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Khoshaba Oleksandr, Candidate of Technical Sciences, Associate Professor
https://orcid.org/0000-0001-5375-6280
Vinnytsia National Technical University, Vinnytsia, Ukraine

MULTIDIMENSIONAL RESOURCE EVALUATION IN BLOCKCHAIN

Khoshaba O. Multi-Dimensional Resource Evaluation in Blockchain. The traditional gas-based metering model used in Ethereum and similar blockchain platforms simplifies execution cost estimation but fails to capture the comprehensive complexity of smart contract workloads. This paper introduces a novel multidimensional resource metering framework, designed to separately quantify computational load (based on floating-point operations- FLOPs), memory access, and execution latency. The study effectively demonstrates the framework's capability across various tasks, including compute-intensive processes, in-memory data handling, and high-latency tasks through detailed conceptual modelling of matrix multiplication operations. The proposed model advocates for fairer, hardware-based metering strategies, fostering more precise resource optimisation, and aligns well with contemporary trends such as multidimensional gas pricing in Layer-2 scaling solutions. Additionally, this framework offers critical insights into constructing theoretical and practical models for blockchain resource metering, significantly enhancing accuracy in cost attribution. Experimental validation using representative computational workloads, such as matrix multiplications, highlights distinct performance metrics- FLOPs, memory bandwidth, and latency- and contrasts these findings with traditional single-dimensional gas metrics. Ultimately, this research provides a robust foundation for a more equitable and efficient computational resource evaluation in blockchain systems, paving the way for better system scalability, optimisation, and sustainable economic models for future blockchain applications.
Keywords: blockchain performance, resource metering, Ethereum, FLOPs, smart contracts, Layer-2, computational profiling

Хошаба О. М. Багатовимірна оцінка ресурсів у блокчейні. Традиційна модель вимірювання на основі газу, яка використовується в Ethereum та подібних блокчейн-платформах, спрощує оцінку витрат на виконання, але не враховує всю складність робочих навантажень смарт-контрактів. Ця стаття представляє нову багатовимірну структуру вимірювання ресурсів, розроблену для окремої кількісної оцінки обчислювального навантаження (на основі операцій із плаваючою комою - FLOP), доступу до пам'яті та затримки виконання. Дослідження ефективно демонструє можливості фреймворку в різних завданнях, включаючи інтенсивні обчислювальні процеси, обробку даних у пам'яті та завдання з високою затримкою за допомогою детального концептуального моделювання операцій множення матриць. Запропонована модель підтримує більш справедливі стратегії вимірювання на основі апаратного забезпечення, сприяє точнішій оптимізації ресурсів і добре узгоджується з сучасними тенденціями, такими як багатовимірне ціноутворення на газ у рішеннях масштабування рівня 2. Крім того, ця структура пропонує важливе розуміння побудови теоретичних і практичних моделей для вимірювання ресурсів блокчейну, значно підвищуючи точність віднесення витрат. Експериментальна перевірка з використанням репрезентативних обчислювальних навантажень, таких як множення матриць, висвітлює різні показники продуктивності - FLOP, пропускну здатність пам'яті та затримку - і порівнює ці результати з традиційними одновимірними газовими метриками. Зрештою, це дослідження забезпечує надійну основу для більш справедливої та ефективної оцінки обчислювальних ресурсів у системах блокчейн, прокладаючи шлях до кращої масштабованості системи, оптимізації та стійких економічних моделей для майбутніх додатків блокчейну.
Keywords: продуктивність блокчейну, вимірювання ресурсів, Ethereum, FLOPs, смарт-контракти, Layer-2, обчислювальне профілювання

Introduction. The increasing complexity and diversity of decentralised applications have highlighted critical limitations in traditional blockchain accounting models, particularly in measuring and pricing computational resources. Initially designed for simple monetary transactions and basic data storage, blockchain platforms like Ethereum implemented a one-dimensional *'gas'* mechanism that charges users based on storage operations and rudimentary logic instructions [1]. While sufficient for earlier applications, this model fails to represent the actual computational costs incurred by modern smart contracts, which frequently involve resource-intensive processes such as matrix computations, cryptographic proof generation, and on-chain machine learning [2, 3]. As a result, a fundamental misalignment has emerged between actual resource consumption and the attribution of economic costs, creating bottlenecks, inefficiencies, and disincentives for developers to build computationally sophisticated contracts.

Problem Statement. The core problem addressed in this study is the inadequacy of current gas-based resource accounting models in representing multi-dimensional computational demands. Despite the rise of computationally intensive tasks, such as high-volume data processing and parallelisable arithmetic operations, no widely accepted method remains for quantifying computing workload beyond simple gas metrics. Traditional models conflate minimal and complex operations under similar fee structures, leading to pricing asymmetry and potential security risks due to under-costed execution. Furthermore, existing blockchain virtual machines cannot monitor advanced metrics, such as floating-point operations per second

(FLOPs), memory bandwidth, and cache efficiency [3]. This absence of granularity hinders fair cost modelling, platform optimisation, and scalability.

Motivation Statement. The motivation for this research stems from the urgent need to evolve blockchain infrastructures into platforms capable of supporting computation-intensive applications with fair and technically justified pricing models. As smart contracts expand their scope into domains requiring high-performance computing characteristics, such as decentralised AI or scientific modelling, traditional gas metering becomes a constraint rather than a safeguard [4]. By proposing and validating an extended framework for resource assessment, this study aims to align economic incentives with physical execution demands. This realignment has the potential to enhance system throughput, foster responsible code design, and ensure the long-term sustainability of blockchain ecosystems.

Relevance of the Work. This work contributes to the critical discourse on the evolution of blockchain cost models by addressing the underexplored intersection between performance engineering and decentralised resource accounting. It builds on prior work identifying the computational gap in gas economics [1] and extends the discussion toward operationalising compute-aware metrics. As such, it serves as a necessary prelude to a focused literature review, which examines related contributions, identifies methodological trends, and highlights empirical findings and technical limitations.

Related Work. Ethereum's execution model charges *gas* for computational steps and storage use, acting as an economic guard against abuse. This gas mechanism ensures that Turing-complete smart contracts are terminated and compensates miners for execution costs [5]. However, several limitations of Ethereum's gas model have been highlighted. Aldweesh et al. [6] propose an opcode benchmarking framework (OpBench) and find that gas consumed by operations is often disproportionate to the CPU time required. Empirical studies further illustrate wide variability in gas usage patterns, identifying code constructs that disproportionately increase gas consumption [1]. Grech et al. [5] demonstrate vulnerabilities arising from gas exhaustion.

Alternative execution engines such as WebAssembly (WASM)-based virtual machines have been explored. Zheng et al. [7] compared WASM and Ethereum Virtual Machines (EVMs), showing significant overheads in current WASM implementations. Li et al. [3] developed SmartVM, optimised for deep learning inference, significantly outperforming vanilla EVM. Chen et al. [8] proposed speculative transaction execution (Forerunner), which leverages parallelism to achieve higher throughput. Hardware accelerators, such as the Blockchain Processing Unit (BPU) and Smart Contract Unit (SCU), further push performance boundaries [9, 10].

Layer-2 scaling solutions, including optimistic and zero-knowledge rollups (ZK-rollups), move execution off-chain, significantly increasing throughput. Thibault et al. [11] report fee reductions and improvements in transaction processing speed (TPS) with ZK-rollups. Yet, ZK-rollups depend on computationally heavy proof generation, centralising proof generation in prover farms. Decentralised approaches, such as CrowdProve, distribute tasks to mitigate centralisation [12]. Aldweesh et al. [6] and Habib [13] analyse performance bottlenecks in ZK-proof generation.

HPC-style metrics integration is emerging in blockchain contexts. Partisia blockchain explicitly prices transactions based on CPU cycles, network traffic, and storage IO [14]. However, comprehensive HPC-style frameworks, such as those for FLOPs, cache misses, and memory bandwidth, remain underdeveloped, highlighting significant gaps in assessing computational resources.

Highlighting Previously Unsolved Parts of the Problem. Despite significant advances in blockchain architecture and resource accounting mechanisms, several core technological challenges remain unresolved in computational resource evaluation. Traditional gas models were designed with storage operations and basic arithmetic logic in mind, and therefore fail to reflect the growing heterogeneity and intensity of modern on-chain workloads [1]. As decentralised applications evolve to include machine learning inference, cryptographic proof generation, and large-scale scientific computation, existing one-dimensional cost models do not capture the diversity of computational demands [2, 4]. The lack of correlation between transaction gas fees and actual hardware utilisation remains a critical gap, resulting in inefficient pricing, potential network congestion, and developer disincentivisation.

A primary unsolved issue concerns the absence of a universally accepted set of metrics for quantifying blockchain computation. Although floating-point operations per second (FLOPs) are commonly used in high-performance computing, they fail to account for memory bandwidth, cache access efficiency, and instruction-level parallelism - factors increasingly critical in smart contract execution [3].

No standardised composite metric currently exists to measure computational workload in a decentralised, hardware-agnostic manner that could be implemented across diverse blockchain environments.

Moreover, while classification of computational tasks into scalar, vector, matrix, and tensor operations has been proposed as a conceptual framework for estimating load, no practical implementation exists that translates this classification into dynamic fee computation at runtime [4]. Existing virtual machines, such as the Ethereum Virtual Machine (EVM), are not architecturally optimised to capture such differentiation in workload types. This limits the platform's ability to enforce fair cost attribution for compute-intensive operations, especially when multiple resources - such as CPU cycles, memory bandwidth, and cache usage - are jointly consumed.

Another unresolved area involves implementing extended gas models that decouple storage from compute resource tracking. Although such models have been theoretically proposed [2], no major blockchain has yet operationalised a robust framework for dual-component gas accounting. Challenges include defining consistent metrics for compute gas, enforcing their measurement without compromising decentralisation, and ensuring backwards compatibility with existing smart contract ecosystems.

Using hybrid off-chain/on-chain computation models presents another frontier with persistent technological uncertainties. While zero-knowledge proof systems like zk-SNARKs and zk-STARKs enable succinct verification of external computations, proof generation costs remain high, and trust assumptions regarding off-chain execution are not fully addressed [15]. Furthermore, there is no consensus on securely and transparently integrating these off-chain resource metrics into on-chain fee structures. This raises concerns about systemic fairness and auditability, particularly when different nodes have varying capacities to verify or challenge off-chain computations.

Lastly, blockchain platforms lack mechanisms for profiling and predicting the execution-time characteristics of smart contracts under real network conditions. Without runtime introspection tools that can measure and log multidimensional resource usage (e.g., memory latency, branch divergence, and throughput), it is impossible to calibrate cost models dynamically. This technological gap hinders the optimisation of contracts and impedes the evolution of blockchain platforms towards truly computation-aware infrastructures.

In summary, while the limitations of current gas models are well recognised, the technological pathway towards a scalable, fair, and performance-aware computational accounting system remains largely undefined. Addressing these gaps requires further research into metric design, virtual machine instrumentation, runtime profiling, and secure hybrid computation protocols, which constitute an unsolved component of the broader problem.

The Purpose of the Article. The scientific novelty of this research lies in its departure from conventional one-dimensional gas metering towards a multi-faceted evaluation of blockchain computational workloads. Traditional gas-based cost models in platforms like Ethereum prioritise storage and simple operation costs while largely overlooking the computing resources consumed by complex on-chain processes [1]. This limitation has become increasingly evident as emerging decentralised applications, such as on-chain machine learning, cryptographic proof generation, and decentralised scientific computing, demand intensive computations that current gas metrics fail to fairly or accurately account for [2, 3]. To address this discrepancy, the article aims to develop an unconventional methodology for assessing computing resource utilisation in blockchain networks that more precisely reflects computational effort.

The primary objective of this research is to develop a multidimensional resource accounting framework that integrates performance indicators, including floating-point operations per second (FLOPs), memory bandwidth, cache efficiency, and execution time, into the evaluation of transaction costs. In pursuit of this aim, the study first critically analyses the inadequacies of the existing gas model by examining how high-complexity operations (e.g. matrix multiplications and tensor contractions) can exhaust gas limits without providing a meaningful or proportional representation of resource usage [1, 2]. A structured classification of computational tasks - spanning scalar, vector, matrix, and tensor operations - is then proposed to delineate their distinct resource footprints, reinforcing the argument that a singular storage-focused metric is fundamentally inadequate.

Building on this taxonomy, the article introduces an extended gas model that conceptually separates storage-related costs from compute-related costs, enabling a more granular and equitable resource allocation. This bifurcated model draws on established performance metrics from high-performance computing, thus representing an interdisciplinary synthesis between blockchain systems and computational

benchmarking [3]. Notably, the framework is designed to be modular and adaptable, enabling dynamic fee calculations based on actual execution profiles rather than static estimates.

In addition, the research explores hybrid on-chain/off-chain models as part of Layer-2 scaling strategies, where computationally expensive processes are executed externally and verified on-chain via succinct cryptographic proofs, such as zk-SNARKs and zk-STARKs [4, 15]. These models offer the dual advantage of scalability and verifiability while laying the foundation for performance-aware cost attribution based on execution provenance. Within this context, the research identifies key tasks: (1) evaluating the empirical correlation between traditional gas consumption and actual computing workload, (2) developing weighted cost functions for various operation classes, and (3) designing a verification and billing protocol for hybrid computations.

By achieving these objectives, the study contributes to the redefinition of fairness and efficiency in blockchain resource accounting, promoting a model where computational effort, rather than just data persistence, drives transaction pricing. This paradigm shift from simplistic gas regimes to multidimensional, performance-oriented metrics constitutes a significant step toward scalable, economically sustainable blockchain ecosystems better aligned with the computational demands of contemporary decentralised applications [1 - 4, 15].

Proposed Methodology. We propose a multidimensional resource evaluation model to assess the computational cost of smart contracts more accurately. This model goes beyond the one-dimensional gas metric used in Ethereum and similar blockchains [16]. Instead of assigning a single *"gas"* value to an operation, we characterise each operation by several resource metrics: (i) floating-point operations (FLOPs), (ii) memory access volume, and (iii) execution latency. These dimensions reflect the CPU and memory consumption, comprehensively characterising the workload.

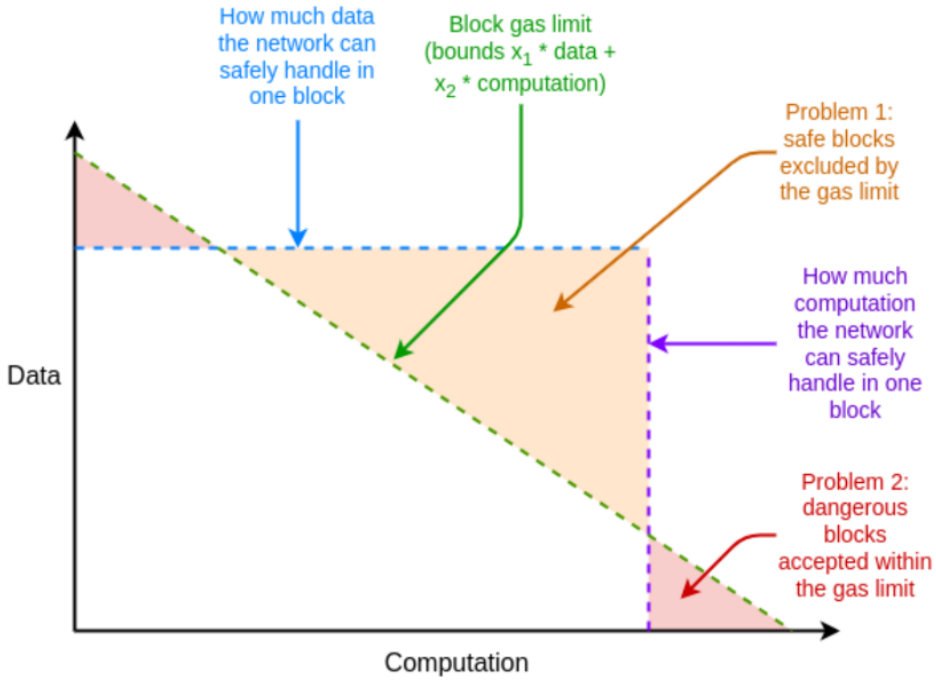

Fig. 1. Conceptual comparison: one-dimensional vs. multi-dimensional resource limits (adapted from [17]).

Figure 1 illustrates the limitations of Ethereum's one-dimensional gas model in capturing the actual multi-resource constraints of block execution [17]. The diagram presents a two-dimensional space, where the horizontal axis denotes the amount of computation in a block and the vertical axis represents the volume of data. Each axis is bounded by the maximum amount of computation or data the network can safely process within a single block. These boundaries are visualised as dashed lines - horizontal for data and vertical for computation - reflecting safe operational thresholds.

The green dashed diagonal line represents the traditional block gas limit, modelled as a linear combination of weighted data and computation terms. While this constraint provides a scalar limit on total

resource usage, it introduces critical inefficiencies. Specifically, two problem areas are highlighted in the diagram. The first, shown in orange, represents blocks that would be safe to execute - i.e., those that lie within the safe zones for computation and data - but are nonetheless excluded due to the linear gas constraint. This constitutes under-utilisation of available resources and indicates inefficiency in the existing metering system.

Conversely, the second problem area, shown in red, corresponds to blocks that satisfy the gas constraint yet exceed safe thresholds for either data or computation. Such blocks are potentially dangerous, as they risk overwhelming network nodes despite being formally accepted under the one-dimensional gas budget. The figure thus underscores the inadequacy of the scalar gas metric in enforcing safety boundaries independently for each resource type. It motivates adopting multidimensional models, where computation and data are metered and constrained along separate axes, aligning execution policies with real system capacities more effectively.

Algorithm 1 (Figure 2) begins by initialising three counters to zero: one for the total number of steps, one for the count of arithmetic operations (denoted as FLOPs), and one for the volume of memory accessed. The algorithm then examines each instruction in the input sequence individually. For each instruction, the steps counter is incremented by one, reflecting the execution of that instruction. If the current instruction is an arithmetic operation (an addition or multiplication), the FLOPs counter is incremented by one. Otherwise, if the instruction is a memory load or store operation (a memory access), the algorithm increases the memory counter by the number of bytes accessed by that instruction. Instructions that are neither arithmetic nor memory operations do not affect the FLOPs or memory counter but are still counted as steps. Once all instructions have been processed, the algorithm returns the three counters corresponding to the total number of steps, the total number of FLOPs, and the total number of bytes of memory accessed. In this way, the algorithm produces a multi-dimensional resource profile of the instruction sequence, quantifying its computational and memory demands.

Algorithm 1 Multi-dimensional resource evaluation

```
function EvaluateContract(instructions)
    metrics ← {FLOPs: 0, MemoryBytes: 0, Steps: 0}
    for each instr in instructions do
        metrics.Steps ← metrics.Steps +1
        if instr is arithmetic then
            metrics.FLOPs ← metrics.FLOPs +1
        else if instr is memory load/store then
            metrics.MemoryBytes ← metrics.MemoryBytes + bytes accessed
        end if
    end for
    return metrics
end function
```

Fig. 2. Algorithm of Multi-dimensional resource evaluation

Table 1 presents a comparative overview of hypothetical computational metrics for operations of increasing complexity, including scalar multiplication, vector dot product, and matrix multiplication. For each operation, four distinct metrics are reported: the number of floating-point operations (FLOPs), the volume of memory accessed in bytes, the estimated execution latency in abstract processing steps, and the corresponding gas cost as per a conventional blockchain metering system. As the table illustrates, scalar operations involve minimal resource consumption across all dimensions. In contrast, more complex tasks, such as vector and matrix computations, incur progressively higher values in each metric category.

In particular, the matrix multiplication operation exhibits a markedly higher resource footprint, with a reported 1900 FLOPs, 8400 bytes of memory usage, and 1000 latency steps, corresponding to a gas cost of 10,000 units (Table 1). Latency is modelled in logical instruction steps, reflecting the sequential operations required in a typical execution path. This trend demonstrates the non-linear scaling of resource consumption as operational complexity increases. The table highlights the central argument of the article: that a one-dimensional gas metric compresses multi-dimensional execution characteristics into a single

scalar, which may fail to capture the cost profile of diverse operations accurately. It also highlights the need for a multi-dimensional metering framework that accounts separately for computational, memory, and temporal resource dimensions.

Table 1. Hypothetical metrics vs. gas for operations of varying complexity

Operation	FLOPs	Memory (bytes)	Latency (steps)	Gas cost
Scalar a × b	1	8	1	5
Vector dot product (len. 10)	19	80	10	10
Matrix multiply (10 × 10)	1900	8400	1000	10000

Algorithm 2 (Figure 3) performs standard matrix multiplication for two square matrices of size $N \times N$. The procedure begins by iterating over each row index of the resulting matrix. It iterates over every column index for each row to compute the corresponding element in the output matrix. Initially, each output element is assigned a value of zero. Then, for each combination of row and column, the algorithm traverses the full range of indices along the shared dimension of the input matrices. At each step of this inner loop, it retrieves one element from the current row of the first input matrix and one element from the corresponding column of the second input matrix. These two elements are multiplied, accumulating the result into the previously initialised output element. This accumulation continues until all contributions for that particular output cell are computed. The process repeats for every element in the output matrix, ultimately resulting in a full matrix product. This algorithm follows the classical triple-nested loop structure, with a time complexity that grows cubically with the size of the matrices. It is widely used as a benchmark in computational resource analysis due to its predictable arithmetic intensity and uniform memory access patterns.

Algorithm 2 Matrix multiplication pseudocode ($N \times N$)

```
for i ← 1 to N do
    for j ← 1 to N do
        C[i, j] ← 0
        for k ← 1 to N do
            C[i, j] ← C[i, j] + A[i, k] × B[k, j]
        end for
    end for
end for
```

Fig. 3. Algorithm of Matrix multiplication pseudocode *(N × N)*

The traditional gas model conflates distinct resource categories. In contrast, our model generates a resource vector: *FLOPs, MemoryBytes, and Latency* per contract. Using the matrix multiplication example *(N=10)*: FLOPs=1900, Memory=8400 bytes, Latency=1000$ steps. The estimated Ethereum gas cost would be approximately 10,000 units, highlighting the memory-bound nature of the task.

This granularity enables improved analysis, optimisation, and potentially multi-dimensional fee markets [18]. Thus, the methodology supports fairness, efficiency, and hardware-aware execution limits for smart contracts.

Experimental Validation. To validate the effectiveness of the proposed multi-dimensional resource model, we conducted a conceptual simulation using matrix multiplication as a representative compute-intensive workload. Matrix multiplication is chosen because it involves many operations and a non-trivial memory footprint, making it an illustrative case for comparing resource accounting models. In the traditional Ethereum gas model, all computational and memory operations are collapsed into a single *gas* metric [16]. This one-dimensional measure simplifies fee calculation but conflates distinct resource types.

In our simulation, we compute the product of two $N \times N$ matrices using the classical triple-nested loop algorithm. We consider three matrix sizes *(N=5, 10, 15)* and measure four quantities: traditional gas cost, number of floating-point operations (FLOPs), memory usage in bytes, and execution latency. Results are summarised in Table 2.

Table 2. Comparison of traditional gas cost and multi-dimensional resource metrics for N × N matrix multiplication

Matrix size N	Gas cost (units)	FLOPs	Memory (bytes)	Latency (ms)
5	925	225	600	0.2
10	7700	1900	2400	1.9
15	26325	6525	5400	6.5

This study's latency is represented using two distinct units depending on the context of the analysis. In Table 1, latency is expressed in abstract *steps*, corresponding to logical execution cycles within a virtualised or algorithmic environment. This abstraction allows hardware-independent comparisons between operations of varying complexity, particularly within a pseudocode or EVM-like model. In contrast, Table 2 adopts a more concrete representation by reporting *millisecond latency* derived from simulated or estimated wall-clock execution time on a hypothetical reference system. This dual representation reflects the theoretical instruction-level view of contract execution and its practical runtime implications. Such a distinction captures an operation's structural complexity and potential performance on real-world infrastructure.

The gas cost curve closely tracks the FLOPs, confirming that Ethereum gas is primarily proportional to the computational steps required. Memory usage increases at a lower rate *(O(N^2))*, and latency scales similarly to FLOPs under a sequential model. These diverging patterns suggest that the traditional model may inaccurately represent the actual workload of memory-intensive or latency-bound tasks.

From these results (Figure 4), the proposed model provides a richer profile: *N=15* matrix multiplication shows FLOPs=6525, memory=5400 bytes, and latency=6.5 ms versus a singular gas cost of 26,325. In future architectures, each component could be priced differently or capped separately. Therefore, multidimensional resource models can support better optimisation, fairer fee design, and improved performance diagnosis for smart contracts.

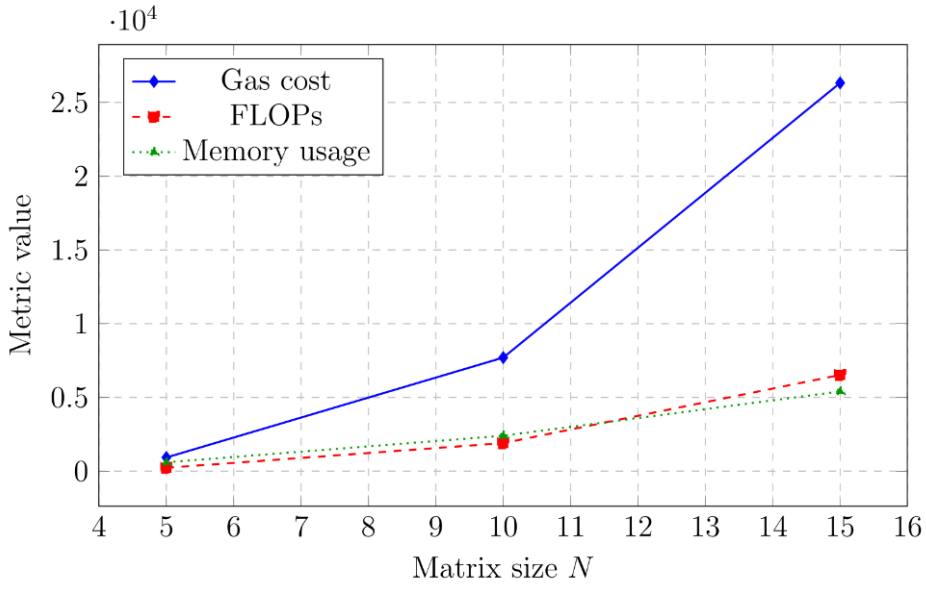

Fig. 4. Scaling traditional gas cost vs. multi-dimensional resource metrics with matrix size.

Figure 4 illustrates the scaling of gas cost, floating-point operations (FLOPs) and memory usage as a function of matrix dimension *N*. All three metrics increase with *N*, but at markedly different rates. In particular, gas cost and FLOPs grow nonlinearly (approximately cubically in *N*, i.e., *O(N^3))*, reflecting the arithmetic complexity of matrix multiplication. In contrast, memory usage increases only quadratically *(O(N^2))*, as storing an *N*×*N* matrix requires approximately *N^2* space. This divergence indicates that a one-dimensional gas metric primarily captures arithmetic operations escalates far more rapidly than the memory requirement as *N* increases. Consequently, relying solely on gas cost to characterise performance would disproportionately emphasise the computational load while understating memory consumption, highlighting the inadequacy of a one-dimensional gas metric in capturing the full resource usage.

Discussion. The proposed multi-dimensional resource model provides a significantly more nuanced assessment of execution costs than the traditional EVM gas metric. By tracking computation (FLOPs), memory usage, and latency separately, the model directly addresses the coarse-grained nature of Ethereum's single-dimensional gas fee [16]. In particular, Buterin observes that treating different resource constraints as a single combined gas limit can exclude many safe blocks or admit unsafe ones, potentially halving the effective throughput [17]. Our analysis confirms this: many blocks deemed "full" under a one-dimensional gas constraint are far from saturating individual resources, allowing separate dimensions to unlock wasted capacity. Empirical studies also show that a single gas budget often misjudges resource-intensive transactions: low-gas transactions may still require substantial CPU or I/O time [19].

Methodologically, a key strength of our approach is categorising operations by their dominant resource usage and exposing hidden cost factors. Previous analyses have noted that Ethereum's gas compresses CPU, memory, and storage costs into a single value [16], inevitably leading to under- and over-priced opcodes. In our model, each EVM opcode's FLOP count, memory footprint and access latency are explicitly accounted for. This fine-grained profiling lets us identify which instructions are CPU-bound versus memory-bound, and suggests more balanced fee adjustments.

These benefits come with notable trade-offs. Block construction becomes a multi-dimensional knapsack problem rather than a simple one-dimensional packing, which is NP-complete. The usual greedy heuristic no longer trivially applies. Similarly, the fee mechanism grows more complex: users must specify bids or tips for each resource type. Implementing this model requires clients to instrument FLOP counts and memory access latency at runtime, which might incur overhead or variance.

By comparison, the traditional EVM gas model sacrifices such precision for simplicity. It compresses heterogeneous costs into a single scalar, yielding efficient market mechanisms, but at the cost of misaligned incentives. As documented, I/O-intensive opcodes were underpriced for years, resulting in denial-of-service vulnerabilities until they were corrected. Our model would align fees with these factors at the protocol level.

Ethereum is already moving in this direction: the Dencun upgrade introduced a "blob" space as a separate fee dimension for rollup calldata [17]. Our framework could extend such ideas to incorporate execution-time or latency dimensions. Likewise, Layer-2 networks could apply a similar multi-dimensional scheme to distinguish settlement from computation costs. Future integration may include EIPs that adjust memory or latency gas formulas, or new fee markets that leverage real-time resource profiling.

Conclusions and Future Work. This work comprehensively analyses blockchain resource metering through a multi-dimensional lens. We introduced a model that concurrently tracks computational (FLOPs), memory, and latency costs, revealing a significant divergence between Ethereum's conventional gas accounting and actual workload. By classifying operations according to dominant resource demand, we have shown which opcodes are CPU-bound versus memory-bound, and thus which are mispriced. Our simulation framework illustrated how pricing and scheduling strategies impact performance under this model. Looking forward, several research directions emerge. One is integration into Layer-2 networks and emerging protocols. Rollup architectures could employ separate price dimensions for on-chain data and off-chain computation. Another direction is the development of adaptive synthetic benchmarks tailored to blockchain workloads. Finally, adaptive resource-profiling systems embedded in clients could monitor performance and dynamically adjust resource pricing. These efforts could yield more scalable and equitable systems by ensuring that fees reflect the actual cost of computation in a heterogeneous network environment.

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