BLOCK BY BLOCK

A Comparative Analysis of the Leading Distributed Ledgers

MERCY CORPS

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EXECUTIVE SUMMARY

Purpose

This report compares nine distributed ledger platforms on nearly 30 metrics related to the capabilities and the health of each project. The analysis looks at a broad range of indicators -- both direct and indirect -- with the goal of synthesizing trends and patterns that define the market leaders.

What's Included

Bitcoin
Corda
Ethereum
Hyperledger Fabric
Multichain
NEO
NXT
Quorum
Hyperledger Sawtooth

Audience

This paper is intended for readers already familiar with distributed ledger technologies and will prove most useful to those that are currently evaluating platforms in order to make a decision where to build or deploy applications. Accordingly, the text often assumes some knowledge on the part of the reader and a level of technical sophistication that does not require explanation of all terms used in this document.[1]

Methodology

We compare each of the systems on a variety of criteria. The criteria are grouped into three categories:

1. **Technical Structure & Feature Set**
2. **Business Considerations**
3. **Health Indicators**

For each category, we examine a variety of largely objective metrics in hopes of being able to draw some meaningful comparisons that will provide you with firm ground for making an assessment of suitability for purpose.

Principal Conclusions[2]

The final section of this paper discusses in detail the conclusions reached in this report. The most significant conclusions being:

- **Ethereum** is the clear leader in the public blockchain space, with broad support and a large number of resources and developers.
- **Corda** and **Fabric** lead in the private blockchain space, with **Fabric** benefitting from the backing of Hyperledger and IBM.
- **NXT** is a project of some concern, whose future seems in doubt.
- **Quorum**, after a strong start, has slowed and appears to be going through some changes that bear watching.

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[1] For a good primer on the technology, consider our previous publication on the subject "A Revolution in Trust," see, https://www.mercycorps.org/research-resources/revolution-trust-distributed-ledger-technology-relief-development

[2] NOTICE OF DISCLOSURE: Note that the author holds several of the currencies discussed in this paper, including: Bitcoin, Ethereum, NXT, Cardano, Neo, Ripple, Stellar, and Stratis.

PRELIMINARY MATTERS

The selection process for this paper began with an examination of 17 distributed ledger platforms[3]. During the course of data collection, the list was narrowed to a final set of nine. Systems were removed from consideration typically for one of two reasons: either they were not yet in a production release[4], or they were focused on a very narrow use case[5]. Nine systems may seem like a small number. The simple fact is, that while there is an increasing array of choices for distributed ledger platforms, the number of options for building an robust (dare we say "enterprise"?) distributed ledger are actually quite limited at this time; we've tried to identify and compare those contenders in this document.

Note that the focus here is on providing information about the systems that decision-makers are most likely to be looking at when they decide where to build or deploy their apps. The selection set is not intended to identify the best, or even the most interesting, new platforms, rather, our selection set includes the names we think are most likely to come up in any discussion of "where to build."[6]

This paper was produced by Mercy Corps' Technology for Development team[7] which cultivates the innovative application of leading edge technology to make global humanitarian and development work more effective and efficient. This analysis seeks to enable users to harness the power of distributed ledger technologies for social good.

A Note on Methodology

As a final note before we get started: Please keep in mind that, from a research perspective, several of the products in our sample group present unique challenges. **Bitcoin**, **Ethereum**, **Neo**, **NXT**, and **Quorum**, in particular, are problematic.

In the case of **Bitcoin**, **Ethereum**, **Neo**, and **NXT**, the difficulty occurs due to the existence of digital currencies of the same names. As the digital coin product and the underlying distributed ledger product lack naming distinction, some research data points are susceptible to distortion. In an attempt to filter out results of the term that are not related to the underlying distributed ledger platform (as opposed to the coin of the same name) we have sometimes used very specific searches, for example, formulating queries that use the word "bitcoin" together with the word "blockchain" (i.e.,

Security & Privacy

While the security and privacy aspects of these systems is undoubtedly of concern to anyone selecting a platform, this report has not attempted to rate or review systems on these factors. While we would have liked to provide guidance on the topics, there is no consistent objective data set available at this time that allows us to compare the systems with confidence -- and without speculation. Note that the list of additional features in Sec. 1 does highlight system features relevant to this enquiry.

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[3] Among the systems considered but rejected were: **Cardano**, **Digital Asset Platform**, **IOTA**, **Lisk**, **Ripple, Sequence**, **Stellar**, and **Stratis**.

[4] E.g., **Cardano**, **Digital Asset**, **Lisk**, **Stratis**.

[5] E.g., **IOTA**, **Stellar**, **Ripple**.

[6] **Bitcoin** has been included, largely due to the fact that the system always comes up in discussions of blockchain platforms. While it is an unlikely choice for most deployments, having the comparative data on the system is likely to be helpful to address the questions that are likely to come up during discussions of platforms.

[7] See, https://mercycorps.org

run the search for ‘bitcoin blockchain’ rather than just ‘bitcoin’).

In the case of **Quorum,** the issue relates to the need to filter out irrelevant references. The problem here is that the product name is also a term in common usage. As with the products above, if unchecked, this problem would result in over-reporting. In an attempt to filter out results of the term that are not related to the **Quorum** blockchain platform, we have sometimes used very specific queries, e.g., searching for the string "quorum blockchain" instead of for the single word "quorum."

Our approach to these problems is of mixed effectiveness. While the modified query strings tend to knock out irrelevant references, they also invariably kill off a certain number of relevant references, hence resulting in under-reporting. It’s a balancing act and one we try to highlight in the “Notes on Interpretation” attached to each exhibit.[8]

The Evolution of Distributed Ledgers

With the publication of a whitepaper in 2008, Satoshi Nakamoto launched the era of blockchain and distributed ledgers. The “chain of blocks[9]” outlined for the first time in Satoshi’s whitepaper existed for one reason only: to act as a ledger tracking the ownership of a digital currency named **Bitcoin**. In January of 2009, the **Bitcoin** experiment was launched and first blockchain was live.

The **Bitcoin** network has grown and the system has been modified over the years by the developers involved in the project.[10] The core functionality, however, has always remained the same: tracking the ownership of **Bitcoin**.[11] While that first blockchain may have been designed to do only one thing, it does it pretty well. In the 10 years since the system’s launch it has never gone down or been hacked and, as **Bitcoin** has grown, it has competently managed large volumes of transactions with significant financial value.

Bitcoin and its immediate progeny represent the first generation of distributed ledger technology (DLT); a convenient label might be “DLT 1.0”. By way of definition: A DLT 1.0 system is narrowly focused on one primary task, managing a digital currency. Bitcoin may have been the first, but it is not the only DLT 1.0 system. A number of the cryptocurrencies that popped up in the wake of **Bitcoin** actually started by forking the **Bitcoin** codeset and then modifying elements of that codeset to create something distinct (e.g., Litecoin).

Fast forward to 2014: Vitalik Buterin envisions the next generation of distributed ledger technology and launches a project known as **Ethereum**. With an innovative technical architecture and investment of over $15 million[12], the system was poised to be a game changer. Here was a blockchain that not only supported tracking ownership of a native coin, but also included a purpose-built business logic layer designed to allow a blockchain to incorporate programming that would automatically execute instructions, a functionality that became known as a “smart contract.” The **Ethereum** blockchain also supported the use of tokens that could be traded independently of **Ethereum**’s native cryptocurrency. **Ethereum**, with its meaningful expansion of functionality for DLT, heralded the

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[8] Once data collection was completed, we forwarded the data sheets to all the projects and asked them to verify the data. Some responded, some did not. As writing wrapped up, we forwarded to all the projects a preview copy of the paper and invited comments. We received a number of comments and modifications were made to this final version you now see before you. It is our hope that this open process has led to a final result that is not only accurate, but also fair and balanced.

[9] As Satoshi called it; the whitepaper did not actually employ the term “blockchain.”

[10] The modifications have largely related to improving scalability by addressing shortcomings in the system’s transaction throughput.

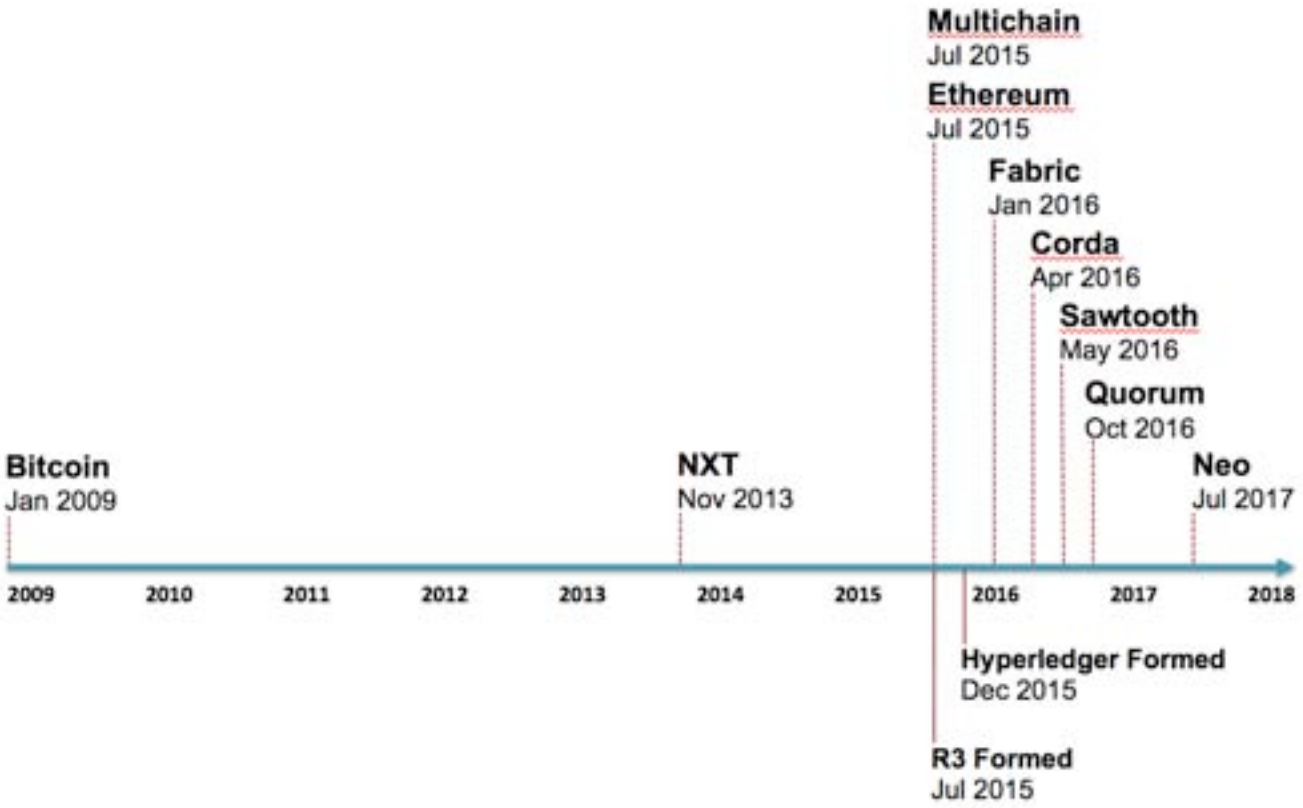
[11] While creative developers have come up with ways to run smart contracts and support asset tokenization, such things were never part of Satoshi’s original design. Additional functionality is often being grafted onto the system via the use of external components that handle at least some of the business logic off-chain.

[12] See, Sec. 3, “Venture Capital and Investors,” below.

arrival of the next generation of systems: DLT 2.0. In addition to **Ethereum**, there were numerous other systems of the same generation, notably including **Neo**, which is included in this survey.

Despite the expanded functionality, the fundamental structure of blockchains and the consensus mechanisms they employed had changed only slightly and still left much to be desired in terms of maturity of the features expected in enterprise applications. The next generation of DLT systems, DLT 3.0, would bring major changes, with an explosion in alternative consensus mechanisms and the birth of systems that included a range of features one would expect to find from enterprise-grade platforms (e.g., highly configurable, more granular control over permissions and visibility, various staging environments). The first of these systems was the Open Blockchain from IBM, which was later rebranded as **Fabric** and transferred to Hyperledger[13]. Within a year, we saw the arrival of a number of DLT platforms aimed at the enterprise. Among the DLT 3.0 systems covered in this report are **Corda**, **Sawtooth**, and **Quorum**, a modified version of the **Ethereum** blockchain.

Fig. 1 : Timeline



Notes on Interpretation

- The dates shown for **Fabric** and **Sawtooth**[14] reflect when those products joined Hyperledger. Both projects started earlier, founded by teams at IBM and Intel, respectively.
- The date shown for **Neo** reflects when it was rebranded and launched publicly; it had existed previously as "AntShares." The AntShares version of the system began development in 2014.

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[13] Hyperledger is part of the Linux Foundation. See, https://hyperledger.org

[14] We recognize that the proper name for these projects are "**Hyperledger Fabric**" and "**Hyperledger Sawtooth**" but for space purposes and readability, we refer to them throughout this paper simply as **Fabric** and **Sawtooth**.

As we review the landscape today, we see multiple approaches to the creation of a distributed ledger, from blockchains, to tangles[15], to even more exotic creatures that remain as yet unproven. The landscape also provides a variety of consensus mechanisms and an increasing number of options for functionality. Choosing the right platform has become significantly more complex. It's time to examine the platforms and create a comparative analysis of systems to see if we can't enrich the process of choice with some objective measures of capabilities and risks that allow technologists and business people to assess suitability for purpose.[16]

Sec. 1 : Technical Structure & Feature Set

We begin the examination by looking at each system in terms of the technical structure and the features offered. When selecting a DLT platform, the answer to two key questions will immediately narrow your selection set:

- **Do you want to deploy on a system that is public or private?**
- **Do you need a system that is permissioned or permissionless?**

We deal with those questions first, then look at a variety of other aspects, including programming languages supported and capabilities.

Public or Private?

Who can run a node in the network?

The question of whether a platform is public or private examines who is allowed to run a node on the network. In a public blockchain, anyone can run a node and those who do so may, in some systems, choose to do so anonymously. The result is that in many public blockchains, no one knows with certainty who is running nodes in the network. Bitcoin, and many of the earliest blockchains, are public in nature. In contrast, a private blockchain restricts membership to only known entities. Private blockchains often also include options to create varying levels of access to the data in the system.

Aside from the issue of access, the key difference between public and private blockchains relates to the resilience of the underlying network. Typically, a public blockchain will have more active nodes and is likely to include greater diversity in the operators of those nodes. More nodes and more diversity creates a network that is more resilient to downtime and more resistant to fraud. The purists in this field, who emphasize the importance of decentralization, unanimously prefer public blockchains over the more restrictive private options.[17]

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[15] A new and unique consensus mechanism from **IOTA**.

[16] How you choose to weight these factors is up to you and should reflect your priorities. There are several good articles on the process, see e.g., https://www.ibm.com/blogs/blockchain/2018/03/top-5-questions-for-choosing-a-blockchain-technology/ and https://medium.com/@abody/blockchain-how-to-choose-the-right-tech-for-your-business-aa4597d7ee7c

[17] Public blockchains require incentive schemes to keep the participants motivated and this means that public chains are typically powered by proof of work consensus mechanisms. Such systems bring with them high-energy consumption requirements, another factor discussed else in this paper. See, "Energy Consumption" in Sec.2, below.

Fig. 2 : Public or Private?

Public	Private	Either (Configurable)
Bitcoin	Corda	Multichain
Ethereum	Fabric	Sawtooth
Neo		Quorum
NXT		

Notes on Interpretation

- **Multichain, Quorum,** and **Sawtooth** can be configured to run in either mode.

Permissioned or Permissionless?

Do you need to control what the network participants can do?

Where public vs. private relates to who may participate in the network, permissioned vs. permissionless is concerned with what the network members can do. In a permissionless environment, all participants can perform all tasks – confirming transactions, reading, and writing data.[18] In a permissioned environment, privileges are segregated: some may be able to read but not write, others may be able to read or write, and still others may be able to perform all those functions, along with administrative powers.

Fig. 3 : Permissioned or Permissionless?

Permissioned	Permissionless	Either (Configurable)
Corda	Bitcoin	Multichain
Neo	Ethereum	Sawtooth
	Fabric	Quorum
	NXT	

Notes on Interpretation

- **Multichain, Quorum,** and **Sawtooth** can be configured to run in either mode.

[18] Public blockchains are most commonly permissionless, though there are exceptions (e.g., Neo).

Consensus Mechanism

How do the nodes arrive at agreement on the state of the ledger?

DLT 1.0 systems invariably used proof of work approaches to consensus, where the participants in a public blockchain compete for the chance to write data to the chain in return for a reward of some sort. Over time, systems began to experiment with alternatives to the computationally intensive proof of work approach; the proof of stake[19] mechanism was one of the first alternatives and remains one of the most common. More recently, a mass proliferation of consensus mechanisms has occurred, with most enterprise systems now providing customers with the option to "plug in" the mechanism of their choice.

Fig. 4 : Consensus Mechanisms

System	Consensus Mechanism
Bitcoin	Proof of Work
Corda	Pluggable Framework
Ethereum	Proof of Work (Ethash)
Fabric	Kafka
Multichain	Distributed consensus among identified validators in a round robin fashion
Neo	Delegated Byzantine Fault Tolerance
NXT	Proof of Stake
Quorum	Raft
Sawtooth	Proof of Elapsed Time (POET)

Notes on Interpretation

- **Ethereum** plans to abandon proof of work and move the platform to proof of stake in the near future.
- While Kafka is the default option, **Fabric** is designed to support a pluggable framework. Simplified Byzantine Fault Tolerance is currently under development.
- **Multichain** can also be configured to support proof of work.
- **Quorum** can also be run with Istanbul Byzantine Fault Tolerance.
- While POET is the default option, **Sawtooth** has a pluggable framework. The system can also be dynamically configured to allow multiple consensus mechanisms on the same chain.

[19] Where participants make a financial commitment or other pledge that acts as a guarantee of their performance.

Languages supported

Which programming languages are supported by each platform?

With most systems supporting several choices,[20] a developer who wishes to write a smart contract, or engage in custom development of a particular ledger, has a wide range of programming languages from which to choose. Go[21] and Java are the most common options, with C++ and Python close behind.

Fig. 5 : Programming Languages

	.NET	C++	DAML	Go	Java	JavaScript	JSON	Kotlin	PHP	Python	Ruby	Rust	Script	Solidity
Bitcoin		■											■	
Corda					■			■						
Ethereum		■		■						■	■	■		■
Fabric				■	■	■								
Multichain	■			■	■	■	■		■	■	■			
Neo	■	■		■	■	■	■			■				
NXT					■									
Quorum		■		■						■				■
Sawtooth		■		■	■	■				■	■	■		■

Notes on Interpretation

- Data derived from various project sites, documentation and the projects themselves.
- Note that the chart, above, does not relate to dApp creation. dApps can be written in any language that is able to make calls to the ledger platform.
- The core of **Sawtooth** was written in Python but is currently being ported over to Rust, but all of the interactions with the **Sawtooth** blockchain are via the SDKs for the languages indicated.
- **Sawtooth** also provides a WebAssembly (WASM) SDK.

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[20] It's worth noting that, technically speaking, distributed ledger platforms are protocols and that a protocol can support various languages. Most distributed ledger platforms have various reference implementations that allow you to work with that platform in the language of your choice. For example: **Ethereum** has three popular reference implementations: C++, Go and Python. Additionally, there are more obscure implementations in Ruby, Rust and other languages. However, most systems do favor a particular language, and coding in that preferred language will bring access to more and better toolkits.

[21] Aka "Golang"

Transaction Rates

How often is data written to the chain, and how long does it take to complete a transaction?

Bitcoin, the first blockchain, was designed to accept new blocks every ten minutes. The system samples how quickly blocks are being generated and adjusts mining difficulty to maintain the ideal 10-minute cycle. Ethereum uses a similar approach but, by design, block generation times in Ethereum are much shorter, ranging from 10 to 19 seconds.[22] Proof of work systems typically impose such limits on their systems in an attempt to prevent miners from dominating the mining process through simple application of more computing power. Proof of stake and other consensus systems typically offer greater flexibility in most aspects of block generation, including not only generation time, but also block size and transaction size, allowing such systems to achieve high transaction rates.

The transactions per second statistics in the chart, below, are approximations (i.e., given a known block generation time, and an average number of transactions per block, you can calculate the effective transaction rate for the system).

Fig. 6 : Block Generation Times & Transactions Per Second

	Block Generation Time	Transactions Per Second (tps)[23]
Bitcoin	10 minutes	Average 3 tps (Max: 7 tps)
Corda	n/a	> 500 tps
Ethereum	10-19 seconds	Average 15-20 tps, but no theoretical limit
Fabric	variable	> 10 tps
Multichain	Configurable (≥ 2 seconds)	Configurable
Neo	15 seconds	10,000 tps
NXT	1 minute	12 tps
Quorum	50 mSec	>500 tps
Sawtooth	Configurable	>500 tps

[22] In the near future **Ethereum** will shift from proof of work to proof of stake. In that process, the difficulty process for **Ethereum** will be manipulated to encourage miners to cease mining. Eventually a point will be reached where difficulty reaches an impossible level, at which point proof of stake will be the sole consensus mechanism in **Ethereum**.

[23] By comparison, the Visa network was tested at 24,000 tps in 2010; the company claims the system can achieve 56,000 tps.

Notes on Interpretation

- Block generation time in all proof of work systems can be significantly longer during peaks in activity on the network, so consider the times shown for the proof of work systems to be ideals.
- **Corda** is a distributed ledger that does not rely on blocks, hence the block generation time statistic is not applicable.
- **Fabric** is listed as having a variable block generation time due to the system's ability to support parallel processing and segregation of tasks between nodes. How long it takes to generate a block depends on the configuration.
- **NXT** allows the operators of the network to adjust the block generation time upon agreement.

Smart Contracts

How complete is the business logic layer?

Most DLT 1.0 systems do not provide the additional ability to execute logical actions beyond those necessary for tracking the system's digital currency. As systems evolved, the ability to allow the participants in the network to automate actions (that is, create smart contracts), became a common feature.

Smart contract functionality is often talked about in terms of whether it is "Turing complete" or "deterministic." Both terms refer to whether the system supports a full range of logical operations or only a limited set of commands and instructions. The chart below shows the extent to which each system supports smart contracts as well as their supported programming languages.

Fig. 7 : Support for Smart Contracts

	Supports Smart Contracts?	Turing Complete?	Language
Bitcoin	No	n/a	**n/a**
Corda	Yes	Yes	**Kotlin, Java**
Ethereum	Yes	Yes	**Solidity**
Fabric	Yes	Yes	**Go, JavaScript**
Multichain	No	n/a	**n/a**
Neo	Yes	Yes	**C#, Java**
NXT	No	n/a	**n/a**
Quorum	Yes	Yes	**Solidity**
Sawtooth	Yes	Yes	**Solidity, Go JavaScript, Python**

Notes on Interpretation

- While the native **Bitcoin** blockchain does not support smart contracts, third party add-ons exist which can enable basic functionality.
- Theoretically, **Fabric** can support any language for creating smart contracts, via Docker (container tech).
- **Multichain** claims this functionality is coming in Multichain 2.0, and the programming language supported will be JavaScript.
- **Sawtooth** supports a wide range of languages for smart contracts via SDKs.

Additional Features

What are the major features of each system?

Across the previous pages we've looked at key technical attributes common to most of the systems. In this section we look at unique or distinctive functionality included with each platform. Note that the list below displays features in addition to those already discussed in previous sections. That said, the list should also not be considered as exhaustive, but rather as a list of highlights.

Fig. 8 : Significant Features

System	Notable Additional Features
Bitcoin	• None • Support for multisignature transactions
Corda	• Communication between nodes is point-to-point; transactions are not broadcast to the entire network • Issuance of certificates (certificate authority) • Support for oracles • Transaction time windows (time as a condition for transactions) • Able to run multiple consensus algorithms simultaneously • Code contracts backed by legal documents • Oracle and SQL Server integration • Enterprise version includes "Blockchain application firewall"
Ethereum	• Support for issuance of tokens • Support for creation of DAOs
Fabric	• Issuance of certificates (certificate authority) • Ability to create distinct channels (i.e., access to content restricted to channel members) • Modular architecture • Transaction execution separated from ordering and commitment
Multichain	• 64MB of data per transaction • Atomic asset exchange • Full multisignature support • External key management • Native multicurrency support • Ability to run multiple networks on single server

Neo	• Support global assets and contract assets • Decentralized storage service • Future-proofed against quantum computing • Digital identity service • Onchain governance • Private smart contracts validated only by parties to contract
NXT	• Setting of account properties via tags • Asset tokenization • Built-in asset exchange • Support for aliases • Ability to issue currencies • Onchain data storage • Build-in marketplace • Messaging layer
Quorum	• Private smart contracts validated only by parties to contract • Every node validates transactions but without revealing parties or data
Sawtooth	• Clear separation between application layer and the core system • Provides transaction families, which allow for faster app development • Ability to subscribe to events • Ethereum Virtual Machine (EVM) smart contracts are supported • Onchain governance • Dynamic consensus mechanism management

Sec. 2 : Business Considerations

In this section we look at the business-related factors that can influence platform decisions. The focus is on potential business continuity risks, the availability of supporting services, and costs.

Project Governance

How is the development of the platform managed?

The DLT movement has its roots firmly in open source. Projects like Bitcoin rely on the traditional laissez-faire approach of community management, where the developers writing the code dictate the development priorities and where achieving an agreement between all the node operators is a prerequisite to major system upgrades. The open source eco-system, while capable of producing capable systems, often lacks certain attributes desired by enterprise IT: predictable release schedules, proper support, and transparency in development path.

Corporate-backed DLT projects are on the rise, with the backing firms typically offering a wider range of ancillary services aimed at the enterprise. The trade-off, of course, is the increased risk that comes with pinning the fate of your platform on that of a privately run company and potentially finding your needs subsumed to shifting business

conditions. At this point in time, the DLT platform market is very dynamic and one substantial pivot made by a platform provider in an effort to stay competitive may see a product change radically.

A middle ground can be found in open source foundation-backed projects, where a non-profit foundation holds at least some of the rights to the brand or the intellectual property and takes a lead role in the governance of the project, thereby providing stability and predictability. The combination of a stable non-profit foundation backed by a supportive open source community has a proven record of success in the open source world[24] and is a model used by many of the projects in the survey, as shown in the chart below.

Fig. 9 : Governance Structures

	Nonprofit Foundation	Open Source Community	Corporate-backed
Bitcoin	--	Yes	--
Corda	R3[25]	Yes	--
Ethereum	The Ethereum Foundation[26]	Yes	--
Fabric	Hyperledger[27] (Linux Foundation)	Yes	--
Multichain	--	--	Coin Sciences Ltd
Neo	Neo Foundation[28]	Yes	--
NXT	Jeluride BV	Yes	--
Quorum	--	Yes	J.P. Morgan
Sawtooth	Hyperledger (Linux Foundation)	Yes	--

Notes on Interpretation

- **NXT** was previously governed by the NXT Foundation. The Foundation's role was taken over by Jelurida BV, which now holds the brand and the IP. It appears that the governance of the project is presently being managed by the Ardor NXT Group (ANG). See, https://ardornxt.io/
- A news article in March of 2018 indicated that **Quorum** may be spun off as a project independent of J.P. Morgan.[29]

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[24] E.g., The Linux Foundation, .NET Foundation, the Apache Foundation, the Cloud Native Computing Foundation.

[25] See, https://www.r3.com/

[26] See, https://www.ethereum.org/foundation

[27] See, https://www.hyperledger.org/

[28] There seems to be little information available about the Foundation.

[29] See, https://www.reuters.com/article/us-blockchain-jpmorgan/jpmorgan-mulls-spin-off-of-blockchain-project-quorum-sources-idUSKBN1GY36O

Licensing

What is the nature of the software license for the platform?

The chart, below, shows the licenses that relate to each of the platforms in the survey. While a full discussion of the pros and cons of the various licenses is beyond the scope of this paper, generally speaking, the MIT and Apache licenses are more permissive than the GPL family of licenses and exhibit broader compatibility with other types of licenses.

Fig. 10 : Licensing

System	License
Bitcoin	MIT License
Corda	Apache 2.0
Ethereum	GPLv3
Fabric	Apache 2.0
Multichain	GPLv3
Neo	MIT License
NXT	GPLv2
Quorum	GPLv3
Sawtooth	Apache 2.0

Notes on Interpretation

- **Ethereum** licensing is a bit confusing. The license cited above (GPLv3) is the license for the Go implementation core – the most popular version. Different implementations may have different licenses. Additionally, various tools have different licenses. You can learn more on the wiki: https://github.com/ethereum/wiki/wiki/Licensing
- The **Quorum** product is based on the **Ethereum** Go version and inherits its license (GPLv3).

Third Party Support

In this section, we look at third party support as an indicator of the extent and maturity of the ecosystem around the platforms. By determining the number of third parties that offer commercial services targeting the users of a specific system, we can make inferences about the demand for the system.

For this metric, we look at four types of service providers:

- **Developers**
- **Publishers**
- **Blockchain-As-A-Service (BAAS) Providers**
- **Partnerships**

Commercial developers and publishers are two of the easiest and most meaningful groups to assess. In the case of developers, the question is: How many developers are offering services for each system? In the case of publishers, the question is: How many books are in print for each of the systems? The third metric we examine, major Blockchain As-A-Service providers,[30] gives us an indication of where these players are seeing demand for DLT platforms from their client base. In all three situations, as the parties have commercial interests, the results should give us some idea where third parties are putting their money and effort and where they think there is market share worth capturing.

Of the four indicators, the Partnerships indicator is likely the weakest in terms of indicating platform strength. While partnerships may be chosen on merit, the reality of business dictates that oftentimes other considerations – considerations unrelated to project quality or popularity – may dictate partner selection.

Developer Support

How many developers are offering services for each system?

Upwork and Guru provide online directories designed to help buyers locate professional service providers. Upwork[31] is focused on web, programming, writing and related professions. The company claims to process more than $1 billion in contract work each year. Guru[32] provides a service similar to Upwork, though their focus is less on technology professionals. Guru does, however, claim more than 3 million active freelance profiles. We visited both sites and searched for developers offering services for each of the systems in our survey set.[33]

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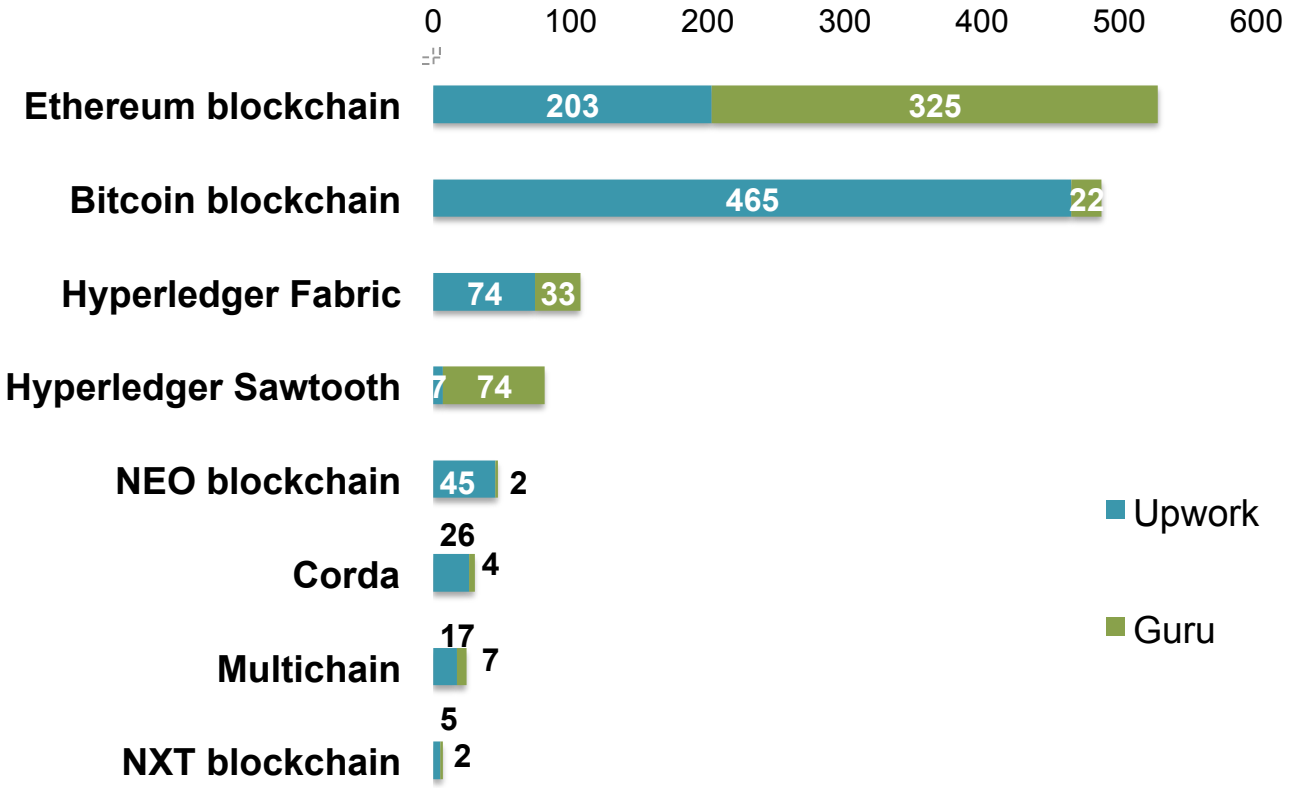
[30] Specifically, Amazon, Google and Microsoft.

[31] See, https://www.upwork.com/

[32] See, https://www.guru.com/

[33] Note that we searched for the various system names, as shown in the chart, as opposed to searching by programming languages. The logic being that, for example, while someone may tag their profile with "go" they may have no actual experience with **Ethereum**. On the other hand, if they tag their profile with a specific platform name, they are more likely to have some experience with that specific platform.

Fig. 11 : Contract Developers, by Platform



Notes on Interpretation

- The data labels in the left column reflect the search strings used in each case.
- Not Included: **Quorum**, due to ambiguous search results, however, given that **Quorum** is a fork of **Ethereum**, most developers able to work with **Ethereum** should also be able to work with **Quorum**.

Publisher Support

How many books are in print for each of the systems?

To gain further insight into the extent each system enjoys support from fans and third parties, we looked at books in print. The search was restricted to English language books only. A visit to Amazon.com produced the information contained in Figure 12.

Fig. 12 : Books in Print

System	Titles on Amazon
Bitcoin blockchain	770
Corda	3
Ethereum blockchain	110
Hyperledger Fabric	14
Multichain	3
Neo blockchain	18
NXT blockchain	6
Quorum blockchain	2
HyperledgerSawtooth	2

Notes on Interpretation

- Data derived from Amazon.com on 6 Aug 2018; English language titles only.
- The label in the left column indicates the search string employed.
- The **Bitcoin**, and likely the **Ethereum**, numbers are overly optimistic. A review of the results set showed that a number of titles were more concerned with the underlying currency than with the capabilities of the associated blockchain platforms.
- Had our search encompassed Chinese language publications, the numbers for **Neo** would be much higher.

Blockchain As a Service (BAAS) Providers

Which platforms are available on major services?

Blockchain As a Service allows customers to leverage cloud architecture to deploy and host DLT platforms. In the BAAS model, a customer typically pays a subscription fee for access and is then able to provision and deploy their chosen platform, with the BAAS provider handling all the tasks necessary to keep the infrastructure functioning. Some systems have a built-in ability to deploy a DLT platform, others use the “bring your own license” (aka, BYOL) model wherein the client may deploy the platform in the cloud but must possess a license for the platform.

The biggest players in the BAAS space at the moment are

- **Amazon Web Services**[34]
- **Google Cloud Platform**[35]
- **Microsoft Azure**[36]

The chart, below, shows which platforms these three major players support.

Fig. 13 : Major BAAS Providers Support for Each Platform

	Amazon Web Services	Google Cloud Platform	Microsoft Azure
Bitcoin			
Corda		Coming Soon	
Ethereum			
Fabric			
Multichain			Coming Soon
Neo			
NXT			
Quorum	Available via Kaleido		
Sawtooth		Coming Soon	Coming Soon

Notes on Interpretation

- According to a representative from R3, **Corda**'s availability on the Google Cloud Platform will announced shortly.
- **Quorum** is available on Amazon Web Services via the Kaleido[37] platform.
- **Sawtooth** data provided by the project.
- **Multichain** data provided by the project.

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34 See, https://aws.amazon.com/blockchain/

35 See, https://console.cloud.google.com/marketplace

36 See, https://azuremarketplace.microsoft.com/en-us/marketplace/apps/category/blockchain

37 A software-as-a-service offering from ConsenSys. See, https://kaleido.io/

Partnerships

What companies are publicly aligned with or supporting the platform?

The chart, below, shows the publicly announced partnerships associated with each system. Several of the systems backed by foundations or consortiums enjoy broad support from large numbers of partners.

Fig. 14 : Notable Partnerships

System	Partners
Bitcoin	n/a
Corda	200+, including Barclays, BBVA, Microsoft, Hewlett Packard, Accenture, Ernst & Young, KPMG, and others
Ethereum	150+, including Banco Santander, Bank of New York, Accenture, Commerzbank, Credit Suisse, and others
Fabric	200+, including Accenture, Airbus, Daimler, Cisco, IBM, SAP, Baidu, Intel, and others
Multichain	80+, including Accenture, Cognizant, HCL, PwC, SAP, Wipro
Neo	WINGS, Alibaba, Binance
NXT	unknown
Quorum	Enterprise Ethereum Alliance
Sawtooth	200+, including Accenture, Airbus, Daimler, Cisco, IBM, SAP, Baidu, Intel, and others

Interpretation

- R3, the backers of **Corda**, includes over 200 members.
- Hyperledger, the backer of **Fabric** and **Sawtooth**, has over 200 members.
- The Enterprise Ethereum Alliance, backer of **Ethereum**, has over 150 members
- **Quorum**, though sponsored by J.P. Morgan, is based on **Ethereum** and likely benefits from some of the same partner support as **Ethereum**.
- No information was available on the **NXT** site and the project did not respond to queries.

Associated Costs

What are the costs associated with operating each platform?

For this metric, we look at three data points:

- **Pricing**
- **Cost per Transactions**
- **Energy Consumption**

To gain insight into the costs associated with operating each of the systems, we looked at both direct and indirect costs. The three statistics are of mixed value. Many of the projects are open source where licensing fees are not an issue. For the systems charging licensing fees, only limited information was available.

In terms of ongoing costs, some of the public blockchain systems will incur a cost for each transaction, but this cost typically does not exist in private blockchains. Energy consumption is another indirect cost, though a cost borne by the network, not by the customer. We, nonetheless, include the energy costs analysis here as it is increasingly an issue of concern in terms of the long-term sustainability of some platforms and the social costs they incur.

The simple fact of the matter, however, is that other costs not outlined here are likely to be the most substantial. Aside from the few systems that require a license or subscription fee, the majority of the costs incurred will relate to design, customization, implementation, training, and ongoing management; those costs are beyond the scope of this paper.

Pricing

What are the licensing costs for each system?

As most of the systems in this survey are open source, they incur no license fee. The exceptions are detailed in Figure 15, on the following page.

Fig. 15 : Licensing Cost

System	Licensing Cost
Bitcoin	None
Corda	Dual License: An Open Source version that incurs no fee, and an Enterprise version that includes expanded features and a commercial license fee. R3 would not disclose the pricing structure.
Ethereum	None
Fabric	None
Multichain	Dual License: Open source version is free; Supported version with commercial license: $25k/yr. for network and first 4 nodes; $2500/yr. for each additional node.
Neo	None
NXT	None
Quorum	None
Sawtooth	None

Cost per Transaction

What is the cost of the network fees associated with each transaction?

The public blockchains in this survey rely on transaction fees for all, or part of, their sustainability. Private blockchains typically do not charge transaction fees, though some may support configuration in such a fashion that the administrator could implement such charges

Fig. 16 : Network Transaction Fees

System	Cost per Transaction
Bitcoin	variable, based on demand
Corda	n/a
Ethereum	variable, based on demand
Fabric	n/a
Multichain	n/a
Neo	$0
NXT	Priced according to the nature of transaction
Quorum	n/a
Sawtooth	n/a

Notes on Interpretation

- At the time of writing, **Bitcoin** transactions cost $0.39 per transaction.[38]
- At the time of writing, **Ethereum** transactions cost $0.18 per transaction.[39]
- While **Neo** transactions are currently free, a user can elect to pay a fee to prioritize processing of their transaction.
- **NXT** fee calculations are more complex than other systems, with the price related to the type of transaction being processed. See, https://nxtwiki.org/wiki/Transaction_Fees for a list of the fees.

Energy Consumption

Which systems are energy intensive?

There's been a great deal of press recently on the energy consumption profiles of systems like Bitcoin. While some of the articles have included a fair amount of hyperbole about the amount of electricity it takes to confirm a block, the fact is that proof of work systems do rely on intensive computing power to determine the block award. The problem of high-energy usage is unique, however, to proof of work systems, as you can see in the chart below.

[38] See, https://bitcoinfees.info/

[39] See, https://bitinfocharts.com/ethereum/

Fig. 17 : Energy Consumption

Low	HIGH	Variable
Corda	Bitcoin	Multichain
Fabric	Ethereum	
Neo		
Quorum		
Sawtooth		
NXT		

Notes on Interpretation

- After **Ethereum** makes the transition from proof of work to proof of stake, **Ethereum** will move to the Low category.
- Note that **Neo**, while a public blockchain, operates in a permissioned fashion using dBFT consensus protocol, which earns it a ranking in the Low category.
- While **NXT** is a public, permissionless blockchain, it does use a proof of stake consensus mechanism, which makes its energy consumption profile fall into the Low category.
- **Multichain** can be configured to use various consensus mechanisms that impact the energy consumption required by the system.

Sec. 3 : Health Indicators

In this final section, we examine various factors that indirectly indicate the health of the projects in our selection set. As many of the projects are open source, we focus on activity levels of the community as indicators of project stability and health, while a look at mindshare gives some insight into the demand for the platform. We also include a very limited financial analysis that focuses on the projects' track records in raising capital.[40]

Development Activity

Is the development of the platform vital and ongoing?

For this metric, we examine two statistics related to the level of development activity of the various platforms.

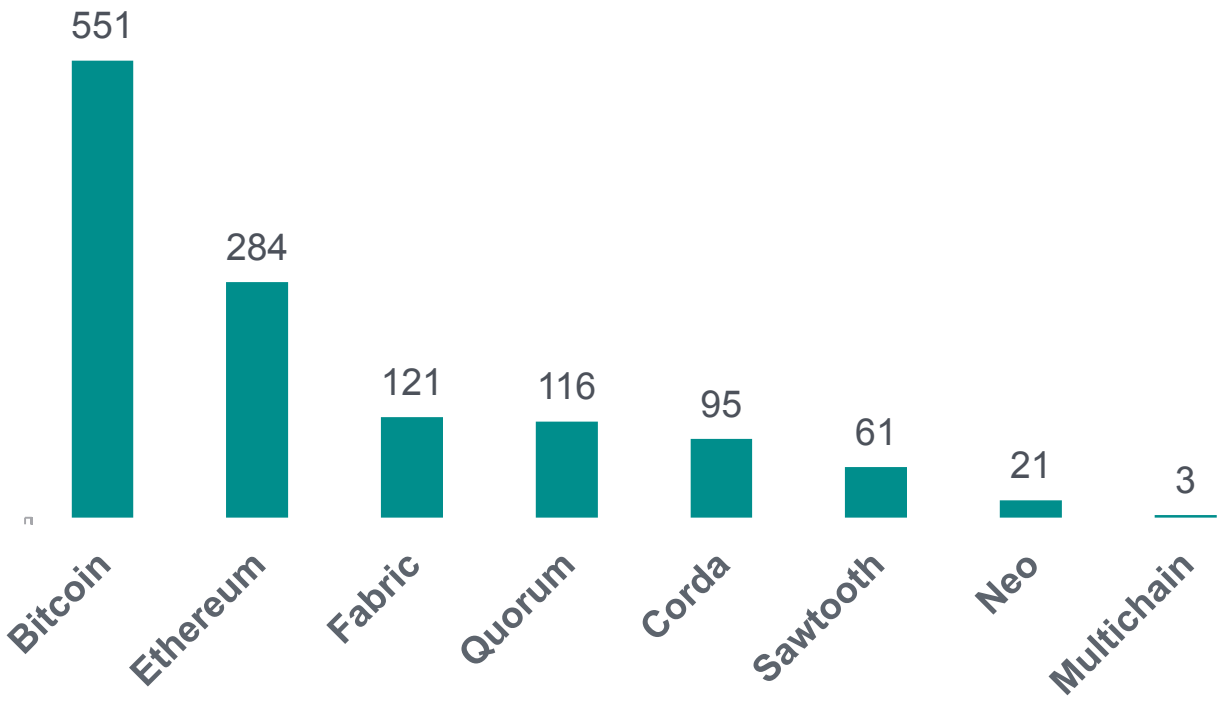
[40] We limited the financial analysis as it was felt that a deeper dive into the balance sheets of the few firms that were backed by public entities who maintained such records would be of very limited use, and would require a significant amount of work to draw any meaningful conclusions.

The source of the data for both statistics is GitHub[41], an online repository used by most of our projects for source code management. For each project on GitHub, the system makes a limited amount of project activity data publicly available, including:

- **Number of Contributors**[42]
- **Number of Commits**[43]

While these numbers are useful, they don't provide the whole picture. First, while most of our projects employ GitHub, not all do, and some do so to varying degrees. Second, while the number of contributors is useful, we also need to consider the diversity of the developers. If a large number of the developers come from one institution, the project is less resilient than a project with a large number of un-affiliated contributors. Similarly, while the raw numbers are somewhat insightful, they tell us little about the trend[44].

Fig. 18 : Number of Contributors



Notes on Interpretation

- Data derived from Github.com on 6 Aug 2018

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41 See, https://github.com

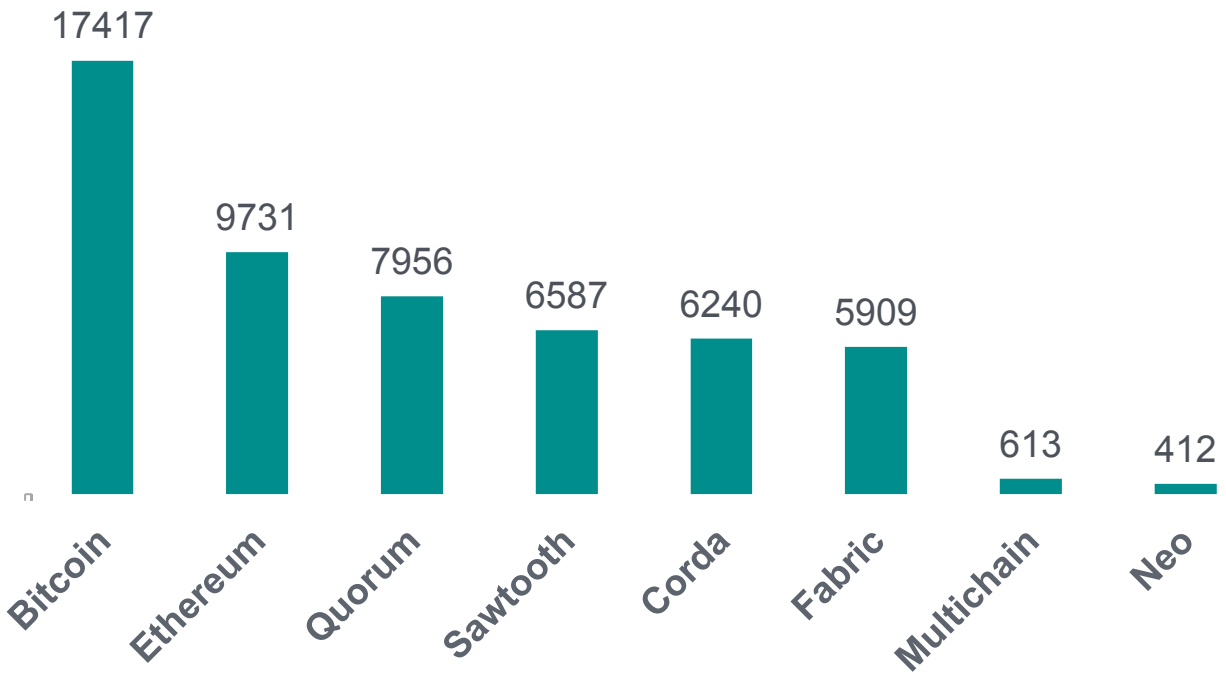
42 I.e., the number of people working on code for the project.

43 I.e., The number of times code has been submitted ("committed") to the project.

44 But see, Figure 30, Quorum Commit Activity on GitHub

- Not included: **NXT** hosts their development on a site that does not include activity statistics and the project did not respond to requests for information.

Fig. 19 : Number of Commits



Notes on Interpretation

- Data derived from Github.com on 6 Aug 2018
- Not included: **NXT** hosts their development on a site that does not include activity statistics and the project did not respond to requests for information.

Mindshare

Which platform are people searching for?

For this metric, we look at two brand strength indicators:

- **Project Site Popularity**
- **Search Engine Query Volume**

Both metrics look to activity on the web in order to provide some insight into the search and web viewing activity for each of the platforms evaluated. Both metrics suffer from the same limitation, that is, we can only derive good data for a portion of the projects. The first metric, project site popularity, provides insights for 6 of the 9 projects evaluated. Three of the projects are hosted inside larger sites, making it impossible for us to isolate traffic to just those sections of the site. The second metric, search engine query volume, also suffers from limitations, as the

generic nature of some of the project names, and the possibility of confusion with some platforms' related digital currencies, impacts the conclusions we can draw from the numbers.

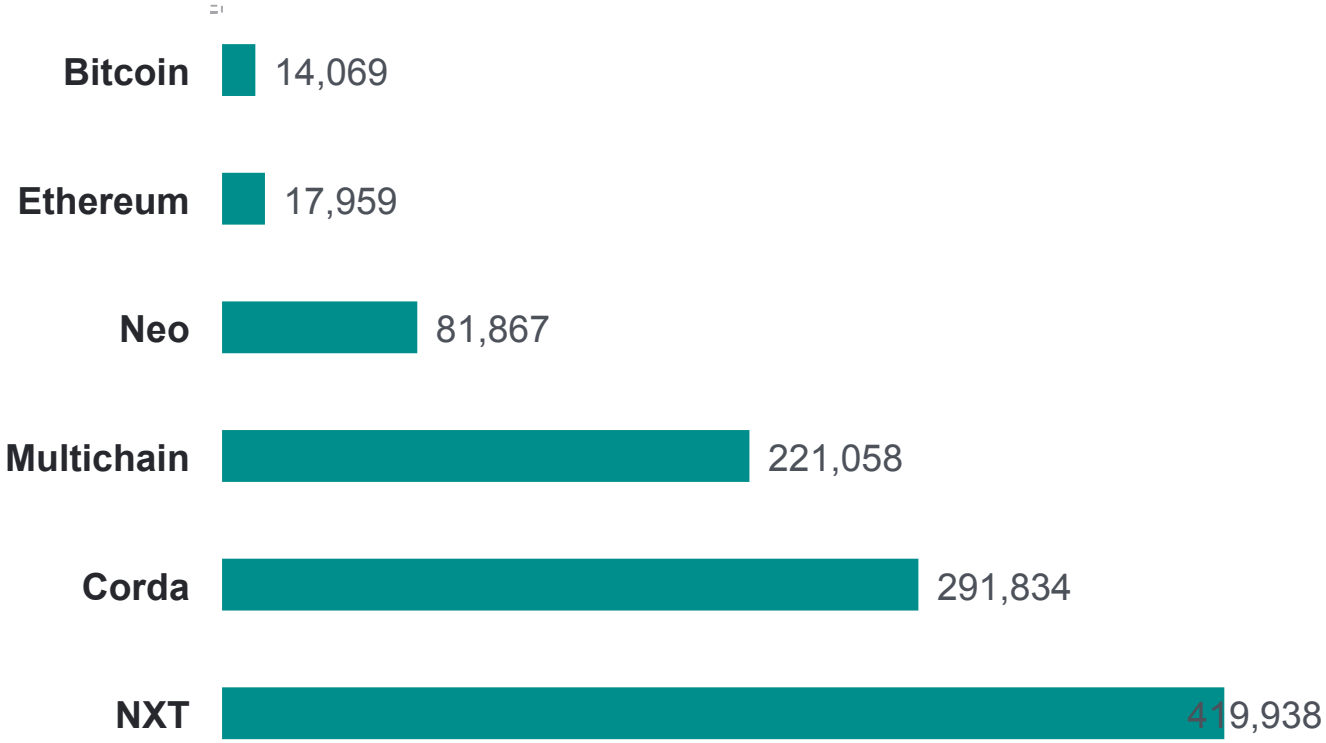
Project Site Popularity

How popular are the project sites?

To gain insight into the relative popularity of each of the systems, we looked at the traffic to each of the primary project websites. Traffic statistics were derived from the ranking services provided by Alexa[45]. The Alexa ranking of a site provides a measurement of a website's popularity, relative to all other websites. While the Alexa metric is not 100% accurate, it does provide a convenient tool with a standardized approach for comparing site popularity.

Note that with Alexa, the lower the score the higher the rank – i.e., the most popular site on the web is ranked #1.

Fig. 20 : Website Popularity, by Traffic Rank



Notes on Interpretation

- Data derived from Alexa.com on 6 Aug 2018
- Not included: **Fabric**, **Sawtooth** and **Quorum**, as each of those platforms lacks a dedicated website to be measured. The **Fabric** and **Sawtooth** pages are hosted inside the Hyperledger website. The **Quorum** pages are hosted inside the J.P. Morgan website. Given that configuration, Alexa data for those platforms would be falsely inflated by unrelated traffic to the site where the pages are hosted.

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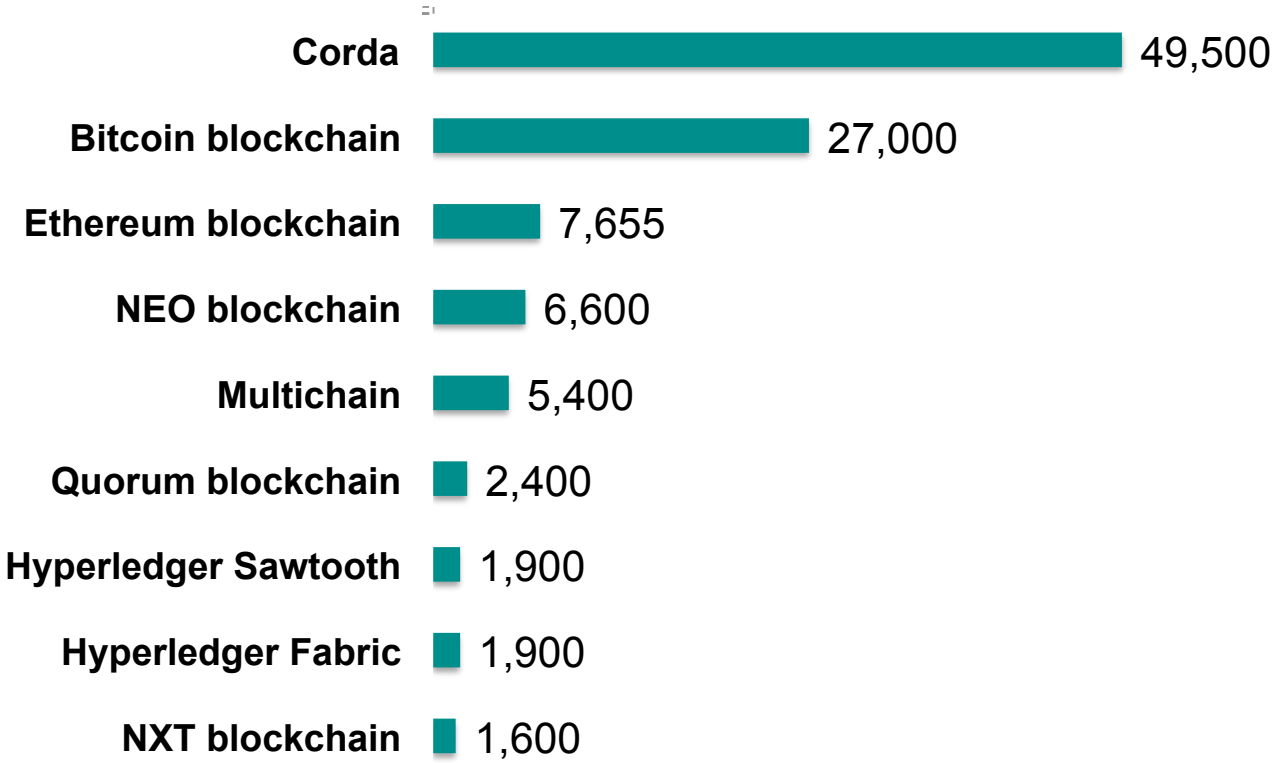
[45] See, https://alexa.com

Search Engine Query Volume

Which brand are people searching for?

Search engine activity levels provide another indicator of interest levels and mindshare. Given Google's dominant role in the global search market, we looked to average monthly query volume on Google across the last 12 months.

Fig. 21 : Average Monthly Google Search Query Volume



Notes on Interpretation

- Data derived from https://app.kwfinder.com/ on 30 Jul 2018
- The data labels in the left column reflect the search strings used in each case.
- Note that the use of query structure "**Bitcoin** blockchain" instead of merely "**Bitcoin**",is designed to remove searches for the digital currency **Bitcoin**. The same approach was applied to **Ethereum** and **Neo** for the same reason. In all cases, it may have lead to an under-reporting of results for those terms.
- Note the use of the query structure "**Quorum** blockchain" and "**NXT** blockchain" was necessary in both cases to separate searches for the relevant product from searches for the generic terms "quorum" and "nxt." Similarly, the **Fabric** and **Sawtooth** searches were run with the qualifier "Hyperledger" added to the query.

Financial Strength Indicators

For this metric, we look at three statistics:

- **Market Cap**
- **24 Hour Trading Volume**
- **Venture Capital and Investors**

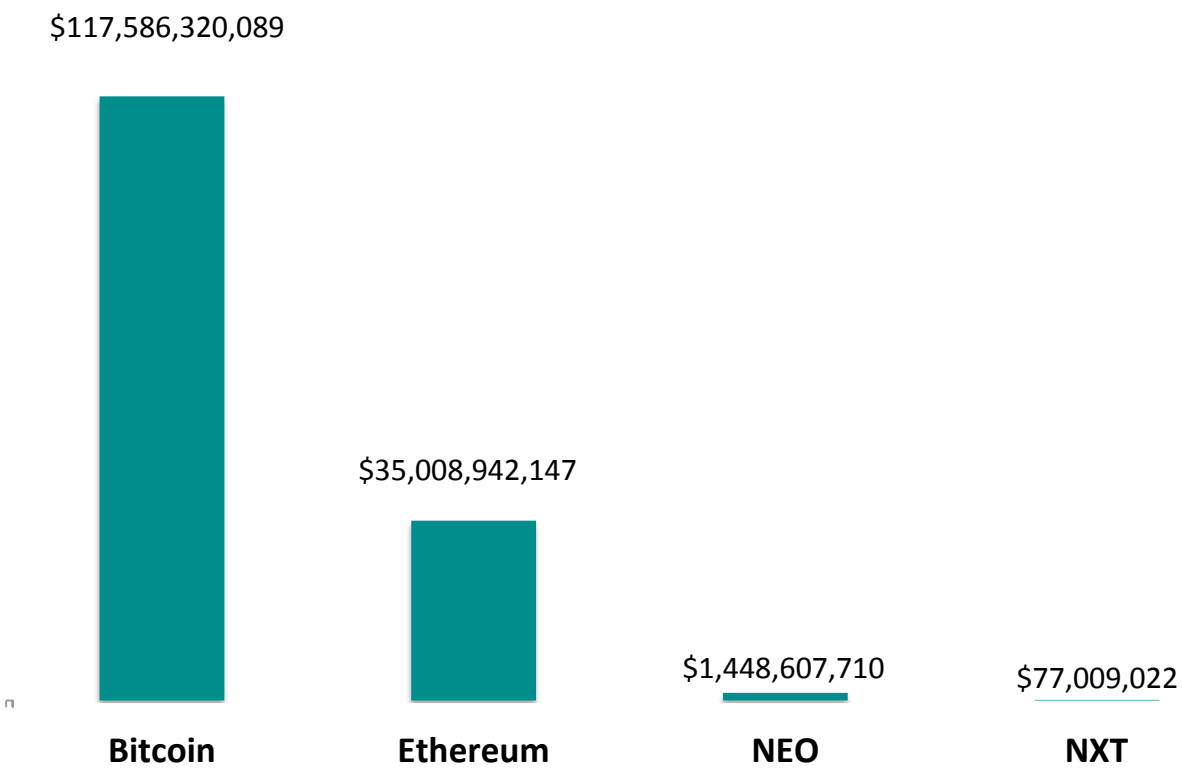
Without peering into the financial records of the various corporations, foundations, and other proponents of the platforms, we're left with looking at public data that gives us some insight into the relative financial strength of the projects. We lack, unfortunately, a common measure to apply to all the systems in the survey. Market Cap and 24 Hour Trading Volume are indicators that only provide insights into the digital currencies associated with four of our systems. Venture Capital and Investors is somewhat more useful, providing insights into 6 of our 9 systems.

Market Cap

How robust is their native coin?

Four of our systems have native digital currencies that are traded on the open market. As we know the number of coins in circulation and the market price, we can calculate the market cap with accuracy. The presumption here is that a higher market cap indicates a more robust market for the coin and therefore more assurance of longevity for the associated project.

Fig. 22 : 30 Day Average Market Cap of Coins



Notes on Interpretation

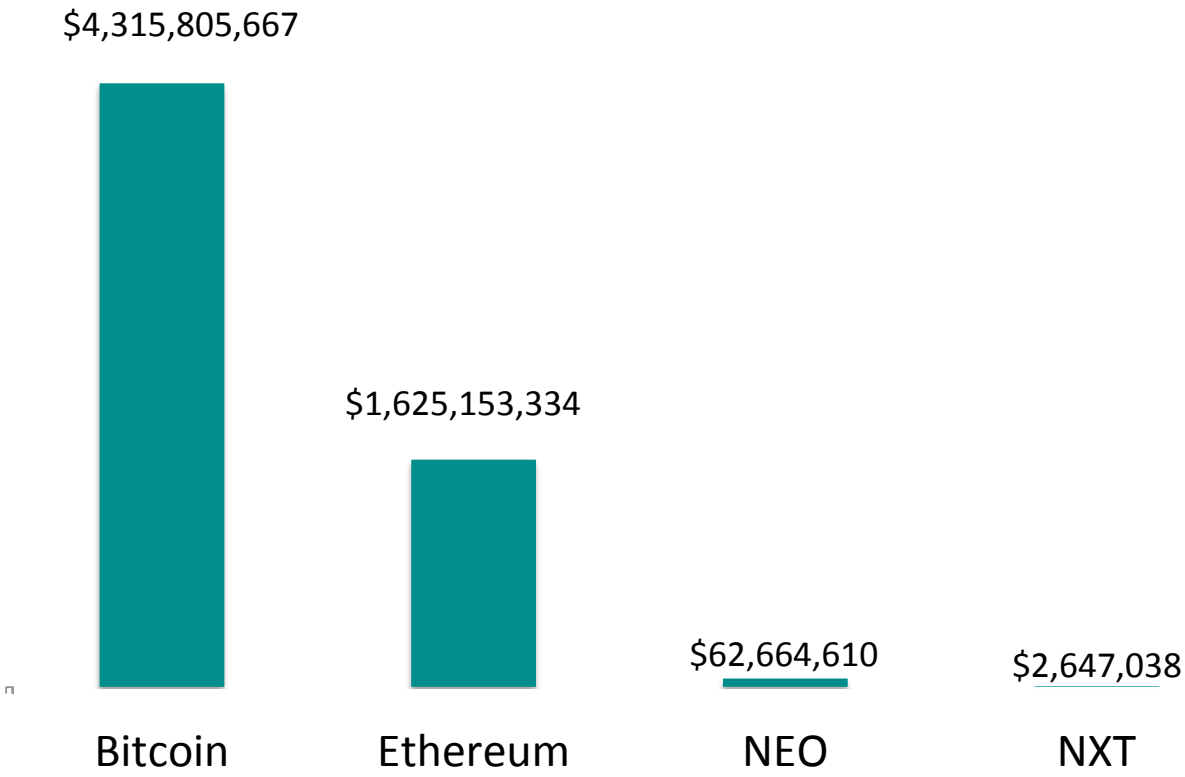
- The data shown is an average market cap for each currency across 30 days.
- Data derived from Coin Market Cap[46] on 28 August 2018
- Shows only those systems that have a native currency traded on public exchanges.

24 Hour Trading Volume

How active is their native coin?

Four of our systems have native digital currencies that are traded on the open market. We can look at the 24-hour volume numbers as an indicator of interest in the currency. The presumption being that higher interest in the currency translates into potentially more interest and sustainability in the underlying project.

Fig. 23 : 30 Day Average 24-Hour Trading Volume



Notes on Interpretation

- The data shown is an average 24 hour volume for each currency across 30 days.
- Data derived from Coin Market Cap[47] on 28 August 2018
- Shows only those systems that have a native currency traded on public exchanges.

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[46] See, https://coinmarketcap.com

[47] See, https://coinmarketcap.com

Venture Capital and Investors

How deep are their pockets and who is backing them?

In the chart, below, we look at the known sources of funding for 6 of the 9 projects. The selection set shows a mix of both traditional venture capital funding and the use of ICOs (Initial Coin Offerings) for their startup capital.

Fig. 24 : Venture Capital and Sources

	Amount Raised	Source(s)
Bitcoin	**n/a**	n/a
Corda	**> $120,000,000**	47 investors, 43 financial institutions plus Intel Capital, CLS, OUE, and TIS
Ethereum	**$15,500,00**	ICO
Fabric	**n/a**	n/a
Multichain	**Unknown**	Mosaic Ventures, Zohar Gilon
Neo	**$5,100,000**	ICO
NXT	**$16,800**	ICO
Quorum	**n/a**	n/a
Sawtooth	**n/a**	n/a

Notes on Interpretation

- "ICO" = Initial Coin Offering
- Data derived from various news sources, project sites, and project representatives.
- "n/a" should not be interpreted negatively, as it simply means those projects have a different funding and/or business model.
- **NXT**, one of the first projects to launch an ICO, is detrimented by being the first mover in the field. Later ICOs, even from much smaller organizations, have netted much higher amounts.
- **Quorum** enjoys the backing of J.P. Morgan.
- **Fabric** and **Sawtooth** are both backed by Hyperledger, and by extension, the Linux Foundation.

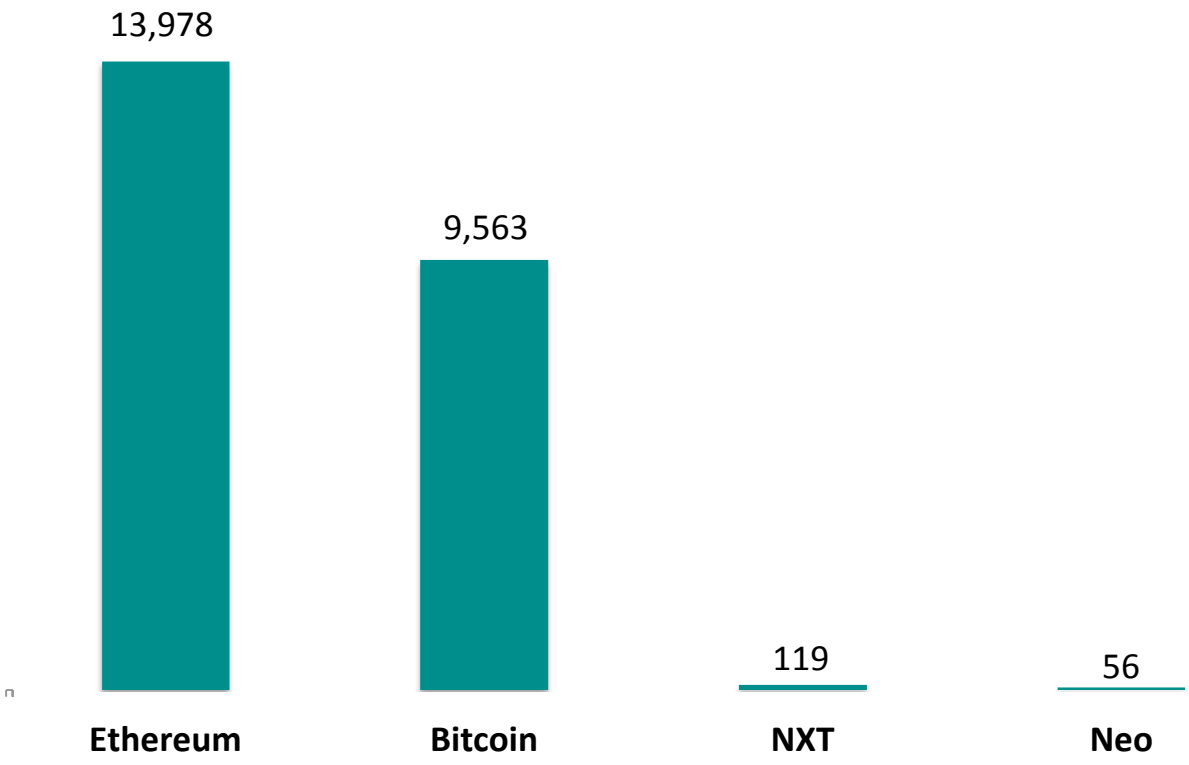
Nodes Online

How robust is the underlying network?

The number of active nodes in operation is a useful metric for comparing the size of the networks supporting a blockchain. The number of nodes is also a good indicator of the resilience of the network and its potential for resisting fraud or manipulation.

The data in the chart below is limited to the public blockchains in the set, but it does reveal some dramatic differences. The crucial missing bit of information here is an indication of the diversity of the owners of the nodes. We only know the IP addresses, not who controls them.

Fig. 25 : Nodes Online



Notes on Interpretation

- Data derived from various blockchain explorer / node explorer sites.
- **Neo**'s node count (**Neo** calls them "end points") is quite low, but note that until early July 2018, end points were only maintained by a small number of **Neo** team members (remember, **Neo** may be a public blockchain, but it is permissioned), so the present number actually indicates an improvement in resilience for the network.

Weiss Cryptocurrency Rankings

How are other experts rating the systems?

The Weiss Cryptocurrency Rankings[48] were launched in January of 2018 by Weiss Ratings, an independent financial institution rating agency. Weiss assigns letter grades to cryptocurrencies, in the same fashion used to rank and rate financial institutions. Weiss also provides a "Technology/Adoption" rating for the currencies in the index. Here's how they describe what goes into those ratings:

- **Technology.** Reflects the capabilities of the computer code. Factors include level of anonymity, sophistication of monetary policy, governance capabilities, ability or flexibility to improve code, energy efficiency, scaling solutions, interoperability with other blockchains, and more.
- **Adoption (formerly called "fundamentals").** Measures actual performance in the world. Factors include transaction speed and scalability, market penetration, network security, decentralization of block production, network capacity, developer participation, public acceptance, and more.
- **Technology/Adoption Grade.** Combines technology and adoption into a single letter grade.

Weiss Cryptocurrency Rankings are available for 4 of the systems in our set: **Bitcoin**, **Ethereum**, **Neo** and **NXT**.

Fig. 26 : Weiss Cryptocurrency Rankings

	Technology	Adoption	Grade
Bitcoin	Fair	Excellent	**B**
Ethereum	Good	Excellent	**B**
Neo	Excellent	Good	**B+**
NXT	Good	Weak	**C**

Notes on Interpretation

- Data derived from the rankings released 25 May 2018.

[48] See, https://weisscryptocurrencyratings.com/

Significant deployments

Who is using each platform?

The chart below shows publicly available information about live deployments for each system. The data has, for some systems, been supplemented by information derived from our contacts at the project.

Fig. 27 : Significant Deployments

System	Deployments
Bitcoin	Intesa Sanpaolo
Corda	Finastra, GuildOne, Gemalto, GuildOne, TradeIX, Tradewinds Market
Ethereum	Amazon, AXA Group, Daimler, Bank of America
Fabric	Maersk, Walmart, Oracle, AIA Group, Airbus, Northern Trust, ABN Amro, Swift, Allianz
Multichain	See, Notes on Interpretation, below
Neo	unknown
NXT	BNP Paribas, National Settlement Depository (NSD)
Quorum	Interbank Information Network (IIN), J.P. Morgan, National Bank of Canada
Sawtooth	T-Mobile, Tel Aviv Stock Exchange, State Bank of India, Vanig

Notes on Interpretation

- In response to our query about significant deployments, **Multichain** replied that there are currently more than 10 networks in operation, but declined to disclose names.
- Research turned up no brand name deployments on **Neo** and the project did not respond to enquiries
- Note that there were no conditions imposed for the nature, or the size, of the projects on this list.

Conclusions

How do you choose?

At the end of the day the right system is the one you can afford that best meets your requirements. There is no "one best system" that is the clear choice for all use cases.[49] What we can say is that, for most people, the selection process will start with two questions[50]:

1. Do you want to control who can operate nodes? (i.e., do you need a **public or private** DLT platform?)
2. Do you want to be able to restrict what participants can do inside the network? (i.e., do you need a **permissioned or permissionless** DLT platform?

Once you answer those questions, your range of choices narrows considerably:

Fig. 28 : Choice Matrix

LEAST RESTRICTIVE ← → MOST RESTRICTIVE

	Public & Permissionless	Public & Permissioned	Private & Permissionless	Private & Permissioned
Bitcoin	■			
Corda				■
Ethereum	■			
Fabric				■
Multichain	■	■	■	■
Neo		■		
NXT	■			
Quorum	■	■	■	■
Sawtooth	■	■	■	■

Given the fundamental nature of the decisions about access and permissions, in the discussion that follows, we divide our selection set into two groups: Public Ledgers and Private Ledgers.

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[49] A situation likely to increase as we see the arrival of new, more specialized platforms.

[50] This paper does not dive into a discussion of whether DLT is right for you; rather it is assumed that you have already made that decision. A useful look at the process used to assess whether DLT is the right answer has been the subject of a number of articles. See e.g., https://www.weforum.org/agenda/2018/04/questions-blockchain-toolkit-right-for-business/

Public Ledgers

Let us assume for a moment that you decide your deployment is appropriate for a public blockchain. Looking at the systems in our survey, a decision to build on a public platform would narrow the selection set only slightly:

- **Bitcoin**
- **Ethereum**
- **Multichain**
- **Neo**
- **NXT**
- **Quorum**
- **Sawtooth**

The primary motivation for building on a public blockchain is having the resilience and integrity of a large network of nodes. If that is your motivation, you are unlikely to choose to deploy **Quorum** or **Sawtooth**, as it would require you to build a supporting network of nodes from scratch. Instead, you are going to build on an established network. If having the resilience of a large network is important, you are left with choosing between **Bitcoin** and **Ethereum**. Given the limited functionality of **Bitcoin**, and the fact that it comes in second in the number of active nodes, the answer for you is likely **Ethereum**.

Indeed, across the board in the public blockchain space, the clear winner at this moment in time is **Ethereum**. With a large number of active nodes, an active developer community[51], foundation support, financial strength, brand strength, a large number of established developer tools and a meaningful pool of talent, **Ethereum** comes out way ahead in the public blockchain race. That said, note the qualifier, “at the moment.” **Neo**, sometimes called “the Ethereum of China,” is poised to threaten **Ethereum**’s dominance. **Neo** provides superior transaction speeds and favorable costs compared to **Ethereum**, and enjoys some every powerful backers.[52] **Ethereum**, while the first to bring business-grade features to blockchain, is likely to face a future of stiff competition[53] and will continue to be challenged to keep apace of innovation in this field.

Private Ledgers

While, as the chart on the previous page shows, the decision to operate on a public and permissionless system would give you the largest number of choices, the market seems to indicate a strong preference from the enterprise for private and permissioned systems.[54] While the decentralization purists may find an issue with private systems and the control and centralization they bring, our research indicates that enterprise level deployments occur almost exclusively in this space, with most organizations willing to trade off decentralization for more control, faster processing times, and less exposure to the vagaries of public blockchains.[55]

Looking at the systems in our survey, a decision to build on a private and permissioned ledger would narrow the selection set to:

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[51] The Ethereum Virtual Machine (EVM) development framework Truffle has been downloaded more than 750,000 times! See, https://truffleframework.com/dashboard

[52] While some criticize **Neo** for centralization (it is a public permissioned blockchain), do not forget that **Ethereum** is moving away from proof of work to proof of stake – an architecture that is also unaligned with traditional decentralization values.

[53] See, Sec. 3 “Projects to Watch.”

[54] The decision to run a private ledger also means a greener, less energy intensive, deployment, which will be a factor to some.

[55] Do you really want to face the possibility of having to explain to someone that your mission critical application was unavailable due to Cryptokitties?

- **Corda**
- **Fabric**
- **Multichain**
- **Quorum**
- **Sawtooth**

The question then becomes, how do we distinguish between those systems?[56]

If we look at the technical architecture and feature set, these systems are very competitive. All five are largely on par in terms of the flexibility they provide to administrators in selection of consensus mechanisms. In terms of transaction speed, there is some variance, with **Fabric** benchmarking at significantly slower transactions per second.

All of the platforms, except **Multichain**[57], provide roughly equivalent support for smart contracts. **Sawtooth** and **Quorum**'s ability to support smart contracts written in Solidity – the language used in **Ethereum** smart contracts – may be a decision point for some[58]. For many, the question may come down to which platform supports their preferred programming language. **Corda**, which supports both the industry-standard Java and the more obscure Kotlin, will appeal to enterprises who are comfortable with Java and want to draw on that large pool of talent. **Multichain** and **Sawtooth** offer the most choices and provide both programmatic flexibility and access to a wide range of developers.

Business continuity is another risk factor you have to consider. Ask yourself: Which of these platforms is likely to be around in five years? If you look at the set of five, when it comes to the business considerations there are some differences worth noting. While **Quorum** and **Multichain** enjoy strong backing from their corporate sponsors,[59] **Corda**, **Fabric**, and **Sawtooth** bring to the table the industry clout of major consortium backing[60]. **Fabric** additionally enjoys significant backing from IBM, with the **Fabric** code acting as the lynchpin of the IBM Blockchain product line[61]. In terms of popular support, **Corda, Fabric**, **Sawtooth,** and **Quorum** also come with large and active open source communities.

A related consideration is whether the platform is available on the major cloud services providers. For many, the added convenience of a managed deployment environment makes the availability of blockchain as a service a factor in the decision. If we add that filter to our list of five, we get a matrix that looks like this:

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[56] Of course, given that the code is open source, you could always download **Ethereum** and set it up on a private network and call it a private blockchain, but in its current state, that is a sub-optimal use of the system. Once **Ethereum** has moved to support proof of stake that decision might make more sense. In the interim, **Quorum** is a better choice.

[57] **Multichain** currently does not support smart contracts, but in response to queries they stated that the functionality will be included in their 2.0 release.

[58] We would add a note that there are a number of voices critical of Solidity and doubtful of it's place in the enterprise. Ethereum is looking to step away from Solidity at some point in the near term, with the release of a new language known as Vyper. Vyper is currently in beta release. See, https://github.com/ethereum/vyper/projects

[59] J.P. Morgan and Coin Sciences, respectively.

[60] R3 and Hyperledger, respectively.

[61] Previously known as "Bluemix" see, https://console.bluemix.net/catalog/services/blockchain/?cm_sp=dw-bluemix-_-cl-deploy-blockchain-starter-plan-network-

Fig. 29 : Availability on Major BAAS Providers

	Amazon Web Services	Google Cloud Platform	Microsoft Azure
Corda		Coming Soon	
Fabric			
Multichain			Coming Soon
Quorum	Available via Kaleido		
Sawtooth		Coming Soon	Coming Soon

A clear advantage here for **Corda**, **Fabric** and **Quorum**, though **Quorum** support on Amazon comes via a third-party service offering.

While BAAS can deliver help with deployment and management of the infrastructure, some firms will also be looking for a support partner for their DLT-powered apps; in this area **Corda** and **Multichain** enjoy an advantage, with both systems offering not only an open source product, but also an enterprise licensed product that is supported.

In terms of health, all five projects seem to be on solid ground at the moment. Developer interest seems solid and the organizations backing the projects seem robust.

Given the relative parity of the five platforms, your decision is likely to hinge on your preferred technical architecture and your use case. Several of the systems seem to be trending towards certain types of solutions. For example, while **Corda** has been applied in a variety of scenarios, the system was originally built for the needs of fintech and enjoys advantages relative to those uses. **Fabric** has been getting wins in supply chain and traceability[62]. **Sawtooth** has seen some success in traceability. If you are looking to build applications in those areas, you would be strongly advised to look at those systems. In terms of which system supports the broadest general usage, **Fabric** is the winner, with its ability to leverage an increasing range of proven applications, courtesy of the work of IBM.

Picking a leader in this category is difficult. With a strong track record and the clout of IBM and Hyperledger behind it, **Fabric** is a serious contender. **Corda** should likewise be considered a serious contender in this space, with strong backing, a coherent architecture aimed at the enterprise, and an increasing number of deployments. While **Multichain** and **Sawtooth** are both interesting platforms with their own advantages, they do not exhibit the

[62] aka, provenance.

maturity and feature set of their peers and are likely the laggards in this set.[63] **Quorum** is discussed in the next section.

Projects to Watch

The research also revealed a number of systems that deserve to be watched in the near to medium term. Among the systems profiled in this paper:

- **NXT** was a source of some concern. The project remains a bit of a cypher. Various data points assessed in this survey pointed to a platform that is slowly ebbing in vitality.[64] The next version of **NXT** will be a completely different platform, released under the name **Ardor**. One source indicates that NXT will continue and the features from Ardor may be backported to **NXT**. The same source indicates that plans to support **NXT** will continue for only a limited time.[65] Given the number of weak health and adoption indicators revealed in the research, and the uncertain future of the platform, users should approach this ledger with caution.
- While market reaction to the launch of J.P. Morgan's **Quorum** platform was strongly positive, recent developments at the project are causing some concern. One of the biggest negative indicators is the downwards trend in developer activity on the project on GitHub, as shown in the Figure 30 below. This concerning trend, when combined with the loss of the project's lead developers in April[66] and rumours that J.P. Morgan may be about to spin the project off[67], leads us to label the project as one to watch. While we view the project positively, and the team was responsive to our requests, we still feel it is important to flag that there are issues you want to watch if you are thinking about selecting the platform at this time.

Fig. 30 : Quorum Commit Activity on GitHub

In addition to the nine projects detailed in this paper, there are a number of other systems that bear watching:

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[63] An observation will are willing to revise as both platforms mature. **Multichain** 2.0 (currently in Alpha 4 release) promises expanded functionality, and **Sawtooth** only achieved a 1.0 production release on 30 January 2018.

[64] See e.g., Our metrics related to developer activity, number of active nodes, project popularity metrics, etc.

[65] "[F]or at least a year or longer, depending on funding…" see, https://www.nxter.org/tag/nxt-blockchain/

[66] See, http://fortune.com/2018/05/14/blockchain-jpmorgan-chase-amber-baldet-clovyr/

[67] See, https://www.reuters.com/article/us-blockchain-jpmorgan/jpmorgan-mulls-spin-off-of-blockchain-project-quorum-sources-idUSKBN1GY36O

- **Axoni: Axoni** is a relatively new fintech-focused platform, with an emphasis on creating a robust platform suitable for capital markets. The firm has several projects in the pipeline, including a major deployment with DTCC. **Axoni** has also raised a significant amount of venture capital and counts among its investors a who's who of financial powerhouses including J.P. Morgan, Wells Fargo, Goldman Sachs, Citigroup and more. Given the system's focus on fintech, **Axoni** may be poised to be a competitor for projects like **Corda**, at least in some narrow use cases.
- **Cardano**[68]: **Cardano** is a relatively new blockchain project launched in 2017 by Charles Hoskinson, one of the co-founders of **Ethereum**. The system is public, but employs a proof of stake approach to consensus. Though, as noted elsewhere in this paper, public blockchains may not be the preferred choice for enterprise applications, the **Cardano** blockchain, with its emphasis on a robust smart contracts architecture is poised to present a challenge to **Ethereum**'s present hegemony.
- **Digital Asset Platform**[69]**:** This platform was originally part of the selection set for this paper but was eliminated as the system had not yet achieved a proper production release. Despite not having a complete working product, the company has racked up some notable wins, including a very high profile partnership with the Australian Stock Exchange (ASX). **Digital Asset** is focused on fintech, and while details are still lacking about the capabilities of the platform, industry backing and a talented team mean this will be a project to watch. Like **Axoni**, above, **Digital Asset Platform** is likely to be viewed as a competitor to fintech specialists like **Corda**.
- **EOS**[70]**: EOS** is a project that brings both high potential and high concerns. The launch of the project's blockchain has been an affair fraught with drama and false starts[71]. Project governance seems a significant concern at this point. Nonetheless, the group raised $4 billion with a record setting ICO. Given a huge bankroll and competent leadership the project has plenty of room to right their wrongs and build something impressive. Only time will tell.
- **Lisk**[72]: **Lisk** does two very interesting thing: First, it is written in Javascript, making it very easy to get started with programming and second, it employs a distinct architecture that relies on sidechains. **Lisk** provides developers SDKs that allow them to develop discreet sidechains that can execute business logic independently of the main chain, yet is still be tied to it. The architecture gives developers a great deal of control over their chain while still keeping the main chain secure and able to scale.
- **Stratis**[73]: The Stratis Full Node is still in Beta release at this time and as such was not considered to be eligible for the selection set in this paper. The system nonetheless bears watching for a number of reasons. Stratis comes to market built for the enterprise, with a BAAS business model and compatibility with the .NET framework. The system will support both smart contracts and sidechains and seems poised to be attractive to firms that would benefit from turnkey deployment services and the ability to draw upon the large pool of existing .NET programming talent.

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68 See, https://www.cardano.org

69 See, https://www.digitalasset.com/

70 See, https://eos.io/

71 See e.g., https://siliconangle.com/2018/06/27/4b-eos-blockchain-chaos-community-rebels-arbitration-decision/

72 See, https://lisk.io/

73 See, https://stratisplatform.com/

Appendix A. Project Links

Project	Resources	Links
Bitcoin		
	Project Website	https://bitcoin.org
	Whitepaper	https://bitcoin.org/bitcoin.pdf
	Source Code	https://github.com/bitcoin/bitcoin http://sourceforge.net/projects/bitcoin/
	User Forum	https://forum.bitcoin.com/
	Blockchain Explorer	https://blockchain.info/
	Documentation	https://en.bitcoin.it/wiki/ https://bitcoin.org/en/developer-documentation
Corda		
	Project Website	https://www.corda.net/
	Whitepaper	https://docs.corda.net/_static/corda-technical-whitepaper.pdf
	Source Code	https://github.com/corda
	User Forum	https://slack.corda.net/
	Blockchain Explorer	https://ci-artifactory.corda.r3cev.com/artifactory/corda-releases/net/corda/corda-tools-explorer/3.2-corda/
	Documentation	https://docs.corda.net/
Ethereum		
	Project Website	https://www.ethereum.org/
	Whitepaper	https://github.com/ethereum/wiki/wiki/White-Paper
	Source Code	https://github.com/ethereum/
	User Forum	https://forum.ethereum.org/
	Blockchain Explorer	https://www.ethernodes.org/network/1 https://www.etherchain.org/
	Documentation	http://www.ethdocs.org/ https://github.com/ethereum/wiki/wiki
Fabric		
	Project Website	https://www.hyperledger.org/projects/fabric
	Whitepaper	https://www.hyperledger.org/resources/publications#white-papers
	Source Code	https://github.com/hyperledger/fabric
	User Forum	https://chat.hyperledger.org/home
	Blockchain Explorer	https://www.hyperledger.org/projects/explorer
	Documentation	https://wiki.hyperledger.org/projects/fabric http://hyperledger-fabric.readthedocs.io/en/release-1.2/
Multichain		
	Project Website	https://www.multichain.com/
	Whitepaper	https://www.multichain.com/white-paper/
	Source Code	https://github.com/MultiChain/multichain
	User Forum	https://www.multichain.com/qa/
	Blockchain Explorer	https://github.com/MultiChain/multichain-explorer

	Documentation	https://www.multichain.com/developers/
Neo		
	Project Website	https://neo.org
	Whitepaper	http://docs.neo.org/en-us/
	Source Code	https://github.com/neo-project
	User Forum	n/a
	Blockchain Explorer	https://neotracker.io/ https://neoscan.io/
	Documentation	http://docs.neo.org/
NXT		
	Project Website	https://nxtplatform.org/
	Whitepaper	https://nxtwiki.org/wiki/Whitepaper:Nxt
	Source Code	https://bitbucket.org/Jelurida/nxt/downloads/
	User Forum	https://nxtforum.org/
	Blockchain Explorer	https://nxtportal.org/monitor/
	Documentation	https://nxtwiki.org/
Quorum		
	Project Website	https://www.jpmorgan.com/country/US/EN/Quorum
	Whitepaper	https://github.com/jpmorganchase/quorum-docs/blob/master/Quorum%20Whitepaper%20v0.1.pdf
	Source Code	https://github.com/jpmorganchase/quorum
	User Forum	n/a
	Blockchain Explorer	https://github.com/jpmorganchase/cakeshop
	Documentation	https://github.com/jpmorganchase/quorum/wiki
Sawtooth		
	Project Website	https://sawtooth.hyperledger.org/examples/
	Whitepaper	https://www.hyperledger.org/resources/publications#white-papers
	Source Code	https://github.com/hyperledger/sawtooth-core
	User Forum	https://chat.hyperledger.org/channel/sawtooth
	Blockchain Explorer	https://github.com/hyperledger/sawtooth-explorer/
	Documentation	https://sawtooth.hyperledger.org/docs/ https://wiki.hyperledger.org/projects/sawtooth

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