Scaling Blockchains: Embracing Modularity

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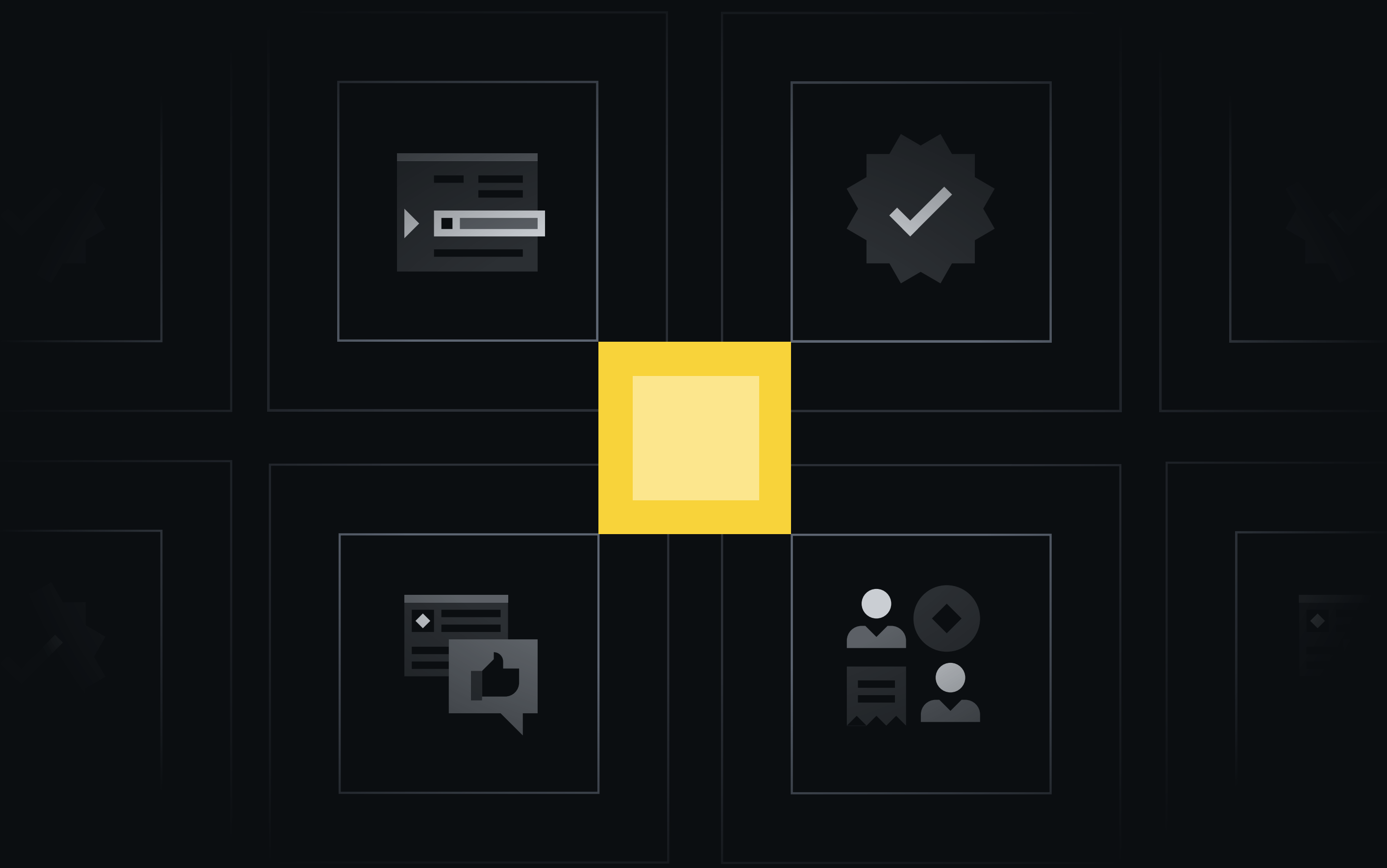

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1 Key Takeaways

- The crux of the modular blockchain thesis is a concept related to the separation of roles. Modular blockchains seek to optimize one or more of the four core functions - Execution, Settlement, Data Availability ("DA"), and Consensus - by delegating responsibility to a separate layer.

- One of the critical bottlenecks in realizing the full potential of Layer-2s ("L2s") for scaling lies in the DA layer, prompting a strong focus on advancing DA capabilities. The developments in the DA space introduce new opportunities for the broader modular ecosystem.

- EIP-4844 is set to enhance Ethereum's DA capabilities by drastically reducing DA costs, which presently constitute a major portion of the L2 overhead. However, there is growing demand towards the adoption of alt-DA layers, driven by the need for greater scalability.

- Celestia is the first public network that is designed to be optimized for DA. Celestia's approach to scalability centers on the decoupling of execution from consensus, and the introduction of key technologies such as Data Availability Sampling ("DAS") and Namespace Merkle Trees ("NMTs").

- Eclipse is Ethereum's first Solana Virtual Machine ("SVM") L2. Specifically, Eclipse takes advantage of the parallel-processing design of the SVM to run a L2 with settlement on Ethereum and DA on Celestia.

- Manta Pacific is a modular L2 that became the first to migrate to Celestia DA. Manta Pacific has grown to become the third largest L2 by TVL, boasting an impressive US$1.9B.

- It's not all about modularity, with scalability improvements also occurring within monolithic Layer-1s ("L1"). Notably, Monad is bringing parallel execution to the Ethereum Virtual Machine ("EVM").

2 Background

Finding the optimal approach to scalability has long been a hot topic in the crypto industry, especially as the rise of sophisticated decentralized applications ("dApps") and the growing demand for block space continue to stretch blockchain throughput limits. Should a blockchain fail to scale effectively, it significantly impacts the application layer and its potential use cases, thereby limiting broader adoption and utility. This challenge is underscored by the so-called scaling trilemma, the idea that no public blockchain can simultaneously achieve maximum decentralization, security, and scalability.

Despite various projects proposing different scaling solutions with their specific trade-offs, modular blockchains have emerged as one of the category-defining approaches to scaling blockchains. Recent progress in Data Availability has pushed the modular thesis a significant step forward, acting as a catalyst for Layer-2s ("L2s") and the broader modular ecosystem. The launch of the first alternative Data Availability layer in Celestia has led to the emergence of new modular L2s, each offering distinct scaling approaches compared to general-purpose L2s. Meanwhile, the other integrated approach to scaling involving monolithic architecture has also seen notable developments, making it an interesting point of consideration against the growing modular space.

In this report, we explore various new approaches to scaling blockchains within a modular framework, covering Data Availability and modular L2s, while also shedding light on emerging solutions in the monolithic side.

2.1 Monolithic vs. Modular Blockchains

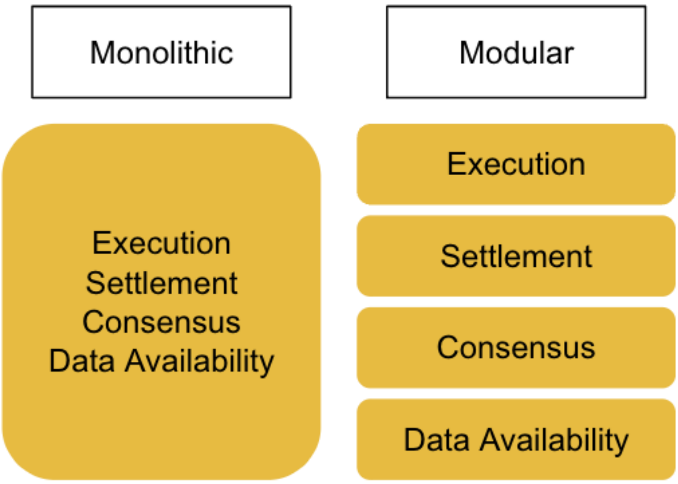
Before diving into the modular blockchain thesis, let's quickly recap the concept of monolithic blockchains. Defining a blockchain at its most basic level as an **immutable ledger of transactions**, we can broadly classify the majority of blockchains, at least those with notable value attached to them, as monolithic blockchains. To meet its **fundamental purpose of recording valid transactions and data chronologically**, a blockchain must perform 4 critical functions:

- **Execution:** processing transactions to update the state of the blockchain.
- **Settlement:** resolving disputes, verifying the validity of transactions, and ensuring the finality of transactions.
- **Consensus:** reaching an agreement between validators or miners on transaction ordering, e.g., Proof-of-Stake ("PoS"), Proof-of-Work ("PoW"), etc.

- **Data Availability ("DA"):** ensuring transaction data is available for the entire network to view.

Monolithic blockchains, such as Ethereum and Solana, perform all of these functions on the same layer and in a generalized manner. **Modular blockchains, on the other hand, seek to separate these functions across multiple different chains**.

Figure 1: Monolithic vs. modular blockchains



Source: Binance Research

Given that **monolithic blockchains seek to perform all the above functions through the same chain**, this **prevents them specializing in any one function**. This effectively binds them to the scalability trilemma[1], which dictates that it's only possible for monolithic blockchains to prioritize **two of scalability, decentralization and security** at the same time. Hence, improving one area necessitates compromises in the others. For instance, Ethereum's Layer-1 ("L1") prioritizes security and decentralization, resulting in high transaction fees and slower processing times during peak periods. Conversely, existing ("alt")-L1s like Solana may prioritize throughput at the expense of some security and decentralization, often by operating with fewer nodes. Though **sacrificing decentralization to boost throughput does not truly constitute scaling**. Ultimately, the monolithic approach entails specific tradeoffs in terms of scalability.

- **Increased hardware requirements:** While monolithic chains can increase the number of transactions they process, it comes at a cost. That cost is higher hardware requirements for nodes to verify the chain, resulting in the centralization of the network.

- **Burden of bootstrapping validators:** Deploying a new monolithic blockchain requires the substantial task of bootstrapping a secure set of validators and upholding a consensus network, adding to the initial overhead.

- **Limited control:** Projects operating on a given chain are bound by its set rules, curbing their flexibility. This includes aspects like the programming framework, forking capabilities, and community culture, among others.

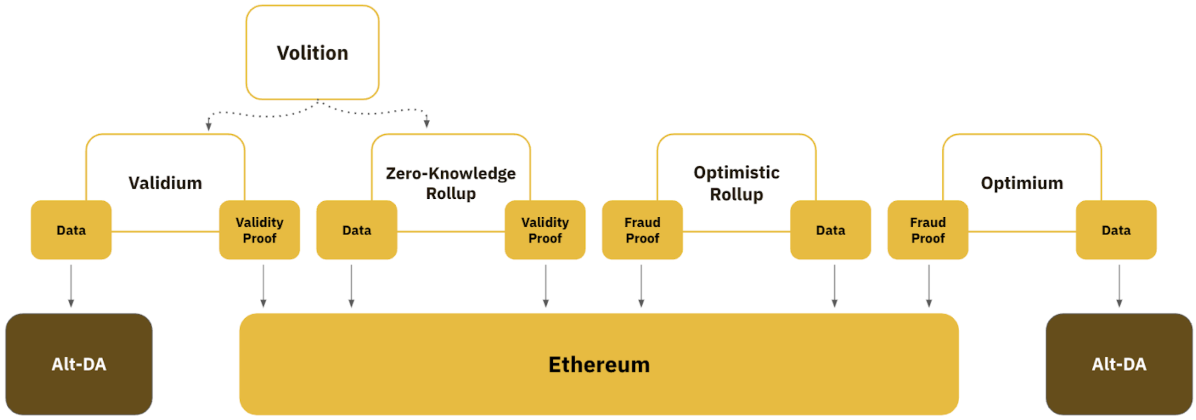
2.2 The Modular Thesis

The crux of the modular blockchain thesis is a concept related to the **separation of roles**. Instead of a single network handling all core functions required for blockchain computations, the **modular approach advocates for a separation of duties -** such as execution or DA - across specialized networks. **By disaggregating different components of a monolithic L1, blockchains can be optimized for specific functions at each layer of the stack**, thereby enhancing decentralization, security and scalability where necessary. The rationale is that the sum of these layers will be able to achieve vastly higher levels of customization and efficiency.

The modular approach initially gained traction with **Ethereum's shift towards a rollup-centric architecture**, which **moved away from emphasizing scalability at its base layer** to focus on consensus, settlement, and DA. Today, L2 rollups[2] represent the most secure type of modular blockchain, offering a variety of configurations for different needs. They enable the **separation and optimization of the execution environment** from the broader responsibilities of the Ethereum network. Rollups work by entrusting the task of execution to sequencers, who process and bundle transactions before posting the compressed data back to Ethereum for verification[3]. **By submitting transaction data to a separate DA layer, rollups can achieve fast and cost-effective transaction execution without bearing the computational load of DA**.

Validiums represent another category of scaling solutions that maintains transaction data off-chain[4], only submitting validity proofs to Ethereum, thus reducing data posting costs but at a trade-off with the full security guarantees of Ethereum. In a similar vein, **Optimiums represent the optimistic variant of Validiums**, employing a different proof mechanism. These solutions rely on Ethereum for settlement while delegating the responsibility of DA to specialized providers such as alt-DA layers. Meanwhile, **Volitions offer users the flexibility to choose between storing data off-chain, like Validiums, or on-chain, akin to traditional rollups**. Vitalik Buterin's blog post does a good job at highlighting the differences among L2s.

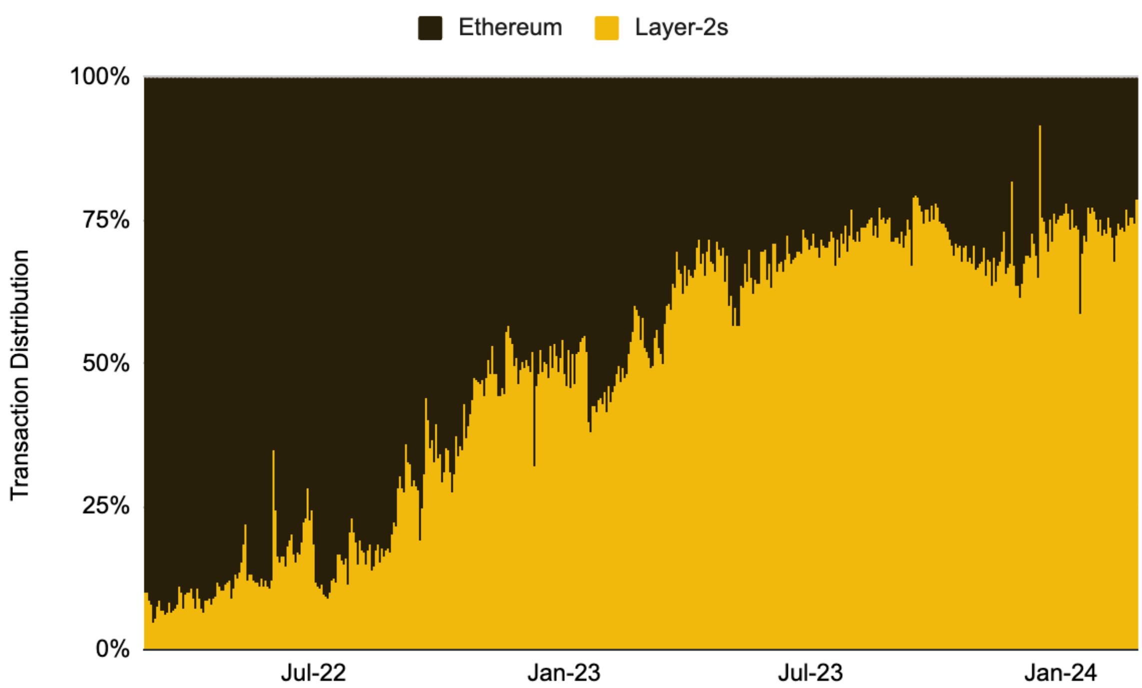
Figure 2: While rollups are the most common form of modular blockchain, others types also exist, including those with variations in how and where transaction data is posted



Source: Binance Research

Broadly speaking, the modular landscape has also witnessed the emergence of various solutions, including **shared sequencers**, **proof systems**, **interoperability protocols**, **order flow abstraction projects**, and infrastructure providers such as **rollup frameworks** and **Rollup-as-a-Service ("RaaS")**. These advancements have **aided improvements in L2 technology stacks** as well as the **abstraction of functionality into specialized layers**, pointing towards the growing importance of L2s. Indeed, over the past year, activity on Ethereum L2s has nearly tripled, boosting L2 dominance to 79.7%.

Figure 3: L2 dominance in daily transaction volumes has experienced a strong upward trajectory, now accounting for over 79.7% of transactions compared to Ethereum



Source: Dune Analytics (@21co), Binance Research, as of February 26, 2024

Most L2s emulate some form of the Ethereum Virtual Machine ("EVM"), typically offering copypasta protocols previously seen in other ecosystems. They have predominantly also relied on their base layer for settlement, DA and consensus. As L2s become increasingly central to the scaling landscape, so should the **diversity in their designs and approaches to scaling blockchains**. Accordingly, many projects are starting to embrace more modular frameworks, aiming to specialize additional functions beyond execution.

One of the **critical bottlenecks in realizing the full scalability potential of L2s lies in the DA layer**. Although Ethereum, as a monolithic L1, serves as a DA layer, it isn't specifically optimized for this role, especially as the dominance of L2s grows and more enter the market. That is why in recent years the modular blockchain space has had a **strong focus on advancing DA capabilities**, as evidenced by the **emergence of alt-DA solutions** like Celestia[5]. **Celestia specializes in DA without directly supporting general-purpose blockchain computations**; instead, it **delegates smart contract execution to other L2s**. This shift towards a modular architecture for both execution and DA is designed to bolster throughput while upholding the network's trustlessness and decentralization characteristics. Let's explore this in further detail and how it pertains to the DA problem.

3 Data Availability (“DA”) Landscape

3.1 The DA Problem

Optimizing blockchains for DA has reignited excitement for modular blockchain design given the **potential they hold for scaling**(6). DA is especially prominent in the context of L2s. **Irrespective of how efficient the execution layer or the proof mechanism used is, the full potential of L2 throughput is ultimately constrained by the DA layer's capabilities**.

The role of a DA layer is to **guarantee that transaction data from L2s is systematically ordered and made publicly available on-chain**. This availability is critical for maintaining the **chain’s liveness and integrity** by facilitating the detection of any invalid transactions. It also prevents the sequencer (L2 block producer) from misusing its control over transaction ordering. DA is thus a fundamental prerequisite for L2s and ensures that the networks are transparent, secure, and decentralized(7).

However, DA has its own set of challenges. Due to the **resource constraints of nodes operating on a DA layer**, the amount of data that can be recorded in a single block from execution layers is limited, even despite sophisticated ways to compress data from L2s in batches. This means that **the transaction throughput of an L2 is effectively bounded by the data throughput of its DA layer**. Put simply, if the DA layer cannot accommodate the volume of data a sequencer intends to submit, the L2's ability to process more transactions is hampered. Therefore, **improving the DA layer's data throughput is essential if L2s are to evolve into execution layers capable of supporting dApps ready for mass adoption**.

Turning our attention to the current market landscape, while Optimistic and Zero-knowledge (“ZK”) rollups have provided some relief to the scalability challenges, they represent a makeshift solution. **Existing L2s like Arbitrum and OP Mainnet still incur sub-optimal costs**, not due to their own design flaws, but because of the **constraints of the L1 architecture they depend on**. Even the most efficient rollups are periodically **bottlenecked by the extensive data submission requirements needed to build consensus on L1**, which isn’t optimized for such storage. This limitation explains why L2s often operate at **reduced transactions per second** (“TPS”) and **incur higher costs during peak demand periods**, making transaction fees for dApps, like on-chain gaming, prohibitively high for widespread adoption.

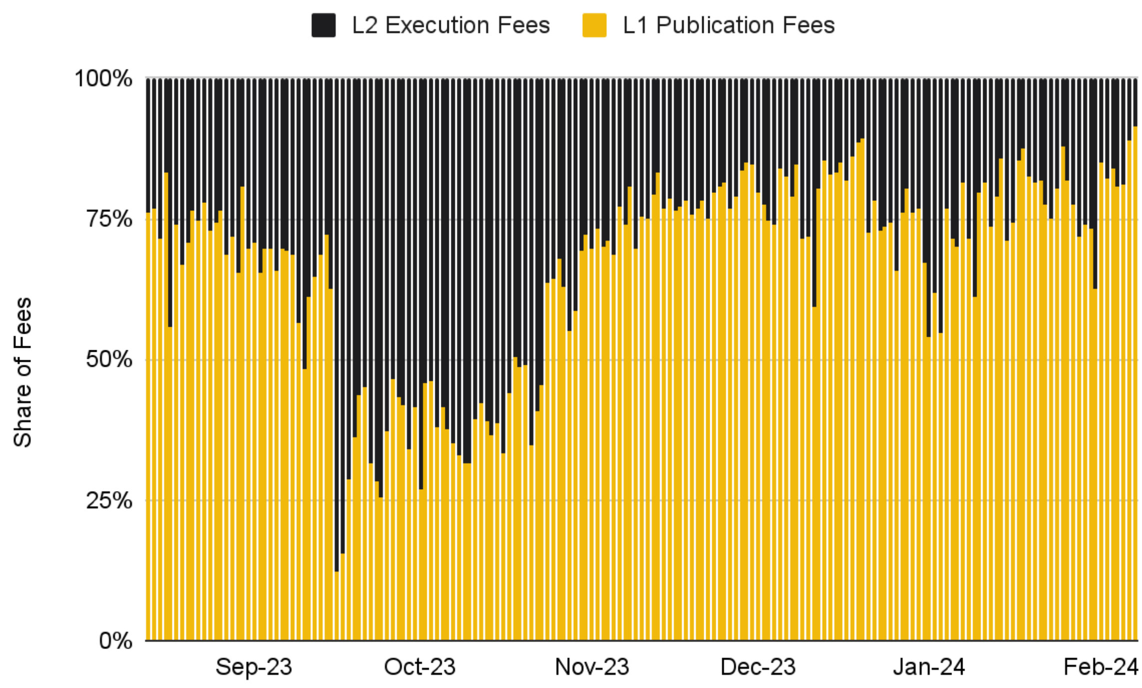
Figure 4: Snapshot comparison of L2s and Ethereum in the current market

Logo	Name	Rollup type	TPS	Cost to send ETH (US$)	Cost to swap tokens (US$)
	Ethereum	Base Layer	12.76	2.31	11.55
	Arbitrum One	Optimistic	9.29	0.24	0.65
OP	OP Mainnet	Optimistic	4.60	0.20	0.39
	Polygon zkEVM	Zero-Knowledge	0.25	0.31	1.16
	StarkNet	Zero-Knowledge	3.18	0.52	1.64

Source: l2beat.com, l2fees.info, Binance Research, as of February 26, 2024

The DA problem ultimately stems from how L2s interact with Ethereum's mainnet; they post their state roots back to Ethereum using calldata for storage, which is **neither optimized for L2s nor scalable to meet their DA needs**. To post data to these chains, sequencers are subject to the same fee market, block size constraints, and block times as regular transactions. This not only **elevates the transaction costs** on L2s but also **imposes a considerable load on nodes** that must download this data. As depicted in Figure 5 below, **over 90% of transaction fees on L2s can sometimes be devoted solely to these data posting costs**.

Figure 5: L1 publication fees are the dominant cost driver for rollups



Source: Source: Dune Analytics (@optimismfnd), Binance Research, as of February 26, 2024

Even with the proliferation of app-chains and Layer-3s ("L3s")[8], they do not necessarily scale blockchains any better than L2s, considering how **L3s are still constrained by the same DA bottlenecks as L2s**. This predominance highlights the core of the problem and the **transformative potential of DA solutions aimed at reducing calldata expenses**. In particular, the **implementation of dedicated storage spaces for DA could be a game-changer** in this regard. Therefore, it is quite evident that **minimizing calldata expenses will markedly improve both the economic viability and scalability of L2s**. Fortunately, Ethereum's upcoming Dencun upgrade, specifically EIP-4844, and the emergence of alt-DA layers like Celestia are addressing this problem.

3.1 DA on Ethereum

While Ethereum is **renowned for its security and resilience**, its role in **posting data has come at the cost of scalability**. As the largest general purpose blockchain, Ethereum itself is undergoing changes to **improve its capabilities as a DA layer**. One of the most anticipated upgrades as part of Ethereum's scaling roadmap is the **Deneb-Cancun ("Dencun") hardfork**, currently earmarked for mainnet on 13 March, 2024[9]. This hardfork consists of several upgrades but the **spotlight is undeniably on EIP-4844, also known as Proto-Danksharding**.

EIP-4844 is set to enhance Ethereum's DA capabilities by drastically reducing DA costs, which presently constitute a major portion of the L2 overhead. It introduces a **dedicated block space exclusively for rollup transactions** and **entirely separate from the main block space**. While transacting directly on Ethereum will continue to be an option, the goal is to **enable cheaper and faster L2s**, expanding Ethereum's capability and versatility. Over the next few years, DA capacity on Ethereum is expected to increase in stages as full Danksharding is rolled out[10]. At the same time, improvements in data compression will enable us to achieve more with less data.

With Ethereum implementing network upgrades to better support L2s, it is likely that a larger proportion of protocol revenue will originate from sequencers rather than direct L1 end-users. As we saw in figure 3 earlier, the growing dominance of L2 transactions suggests they will progressively contribute more to Ethereum's gas fees over time[11]. The assumption is that **the bulk of user and dApp activities will eventually migrate to L2s**, rendering Ethereum's base layer to primarily serve DA, consensus, and settlement functions. Though, for this to happen, the on-going technical challenges with L2s related to decentralization and interoperability would need to be resolved first. **The impact of DA enhancements is intricately linked to the maturity and widespread adoption of L2s**.

Blob-Carrying Transactions

EIP-4844 marks a significant innovation with the **introduction of blob-carrying transactions**[12]. This new transaction type **enables the cheap publication of arbitrary data across the network** without necessitating its permanent storage. Put simply, these are **data chunks - up to 128KB each - appended to transactions**, which significantly reduces DA costs and paves the way for **expanded data storage capacity**. Hence, the use of blobs offers a more attractive and **cost-effective alternative to the current calldata space that L2s rely on** for posting data to the Ethereum mainnet.

While the number of blobs that may be attached to a block is dynamic, 3 blobs will be targeted per block, with a maximum of 6. This means that EIP-4844 may **increase the data associated per block by 768KB** (128KB per blob x 6 possible blobs). This space will be governed by a **distinct fee market**, separate from that of regular user transactions, and is designed for temporary data storage only. **By removing the burden of long-term storage, Ethereum can affordably price these blob transactions, considering they do not add to the state and history growth** - factors that significantly impact resource pricing and fee markets on the network.

Figure 6: Blobs are 128KB in size and each Ethereum block can include up to 6 blobs, with a target of 3 blobs per block

	Blockspace	Blobspace
Seen by all nodes	Yes	Yes

Storage	Execution Client	Consensus Client
EVM access	Yes	No
Longevity	Indefinite	18 days

Source: eip4844.com, Binance Research

Yet, one of the main concerns about Ethereum's future as a performant DA layer is the extent and the pace to which the L1 is able to release upgrades. **As the largest monolithic L1 blockchain, Ethereum faces inherent constraints in terms of pivoting or adapting to different technological designs**. Optimizing Ethereum scalability is likely to take some time, which is why full Danksharding is still a few years away.

Moreover, **the effectiveness of Ethereum as a DA layer post-EIP-4844 remains to be fully realized**. For highly cost-sensitive use cases, Ethereum may still be too expensive, even after these upgrades. In response, **alt-DA layers have entered the market, already offering more affordable solutions for L2s**. This makes the introduction of EIP-4844 critical, especially as L2s built atop Ethereum have started to migrate and become increasingly interoperable with alt-DA layers like Celestia.

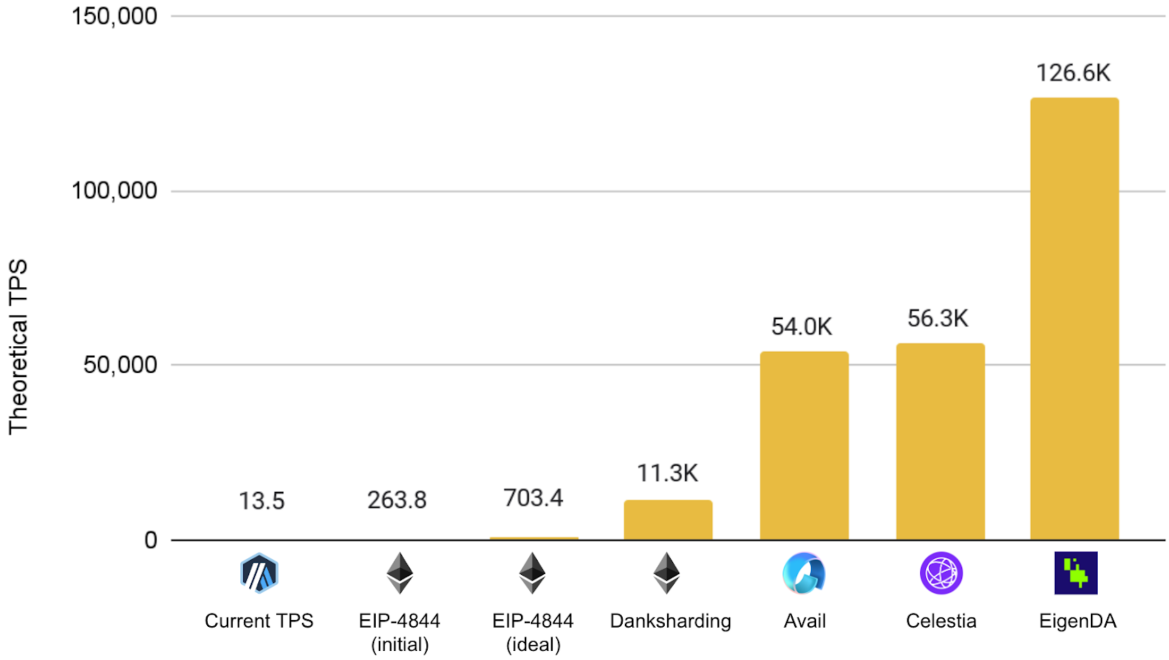
For more details on Ethereum's roadmap and EIP-4844, please refer to our earlier report, Ethereum: Beyond the Merge.

3.2 Alternative-DA Layers

So far we have seen many L2s use Ethereum for DA as the most typical approach. Yet, an emerging trend in the industry is that of L2s utilizing other protocols for DA while maintaining a validating bridge to Ethereum for settlement purposes. With full Danksharding still a few years away, there is a **growing demand towards the adoption of alt-DA layers**. This shift is driven by the **need for greater scalability** that Ethereum, in its current state, cannot fully satisfy, prompting L2s to seek solutions specifically designed from the ground up for DA.

Figure 7 below illustrates a comparison of theoretical TPS, highlighting the potential **limitations of Ethereum's current and near-future scalability**. For instance, the largest L2 today, Arbitrum, would still experience restricted throughput under EIP-4844's ideal state, and the initial implementation will only allow about 263.8 TPS. In contrast, the **theoretical TPS achievable with alt-DA layers is significantly higher**, indicating that L2s opting to use solutions like Celestia could benefit from cost efficiencies and potentially higher margins.

Figure 7: Even with EIP-4844, Ethereum may continue to lag behind alt-DA layers



Note: The provided figures are theoretical and derived from estimates, intended solely for representational purposes
Source: 1kxnetwork, Binance Research, as of February, 2024

With EIP-4844 already reducing the fees paid by L2s, the rising competition from alt-DA layers may act as an additional headwind to Ethereum's fee-derived protocol revenue. However, this competition is unlikely to completely erode Ethereum's role as a DA layer. The intrinsic value and demand for using Ethereum means that any significant migration to alt-DA by L2s could inversely trigger a renewed interest in deploying on Ethereum. **It's important to recognize that while alt-DA solutions do offer economic benefits, they don't necessarily inherit the full security properties of Ethereum**. Ultimately, no DA solution except for EIP-4844 or Danksharding itself can inherit the full extent of Ethereum security.

Nevertheless, all of this places alt-DA layers in a unique position. As the modular blockchain narrative gains traction, and the benefits it unlocks becomes more tangible, **alt-DA layers are set to become increasingly popular**. On one front, they offer a crucial stopgap for **L2s requiring immediate scalable DA**. On the flip side, they emerge as compelling options for **L2s built on modular RaaS frameworks** or **specific app-chains**, **targeting cost-sensitive use cases** that may not require the full DA assurances of Ethereum.

Celestia

The alt-DA landscape has been significantly shaped by the emergence of Celestia, particularly after the market's enthusiastic response to its launch in November 2023. The project's launch was marked by an airdrop that initially valued it at US$2B; since then its fully diluted market cap ("FDV") has increased to over US$18B[13]. **Celestia is the first public network that is designed to be optimized for DA, offering a dedicated space for L2s to temporarily post batched transaction data**. The Celestia DA layer consists of a **PoS blockchain**, and is built using the **Cosmos SDK**.

In essence, **Celestia assumes the responsibilities of DA and consensus**, shifting the load of transaction execution and settlement onto other networks[14]. It does not possess the capability of executing transactions through native smart contracts, nor does it support cross-rollup bridging or dispute resolution mechanisms. Its main purpose is to **store and encode data in a trust-minimized manner**, **establish consensus on the order of data**, and **enable users to retrieve the data**. Given this framework, Celestia acts more as a **decentralized data platform with distributed consensus** than a fully-fledged blockchain like Ethereum. This specialization enables L2s on Celestia to avoid the high data posting fees and congestion typically seen on Ethereum.

Celestia's approach to scalability centers on the **decoupling of execution from consensus** and the **introduction of key technologies** such as Data Availability Sampling ("DAS") and Namespace Merkle Trees ("NMTs")[15]. **DAS is a mechanism for light nodes to verify DA without having to download all data for a block**. It works by having light nodes conduct multiple rounds of random sampling for small portions of data within a block, rather than the entirety of the block itself. Meanwhile, **NMTs enable applications to process only the data relevant to them, thereby significantly reducing data processing requirements**. Presently, **DAS grants Celestia a notable edge in scaling DA for blockchains**, especially in contrast to Ethereum, which is still developing its comparable solution. Celestia also surpasses Ethereum by offering a **more expansive dedicated block space**. In their initial launch, blocks are between **2MB and 8MB in size**, and will also be upgradeable based on on-chain governance.

On the other hand, opting for Celestia over Ethereum for DA does involve certain security tradeoffs. Instead of relying on Ethereum's consensus mechanism, **L2s built atop Celestia must trust its consensus and economic guarantees**. Hence, the natural risk is the possibility for Celestia validators to not disclose transaction data yet assert its availability to the Ethereum bridge. That being said, **due to Celestia's PoS consensus, data withholding on the network is slashable**, making this risk probabilistically low. Additionally, for developers using Optimism's OP Stack, **Celestia introduced Ethereum fallbacks - a backup solution for DA**. This allows L2s to revert to Ethereum's mainnet for posting transaction batches should Celestia face temporary disruptions, thereby safeguarding against the risk of inaccessible end-user funds.

From a market viewpoint, **Celestia's competitive advantage lies in its ability to be a more performant DA layer**, characterized by **lower costs** and **enhanced speeds**, over existing blockchains. Its future success is predicated on widespread adoption by applications and protocols that depend on its DA layer. This is particularly true for **execution and settlement layers**, as they serve as **key drivers for attracting end-users and capital**. Celestia's impact in this area is already evident, welcoming notable L2s such as Manta Pacific[16], which also emerges as the network's largest user. Moreover, app-specific chains like Aevo and Lyra have switched to Celestia's DA layer, a move dictated by their **high throughput needs in the derivatives sector**. To date, Celestia has processed **over 12.4M transactions, with a cumulative blob size of 4.28GB and 972.8K accounts**, as per the data from Celestia's block explorer, Celenium[17].

Figure 8: Manta Pacific stands as the largest consumer of Celestia's data space to date

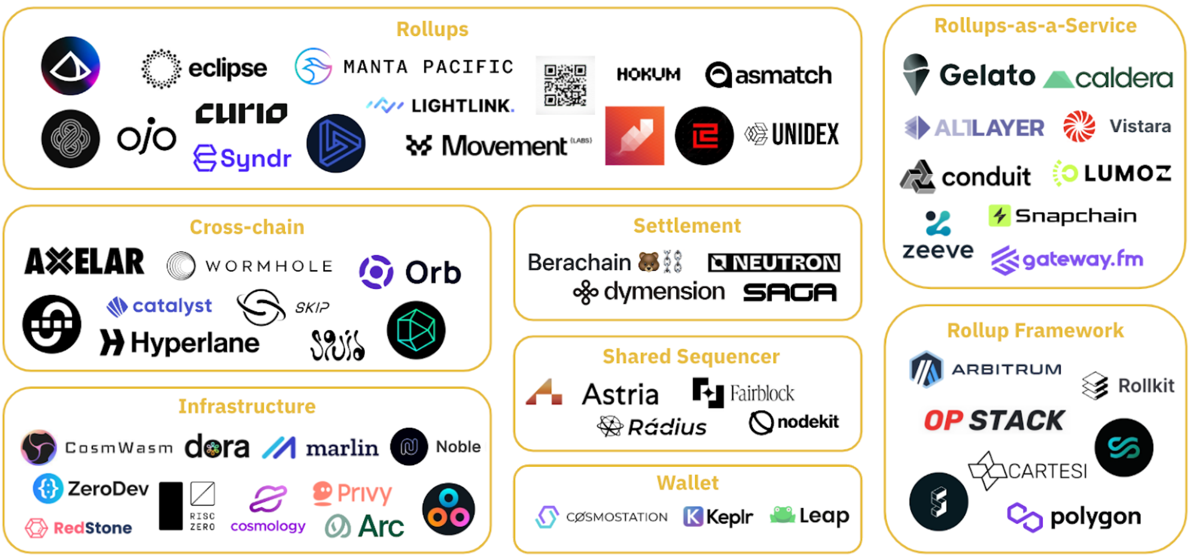
Logo	Name	Size (MB)	Blobs
	Manta Pacific	1,150.0	13,713
	Aevo	335.7	3,308
	Orderly	333.3	6,768
	Lyra	123.4	3,540
	Public Goods Network	85.7	1,542
	Hypr	72.5	1,263
	Ancient8	64.0	4,787

Source: celenium.io, Binance Research, as of February 27, 2024

These figures have been driven by Celestia's ability to attract a growing list of projects seeking to optimize DA. Celestia is **set to host a series of L2s and L2 providers,** including Eclipse, Dymension, AltLayer, Saga, among others. Although the alt-DA space is still young, **Celestia has capitalized on its early entry into the market** and **now boasts a large and diverse ecosystem**, which is poised to significantly contribute to the network's expansion. Indeed, several L2s already operating on the Celestia mainnet have come via RaaS providers like Conduit[18]. Hence, to further stimulate ecosystem growth, Celestia has been **actively pursuing integrations**, such as with Polygon CDK[19], to make its DA layer more

accessible to developers in the industry. Moreover, the growing ecosystem has also positively impacted Celestia's staking network. Projects such as Manta Pacific, Altlayer, Dymension, and Saga all announced airdrops for $TIA stakers, which has led to a notable increase in the number of unique Celestia delegates since the beginning of the year.

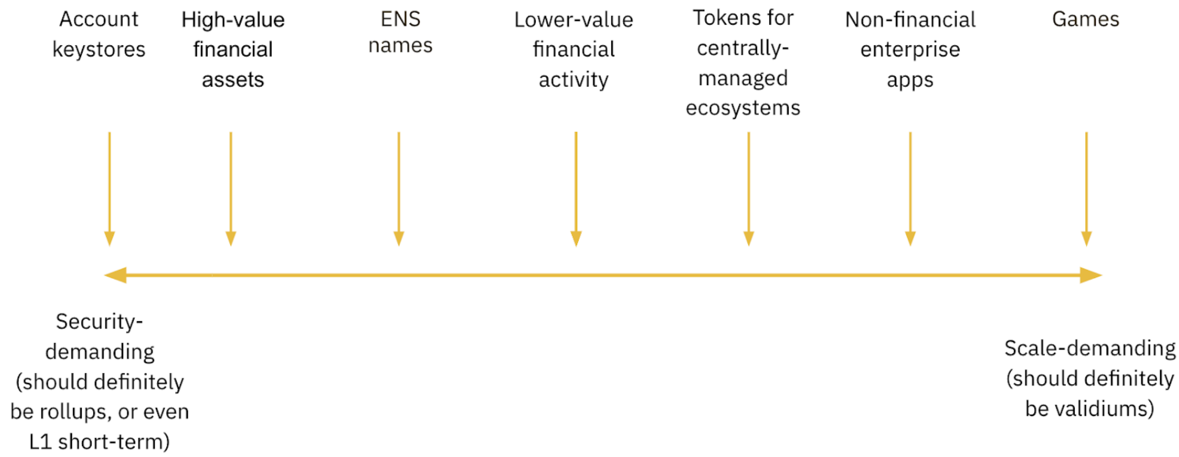
Figure 9: Celestia has capitalized on its early market presence, now boasting a large and diverse ecosystem.



Note: This figure is not an exhaustive representation of the Celestia ecosystem
Source: Celestia, Binance Research

At the application layer, Celestia serves as a compelling choice for projects with scalability at their core, including in gaming, social media or artificial intelligence sectors. Emerging dApps, **especially those without strong ties to the Ethereum Foundation and where cost reduction might be a priority**, are likely to be strong adopters of alt-DA layers like Celestia. Though the decision between leveraging Ethereum for its security advantages and opting for Celestia will vary across different markets and application requirements. The key consideration for dApps revolves around **the trade-off between scalability and security**. For financial dApps, the cost of forgoing security could be significantly higher, necessitating a different approach compared to gaming and social media dApps, where user engagement is frequent but involves lower-value transactions.

Figure 10: The tradeoff spectrum varies across different markets and application requirements



Source: vitalik.eth.limo, Binance Research

Of course, all of this is contingent upon the assumption that notable cost disparities persist between alt-DA layers and Ethereum. Hence, **Ethereum's progression towards full Danksharding will be important to monitor**, as **the extent of these cost differences will dictate the scale of the tradeoff** and, ultimately, where DA activity predominantly gathers. Moreover, **the impact of network effects cannot be overstated** and **relies on the maturity of L2s built atop alt-DA layers**. **Improving the interoperability and composability** for dApps across these modular networks will also affect the overall dynamics. Projects like Caldera, Hyperlane and Polymer are developing tools that enable L2s to operate smoothly across multiple DA layers. This ensures that users and their liquidity can easily flow between different layers, thereby keeping the user experience free from disruptions.

Ultimately, the **activation of near-term upgrades like EIP-4844**, combined with the **increasing flexibility of L2s to migrate from using Ethereum for DA**, presents an intriguing space to follow. Celestia is so far the leading contender in the market but **EigenDA and Avail are two other notable mentions** expected to make their debut in 2024. Additionally, **NEAR has integrated DA capabilities** into its chain, while also bringing unique properties from its extensive sharding research over recent years.

4 Embracing Modularity

The DA space is changing, introducing new opportunities for the broader modular ecosystem. But what does this mean in practice? Let's take a closer look at this through the lens of some emerging projects in the modular space.

Traditionally, the design space for L2s has been dominated by general-purpose execution layers, like Arbitrum and OP Mainnet[20]. These solutions often sought to **mirror Ethereum's execution environment and virtual machine**, while also **relying on Ethereum's DA -** an approach that, as previously mentioned, may not be the most optimal in the current market. The overarching goal for many of these L2s was **simplifying the process for dApp developers to migrate from Ethereum to their platforms**. Yet, with the **introduction of the first alt-DA layers** and the **growth of the modular ecosystem**, we are starting to see **new and innovative ways to scale blockchains**.

A growing number of modular L2s are being developed, each **customizing the modular stack's components** to meet their specific requirements. Whether it's **utilizing alt-DA layers like Celestia** or **employing more performant execution engines**, or perhaps a synergy of both, their goal remains clear: **to capitalize on the latest technology available at each layer**. Certain projects are also focused on creating execution layers designed to interlink L2s, acting as a separate settlement layer for bridging assets across L2s. As the L1/L2 sector further embraces modularity, projects aimed at **enhancing interoperability** and **developing tools for easy deployment across modular stacks** grow increasingly important.

4.1 Eclipse

Eclipse is **Ethereum's first Solana Virtual Machine ("SVM") L2**. Their aim can be simply thought of as combining **'the speed and low cost of Solana, with the network effects of Ethereum'**. Eclipse serves as a prime example of **how L2s can adapt and utilize different parts of the modular stack to maximize scalability**. Specifically, it takes advantage of the **parallel-processing design of the SVM** to run a L2 with **settlement on Ethereum** and **DA on Celestia**. In this setup, $ETH will be used as the gas token, with transaction fees converted into $TIA to cover DA costs.

While Optimism's Superchain, zkSync's Hyperchains, Arbitrum's Orbit chains all have **multi-chain visions with shared infrastructure**, they **don't necessarily address ecosystem-wide interoperability** (e.g. Superchain to a Hyperchain). Navigating multiple chains for users can pose complexities, alongside the considerable expenses tied to relying on infrastructure providers for maintaining these chains. Eclipse, on the other hand, is able to provide **one highly optimized shared state machine** with the scale to support a large number of use cases. The following details how Eclipse optimizes for the different parts of the modular stack[21]:

- **Execution:** Eclipse **runs the highly performant SVM as its execution environment**. In contrast to other single-threaded virtual machines, the SVM, and its Sealevel runtime, is designed to enable **greater parallelism across transactions**. This means that **transactions that do not affect overlapping states can be executed in parallel rather than sequentially**, thereby enhancing overall performance. While we won't delve into exhaustive technical details regarding parallel execution here, we recommend referring to our comprehensive report, Technical Deep Dive: Parallel Execution.

- **Settlement:** Similar to other major L2s today, **Eclipse settles on Ethereum**. This involves **integrating Eclipse's validating bridge** directly into Ethereum, thereby providing Eclipse users with some of the security features inherent to the Ethereum network. The bridge ensures the validation of all Eclipse transactions, preventing the submission of invalid states, and upholding eventual liveness and censorship resistance in specific failure scenarios.

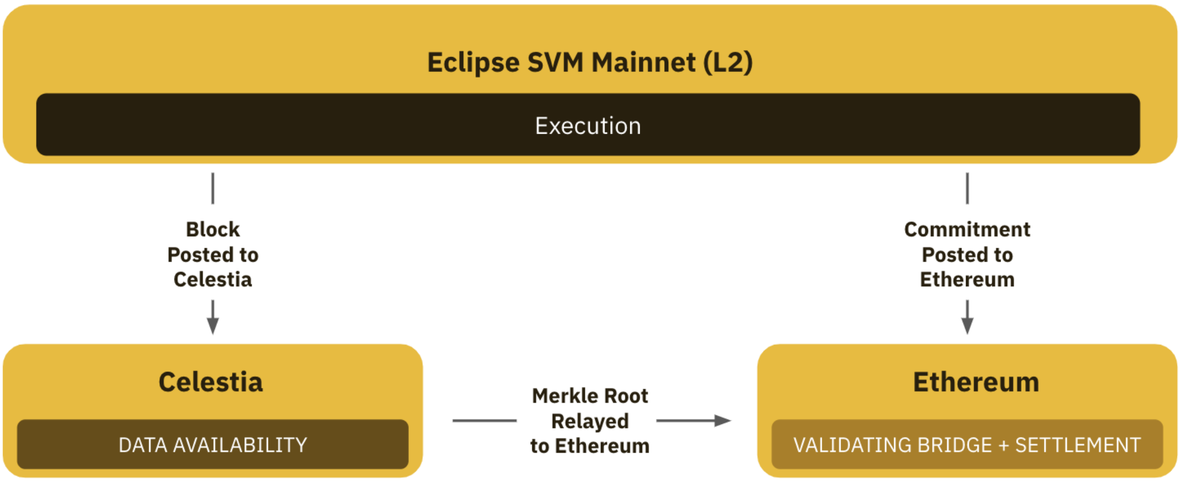
- **Data Availability ("DA"): Data is posted to Celestia for DA**, which offers better scalability compared to Ethereum. Eclipse highlights Celestia's **support for DAS light nodes**, **robust crypto-economic security properties**, and **highly scalable DA throughput**, making it the preferred choice for their L2. Eclipse's **target throughput and fee requirements** also **surpass Ethereum's current bandwidth capacity**, even post-EIP-4844 implementation. Nonetheless, the team continues to monitor Ethereum's DA advancements post-EIP-4844. If Ethereum can offer greater scalability suitable for Eclipse's needs, Eclipse may consider migrating to Ethereum for DA.

- **Proving:** Eclipse utilizes **RISC Zero to generate ZK proofs** without intermediate state serialization.

Eclipse's **key distinguishing factor is undoubtedly its use of the SVM**[22], especially in a sector where every other L2 for the most part are general-purpose EVMs replicating similar design frameworks. Leveraging the SVM, and in time the Firedancer client, allows Eclipse to **maintain high TPS while mitigating congestion during peak demand periods**. Notably, **parallel transaction processing**[23] and **localized fee markets**[24] (facilitated by Solana's uniquely parallelized runtime) play a key role here. In the independent fee market model, **users pay more to interact with frequently used contracts and less for standard transfers**.

Another benefit is lower fees, stemming not only from **enhanced compute throughput** but also **increased data throughput facilitated** by Celestia's optimized DA. However, unlike traditional rollups that rely on trust minimization and security assurances from Ethereum, Eclipse's design introduces an additional trust assumption. This involves the **honest operation of Celestia validators** and the **bridge relaying DA attestations to Ethereum** to guarantee liveness and security of the L2. What's more, the full irreversibility of transactions will hinge on the finality of both Celestia and Ethereum sequentially.

Figure 11: Eclipse aims to combine the best pieces of the modular stack by running the SVM as its execution environment, posting data to Celestia, and settling transactions on Ethereum



Source: Eclipse Documentations, Binance Research

Interestingly, developers will also have the **capability to deploy Ethereum-like dApps on Eclipse** leveraging tools like **Solang**, along with an instance of **Neon EVM**. This effectively **brings EVM compatibility to Eclipse** with **greater throughput than single-threaded EVMs**[25]. While this entails support for both the SVM and EVM, it's worth noting that Neon EVM applications and SVM-based Eclipse applications will not be interoperable. DApps deployed using Neon EVM will resemble app-specific rollups deployed to Eclipse, with different security guarantees.

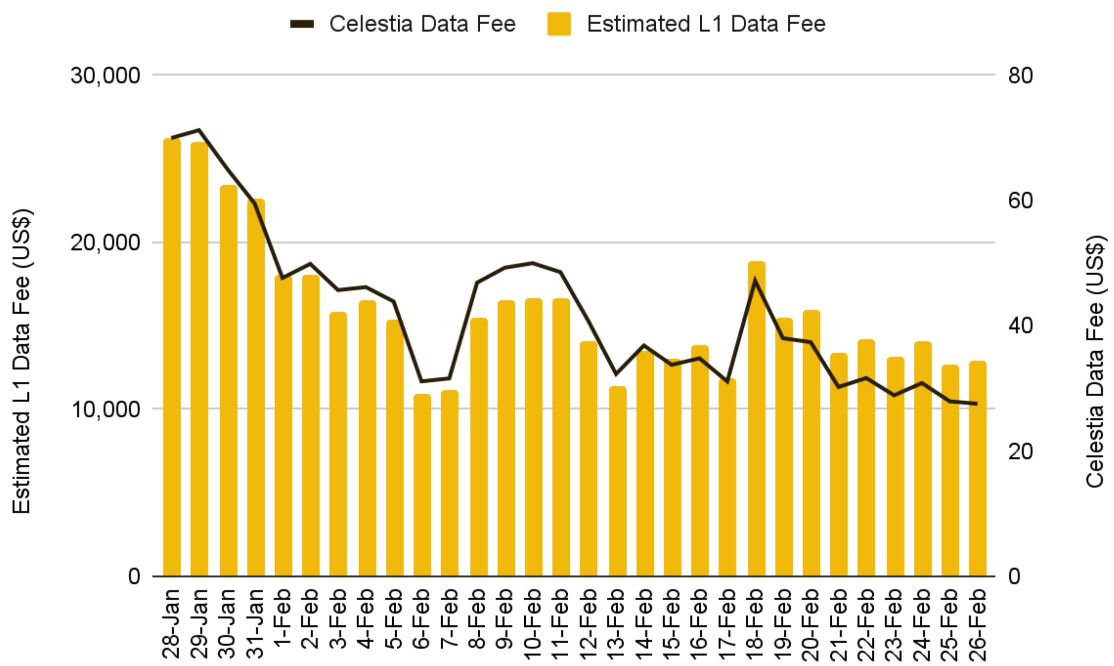
Ultimately, the advent of an SVM L2 opens the door for **new types of dApps to be built on Ethereum** while simultaneously **cultivating a new developer ecosystem**. It creates potential **synergies with the Solana ecosystem**, enabling developers to seamlessly **deploy Solana-like dApps on Eclipse** if desired. Hence, Eclipse becomes particularly **appealing for Ethereum ecosystem developers seeking Solana-like advantages**. On the other side, by serving as an execution point for Solana-based dApps on Ethereum, Eclipse grants Solana developers access to liquidity derived from the L1 with the largest network effects. A key outcome for Solana is the potential **increase in developer incentives and familiarity with deploying dApps on the SVM**. This, in turn, contributes to the growth of the developer and tooling ecosystem surrounding the execution environment. Eclipse is certainly interesting in terms of the dynamics between two major L1s, especially as the Solana and Ethereum ecosystems have typically been isolated.

4.2 Manta Pacific

Manta Pacific is an **EVM-native modular L2** offering an out-of-the-box toolkit catered towards ZK-based applications. Since its mainnet debut in September 2023, Manta Pacific has grown to become the **third largest L2 by TVL, boasting nearly US$1.9B**[26]. This growth is particularly noteworthy considering Manta Pacific's later entry into the market compared to other L2s. A key driver behind Manta Pacific's success is its strategic **adoption of alt-DA layers**. Notably, it became the first L2 to adopt Celestia mainnet for DA.

By utilizing Celestia's DA capabilities, Manta Pacific aims to significantly reduce transaction costs for its users, offering fees that are substantially lower than those of competing L2s. This cost advantage has been a key selling point, as demonstrated by the significant cost savings depicted in figure 12 - offering a clear visualization of the reduction in expenses achieved by choosing Celestia over Ethereum. In particular, **Manta Pacific has saved its users over US$1.9M in gas fees thus far**.

Figure 12: Following Manta Pacific's integration with Celestia, data fees have seen a substantial reduction, decreasing by approximately 99.8%

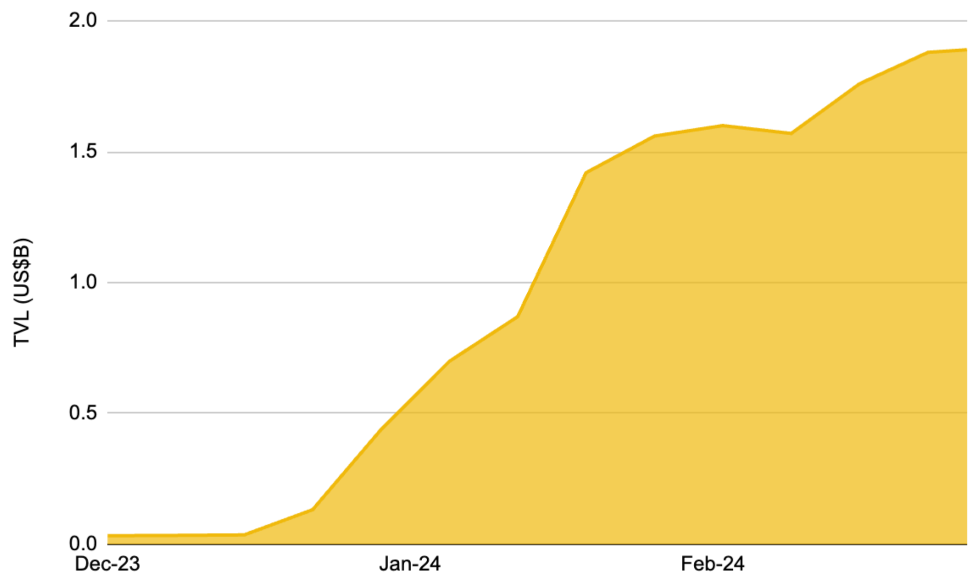


Source: manta.socialscan.io, Binance Research, as of February 26, 2024

The L2 differentiates itself further by enabling **native composability for ZK applications** through its **use of universal circuits**[27]. These circuits constitute a **versatile library of ZK circuits** designed for **general applicability and effortless dApp development**. Essentially serving as **ZK-as-a-Service**, universal circuits empower Solidity developers to **seamlessly integrate ZK functionalities** into their applications with **minimal coding efforts**. With ZK-based technology forming a core part of the Manta Pacific vision, the next significant milestone on their roadmap involves **transitioning to a zkEVM built on the Polygon Chain Development Kit ("CDK")**[28].

Moreover, Manta Pacific's **ability to handle high-throughput DA** has improved its capacity to direct sequencer revenues toward **public goods** and **ecosystem growth initiatives**. This focus is part of a **broader strategy to grow network liquidity** and has been a contributing factor to its recent TVL performance. **To help bootstrap its growth, Manta introduced** [New Paradigm](#) in December 2023; a strategy that **combined crypto-economic incentives with effective marketing techniques**. With New Paradigm, users could earn native yield on their collateral while maintaining liquidity through liquid tokens, enabling **participation in over 150 network projects**. This initiative also **distributed 20M $MANTA as rewards** and **an additional 30M $MANTA for airdrops**, including allocations to $TIA stakers[29].

Figure 13: Manta Pacific has emerged as one of the fast-growing L2s in terms of TVL, having expanded from a mere US$30M to US$1.9B in just three months



Source: l2beat.com, Binance Research, as of February 26, 2024

Considering the difficulties other L2s have previously faced in bootstrapping liquidity, Manta Pacific's growth figures are certainly impressive. This could become even more pronounced should the L2 manage to sustain positive feedback loops with all the liquidity flowing into their network. **While incentives have influenced growth in the short-term, the real test will be in cultivating a loyal user base for the long haul**. Attracting users and capital with airdrops and other token-based incentives is one aspect, but retaining them is an entirely different challenge.

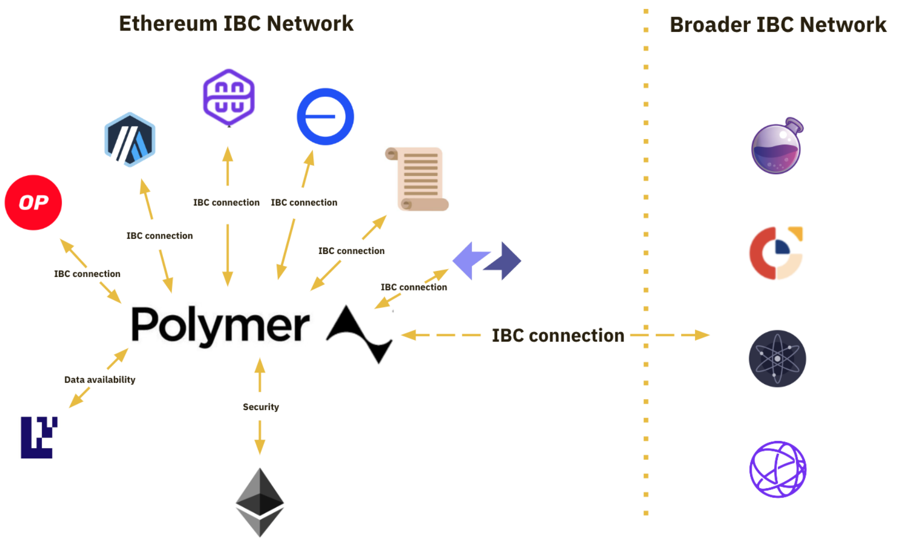
The ability of emerging dApps on Manta to maintain a lasting product-market fit after the initial incentives subside is an important factor here. Equally important is striking a balance **between offering compelling incentives and advancing the core technology**. In the long-term, advancements in network **scalability**, **interoperability**, **decentralization**, **security** and **user experience** may prove deterministic[30]. Looking ahead, it will be interesting to monitor Manta's progress on the ZK front and its competitiveness as a zkEVM.

4.3 Polymer

While this report won't delve into the topic extensively, it's important to mention considering its implications. The growth of the modular space has sparked discussions regarding the **fragmentation of L2s into siloed ecosystems**[31], particularly with **L2s being designed for specific parts of the modular stack**. Modular systems, unlike shared state machines, aren't able to offer the same **composability benefits** and instead create **isolated execution environments**, which in turn **complicates the user and developer journey**. The challenge for building L2s on alt-DA layers is the inevitable **fragmentation of liquidity**; how will these modular chains and layers connecting to Ethereum preserve interoperability? Successfully navigating these challenges will require **strong underlying infrastructure**. One example is the development of a **standardized, reliable interoperability layer** capable of achieving composability across various modular L2s.

Polymer utilizes the **Inter-Blockchain Communication ("IBC") Protocol** to serve as **Ethereum's Interoperability Hub** for its ecosystem of L2s[32]. Its design involves incorporating the **settlement functionality of the OP Stack** with the **developer experience and native interoperability of the Cosmos SDK**, and **DA from EigenDA**. Polymer also acts as a "port city", connecting Ethereum L2s to the growing IBC network, thereby integrating the Ethereum ecosystem with the wider network of IBC-connected chains.

Figure 14: Polymer not only serves as an interoperability hub for Ethereum L2s but also seamlessly connects them to the broader IBC network



Source: Polymer Documentations, Binance Research

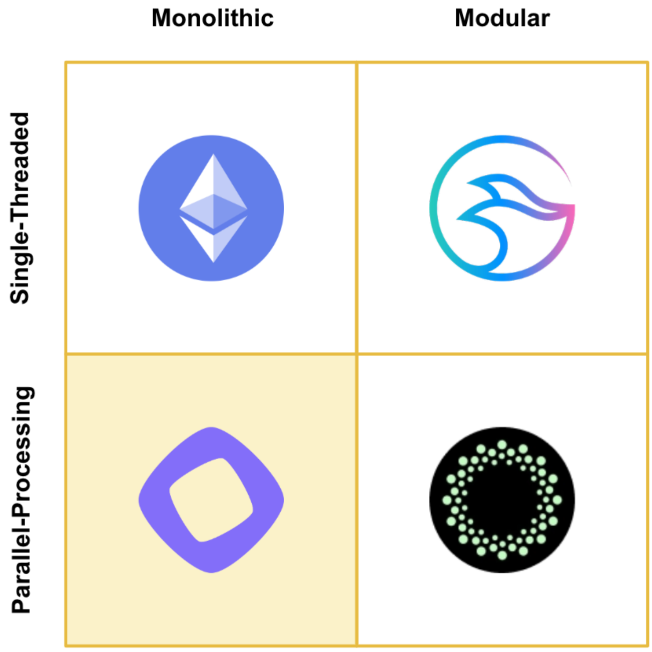
5 Still Monolithic

It's not all about modularity though. The recent **resurgence of alt-L1s** would suggest otherwise. While monolithic chains have, at times, encountered difficulties when in direct competition with Ethereum, they can bring their own distinct advantages. Their success often depends on their **ability to address prevalent gaps or limitations** in incumbent networks like Ethereum. This involves **identifying a compelling value proposition** and **targeting specific markets effectively**. With that in consideration, the focus on **execution-optimized virtual machines** ("VMs") by monolithic L1s is particularly interesting. **Parallelizing the EVM**, for instance, demonstrates how monolithic L1s can enhance blockchain scalability.

5.1 Monad

For a period, the need for various technical optimizations to enable parallel execution, coupled with limitations in the EVM, had prompted the emergence of non-EVM execution environments. However, this is changing with Monad. Monad, an upcoming EVM-based L1, aims to **significantly enhance throughput by integrating parallelization** into the EVM[33]. In contrast to the SVM L2 Eclipse discussed earlier, the major distinction is that Monad operates as a monolithic L1, **directly re-engineering the EVM from a single-threaded to a multi-threaded capability**.

Figure 15: Monad is a monolithic blockchain that enables parallel execution for EVM transactions



Source: Binance Research

Monad offers **full bytecode compatibility with the EVM**, allowing EVM-compatible applications to seamlessly migrate to Monad without incurring additional costs. The L1 also ensures **full Ethereum RPC compatibility**, enabling the utilization of infrastructure such as Etherscan.

Additionally, Monad implements **meaningful changes across all levels of blockchain computation**, contrasting with the typical focus of other EVM modular blockchains on innovating specific functions. As a monolithic L1, there are several factors that sets Monad apart from other L2s and modular projects aiming to scale Ethereum. The below reviews this from a **performance** and **decentralization** perspective[(34)]:

- **Performance:** Monad's mission statement is to be the **most performant** and **least costly** system possible. By introducing several **pipelining techniques** (i.e. performing multiple actions in parallel), Monad seeks to break the current barriers on scaling and provide a **throughput that reaches 10K TPS**. In particular, Monad is working on **optimizing for four key areas**, with each improvement making Monad nodes extremely efficient at execution relative to other types of network nodes.

    - **Parallel Execution**: Unlike other EVM blockchains that execute transactions one by one in a linear manner, **Monad executes transactions in parallel, allowing multiple transactions to be processed simultaneously**. For instance, whether it's minting an NFT or depositing collateral into DeFi, they are all **orthogonal transactions** that could be parallelized.

      Specifically, Monad uses **optimistic execution**, which means that the chain will start executing transactions before earlier transactions in the block have completed. The optimistic model operates on the **initial assumption of transaction independence**. It then has a mechanism to subsequently verify this assumption, making necessary adjustments to correct any dependencies identified post-execution.

    - **Deferred Execution**: In most blockchains, execution and consensus are generally interdependent, requiring one to be completed before the other. Monad, however, **decouples execution from consensus**. This allows for significant throughput increases as nodes can reach consensus on transaction order without having to execute said transactions.

    - **MonadBFT**: With 1 second slot times and single slot finality, MonadBFT is a **high-performance consensus mechanism** for achieving agreement about transaction ordering.

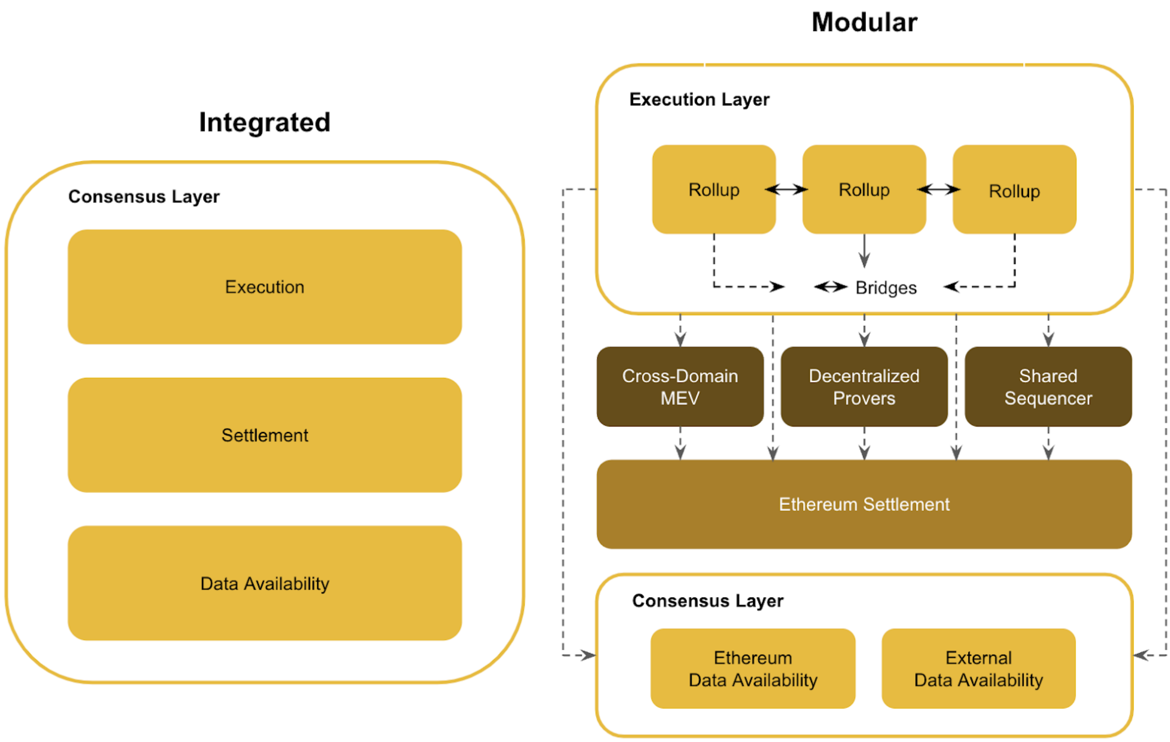
    - **MonadDb**: A parallelized execution engine doesn't add much to the blockchain performance if there isn't also a state database that allows for parallelized reading and writing to the disk. MonadDb is a **custom database for storing blockchain state** that assists to **unlock parallel-processing** and for **execution to be substantially accelerated**.

Ultimately, it's worth noting the value of Monad's integrated approach here. All of the above customizations are as a result of **Monad being a standalone L1**. While the modular approach can offer flexibility, the growing number of actors within a modular stack can increase associated costs, including **fragmentation** and **complexities in UX**[35]. Building as an L2 would have also imposed limitations to Monad's scalability. This is because L2s are a **function of some other infrastructure layer**. For example, the order of transactions on the DA layer officially defines the true state on the network. This **dependence on the DA layer** may act as a limiting constraint in the following ways:

- **L2s inherit capacity limitations of the DA layer**: Utilizing DA layers would effectively mean incurring the **costs of pushing calldata** and inheriting its **data limits**. Even with the emergence of EIP-4844 and alt-DA, Monad strives for a much **larger scale factor in throughput** and **lower fees**.

- **L2s inherit the time-to-finality of the DA layer:** Inheriting the DA layer's finality may not always be the most optimal. If we take Ethereum as an example, Gasper, the mechanism that upgrades certain blocks to be finalized, takes between 64 and 95 slots to finalize blocks. As each slot is 12 seconds, this corresponds to approximately 15 minute finality. Meanwhile, Monad uses a **hotstuff-based BFT algorithm**, which has single block finality.

Figure 16: As the number of participants in the modular stack grows, the burden of associated costs within a multi-chain economy may also increase



Source: Syncracy, Binance Research

- **Decentralization:** Monad avoids certain constraints faced by L2s concerning decentralization. Several L2s currently lack a mechanism for decentralized block production, which is essential to **censorship-resistance** and true **decentralization**. They utilize a **centralized sequencer** that has absolute authority to determine the official transaction order and to censor transactions.

  While **decentralization of the sequencer** remains a pressing topic, and various L2s have stated intentions to decentralize it, progress is still required before it becomes a reality in their respective roadmaps. More generally, most L2s currently have a variety of training wheels, as outlined in L2Beat's comprehensive list of outstanding risk factors. This ranges from implementing actual fraud proofs to having a backup option in the event of sequencer failure. For additional reading on decentralized sequencers, check out our previous report, Ethereum's Rollups are Centralized. A Look Into Decentralized Sequencers.

A noteworthy consideration is the potential of L2 VMs shifting away from the EVM and towards more **execution-optimized VMs**. As Monad positions itself as a VM-optimized L1, it may become a target for EVM alternatives on L2s. This aligns with the **inclination among L2s to better differentiate themselves in a fast growing modular ecosystem** (i.e. Eclipse adopting the SVM). Hence, there may be increased interest in **adopting a new VM specification that prioritizes execution optimization** over merely replicating the L1 EVM. Ultimately, the key aspect to monitor is how established players like Arbitrum, Optimism, and other EVM-based chains respond to these developments and advance their own VM optimizations. With Monad poised to launch on mainnet later this year, it will certainly be an interesting space to keep close tabs on.

6 Closing Thoughts

New approaches to scaling blockchains are emerging, signaling a shift in how we think about improving network capacity and efficiency. Central to this is the modular approach, which in theory states, the more a blockchain's functions are modularized, the greater the efficiency and scalability developers can achieve for specific core functions. As a result, we're seeing advancements across the modular ecosystem, from execution and DA to the infrastructure and dApps built on it.

The soon-to-arrive Dencun upgrade for Ethereum marks a crucial step forward, expected to improve Ethereum's DA capabilities and favorably impact the fee structure for L2s. This comes at a time when Ethereum's DA layer finds itself in competition with the alt-DA sector, which effectively gained motion after Celestia's launch. The success of alt-DA layers hinges on the widespread adoption of applications and protocols developed on top of them. That said, as the DA space braces for increased competition, the presence of multiple competing solutions is only likely to spur innovation and ultimately benefit the ecosystem.

The developments in the DA space are paving the way for new modular L2s to capitalize on the scalability benefits on offer - whether through leveraging alt-DA layers like Celestia, integrating more efficient execution engines, or a combination thereof. Though, as some of these L2s are still pending mainnet launch, their impact on developer and end-user experience remains to be seen. That is why the conversation does not end with modular L2s. Scalability improvements are also underway with monolithic L1s, which offer their own set of advantages. The emphasis on execution-optimized VMs, such as bringing parallelization to the EVM, is of particular note. Collectively, as the different approaches to blockchain scalability come to light, this space becomes one to watch closely.

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Macro Researcher

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