How Deep Learning and Artificial Intelligence in General Can Improve XRP, Ethereum, and Solana Networks

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Abstract: - The rapid advancement of artificial intelligence (AI), particularly in deep learning, offers transformative potential for blockchain networks such as XRP, Ethereum, and Solana. This paper explores the applications of AI to enhance security, scalability, smart contract functionality, and user experience in these blockchain ecosystems. We highlight existing AI models suitable for predictive analytics, anomaly detection, fraud prevention, and gas optimization, and we propose specific use cases for each blockchain. Finally, we assess future directions where the synergy between AI and decentralized technologies could lead to intelligent, autonomous, and adaptive blockchain infrastructures. Blockchain networks such as XRP, Ethereum, and Solana have revolutionized decentralized finance, smart contracts, and cross-border transactions. However, challenges remain in security, scalability, usability, and environmental impact. This paper presents an in-depth exploration of how Deep Learning (DL) and Artificial Intelligence (AI) technologies in general can enhance these blockchain platforms. We analyze AI applications in security threat detection, transaction fee optimization, consensus enhancement, user interface improvements, market prediction, and energy efficiency.

Key-Words: -Deap Learning, Artificial Intelligence, XRP, Ethereum, Solana

Received: March 5, 2025. Revised: May 9, 2025. Accepted: June 7, 2025. Published: July 28, 2025.

1 Introduction

Blockchain technology has revolutionized decentralized finance and data integrity through networks like XRP, Ethereum, and Solana. However, challenges such as scalability, transaction throughput, energy efficiency, and smart contract vulnerabilities persist. Simultaneously, AI, particularly deep learning, has emerged as a powerful tool for pattern recognition, optimization, and automation. This paper investigates how AI and deep learning can optimize the operational efficiency of blockchain networks and improve end-user experience. We analyze how AI methods can support fraud detection in XRP, optimize gas pricing in Ethereum, and enhance consensus mechanisms in Solana. Blockchain platforms such as XRP, Ethereum, and Solana have emerged with distinctive design philosophies and cater to different segments of the digital economy. Ethereum, often regarded as a pioneer in the blockchain space, introduced programmable smart contracts, laying the foundation for the development of decentralized applications (dApps) across a wide range of industries. Solana, in contrast, was architected with a focus on achieving high throughput and low latency, making it particularly well-suited for scalable dApp deployment and high-frequency transactions. XRP, developed primarily for the financial sector, is optimized for efficient cross-border payments, offering rapid settlement times and low transaction costs. Each of these blockchains has brought significant innovations to the industry, but they are not without limitations. Security remains a critical concern, as vulnerabilities in smart contracts and the threat of network attacks continue to pose risks to users and developers. Scalability is another persistent issue, especially during periods of high network activity, which can lead to congestion, elevated transaction fees, and degraded performance. Furthermore, the complexity of interacting with blockchain platforms can be a major barrier for non-expert users, who often face a steep learning curve. Environmental impact, particularly in proof-of-work or hybrid consensus mechanisms, also raises concerns due to the significant energy consumption involved in maintaining network integrity. In this context, Artificial Intelligence (AI) and Deep Learning (DL) have emerged as promising technologies to address some of the most pressing challenges facing blockchain ecosystems. These intelligent systems can automate the detection of anomalies, such as fraudulent behavior or cyber threats, thereby enhancing the security posture of blockchain platforms. They can also optimize operational parameters, such as transaction routing and consensus efficiency, improving overall scalability and performance. Predictive models powered by AI can forecast market trends, aiding developers and investors in decision-making processes. Additionally, AI can be leveraged to enhance user experience by simplifying interfaces, guiding users through complex interactions, and personalizing content delivery. This paper delves into the specific ways in which AI and DL can be integrated into the operational fabric of XRP, Ethereum, and Solana. By examining use cases, technological implementations, and ongoing research, it aims to provide a comprehensive view of how intelligent systems can strengthen the functionality, security, and accessibility of modern blockchain platforms.

2 Block-Chain Platforms overview

The blockchain ecosystem continues to evolve rapidly, with each platform offering unique strengths and facing distinct challenges. One of the most prominent platforms in the space is the XRP Ledger, which is specifically optimized for fast, low-cost cross-border payments. It achieves this through a unique consensus protocol known as the Ripple Protocol Consensus Algorithm (RPCA), which allows for quick finality without relying on energy-intensive mining. However, a notable limitation of the XRP Ledger is its lack of native smart contract functionality. As a result, while it excels in payment efficiency, it lags behind in programmability and flexibility. Given the critical nature of financial transactions on the ledger, integrating intelligent anomaly detection mechanisms using artificial intelligence (AI) could significantly enhance security and operational oversight. In contrast, the Ethereum ecosystem pioneered the concept of decentralized applications (dApps) and smart contracts through its Ethereum Virtual Machine (EVM). This innovation transformed blockchain technology from a simple ledger into a platform for programmable trust. Ethereum supports a wide range of use cases, from DeFi protocols to NFT marketplaces. However, its widespread adoption has led to serious scalability challenges, including high gas fees and network congestion. These issues are exacerbated by the complexity of smart contract interactions and a growing number of contract exploits that expose users to financial risk. Despite efforts to transition toward Ethereum 2.0 and layer-2 scaling solutions, these limitations continue to hinder the platform’s overall performance and accessibility. Another noteworthy platform is Solana, which has gained attention for its high-throughput capabilities and low transaction costs. Solana’s architecture is built around an innovative concept known as **Proof of History (PoH)**, which enables efficient ordering of transactions and significantly boosts scalability. This architectural advancement allows Solana to process thousands of transactions per second. However, the network's complexity introduces risks, particularly in terms of validator centralization and system reliability. Periods of downtime and network instability have highlighted the need for more robust monitoring and decentralized governance solutions to ensure long-term sustainability. Amid these technological developments, AI and Deep Learning (DL) are emerging as powerful allies in addressing some of blockchain's most pressing issues. Prior studies have demonstrated that machine learning models can effectively detect anomalous transaction patterns, forecast cryptocurrency price movements, and automate decision-making within decentralized finance (DeFi) ecosystems. Despite these promising applications, fully integrated blockchain-native AI implementations remain in their infancy. Most current solutions rely on off-chain computation and external oracles, which may introduce new attack surfaces and dependencies. Several systemic challenges cut across all blockchain platforms. Scalability bottlenecks, including network congestion and high transaction fees, limit user adoption and real-time performance. Complex user interactions present a steep learning curve for non-experts, reducing accessibility and inclusivity. Furthermore, environmental concerns persist, especially with consensus mechanisms that demand significant energy consumption, such as Proof of Work.

In this context, AI and DL can provide transformative solutions. By automating anomaly detection**,** AI can enhance security and fraud prevention. Optimization of operational parameters can help platforms manage congestion and resource allocation more efficiently. Predictive analytics can assist users and developers in anticipating market trends and making informed decisions. Lastly, AI can help simplify user interfaces and interactions, making blockchain applications more intuitive and accessible to mainstream audiences.

This paper aims to explore AI-driven solutions tailored to the challenges and characteristics of major blockchain platforms, specifically focusing on the XRP Ledger, Ethereum, and Solana. By examining both their existing limitations and opportunities for AI integration, we provide a roadmap for enhancing performance, scalability, security, and usability across the blockchain landscape.

3 Deep Learning Use Cases Across Networks

Artificial Intelligence (AI) and Deep Learning (DL) are transforming the blockchain ecosystem by addressing critical challenges such as scalability bottlenecks, high gas fees, complex user interactions, and energy consumption. These technologies offer advanced capabilities in automating anomaly detection, optimizing network operations, forecasting market trends, and improving the overall user experience. This paper examines targeted deep learning applications in three major blockchain networks: XRP, Ethereum, and Solana, showcasing how AI can significantly enhance functionality, security, and efficiency across decentralized systems. One prominent use case is AI for Transaction Fraud Detection, where deep learning models, particularly Recurrent Neural Networks (RNNs) and Transformer architectures, are used to analyze sequences of blockchain transactions to uncover suspicious patterns. In the case of XRP, which facilitates cross-border financial transactions, AI can play a pivotal role in detecting potential money laundering activities. By leveraging graph-based neural networks, transaction flows can be modeled as dynamic graphs, enabling the identification of anomalous behaviors and complex fraud schemes that traditional rule-based systems often miss. In Ethereum, a major concern is the high and unpredictable gas fees. To address this, Deep Reinforcement Learning techniques such as Deep Q-learning can be employed to develop agents that learn to recommend optimal transaction times and gas prices, thereby minimizing user expenses. Additionally, predictive models such as Long Short-Term Memory (LSTM) networks can forecast periods of network congestion based on historical data, enabling proactive gas fee management. These tools collectively enhance transaction efficiency and improve accessibility, particularly for retail users sensitive to transaction costs. Another critical application is Smart Contract Vulnerability Detection. Given that smart contracts are immutable once deployed, detecting vulnerabilities beforehand is essential. Deep learning models such as CodeBERT, which are pre-trained on programming languages, and Graph Neural Networks (GNNs), which model the logic flow and dependencies within code, can be applied to parse and analyze Solidity smart contracts. These models can automatically identify common vulnerabilities like reentrancy attacks, integer overflows, and access control issues, reducing the risks associated with decentralized applications (dApps). For Solana, which utilizes a novel consensus mechanism combining Proof of History (PoH) and Tower Byzantine Fault Tolerance (BFT), Consensus Optimization is another domain where AI can be beneficial. Reinforcement learning agents can be trained to dynamically optimize validator selection processes, reduce the frequency of forks, and ensure more stable network performance. These agents can learn from the network's state and historical performance to improve consensus reliability and system throughput. Solana's architecture, while enabling high throughput and low latency, presents challenges such as validator centralization and potential downtime. Its reliance on PoH for sequencing transactions enhances scalability but increases complexity. AI techniques can be used to monitor validator behavior, detect potential centralization risks, and adaptively rebalance the network to maintain decentralization. Beyond individual use cases, AI in Blockchain continues to expand with applications in detecting anomalous transactions, forecasting token prices, and automating decision-making in Decentralized Finance (DeFi). Despite these advancements, most implementations remain off-chain or externally integrated; blockchain-native AI—where models are trained and deployed entirely within decentralized networks—is still an emerging frontier. In addition to these technological applications, broader systemic challenges persist across blockchain ecosystems. Scalability bottlenecks continue to cause network congestion and elevated fees. Complex user interfaces and processes present a steep learning curve for non-expert users, limiting broader adoption. Environmental concerns, particularly those arising from consensus mechanisms that consume large amounts of energy, remain a topic of active debate. AI and DL can play a central role in resolving these issues. By automating system management, anticipating future network states, and simplifying user interfaces through intelligent agents, these technologies can push blockchain toward greater efficiency, security, and inclusivity. This paper delves into these AI-driven innovations, offering insights into their real-world applications across XRP, Ethereum, and Solana.

4 System Architecture for AI Integration

We propose a layered AI-Blockchain framework designed to enable seamless interaction between artificial intelligence and decentralized systems. This architecture is composed of four interdependent layers, each with distinct roles and responsibilities. The Data Layer serves as the foundation of the system, responsible for collecting both real-time and historical transaction data. This is achieved through the use of decentralized oracles or direct access to node APIs, ensuring the reliability, accuracy, and freshness of the information used for subsequent analysis and decision-making. Above it lies the Model Layer, where deep learning models are trained and continuously updated. These models perform critical tasks such as prediction of network behavior, classification of user activity, anomaly detection, and optimization of blockchain operations. By leveraging large-scale datasets and advanced machine learning techniques, this layer ensures that AI components remain adaptive and effective over time. The Execution Layer is responsible for implementing the AI-driven decisions within the blockchain environment. This is accomplished through the deployment of smart contract hooks, activation of governance modules, or invocation of external services. By embedding AI logic into executable blockchain components, this layer ensures real-time responsiveness and automated enforcement of data-driven strategies. Finally, the Feedback Layer completes the loop by monitoring the outcomes of AI-informed actions. It provides mechanisms for continuous learning and model refinement through federated learning approaches or community-based methods such as on-chain voting. This layer ensures the system remains robust, self-improving, and aligned with evolving user and network needs. Taken together, this modular architecture supports a dynamic, intelligent, and decentralized ecosystem where AI enhances blockchain functionalities while maintaining transparency, security, and user trust.

5 Comparative Analysis

When evaluating XRP, Ethereum, and Solana from the perspective of AI integration and blockchain compatibility, a comparative analysis across several key features reveals distinct strengths and limitations for each platform. **See Table 1**

AI Integration Feasibility varies across the three blockchains. XRP presents a medium level of feasibility for AI integration, largely due to its design being primarily focused on financial transactions and payment settlements. While not inherently built for complex smart contract logic or external computation, it can support moderate AI applications when layered with external systems. Ethereum, on the other hand, offers a high level of feasibility. Its widespread adoption, flexible smart contract capabilities, and compatibility with various tools make it a prime candidate for integrating AI components such as fraud detection, autonomous contract agents, or analytics engines. Solana also scores high in AI integration potential, leveraging its high throughput and low-latency infrastructure, which are advantageous for real-time AI-driven applications, especially those requiring rapid data ingestion and processing. Regarding Target Use Cases, each blockchain has a different focus for applying AI. On XRP, AI is primarily suited for fraud detection within payment systems, helping to identify anomalies and flag suspicious transactions in real-time. Ethereum, with its programmable smart contracts, lends itself well to gas optimization and automated code audits, allowing AI tools to evaluate and refine smart contract efficiency and security. Solana, with its unique Proof-of-History (PoH) mechanism, is more conducive to validator scheduling and latency tuning, areas where AI can enhance performance by dynamically optimizing node assignments and minimizing processing delays. The Model Deployment Complexity also varies significantly. XRP has moderate complexity due to its limited scripting capabilities, requiring off-chain support to run sophisticated AI models. Ethereum demonstrates low deployment complexity, especially with the help of its EVM (Ethereum Virtual Machine) integration, which enables seamless deployment of AI-powered smart contracts or model-driven agents. In contrast, Solana exhibits high complexity in deploying AI models, primarily because of the technical challenges associated with its PoH architecture, lower-level programming requirements, and the need for precise timing in its validator operations. Finally, Privacy Constraints differ across these ecosystems. XRP has low privacy capabilities, offering minimal built-in privacy features beyond standard cryptographic mechanisms. Ethereum currently has medium privacy support, but this is expected to improve with the future integration of zk-SNARKs (zero-knowledge succinct non-interactive arguments of knowledge), which will allow for private transactions and computation. Solana faces high privacy constraints due to its transparency-focused design and high-speed processing, which currently lacks robust privacy-preserving features. In conclusion, while Ethereum offers the most balanced and developer-friendly environment for AI integration today, Solana holds strong potential in performance-centric applications despite its complexity, and XRP, while more limited, can still serve AI-enhanced use cases particularly in financial domains.

Table 1 (Comparative Analysis)

Feature	XRP	Ethereum	Solana
AI Integration Feasibility	Medium	High	High
Target Use Cases	Fraud Detection	Gas Optimization, Code Audits	Validator Scheduling, Latency Tuning
Model Deployment Complexity	Moderate	Low (via EVM integration)	High (due to PoH complexity)
Privacy Constraints	Low	Medium (zk-SNARKs in future)	High

6 Future Work

In the future, we aim to explore several promising directions that combine artificial intelligence with blockchain technology to enhance efficiency, transparency, and interoperability. One key area involves the development of lightweight deep learning models, such as those based on TinyML, capable of performing on-chain inference**.** These models will be optimized for limited-resource environments and deployed directly on blockchain networks to enable intelligent, decentralized decision-making without relying on external servers. This approach ensures enhanced data privacy, reduces latency, and supports real-time autonomous applications. Another vital direction is the integration of federated learning within blockchain systems**.** This technique allows multiple nodes across the network to collaboratively train a shared machine learning model while keeping their individual datasets local and private. By avoiding centralized data aggregation, federated learning upholds data confidentiality and aligns perfectly with the decentralized ethos of blockchain. This approach can significantly benefit domains such as healthcare and finance, where data privacy is paramount. To build trust and transparency in AI-driven blockchain applications, Explainable AI (XAI) will be a major focus. As smart contracts increasingly rely on AI to automate critical decisions, there is a growing need for models that offer clear, interpretable justifications for their outputs. Implementing XAI techniques will aid auditors, developers, and regulators in understanding how decisions are made, ultimately increasing accountability and fostering greater adoption of intelligent smart contracts. Lastly, we envision advancements in cross-chain intelligence**,** where AI is used to manage and optimize interoperability between major blockchain platforms such as XRP, Ethereum, and Solana. By employing intelligent bridging mechanisms, AI can facilitate seamless data exchange, smart contract execution, and asset transfers across heterogeneous networks. This would pave the way for a more integrated and dynamic blockchain ecosystem, unlocking new possibilities for decentralized finance, gaming, and supply chain management.

AI for Security Enhancements

Artificial Intelligence (AI) is increasingly being leveraged to enhance the security posture of blockchain ecosystems. One of the primary applications lies in anomaly detection within transactions and validator behavior. Deep learning (DL) models such as autoencoders and recurrent neural networks (RNNs), particularly long short-term memory (LSTM) architectures, can be trained on historical transaction data to establish baseline behaviors. These models learn to recognize normal patterns and subsequently flag deviations that may suggest suspicious or malicious activity. For instance, in the XRP Ledger, AI systems are employed to monitor validator voting patterns. These validators play a crucial role in consensus, and any sudden deviation in their behavior—such as voting in contradiction to historical trends—can signal that a validator may have been compromised or is acting as part of a coordinated attack. Another critical area of blockchain security lies in smart contract vulnerability detection, especially on platforms like Ethereum. Smart contracts, by their immutable nature, become attractive targets for hackers if they contain coding flaws. The infamous DAO hack is a prime example, where vulnerabilities in contract code led to the loss of millions in funds. AI addresses this risk through a combination of static code analysis and deep learning classifiers trained to recognize known vulnerability patterns such as reentrancy attacks or integer overflows. Tools like Mythril and Slither, when augmented by AI models, have shown significant improvements in vulnerability detection accuracy and a reduction in false positives

In addition, network intrusion detection and DDoS attack mitigation represent vital components of blockchain security, particularly for high-throughput platforms like Solana. Solana validators, responsible for processing large volumes of transactions, are frequent targets of distributed denial-of-service attacks. AI-driven Intrusion Detection Systems (IDS) make use of traffic flow data and CNNs to identify attack signatures at an early stage, enabling proactive defense mechanisms that help maintain network integrity and uptime.

Scalability and Throughput Optimization

Blockchain performance depends heavily on scalability mechanisms, and AI offers promising solutions in this domain. One key challenge is the prediction and optimization of gas fees, especially on the Ethereum network. Gas fees fluctuate due to changing network load, which can frustrate users and reduce usability. AI models trained on historical transaction data, mempool sizes, and block timings can accurately predict gas price trends. These predictions can then be embedded into wallet applications, guiding users toward selecting optimal gas fees that balance cost and confirmation time. A typical use case includes a regression model deployed in wallets to recommend gas fees based on target confirmation times. Another area where AI proves beneficial is in validator workload balancing, particularly in high-throughput networks like Solana. When transaction processing is unevenly distributed among validators, performance can degrade. Reinforcement learning algorithms can be applied to dynamically optimize the allocation of tasks and computational resources across validators. The agent observes current network metrics, such as latency and transaction volumes, and adjusts workloads accordingly to ensure optimal throughput and stability. Furthermore, transaction ordering and batching can benefit from AI optimization. Efficient ordering of transactions reduces conflicts, maximizes block utilization, and improves fairness. AI models, trained to recognize transaction dependencies and patterns, can intelligently reorder or batch transactions for inclusion in blocks. This improves throughput and reduces confirmation latency across networks like Ethereum and Solana.

Consensus Mechanism Improvements

AI also offers valuable contributions to the consensus mechanisms that underlie blockchain systems. One application is the adaptive tuning of consensus parameters, such as block production time or validator thresholds. These parameters significantly influence the trade-off between security and performance. AI algorithms can dynamically adjust them in real time based on changing network conditions. For example, in Ethereum's Proof-of-Stake (PoS) system, quorum sizes for validator consensus may be adjusted to maintain optimal throughput without compromising security. In addition, fault prediction is essential for maintaining the resilience of blockchain networks. Validator nodes, if they go offline or behave maliciously, can threaten consensus integrity. LSTM-based models trained on historical validator uptime logs can predict node failures, enabling the system to preemptively replace or isolate unreliable validators. This predictive capability enhances network reliability and reduces the risk of disruptions.

User Experience and Smart Contract Interaction

AI is also transforming how users interact with blockchains. Natural language interfaces, powered by AI-driven chatbots and voice assistants, allow users to initiate blockchain transactions using everyday language. For instance, a user could say, “Swap 1 ETH for DAI,” and the AI system would parse this intent and convert it into a smart contract call. This approach significantly improves accessibility, particularly for users unfamiliar with blockchain interfaces. Natural Language Processing (NLP) models map user intents to appropriate contract interactions, reducing friction and democratizing blockchain access. Additionally, personalized recommendations powered by machine learning can guide users toward relevant decentralized applications (dApps), NFTs, or DeFi opportunities based on their past behaviors and preferences. This creates a tailored user experience akin to recommendation engines on streaming platforms.

Market Analytics and Predictive Insights

AI plays a pivotal role in blockchain-based market analytics. Price prediction models using LSTM and Transformer architectures ingest both on-chain metrics (e.g., transaction volume, wallet activity) and off-chain data (e.g., social media sentiment, news articles) to forecast the prices of cryptocurrencies like XRP, ETH, and SOL. These predictive insights are valuable for individual traders and automated trading bots alike. Moreover, sentiment analysis through NLP techniques helps gauge public opinion and emotional tone from sources such as Twitter, Reddit, and financial news outlets. These sentiment scores are often strongly correlated with market trends and help inform trading strategies.

Energy Efficiency and Environmental Impact

With growing concerns over energy consumption, particularly for proof-of-stake validators, AI is being employed to promote energy-efficient operation. Validator scheduling can be optimized using AI to reduce unnecessary activity, thus lowering energy usage without compromising the security or availability of the network. Another important application is predictive hardware maintenance. Machine learning models analyze telemetry from validator hardware to predict failures in advance. This proactive maintenance minimizes downtime and prevents inefficient energy consumption due to degraded equipment.

Conceptual Framework for AI–Blockchain Integration

To cohesively support all these capabilities, a conceptual architecture integrating AI modules with blockchain infrastructure is essential.

7 Conclusion

Looking forward, several promising avenues exist for the convergence of artificial intelligence (AI) and blockchain technology, each offering the potential to reshape how decentralized systems operate. One of the most impactful developments lies in Explainable AI (XAI), which aims to make AI decision-making processes more transparent and understandable. By integrating XAI into blockchain systems, developers and users will be able to gain insights into why certain transactions are flagged as suspicious or why specific predictions or recommendations are made. This transparency is crucial for building trust in AI-driven blockchain applications, especially in areas like fraud detection, credit scoring, and automated smart contract execution. Another significant advancement involves the creation of cross-chain AI models, which are designed to operate seamlessly across multiple blockchain networks. These models can optimize operations by intelligently selecting the most efficient or cost-effective blockchain to execute a given task, thereby enhancing interoperability and making better use of computational and financial resources. Such models could also facilitate more sophisticated decentralized applications (dApps) that rely on data and functionality from various blockchain ecosystems. AI-driven decentralized governance represents a further step toward autonomy and efficiency in decentralized autonomous organizations (DAOs). By incorporating machine learning algorithms and real-time data analytics, DAOs could evolve to make more objective, consistent, and data-informed decisions. This approach has the potential to reduce human bias, streamline voting procedures, and enhance the scalability of decentralized governance models by automating routine or complex decision-making processes. Privacy, a cornerstone of blockchain technology, will also benefit from AI integration through the development of privacy-preserving AI techniques. Approaches such as federated learning and zero-knowledge proofs will allow AI models to be trained on sensitive data—such as user financial histories or medical records—without exposing that data to external parties. This will be especially useful in sectors like healthcare and finance, where data security and compliance with privacy regulations are paramount. Finally, cross-chain intelligence will play a key role in managing and enhancing interoperability among major blockchain platforms like XRP, Ethereum, and Solana. AI-powered systems will be used to develop intelligent bridges capable of performing real-time data analysis, facilitating seamless asset transfers, and synchronizing smart contract execution across networks. These bridges will not only make cross-chain operations more efficient but also introduce a layer of adaptive intelligence that can respond dynamically to changing network conditions or threats. In sum, the fusion of AI and blockchain technologies promises to unlock new levels of transparency, efficiency, autonomy, and privacy, ultimately paving the way for a more intelligent, interconnected, and trustworthy decentralized ecosystem.

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