various forms could be integrated easily.
- Ideas and hypotheses can be submitted anonymously using the blockchain fostering more innovation. With the lack of peer pressure, researchers are encouraged to think more freely and share ideas that cannot immediately be placed in contemporary paradigms.

"Having information shared on the blockchain provides the opportunity for a marketplace for research where labs or groups specialise in specific aspects of the research workflow."



A "blockchained" science would make the research process up to publication significantly more open and transparent, argues Dr Bartling. "Blockchain in science bears the unique chance to realign science's incentive structures with honesty, effectiveness, collaboration and true inventiveness".

Figure 1. How blockchain could open the research process. Traditional science only becomes open at the point of publication. Although the pre-registration of studies and the publication of data opens up research at multiple stages, a blockchained science would do that in the most comprehensive way.

Figure provided by Dr. Soenke Bartling under CC-BY license.

"Blockchain holds the promise to change how publishers serve as middlemen in the dissemination process."

Disseminating Content

One of the main roles of a publisher is the dissemination of content. After manuscripts are reviewed and accepted by the editorial board, publishers distribute this content to the academic community. Today, this happens largely through online platforms with subscriptions or open access fees as underlying business models. But blockchain holds the promise to change how publishers serve as middlemen in the dissemination process. The role of blockchain has been researched predominantly in general (i.e. non-academic) publishing, where the move to online has led to a shift in revenue allocation from content creators and publishing companies to hosting companies, social media giants, and advertising intermediates. To some extent, this is caused by an inherent characteristic of the World Wide Web[5], namely the use of hyperlinks. Hyperlinks are one-way pointers to content but do not point back to the users that click on them. Hence, there is no mechanism for allowing small automatic payments for usage. Given this, the only choice for publishers is to open up content and base a business model on advertising, or impose unfriendly paywalls with expensive credit card payments.

Several applications have been developed that allow for content distribution coupled with micropayments that flow directly to the producers of content. DECENT[6] is a Swiss-based organisation that has built a blockchain driven content distribution platform. Through this platform, which was launched in June 2017, digital media content including audio, video, text, software and video games can be distributed in a decentralised network of individuals and organisations. Content can be paid for with micropayments at prices set by the content owners.

Similar platforms have been developed by Boston-based LBRY[7] and Amsterdam-based Katalysis[8].

Although these platforms were developed to remove middlemen that do not play a large role in academic publishing, they could be used to change the commercial landscape in scholarly communication. For example, the platforms allow micropayments to be made for individual content items in a simple way. The open access and subscription based models both come with disadvantages, and the use of micropayments could form the basis of a reasonable and sustainable business model whereby content is paid according to usage.

"Through the blockchain, ownership of content is automatically established, and the use of content and the payment of royalties are executed through smart contracts in which the rights are stored."

An interesting potential dimension of the blockchain is digital rights management[9]. The coupling of usage to micropayments already makes rights management more straightforward, but digital rights can also relate to more complex aspects like re-use, permissions and royalties that are currently intermediated through large institutions and complex products. The combination of a central database with smart contracts could bring huge advantages. Through the blockchain, ownership of content is automatically established, and the use of content and the payment of royalties are executed through smart contracts in which the rights are stored.

An additional advantage of content being disseminated via the blockchain is that usage can be accurately counted[10]. Currently, content is downloaded and shared via different platforms (e.g. publisher platforms, ResearchGate, PubMed Central), which makes the tracking of usage difficult. This

is problematic not only for publishers, but also for researchers and institutions for whom readership and usage is an important metric. A blockchain would make usage counting and reporting both accurate and simple at the same time.

A blockchain publishing system could potentially disintermediate the publisher itself. Platforms such as DECENT allow authors to upload content, set the prices, after which the content is distributed and, if required, paid for without the need of a publisher. Or it could simply mean that the role of publishers shifts, focusing on providing services like copy editing and peer review (which ensures quality but of also serves as an important filtering mechanism through which content is brought to the most relevant academic community) instead of providing a platform for disseminating content, which would be established through the blockchain.

"Research on the blockchain could have a huge impact on the way researchers build their reputation and become recognised."

New Metrics

Research on the blockchain could have a huge impact on the way researchers build their reputation and become recognised. The big advantage of a blockchain for research is that all activities of scientists can be automatically stored. Whenever a researcher uploads data, performs statistical analyses, writes and submits an article or reviews a manuscript, this is automatically tracked and recorded. By working on a blockchain, the risk of fraud is significantly reduced making it significantly easier to collect reliable and complete data on the performance of researchers, research groups and universities. This would allow for more sophisticated as well as reliable metrics to be built on top of that. Moreover, it will allow metrics to be based on activities that are currently not well recognised (e.g., peer review).

A more comprehensive reform of academic endorsement has been proposed in the manifesto 'Towards Open Science: The Case for a Decentralized Autonomous Endorsement System[11]', published anonymously. The author(s) propose a new academic endorsement system that is not based on current journal publication practices which are argued to be expensive, slow, disregard non-traditional output and negative results, and which give too much power to editors and publishers. Built on the blockchain, the Academic Endorsement System (AES) is based on a new form of currency, coined academic endorsement points (AEP), which can be used by scientists to reward scientific work that is worthy of endorsement. Moreover, the amount of AEP credited to a scientist is based on the AEP received for previous work. Researchers whose output has been endorsed to a high degree will have a larger influence in the community. Any kind of research output could be endorsed, for example blog posts, data sets, software etc. Another advantage is that this system would be faster than the time it takes for citation metrics to accrue.

"A science blockchain could accompany the introduction of a cryptocurrency, which would add an economic layer to the blockchain. This 'bitcoin for science' could be used to make micro payments to publishers for consuming content, and could also introduce a monetary reward scheme to researchers themselves."

Alternative Economic Models

A blockchain for research could accompany the introduction of a cryptocurrency, which would add an economic layer to the blockchain. This 'bitcoin for research' could be used to make micro payments to publishers for consuming content, and could also introduce a monetary reward scheme to researchers themselves. For example, the blockchain could disintermediate publishers and reward authors directly with cryptocurrencies that can be used to purchase other content or services. It could also introduce rewards for research activities, such as peer review, statistical support, exchange of lab equipment, outsourcing specific research, or the hosting of data. Eventually, initial coin offerings (ICOs[12]), a form of crowdfunding using cryptocurrencies, could be used to fund entire research projects. In this way, a crypto economy could evolve in science reflecting the value merits of a number of activities.

The startup Matryx.ai[13] aims to transform the nature of research collaboration itself. Its initiators claim that one of the problems with current scientific practices is its incentive structure. Scientific awards, for example, are based on competition rather than on collaboration, despite the fact that new ideas are usually collaborative in nature. Moreover, different researchers and research groups are often working on the same problems, wasting, as they claim on their website, 'brain power', time and money. Matryx intends to provide a platform enabling and incentivising research collaboration while discouraging solitary and siloed research. On Matryx, a research project starts when users set a bounty on a problem that they want the community to solve. Contributors solve these problems by working with each other on the platform. The collaboration is tracked through the blockchain thus ensuring contributors are credited appropriately when the problem is solved. In principle, everyone can contribute in the collaboration: scientists, PhD students and even enthusiastic amateurs.

1. It is important to note that although all activities and interactions (e.g. content submission, citations) would be stored on the blockchain, this does not mean that all information in its original form is immediately accessible via the platform. The blockchain merely allows the storing of an immutable data trail that can be made public at will, but cannot be manipulated. References (links) to original content can be incorporated in the blockchain, however. Moreover, new and improved protocols can be utilised, such as IPFS, which are designed to to create a permanent and decentralised method of storing and sharing files over a peer-to-peer network.

2. http://www.blockchainforscience.com/

3. https://en.wikipedia.org/wiki/Hackathon

4. http://www.blockchainforscience.com/2017/02/23/blockchain-for-open-science-the-living-document/

5. https://www.linkedin.com/pulse/web-might-have-been-don-peppers?trk=hp-feed-article-title-share

6. http://www.decent.ch

7. https://lbry.io/

8. https://www.katalysis.io/

9. https://publishingperspectives.com/2017/10/frankfurt-blockchain-potential-implications-publishing/

10. https://scholarlykitchen.sspnet.org/2016/06/01/bitcoin-a-solution-to-publisher-authentication-and-usage-accounting/

11. https://zenodo.org/record/60054

12. https://en.wikipedia.org/wiki/Initial_coin_offering

13. https://matryx.ai/

Hype or Game Changer? The Future of Blockchain for Scholarly Communication & Research

In light of its obvious advantages over the current ecosystem, it is tempting to predict that scholarly communication and other research activities will eventually take place on the blockchain. Its potential impact touches many, if not all, challenges around scholarly communication, especially those to do with trust, reproducibility, transparency, and access. However, there are also reasons to be cautious.

Science has evolved over hundreds of years, and with its history comes a significant amount of legacy in technology, systems, organisation as well culture. This legacy makes any change difficult, despite the challenges associated with the current system. As already mentioned, the adoption of online publishing has been swift in the academic world, but this transition has predominantly impacted the mode of dissemination of content and has left other fundamental aspects such as business models, credit systems and peer review untouched.

Moreover, there is an aspect of blockchain that makes a transition to this technology even more challenging. Adopting a blockchain for research successfully implies that it is adopted widely, and this requires a fundamental transformation on the level of funders, institutions, publishers, as well as scientists themselves, which increases the level of change required.

For this reason, it is important to question whether scholarly communication really needs a blockchain, or whether improvements could be achieved with a less drastic change in the ecosystem. In the article '[Do you really need a blockchain for that]!', a checklist is presented to determine whether a blockchain is really a solution. To summarise this article, blockchains are beneficial when certain criteria are met - that there is a shared database with multiple writers with a lack of trust amongst them, and there is no trusted intermediary, or a lack of desire to have one. A blockchain is also relevant once changes on the database can be made collaboratively by multiple writers, and transactions depend on each other. Also, when developing a blockchain it should be clear whether it should be open or closed, and permissioned or permissionless (see 'what is blockchain').

In the case of scholarly communication, all these criteria seem to be met. As we concluded earlier, scientific information is in essence a large, dynamic body of information and data that is collaboratively created, altered, used and shared. Competition between researchers for scientific discoveries and an increasing number of fraud cases means there is a level of mistrust. Moreover, it is hard to think of a single organisation that would be trusted, able and willing to act as a single trusted intermediary. At the same time, the availability of computer facilities at academic institutions and an ecosystem of libraries constitutes a unique opportunity to develop a network of nodes that can validate and maintain the - open and permissioned - science blockchain.

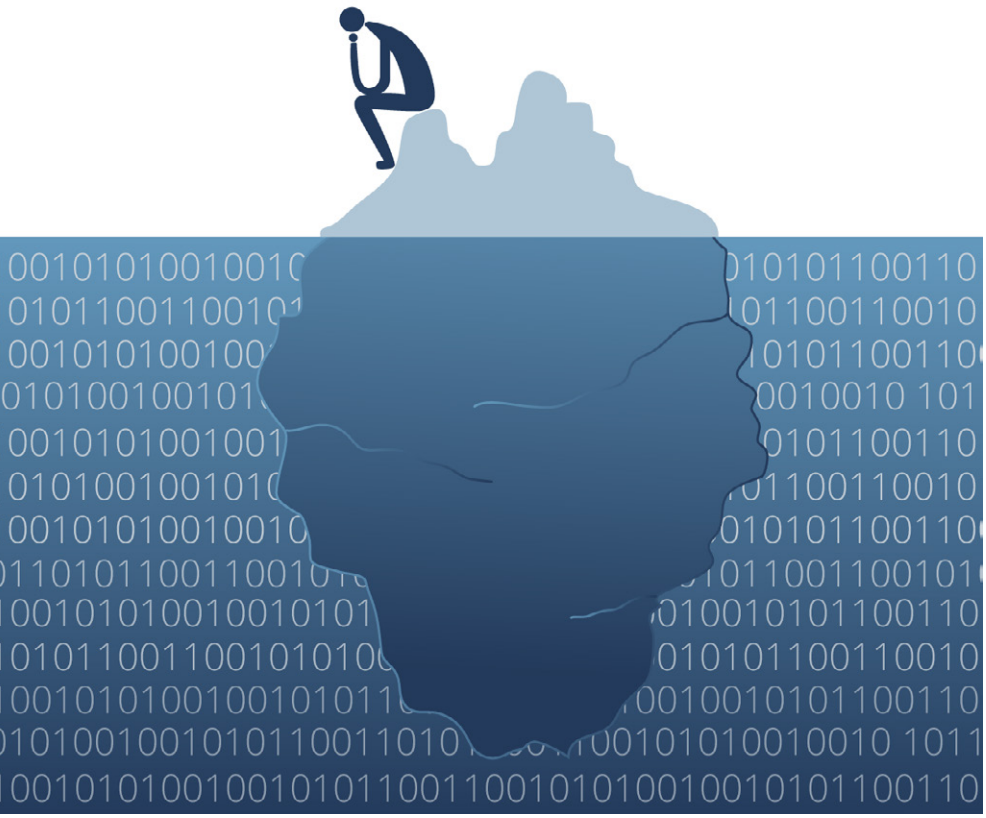
"It is tempting to predict that scholarly communication and other research activities will eventually take place on the blockchain. Its potential impact touches many, if not all, challenges around scholarly communication."

"Adopting a blockchain for research successfully implies that it is adopted widely, and this requires a fundamental transformation on the level of funders, institutions, publishers, as well as researchers themselves."

"The blockchain could have an even broader scope, transcending scholarly communication."

The likelihood and success of a blockchain for scholarly communication would also depend on its level of implementation. For example, information stored on the blockchain could be restricted to traditional researcher roles, publications and use of content (e.g. authorship of scientific articles, usage and citations). But it could also reward unconventional roles and affect wider aspects of the research workflow including peer review, publication of datasets, hypotheses, etc., which would increase the level of complexity. The blockchain, however, could have an even broader scope, transcending scholarly communication. As we have already seen, lab equipment and resources could be shared amongst research groups using the blockchain, with aspects such as credit or financial compensation being managed through the platform. Funding could also take place using a blockchain, and spending could be tracked and made transparent. Distribution of funds amongst scientists could be managed and supported by smart contracts, and a money-back functionality built in dealing with irreproducible results or fraud. The more fundamental the application of the blockchain, the higher the level of complexity will become.

Whether scholarly communication takes place on a blockchain will also depend on developments in adjacent fields. In education, for example, blockchain developments are moving at a faster pace. Blockcerts[2], developed by MIT's Media Lab[3] and Learning Machine[4], is an open initiative that has introduced verifiable blockchain-based certificates for academic credentials (amongst others). Another example is Sony, who announced[5] in the summer of 2017 that it has finished developing a digital system for storing and managing educational records on the blockchain (that no such system currently exists undoubtedly increases the speed of adoption in this area). Obviously there is an overlap between an educational record and the academic record of a researcher, so it is possible that developments in education may speed up the development



"Introducing a blockchain for research and its successful adoption will depend on the collaboration between all stakeholders: funders, government, institutions, publishers, and researchers themselves."

of a blockchain in research as well (for example, a framework or protocol used for a blockchain for education could be reused for a more general protocol or framework for research).

These questions will, to a large extent, also determine the future role of publishers. If the writing of manuscripts, peer review, and the dissemination of content takes place on the blockchain, the role of publishers could, in theory, be considerably reduced. These activities could take place without the mediating role of a publisher. We have seen that the DECENT and LYBR platforms will allow authors to upload content themselves, as well as setting a price and collecting revenues based on readership. But it could also mean that the role of publishers will change towards a focus from content dissemination towards providing author services and peer review.

Overall, the speed of adoption of a blockchain will to a large extent depend on the willingness of, and urgency for this, in the academic community. It will also depend on the level of adoption on the one hand, and the subsequent resistance it will meet as a result of vested interests and a general inertia in the academic ecosystem on the other. A separate question is how to get started. As we have concluded, introducing a blockchain for research and its successful adoption will depend on the collaboration between all stakeholders: funders, government, institutions, publishers, and researchers themselves, whether in their role as researcher, reviewer, editor or author. A platform where these parties come together and reach a consensus on priorities and the way forward will therefore be an important first step. Furthermore, support for initiatives and companies in blockchain, whether in the form of funding, providing access to data or undertaking pilot studies, will be necessary to create momentum in making scholarly communication and research itself more efficient, transparent, open and collaborative through this revolutionary new technology.

"What value would a blockchain add in a demonstrably better way to justify the switching costs of moving over its current assets to a new system? Can it replace its trust in an anonymous, decentralised system that claims to handle matters in a secure and encrypted way?"

"Blockchain looks to me like an infrastructure technology. That means that most of us may not even notice if and how fast it gets implemented in the near future."

Eefke Smit, Director, International STM Association, Standards and Technology, was asked to give her insights.

"For me, the most intriguing facet of blockchain is its characteristic of a decentralised, encrypted peer-to-peer network of trust. It goes without saying that the STM publishing world is suffering its own set of trust issues at present. But even with its imperfections, the current system of academic publishing is strong and offers an efficient infrastructure that serves 10 to 20 million researchers and scientists worldwide. It is a huge community who conform themselves to its deeply embedded terms of engagement and codes of conduct, of academic individuals who join the worldwide system of mutual peer review, of duly referencing previous work, for communication, acknowledgment, reward and recognition.

So what value would a blockchain add in a demonstrably better way to justify the switching costs of moving over its current assets to a new system? Can it replace its trust in an anonymous, decentralised system that claims to handle matters in a secure and encrypted way? I am not convinced. Why would we trust an anonymous network better than people and organisations, including publishers? In addition to this general technology caution, combined with a certain anxiety for autonomous networks, I have never been a true believer in drastic overhauls of current systems, certainly not if they run generally well despite their own imperfections here and there.

Rather, I could see current players adopting and creating bits of blockchain infrastructure where they can really make a differences. And if it all runs well, these initiatives might scale, they may go public to invite more parties in and standards will evolve and be set.

Some possibilities for the STM world spring to mind: it would be interesting if a blockchain could be set up for a virtual currency that rewards referees for their peer reviewing which coins could then be used for – just as an example – publishing services like paying APC's or even personal subscriptions and document downloads. If enough players jump aboard, it could even become a recognised currency across publishers, libraries, social networks. Similarly, citations could be expressed in points or coins of cryptocurrencies, same for support ('likes') for research proposals – enough points or coins could create research funding. Next to these virtual currencies that blockchains can support, the idea of smart contracts established in blockchains is also attractive. If enough positive reviews are added to a manuscript, it gets automatically published. If enough business support exists for a research proposal, it gets funded. Other interesting examples are mentioned in this report: blockchains could serve as the better tools for rights management, micro-payments to authors as rightsholders, identity management, subscription entitlements, usage accounting, patent registries, assertions of scientific breakthroughs, endorsement management, and much more.

To a large extent, blockchain looks to me like an infrastructure technology. That means that most of us may not even notice if and how fast it gets implemented in the near future. We know about Bitcoin, but how many know or truly understand how blockchains underpin that. Applications of blockchain in the STM world may follow a similar path. Digital archives might well run much better and offer more secure preservation using blockchains. Preprint servers and collaboration networks may empower themselves with blockchains. Peer

review may become easier if author identities and credentials can be checked in blockchains, altmetrics may work better if secured by blockchains, but we may not even realise. It may prove to be a game changer as much as a hype, but much of it may go unnoticed to us non-geeks. Because basically it is just an enabling technology. Full of promises."

Prof. Dr. Philipp Sandner is Head of the Frankfurt School Blockchain Center at the Frankfurt School of Finance & Management. The center, launched in February 2017, analyses implications of blockchain technology on companies and business models.

"In general, I think there is certainly a potential to employ the blockchain technology for scholarly communication and science, and I like many of the ideas that are presented in this paper. For me, the essence of blockchain is that it allows transactions of value without intermediaries, and can enable decentralised business models. And it is also in the 'economy of science' where I especially see opportunities for this new technology.

For example, imagine that researchers can publish their research and invite peers to contribute and assist. Everybody who does this, receives virtual tokens for their contribution. These contributions could be reflected in the smart contract organising the royalty distribution. In my mind, communication is key to science, but why are people communicating, revising manuscripts, or supporting other scientists in general? These tokens, facilitated through the blockchain technology, might be the reason in the future. These tokens might provide the incentive to increase the quality and speed of contributions. Smart contract could govern this. For example, each month it takes longer for me to finish my peer review will "cost" me a certain percentage of the tokens.

Additionally, blockchain could enable new funding methods for science. Via crowdfunding schemes leveraged by blockchain technology, interested parties could directly take part in funding specific projects – and get a return for it. This does not necessarily need to involve private organisations. A smart contract "collecting" funds for a project could also be the fund raising mechanisms for multiple funding organisations such as foundations or state-owned organisations. In doing so, a researcher could create a project offered to funding institutions which then contribute in a non-exclusive way to the project. Here, the smart contract governs the way funds are raised and the value generated might be re-distributed to the funding institutions."

"The essence of blockchain is that it allows transactions of value without intermediaries, and can enable decentralised business models."

1. https://coincenter.org/entry/do-you-really-need-a-blockchain-for-that
2. https://www.blockcerts.org/
3. http://learn.media.mit.edu/
4. http://www.learningmachine.com/
5. https://www.sony.net/SonyInfo/News/Press/201708/17-071E/index.html

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