# MIRACULUM:
# A technology platform using transaction-based blockchain databases to create Data Assets and Data Economies for the health sciences sector

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**ABSTRACT—** The potential for blockchain-based applications in health care has been widely discussed, but few technology platforms are able to meet the requirements of this complex sector. Miraculum™ fulfills such requirements through a health-care-specific implementation of the Lydion "data economics operating system" platform via a cryptoeconomic approach without coins or tokens. Using innovative data structures to operationalize an economic theory of "data as labor," Miraculum creates opportunities for diverse applications that can generate efficiencies in the health sciences sector, and a potential model for data economic applications in other sectors that require handling of sensitive enterprise or individual data.

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**Introduction: Blockchain and health care**

Blockchain has been touted as a potentially "revolutionary" new technology for industries including health care and life sciences.[1] Interest in the intersection of blockchain technology and the health care sector has grown to the extent that a peer-reviewed journal entitled *Blockchain in Healthcare Today* is regularly published.[2] Proposed blockchain use cases in health care are diverse. They include ensuring supply chain integrity for drugs, credentialing health care providers, implementing value-based payments for pharmaceuticals and care delivery, developing new reimbursement mechanisms, facilitating data sharing in clinical research, and securing the longitudinal integrity of patient records.[3–9]

While these use cases are being considered and developed by technologists and health care industry stakeholders, existing blockchain-based software platforms are generally insufficient to meet the needs of this complex sector across the board. No platform has previously been presented that could handle all of the use cases described above while simultaneously allowing for interoperability, financial interchange, scalability, rapid transaction speed, economic incentive alignment, and data privacy to GDPR, HIPAA, and stricter country-specific or state-specific data handling standards. The Miraculum software proposed in this paper addresses the inabilities of other platforms to meet the requirements of this sector by proposing a new, data-first and transaction-first approach to the generation of digital data assets managed by distributed, linked databases, or blockchains.

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**Miraculum as an Implementation of a New Blockchain Category**

Platforms for building blockchain-based and distributed applications have typically been developed in one of two broad categories: *cryptocurrency blockchains* and *distributed ledger technology (DLT) software-as-a-service (SaaS) platforms.*

Cryptocurrency blockchains include Bitcoin, Ethereum, and others. Most cryptocurrency blockchains use competitive, computational proof of work (CPOW) mining as a consensus algorithm suited to their public nature.[1] Cryptocurrency blockchains were primarily developed for financial (store of value, speculative investment, or exchange of value) use cases.[10] For cryptocurrency blockchains, uses that move away from the core financial use case, including uses related to the ability to build distributed applications atop the currency architecture, are not core functionalities. However, the positioning of "cryptocurrencies as platform" has been an approach to help gain network participation and expand the functionality of such cryptocurrency blockchains with additional features.[2] The second category of platform, DLT SaaS, moves away from the starting premise of a currency and is characterized by distributed ledger technology (DLT) without a core cryptoeconomic feature tied to mining, block generation, and transaction confirmation.

Miraculum implements a new, third category of blockchain-based platform of which the Lydion data economics technology is an example. Lydion's approach bridges the features of public, cryptocurrency blockchains and permissioned, distributed ledger platforms in a manner that facilitates both economic incentivization and enterprise-level privacy through a permissioned, matrixed architecture.[3] Lydion's unique transactional proof of work (TPOW) methodology uses data originating from validated stakeholders[4] to power rapidly scalable matrix of blockchain databases where both consensus domain and trust domain can be defined by participants. By treating data essentially as a digital representation of work completed, each block within these blockchain databases is generated via data-backed demonstration of real-world outcomes. The data from these outcomes form "Data Assets," or secured digital packages of information that underpin the dynamic economic functionality of Lydion Data Economies. Lydion therefore seeks to create a "best of both worlds" approach by combining the economic incentivization and data integrity features of cryptocurrency blockchains with

[1] We recognize that other consensus mechanisms such as Proof of Stake (POS) and "gossip protocols" (example: Hashgram) exist. The most prominent consensus protocol for public distributed blockchain immutability and security remains computational Proof of Work using cryptographic algorithms. Bitcoin and Ethereum use computational Proof of Work. EOS uses a delegated POS mechanism. Generally, the authors find POS to have significant limitations and risks around market control and security.
[2] These "additional features" may include aspects such as off-chain transactions and validation, "side chains," and "smart contracts," none of which are discussed in-depth in this paper, but are topics of robust discussion within the cryptocurrency environment.
[3] For more information, see Lydion technical documentation and patents available from The Data Economics Co.
[4] "Validated stakeholders" define a consensus domain.

the permissioning flexibility, confidentiality, transaction speed, and low-cost scalability of non-currency distributed ledgers.

Lydion Data Assets, or Lydions, can therefore serve as analogous economic drivers to cryptocurrency coins, allowing for the development of "cryptoeconomic" or data economic blockchains without the potential downsides of cryptocurrencies. The risks of building enterprise-level applications on cryptocurrency blockchains are numerous (according to the authors' research in this sector and more 100 conversations with executives in the life sciences industry), including the risk of unpredictable transaction rate changes due to speculation and fluctuating crypto exchange rates, the electricity consumption inherent in computational POW mining operations, limits on transaction speed and scalability, regulatory scrutiny (and risk) related to securities and tax legal compliance, antitrust/competition regulation that prevents multiple companies in the same sector from storing data in the same database, and risk of contagion due to issues of unrelated assets or contracts on a public blockchain. [11–15] The Lydion engine specifically addresses these risks, among others.

Miraculum is therefore a health-sciences-specific platform and Lydion Data Asset environment specifically for the life sciences and health care sector. A sector-specific environment is important for three primary reasons. First, health care has unique requirements distinct from other industries in terms of data privacy, data handling, and the interaction of scientific, clinical, and financial data elements. An operating environment developed with another sector in mind may not meet these requirements, or may require significant re-engineering to meet them. Second, health care businesses, particularly ones that may "disrupt" with new technologies, have significant social responsibility to ensure that such disruption or disintermediation does not adversely impact patient care or cause harm. To minimize the risk of harm, individuals with significant experience in patient care, research science, health policy, and health economics, as well as key stakeholders including patients and physicians, must be engaged and involved in development; such stakeholder engagement necessitates a focused, sector-specific effort and subsequent buy-in from communities representing clinicians, patients, business leaders, and health policy makers. Third, the business of health care and life science is a significant part of the global economy; this fact supports a specific yet comprehensive approach that aims to leverage considerable clinical, technology, and economic expertise to develop a scalable, sector-specific platform.

**What Miraculum Enables for the Health Sciences Sector**

Applications built on the Miraculum platform enable the construction of Lydions and Lydion Data Economies for health sciences use cases. These data assets and data asset markets aim to align incentives across stakeholders, create new channels for sector investment, and reduce inefficiencies.

An key use case for the Miraculum platform is the design, simulation, implementation, and securitization of innovative drug pricing and contracting mechanisms. Other health care

industry use cases fall into the following broad categories: Regulatory and Legal Compliance, Behavioral Economics and Incentives, Dynamic Payment Models, Real World Evidence Development, Risk and Insurance Tools, and Transaction Traceability and Auditing. Miraculum has identified more than two dozen applications (use cases) for its platform; some of these are already in production and being used by health sciences and biopharmaceutical companies.

**Doing More with Data in the Health Care Economy**

While an economy for data exists in health care, it often takes the form of aggregated, anonymized datasets that are sold via third-party data brokers and are impossible to link back to specific real-world transactions. These datasets serve numerous functions in underpinning analytics and decision-making across the industry, from forecasts of spending and revenue for health insurers and hospital systems to critical business investment decisions across the sector, yet at best, are merely hypothesis-generating because of their inability to be linked to ongoing or prospective data streams or real-world patient identities. In recent years, some of the most promising data aggregator companies have been acquired by pharmaceutical companies or health care delivery systems; elsewhere in the industry, large managed care companies have sought to create their own divisions or subsidiaries solely devoted to data collection, management, and analysis. This aggregation-and-anonymization has been supported by business, regulatory, and privacy rationales, but delivers a severely suboptimal data market in the health care sector.

The lack of shared, structured, and disintermediated[5] data across this sector leads to critical inefficiencies: the majority of transactional business processes in health care are difficult, if not impossible, to audit or automatically adjudicate. Furthermore, the true market value of data, as well as the appropriate allocation of that value to the entities that generate this valuable data, are not realized at present.

Transactions across the health care sector are rife with inefficiencies, opaqueness, and high transaction costs. Examples include:

- Insurer inability to validate and audit delivery of a service prior to its reimbursement
- Long lag times for payer authorization for a newly introduced clinical product or service
- Lack of physical and financial supply chain traceability for biopharmaceutical manufacturers
- High costs and analytic overhead to implement value-based agreements or novel pricing schemes among drug manufacturers, payers, and care delivery groups
- Limited auditability of product discounts and rebates, including those for government programs including Medicaid
- Little to no provider visibility into adjudication and financial attribution for shared savings programs and Alternative Payment Models

[5] Also: shareable, findable, and commoditized.

- Patient difficulty in obtaining longitudinal records from numerous providers
- Patient and provider effort and information overhead when having services or products authorized by insurers

Addressing even a handful of these inefficiencies in a manner that reduces transaction costs and smoothes the appropriate application of data to problem-solving could potentially free billions of dollars for investment in scientific and clinical innovation and advancement in this sector alone.

**Innovative Contracting as a Health Care Data Business Problem**

The Miraculum team includes experts in health economics, biopharma business, care delivery, and computer science including the above authors. While numerous applications and assets can be designed and implemented using Miraculum as described above, this whitepaper will focus on the implementation and adjudication of sophisticated outcomes-based contracts between drug manufacturers and commercial insurers as one illustrative example for the capabilities of the Miraculum platform.

The market opportunity in this contracting use case alone is significant; there are dozens of value-based or outcomes-based contracts being attempted in the US with varying degrees of success, and at an estimated administrative cost of $600k to $1.2M per contract. [16, 17] European health care systems also initiate such contracts, sometimes called risk-sharing agreements or managed access schemes, with significant overhead from data collection, data analysis, and contract performance adjudication. The lack of a technology infrastructure that can easily replicate, scale, and adjudicate sophisticated contracts such as these is regularly cited as a hurdle to their wider adoption. [18, 19]

We have presented that this lack of infrastructure also creates hurdles to agreement negotiation because parties entering contracting discussions may not have visibility into what data is available to adjudicate such contracts; the expense of accessing such data; how the data can be used; whether it adequately captures the risks to all sides; and whether it is of high integrity and fidelity, and of adequate provenance.

The ideal technology solution to the value-based (or outcomes-based, performance-based, or risk-share) contract in pharmaceutical markets would have the following features:

- An easy-to-use, template-based system for contract development that did not require knowledge in computer science to use; in other words, a contract development module that would make sense to the business people in life sciences and managed care companies who design and negotiate contract terms.
- The ability of parties to run simulations or pilot programs of potential contracts in real time, based on real world data, without having money at stake.

- The ability to conduct contracts in US Dollars, Swiss Francs, or another fiat currency according to the operating countries of the involved parties, and to not require the use of a cryptocurrency coin or token that could be speculative.
- The ability to automatically adjudicate contracts in an accurate, time-relevant manner based on real world data points occurring in real time or near-real time.
- A native economic functionality, most likely a method for aligning incentives so that all parties have economic reasons to adopt this technology for the purposes of contracting.
- The ability of contracts to have a high level of sophistication over time, and functions that would allow updating when parties agree or when certain external or environmental conditions are met and demonstrated in the data, such as market entry of new competitors or data about risks or benefits that were previously unknown.
- The ability to securitize the future receipts of contracts in a manner so that contract futures could be resold to a third party, such as a reinsurer or an acquiring pharmaceutical company in a merger or acquisition.

Because no off-the-shelf blockchain-based solutions existed that met all of these requirements, the authors set out to establish a platform that did.

**Data Economics: "Cryptoeconomics" without Coins or Tokens**

Prior to developing a bespoke technology platform, the team evaluated existing blockchain and distributed ledger technologies, identifying these platforms' core features and limitations to establish whether existing technologies could suitably operationalize these use cases.

*Insufficiency of Tokens or Coins for the Miraculum Use Cases*

The conclusion was made that a token-based system could not adequately address the needs of the health sciences sector. Specific business, scientific, and economic requirements did not fit with a strictly "tokenized" model. The four primary concerns were the legal and regulatory complications of ICOs (Initial Coin Offerings) and similar token-based funding mechanisms, the seeming impracticality of "tokenization" in a diverse business setting, the lack of native economic incentives in distributed ledger SaaS platforms, and risk of instability or deflation in cryptocurrencies.

*ICOs and similar token offerings: Regulatory, Ownership, and Legal Issues*

Tokens or coins offered through an ICO frequently become speculative investment instruments, and are often purchased by parties not involved in the platform or even uninvolved in industry-related transactions. Most ICO coins or tokens are framed as "utility tokens" to avoid being categorized as a security and thus subject to SEC regulations.[6] Utility

[6] The SEC is the United States Securities and Exchange Commission. If a token is deemed to be a security (using the Howey Test based on *SEC v. W. J. Howey Co.* Supreme Court decision), it is subject to federal securities law, including registration of the securities with the SEC or finding an exemption from

Tokens are tokens typically sold before a platform "goes live" with the promise that the tokens will be the only means to purchase a future service on the platform (such as the implementation of a value-based contract) or that the tokens will convey a specific utility within the walled garden of a particular platform such as a discount on platform fees.

If a Utility Token for a particular industry or sector is floated as part of an ICO, true industry partners are unlikely to be the primary token buyers at time of launch; most ICO purchasers have been individuals who are seeking to diversify large holdings of Bitcoin and Ethereum or are Crypto-focused investors including venture funds specializing in blockchain technologies and cryptocurrency investments. As a result, if a platform was built dependent on the use of a token for its operationalization, health sciences industry partners could be forced to purchase tokens at an inflated price from investors at a later date once the platform is live, and at fluctuating rates. While a platform company could theoretically control pricing to adjust for fluctuating Utility Token rates, this approach is unnecessarily complex. Moreover, based on our conversations with biotech industry leaders and health policymakers, this mechanism will not be able to win business buy-in from life sciences and health care enterprise finance leadership as a means of using such a platform for a business-critical function.

*Fluctuating and Potentially Deflationary Economics of Cryptocurrencies*

Cryptocurrencies are also highly volatile financial instruments on secondary trading markets.[20, 21] The fluctuating nature of coin values creates unacceptable levels of financial risk for most potential enterprise customers, where accurate forecasting of expenses is an essential business requirement. Whether a cryptocurrency is used to settle contract accounts, used to "power" contracts through transaction fees paid in a specific cryptocurrency (or via a Utility Token), or both, volatility creates price fluctuations that are not acceptable for the majority of health sciences enterprise customers.

Furthermore, most cryptocurrencies and utility tokens are expected to appreciate in value as CPOW mining becomes more competitive or supply becomes constrained due to platform use and "spend" of coins or tokens; the effect would therefore lead to the opposite of the economy of scale effect that Miraculum seeks to create, where costs to participate increase rather than decrease over time. Life sciences executives are not willing to adopt a technology platform for a business-critical function where the operational costs may fluctuate wildly after significant up-front investment is made in adopting the technology.

*Where's the "Tokenization" in a Platform with Infinite Use Cases?*

From a cryptoeconomics standpoint, the desire to be able to implement an array of simultaneous contracts involving different manufacturers, drugs, regimens, disease states, and

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the requirements to do so, such as selling only to entities qualified as accredited investors (Rule 506 of Regulation D).

outcomes also posed a challenge for "tokenization." Beyond the issues addressed above regarding token mining and economies of scale, we did not believe that a token should be used simply as a pre-paid gift card for services or products in the future, so the option of a singular system token that simply was a Utility Token to pay for future services lacked palatability, and seemed redundant as large health care industry customers (biopharma, hospital systems, governments) prefer to transact in fiat currencies (US Dollars, Swiss Francs, British Pounds, and the Euro as primary examples).

Thus we asked: If the Miraculum platform were to have a token, what would the token represent? If it represented value of a drug, that token's value should fluctuate over time, perhaps higher due to real world performance and scientific discovery of new indications, but also lower if a new market entrant with superior efficacy and lower toxicity data were to gain regulatory approval. Also, the token's value *shouldn't* fluctuate on secondary trading markets independent of this environmental data, as that would convey a value not linked to a drug's performance. Furthermore, if one potential contracting mechanism is to have differential pricing for different indications or uses of the same drug agent, how would a token representing a drug agent account for this? Lastly, the US FDA (Food and Drug Administration) has approved approximately 1500 drug and biologics agents in its history; a token for each drug agent lacks feasibility due to sheer numbers.[7]

If a token were to represent a drug company and its portfolio of molecular assets, how does that differ from a token that represents equity in the company, which has infinite regulatory and legal pitfalls, particularly if not issued by the company itself? And how could a tokenized system account for instances in which a pharmaceutical company sells or licenses a molecular asset to another company if the seller had a tokenized contract attached to such a molecule?

Ultimately, tokenizing individual contracts, drug molecules, regimens, pharmaceutical companies, or disease states each appeared impractical for a number of our key use cases. The creation of a token for any vertical in the medical sphere would be introducing a new, fluctuating method of payment into an industry already struggling at times to balance, for example, the US Dollar and Swiss Franc in global forecasts and reserve payments. In our simulations, the value instability of tokens was too large a deterrent to adopt for health care applications. We needed to develop a different approach that could create additional value for "native" industry participants in the market without destabilizing enterprise platforms through unpredictable token sales to speculators.

[7] This example is specific to a value-based contracting use case, and does not negate the potential for development of drug-specific Data Assets that represent a performance aspect of that product. Examples already exist in the market of biopharmaceutical companies raising investor funds for a particular molecular asset based on a security token structure.

*Insufficiency of Distributed Ledger SaaS for the Miraculum Use Cases*

Distributed ledger software-as-a-service was likewise seen as unsuitable, but for different reasons. Many aspects of the permissioned distributed ledger or permissioned distributed database structure are desirable. Those features include the ability for competitors to run instances of a contract application without viewing the contract or transaction details of a competitor (essential in the biopharmaceutical industry to remain compliant with antitrust regulation). However, by removing coins and tokens, distributed ledger platforms lose the core economic motivation to participate in the market. If the promise of blockchain technology lies in the potential for cryptoeconomics to incentivize behaviors and drive alignment across stakeholders who are using a common state of data as a scorecard, many of the distributed ledger technologies fail to capture this entire vision, and thus are left with a neutered version of blockchain with few distinguishing capabilities beyond any distributed database.

*Permissioned, Coin-Free Cryptoeconomics Using Data-Backed Data Assets*

To guide our economic approach, we considered the economic aspects of cryptocurrency platforms that make these currencies such powerful tools: scarcity, competition, and incentives. When miners on a computational POW cryptocurrency blockchain such as Bitcoin compete to be the fastest to crunch cryptography algorithms using high-powered GPUs to find a “nonce”, the rewards go to those who can outspend on hardware and/or locate their hardware in jurisdictions with low energy costs, given the electricity intensiveness of computational POW mining. The incentives therefore drive towards the development of large server farms in heavily subsidized electricity markets. The paucity of correct answers to difficult cryptography algorithms (the difficulty of finding the nonce) coupled with reward mechanisms and, in many cryptocurrencies, a set total number of coins that can ever be mined, creates an artificial scarcity that drives competition; as an aside, the artificial scarcity also drives speculative acquisition of coins with the hope that they will appreciate in value as mining becomes more difficult.

However, neither hardware spend or energy costs are core to the health care market. The concept of tying the price of health business transactions to electricity or GPU prices seems arbitrary, and introduces risk that energy markets could adversely impact a health care technology product that “hard coded in” such a link.

We proposed that difficulty of new block generation should not be based on artificial scarcity or countdown algorithms to the next level of difficulty, but rather on real-world value and the scarcity of desirable outcomes for any specific industry transaction. If the Miraculum platform were to incorporate competition and rewards as part of our cryptoeconomic matrix, we sought to incentivize the following across all participants:

- Submission of high quality real world data to contracts (or other applications)
- Design of contracts or applications that would generate a relatively consistent velocity of transactions (consistent velocity of economic activity, with the overall relative rate

differing among various applications depending on the type of real-world market they represented)
- Direct participation with other economic players, disintermediating data aggregators and re-sellers, approximating a "Data as Labor" philosophy [22, 23]
- Fair and collaborative contract term setting (disincentivizing "gaming")
- Rewards attached to the meaning of data within the context of the health ecosystem rather than rewards attached to solving an algorithm that doesn't have meaning in this ecosystem
- Potential to achieve economies of scale, commoditization of infrastructure, and lower transaction costs over time without sacrificing the potential financial upside for participants
- Potential for participants, and potentially for third parties, to invest in the achievement of desirable and high-value outcomes (which could be clinical, economic, or administrative in nature) and the generation of high-value or meaningful data
- Intrinsic economic links to the real world economics of health care and health sciences markets

Ideally, we sought the flexibility and confidentiality of a permissioned ledger, but we also wanted a core economic component that could deliver incentive alignment and the context of a "data economy" within the environment. Given the lack of suitability of off-the-shelf options, our solution was to implement this health sciences environment using the unique Data Economics design approaches and technology tools developed in the Lydion Engine.

**Health Care Data as Work and Outputs?**

An increasingly popularized thread of economic debate has centered on whether data, as "the new oil", behaves (or should behave) as capital or labor as described in classical economics. [24, 25] The "Data as Labor" (DaL) argument is currently promoted by thinkers including economist Glen Weyl at Princeton, technologist Jaron Lanier, and law professor Eric Posner at University of Chicago. [22, 23, 26]

In classical economic theory, capital and labor are two "factors of production" where each have distinct characteristics. Capital typically refers to good that facilitate the production of other goods; capital is mostly seen as a means, and can typically be invested in the production of more outputs. Capital is non-productive on its own, but leads to or improves productivity. Data as Capital (DaC) proponents see data as a byproduct of actions in the real world and as a means of the production of both humans and machines, as "big data" can be fed to algorithms to fuel machine learning and artificial intelligence advancements.

Labor, in classical economics, is an active component of production. It is typically time-bound—a laborer can only work for a limited period of time, and today's work outputs may differ from tomorrow's. Labor also is impossible to separate from the laborer; the output,

in a sense, is attributable to the individual or entity that generated that output, regardless of whether the financial rewards of the output are owned by that entity.

The core argument of the Data as Labor (DaL) theorists is that "data work" such as that done by contributing photographs to "free" social media sites, participating in online labor such as Amazon's Mechanical Turk, or identifying text or photographic CAPTCHAs, should be treated as labor; however, the data resulting from such work is presently treated as capital, particularly by large data aggregating companies that may feed such data to ML/AI machines, resell aggregated data to third parties, or use the data to offer other services such as targeted advertising. The DaC camp presents data as "exhaust" from digitized interactions that has limited value until churned through such computational tools. Weyl and colleagues argue instead that treating data as labor will allow for economic empowerment of data contributors and data workers, and the value of data will thus be amplified. [23]

The philosophy behind the Lydion Data Economics Operating System (DEOS) approach goes further, presenting that data *is* work (or at minimum, a digital facsimile of it) if that data can be demonstrated via a blockchain database or similar structure to be authentic and non-duplicative. Lydion makes an additional argument that specifically organized, quantized, provable data can represent a *proof of work* sufficient for securing an asset on a blockchain database.

In the context of health sciences and health care, data has frequently been treated as capital when in fact it may be much more efficient to treat it as labor. We see a paradox in how health sector data is treated that illustrates the "Data as Capital" and "Data as Labor" divide. On one hand, arguments are presented that health data belongs to and should be controlled by those who contribute the data (although among the contributors of patients and practicing clinicians, difficulty exists in dividing the ownership). Health data reflects actions and occurrences in time, and data is a key factor in advancing (or creating productivity in) both patient care and scientific discovery, all factors that could argue towards health data as labor. On the other hand, health data is used as a supporting tool of clinician or researcher productivity, and current regulations allow it to be aggregated and resold without the compensation of its generators or contributors, similar to capital, although this resold, anonymized "big data" typically removes details of provenance that could attach any data point to its original data generator(s) or a moment in time.

A strong argument can be made that many forms of data within the health care sector could be treated as labor, whether the data is specific to patients or specific to clinicians, health systems, or even health sciences businesses. First, data is one of the key "fuels" powering health care productivity, along with the labor of those in the sector; whether in the context of an individual patient consult (e.g. results of a lab test) or in the context of drug development (e.g. outcomes in a clinical trial), decisions do not move forward without the generation of data. Second, this data, while it can be aggregated or anonymized, is impossible to truly separate from its generators, whether those are patients, clinicians, researchers, or a

combination of those and other entities. A health outcome is a data point that is only generated specific to a *patient* in a specific and defined *point in time* and in the *context of defined products and services* such as clinical care, procedures, and drugs.

Miraculum treats health data as work, and specifically looks at data that represents desired outcomes in the health care ecosystem and economy. Miraculum's use of the term "outcomes" differs from the typical use of this word in health care settings, where "clinical outcomes" describe the evaluated endpoints of disease progression or specific interventions. Miraculum's data outcomes are not limited to clinical outcomes; they can include financial, administrative, economic, and other categories of result. Our use of the term "outcomes" can also include the results of what would typically be termed "process measures" in health care, such as whether or not a specific intervention has been delivered, regardless of the clinical outcome of such process.

**Examples of Defining Data Assets in a Miraculum Data Economy**

Each Data Asset in Miraculum is defined by a desired, scarce outcome in the health care ecosystem. The matrixed nature of blockchain databases implemented by Lydion allows Data Assets that are "outcomes" to be "inputs" to other Data Assets, thus solving for the realization that the same data instance may represent a financial liability (e.g. a billing claim that must be paid by a health care insurer) to one health care ecosystem stakeholder and revenue to another stakeholder (e.g. a hospital due to receive payment for the claim). At the same time, this same data instance may have other value to other stakeholders, including patients, pharmaceutical companies, and public health organizations.

*An Example: A Duration-Based Value Contract for Medicine X*

In a relatively simple duration-based contract structure, we can propose a Lydion that describes the "administrative outcome" of a patient's duration on a particular therapy, "Medicine X." For this scenario, we will assume that Medicine X maintains a patient's disease without worsening for a subset of patients as long as the patient is able to stay on therapy, and some stay on this therapy for many years with good response and high quality of life, but patients may drop off of therapy for one of the following reasons: no initial disease response to therapy, intolerable side effects that impact quality of life, or disease worsening for an unknown reason after some time on therapy. We will assume that, as of yet, there is no biomarker or predictive measure that can prospectively inform whether a patient will be in the "long tail" of those who benefit from this medicine over a longer period of time, or whether that patient will be a non-responder or experience an intolerable side effect.

If Medicine X is expensive, an insurance company may be interested in establishing market access limits or "utilization management" (UM) to limit financial exposure. UM measures can include tactics such as step therapy, where patients must try a less expensive medicine first; a high cost share or co-payment for Medicine X that may discourage patients from its use; and a

prior approval where the prescriber and/or the patient must receive affirmative permission from the insurer before the drug can be given to the patient.

From the perspective of Medicine X's manufacturer, because it is difficult or impossible to predict which patients are most likely to benefit from Medicine X at the present time, there would be interest in having as many clinically eligible patients start therapy on Medicine X so that those who benefit can stay on therapy and receive value from this product. The Medicine X manufacturing company may be willing to offer a deep discount, or even a complete refund to both insurer and patient, for any patient that tries therapy and does not respond, or for a patient who may respond but who experiences an intolerable side effect. The company may also be willing to go at risk for the duration of benefit, perhaps providing the drug at a discounted price for patients who do not reach the median duration of benefit in a clinical trial while charging a relatively higher price for patients who stay on therapy for significantly longer than the predicted benefit from previous research.

To implement such a scenario using Miraculum, the following Lydion Data Assets are built:

*Lydion 1: Represents "Medicine X Administration"*

The "Medicine X Administration Lydion" could be generated when claims data coming from the health insurer indicates that Medicine X was administered to a patient. Other data sources could include Electronic Health Records (EHR) or Medication Administration Records (MAR) held at the provider or delivery system level, or if the drug is orally administered, records from a Pharmacy Benefit Manager (PBM), Specialty Pharmacy (SP), or retail pharmacy. [8]

Other parameters contained in the same dataset could determine constraining factors, or other required inputs, for a Medicine X Administration Lydion to be generated. In this scenario, parameters could include the site of administration, the patient diagnosis as expressed by an ICD-10 code or other data element, the co-administration of other drugs, the absence of certain comorbidity diagnoses or the absence of certain other drugs, or demographic factors.

If the primary purpose for the Medicine X Administration Lydion is to underpin a duration-of-benefit-based contract, this Data Asset does not necessarily have to attach itself to any financial value, although it could be used as a benchmark to represent payment in a Fee-for-Service (FFS) environment where drug reimbursement is linked to drug administered (medical benefit) or drug dispensed (pharmacy benefit) to the patient.

*Lydion 2: Represents "Medicine X Duration of Benefit"*

[8] The contracting stakeholders can determine both the consensus domain of the incoming data and the necessary trust domain within which the data will be used; external stakeholders could decide to place greater or lower value on this Data Asset depending on their assessment of the quality of data source. Different versions of the Data Asset could also be built using different data sources and compared.

Once our Medicine X Administration Lydion is established, other Lydions can be built that *reference* that Lydion, but *do not impact* it.[9] One such asset could be the "Medicine X Duration of Benefit Lydion." This asset would query the Medicine X Administration Lydion and essentially ask it: "For this instance of the Medicine X Administration Lydion, what other Medicine X Administration Lydions exist previously in the chain that would meet our definition of 'continuous therapy for the same patient' and meet any other internal or external data parameters that we specify"? The Medicine X Duration of Benefit Lydion can define the above criteria however it wishes, as long as the input data needed is available. Most simply, all of the input data could come from the Medicine X Administration Lydion chain, but the Medicine X Duration of Benefit Lydion could also query other data sources; the Lydion Engine's mechanisms of "Chain Controller Machines" and "Economy Controller Machines" allow for such data interface and interoperability.[10]

The Medicine X Duration of Benefit Lydion could relate to various financial parameters in the real world, both through input requirements and through outputs; those financial parameters could be managed via another Lydion or could be managed outside of the Miraculum economy.

For example, participants in the Medicine X Duration of Benefit Lydion (MXDBL) could use that Lydion as a scorecard for external financial transactions governed by a contract that linked discounts and bonus payments to duration of therapy. Medicine X's manufacturer and an insurer could include additional data parameters to the MXDBL, such as a minimum number of patients on therapy per year and the presence of funding in an escrow account (whether fiat or cryptocurrency), that would determine whether or not the contract is "in play." The MXDBL could thus be used to generate "scorecard reports" that essentially would be secure, verified invoices for discount or bonus payments to be made. The level of discounts and bonuses could be "hard coded" into the MXDBL chain, could be coded into another Lydion chain that references the MXDBL, or could exist in a contract governance structure external to the Miraculum platform.

In a more complex ecosystem where automated payments via cryptocurrency smart contracts were desired, the MXDBL could feed data to another Lydion chain, including one that

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[9] Miraculum, and the Lydion platform by corollary, allows for the construction of asset matrices within a Data Economy, but these assets function in a "one way flow" manner as to not allow for contagion or the "contamination" of an asset closer to the original data source by a potentially dubious assumption further up the line, similar to a backflow preventer on a water pipe. This one-way matrix data structure also has positive implications for data privacy and ownership, as data can be transformed into a Data Asset that "lives" in a closely held, private environment while being queried for potential inputs that lead to a potential output on a more widely held environment. The data from the "closer level" chain is never revealed on the "wider level" chain, although its data can contribute to the outputs visible on the "wider level" chain through transformation, and all data through to the closest level can be traced back and audited, which has specific implications for financial, legal, regulatory, and privacy needs.

[10] See Lydion technical documentation.

automated payments using the MXDBL outputs as inputs to determine if funds should be moved from one account to another.

**Potential Securitization and Exchange of Miraculum-generated Lydions**

One of the learnings from the "blockchain revolution" and the advent of cryptocurrencies is that once data is secured by a blockchain, that data or associated data on the chain can potentially be *securitized*. The ability of a blockchain to provide a shared, difficult-to-defraud and difficult-to-hack scorecard for transactional activity can translate into the ability to place bets on the future outcomes generated by or transactions inscribed upon such a blockchain.

Lydions built with Miraculum applications could likewise be crafted into instruments of financial exchange, whether as securities or other types of assets. For example, in the contracting scenario above, a pharmaceutical company or insurer entering into a contract using MXDBL as the scorecard could re-sell its future earnings or liabilities on that contract to a third-party entity, or could purchase insurance against potential liabilities originating from that scorecard. In a world with potentially hundreds or thousands of similar contracts, one can imagine a "fund" approach where a third party may package or bundle many contracts together, and either sell the contract futures directly to third party investors, or may create additional Data Asset scorecards that reflect the performance of a group of contracts. The full implications of such markets for Lydions, including dimensions such as health economics, political economics, finance, ethics, and health sciences business impact are topics currently in exploration by The Data Economics Company and its academic research partners.

**Comparison of Miraculum Platform Features to Stated Requirements**

Below, we compare the requirements we stated above to the features and capabilities of the Miraculum platform, with a description of how this platform meets each requirement.

**Table 1.1: Miraculum Platform Features and Stated Requirements**

| Features | Requirements |
|---|---|
| An easy-to-use, template-based system for contract development that did not require knowledge in computer science to use; in other words, a contract development module that would make sense to the business people in life sciences and managed care companies who design and negotiate contract terms. | Achieved through the use of templated contract designs aka "Data Economy Designs" that map to approaches in the Lydion platform. |
| The ability of parties to run simulations or pilot programs of potential contracts in real time, based on real world data, without having money at stake. | Ability of Miraculum blockchain platform to run as a full sandboxed implementation on test servers to simulate potential Lydion outputs without the need |

| | |
|---|---|
| | to spend cryptocurrencies. |
| The ability to conduct contracts in US Dollars, Swiss Francs, or another fiat currency according to the operating countries of the involved parties, and to not require the use of a cryptocurrency coin or token that could be speculative. | Lydions generated by Miraculum can be used as scorecards to underpin verified invoicing in fiat currencies. |
| The ability to automatically adjudicate contracts in an accurate, time-relevant manner based on real world data points occurring in real time or near-real time. | Each new Lydion in a Miraculum-generated Lydion chain is only generated when real-world data inputs match requirements. Transaction speeds are determined by the Data Economy Design, not by the transaction speed limit for waiting for a public blockchain block to be mined/confirmed. |
| A native economic functionality, most likely a method for aligning incentives so that all parties have economic reason to participate in this technology for the purposes of contracting. | Lydions are designed for the needs of each particular use case. Because they don't require a catchall cryptocurrency or token, their economic functionality is determined at the specific Asset level and is more flexible than a token or coin. |
| The ability of contracts to have a high level of sophistication over time, and functions that would allow updating when parties agree or when certain external or environmental conditions are met and demonstrated in the data, such as market entry of new competitors or data about risks or benefits that were previously unknown. | Lydions can be designed to incorporate any “outside world” data via communication with the Lydion Engine’s Economy Controller machine structure. Additional Lydions can be built “on top of” existing or previous Lydions in a one-way, matrixed method to incorporate new data that was previously unavailable or unknowable. |
| The ability to securitize the future receipts of contracts in a manner so that contract futures could be resold to a third party, such as a reinsurer or an acquiring pharmaceutical company in a merger or acquisition. | Lydions can serve as a securitized scorecard that allows for resale to transfer to, or investment from third parties, as well as insurance and other forms of hedging. |

## Discussion

The above examples merely scratch the surface of Lydions and the application of Data Economies and Data Economics science for the health care sector made possible through Miraculum. As health sciences customers test and adopt the Miraculum platform, they identify new potential use cases and Data Economies that may further the alignment of incentives among the diverse stakeholders and business interests within this sector.

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