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Secure and Distributed Computing Mechanisms for Electric Vehicle Charging Management: The Past, Current and Future Trends

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Abstract

Electric Vehicles (EV) are recommended in many countries owing to its economic and environmental benefits. The charging demands posed by EVs keep increasing day by day and the same could not be met by existing charging infrastructures. Though shared charging schemes exist, it is crucial to ensure the trustworthiness of the participating entities. Several systems employing advanced computing techniques were proposed in the past for effective EV charging. This review paper will provide an overview of various electric vehicle charging schemes, their characteristics, limitations and management. Further, this review will cover recent secure computing and blockchain based approaches deployed in the arena of EV charging management.

Keywords: *Electric vehicles, charging management, blockchain, distributed computing, security, shared charging.*

1. Introduction

Transportation is considered as one of the fastest growing sectors in the world. It has played a major role in the development of many nations over the past few decades. Though vehicles aid transportation and provide immense benefits to society, there exists a severe problem of pollution associated with most of the automobiles [2]. The world is united in the goal of decarbonizing the transportation to tackle the problem of pollution. There has been wide range of efforts from governments, private organizations and research establishments on reducing greenhouse gases so as to preserve global climatic condition. Electric vehicles have become a boon for the mankind owing to its suitability in enabling transportation with reduced environmental pollution [8]. Reduced carbon emissions and lower fuel costs make EVs becoming more popular day by day and they are considered to be the most suitable choice of the commuters of the modern world. While the expectation for the adoption of electric vehicles is very high, the key factor for realization of the same is the availability of ample charging infrastructure. Public may not wish to switch to electric vehicles as long as they feel that their driving comfort would get affected because of the charging bottlenecks. In reality, non-availability of public charging infrastructure is a major hindrance to the deployment of EVs in most of the places today [1]. Several models of charging have been developed in the past for dealing with the problem of lack of infrastructure. Sharing of charging piles is one of the effective solutions for dealing with the aforesaid problem. The private charging piles are made available as shared charging piles to meet the requirements of group of electric vehicles. This enables better utilization of the private charging piles and also provides better quality of experience for the users of electric vehicles. Nevertheless, the security and privacy issues are more common in operations associated with any of these cases [6]. The participating entities may lack trust among themselves. Besides, there also exists a possibility of security threat due to the malicious users and compromised entities [16]. Figure 1 depicts the modern computing technologies that aid advancements in several fields. Emergence of technologies such as distributed computing,

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cryptography, artificial intelligence, blockchain etc. has paved way for alleviating the security and privacy concerns associated with the process of electric vehicle charge management. [1-10]

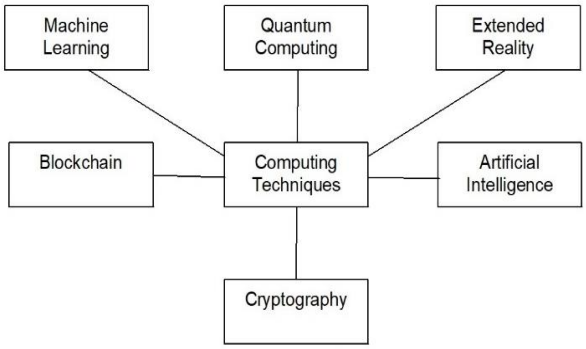

Figure 1 Modern Computing Techniques

1.1. Motivation

As per the forecast of International Energy Agency, a stock of nearly one hundred and thirty million electric vehicles is expected by the end of this decade [22]. However, the ideas on the means of rendering charging services, the policies, the technological framework and implementation schemes are still in the stage of infancy. There has been a minimal contribution in the literature pertaining to the coverage of computing-based approaches deployed for the improvisation of electric vehicle charging. Therefore, this paper intends to review how computing techniques are deployed for facilitating operations of electric vehicle charging and management. The holistic understanding could aid design and development of novel models in this field in the near future.

1.2. Paper Organization

This review paper is organized as given below. Section 1 provides the introduction which includes background of the study, motivation and purpose of the review. This section will provide an overview of electric vehicles, charging mechanisms and associated characteristics. Also, the need for effective computing methods for electric vehicle charging will be discussed. The organization of paper and contributions of the study will be provided. Section 2 discusses the common approaches for electric vehicle charging. Section 3 elaborates various existing works on computing based approaches for electric vehicle charge management. The diverse techniques employed in existing literature for solving security and trust related challenges in electric vehicle charging will be highlighted. Section 4 provides a comparison on the popular approaches and architectures used for electric vehicle charging management. Section 5 provides the challenges associated with the implementation of the approaches and Section 6, the conclusion, provides a summary of the review paper in brief along with the inferences obtained. Further, an outline of possible avenues for further research is presented.

1.3. Contributions of the Review

The contribution of this review paper is to cover in detail the vast subject of electric vehicle charging and provide an indepth understanding of various computing-based approaches deployed for electric vehicle charge management. The review is novel in its way as it collates the contributions of several leading researches pertaining to the arena of electric vehicle charging as a single article. This review is unique as it focuses on various security and trust based approaches along with corresponding implementation methods, navigating through the length and breadth of the computational models deployed for management of electric vehicle charging. This review covers different existing methods for electric vehicle charging, the computational architectures involved, the associated methodologies, their shortcomings, comparison and possible improvements. [11-20]

This paper intends to provide answer to the following questions:

- What are the different mechanisms available for charging the electric vehicles, and what are their characteristics and limitations?
- What are the computing models that are currently used for aiding development and management of electric vehicle charging infrastructure? What problems are addressed by the schemes and what are the associated benefits and limitations?
- How does the blockchain technology support deployment of charging infrastructure, what are the challenges involved and what are the possible avenues for further exploration?

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2. Existing Methods of Electric Vehicle Charging

This section discusses in detail about the concept of electric vehicle charging, recent advancements in electric vehicle charging methods.

2.1 Types of Charging

Slow charging, slow to fast charging using AC and DC Fast Charging are commonly adopted schemes. Charging at home is the most common practice found in many countries. Thanks to the provisions given by the governments to install chargers at their home many purchasers of electric vehicles seamlessly prefer this option. Nonetheless this requires a vast parking space. The various types of available charging options are depicted in figure 2.

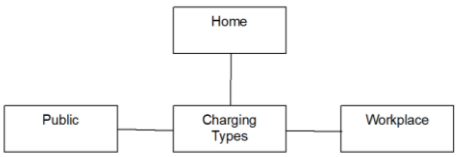

Figure 2 Types of Charging

The charging needs of the user often demands frequent charging events. It is however impractical to reach home at all times. Hence there arises a need for public charging. Places like hotels shopping, malls, government offices and universities can facilitate public charging by establishing suitable infrastructure. Workplace charging is also found to benefit most of charging needs.

2.2 Levels of Charging

Level 1 charging refers to 120 V 3.3 kW Single Phase AC charging which is also called slow charging. Level 2 charging refers to 240V 7.4 – 22 kW single or three phase AC charging and 480-600V 50+ kW DC charging is called as DC Fast charging. In order to maximize the utilization of the infrastructure, it is indeed critical to align the charging requirements of the user with the charging facility.

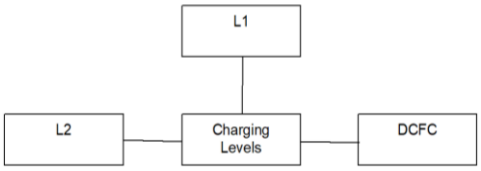

Figure 3 Types of Charging

The behavior and preference of the user also contributes towards improved utilization of the facility. The various levels of charging are depicted in figure 3.

2.3 Charging Infrastructures and Concerns

The charging stations do not flourish in abundance owing to the hardware expenditure, installation costs, uncertainties in utilization, lack of standards, etc. The operational costs such as maintenance purchase and local tariff also needs to be considered. There is concern of degradation of the batteries in case of fast charging. The temperature and state of the charge keeps varying rapidly in the battery due to the charging and discharging process and there exists a concern on lifetime and degradation of the batteries. Despite the above, security and privacy concerns needs to be addressed during the realization of the charging models. [21-30]

2.4 Need for Advanced Charging Schemes

In the present scenario, level 2 charging at public facilities play a major role in catering to the charging needs of the electric vehicle users. The provision of charging during the shopping time or during their work hours enable users hassle free travels without requirement of allocating a dedicated time and effort for the purpose of charging. Shared charging is a scheme in which the private charging piles are made available to a group of electric vehicle users. This enables better utilization and profit for the pile owners whereas it provides better quality of experience and availability to the electric vehicle users. In case of the charging needs that a massive, fast charging is found to be more apt. A typical scenario of travel of hundreds of miles would be well supported by the aforesaid mechanism as it would alleviate the necessity of frequent charging. The charging demand of the users keeps increasing at a rapid rate and at the same the users also expect the charging process to be quick. The quality of service should be at its highest so as to enable more commuters opt for electric vehicles. In order to achieve the above, it is very essential to establish sophisticated charging infrastructure. The technology needs to evolve further to attain a state of charging of beyond 50 kW, by which even massive charging needs can be catered in a time quantum of few minutes. Nevertheless, the security

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and privacy concerns coexist with them and have to be dealt with effectively.

3. Computing Based Approaches for EV Charging Management

This section discusses in detail various computing based approaches for electric vehicle charge management. The diverse techniques employed for solving security and trust related challenges in electric vehicle shared charging are discussed below.

3.1 Block Chain based Approaches

Blockchain emerged as powerful technology for providing effective electric vehicle charging management. A Blockchain is a collection of data blocks each possessing a header and body. The details of transaction are held in the block and all the blocks are linked together by means of pointer. The transactions recorded are validated by all the participating nodes. If the transaction is found to be valid, then the same is added to the blockchain. The transactions of the system are immutable as it is impossible to revoke the same. Blockchain may be of the type public or private or consortium. The features of blockchain are presented in Figure 4.

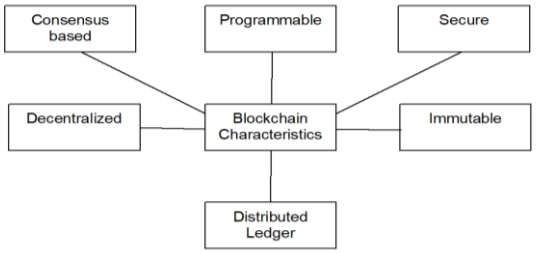

Figure 4 Characteristics of Block Chain

Investigations are carried out regarding the methods for storing the EV charging and the payment related data on blockchains. The deployment of smart contracts, the feasibility and scalability of the solution and the factors of trust and interoperability were studied in Kirpes et al [18] et al. However, transactions pertaining to vehicle to vehicle charging were not taken into investigation and deployment of electric vehicles as dynamic storehouse of energy was not experimented. Interaction between untrusted agents in EV charging ecosystem is secured by means of a novel blockchain based approach proposed by Christian Gorenflo et al. [19]. A chain code on the blockchain handles all transactions and the smart contract facilitates verification of the bill of payments. The mechanism facilitates direct interaction between the property owner and the customers. The work can be further extended by delegating the task of managing the nodes by property owners so that the charging service providers can focus on better maintenance. Thus the problem of lack of trust can be eradicated. Further, wallets for the participating entities could be maintained on the chain, wherein the vehicles could better decide on the location of charging, identify the one in the proximity and initiate secure payment. Payments for bills of various smart vehicles are also secured by means of using blockchains. Sensitive information sharing is facilitated by the system deploying a novel blockchain based strategy proposed by Jamil et al. [20] whilst the privacy preservation is completely effected in the system. Yet, variety of consensus approaches can be implemented in the system with the objective of improving throughput and response time. Blockchain based pile sharing system has been designed and implemented by Jian Wang [32]. A decentralized scheme offering transparency, reliability of transactions among multiple entities such as charging station, maintenance and supervising agents was proposed. Trust among pile owners, operators and vehicle users are achieved by means of blockchain aided systems. Yunhua et al. [33] proposed a novel architecture for secure shared charging in which reputation based incentive is used for providing better quality of experience and multiparty contracts are used for secure storage and computations. The investigation may be extrapolated further in the dimensions like consensus algorithm, fair pricing, better authentication and efficiency. Models for secure sharing of abundant electricity to the charging stations are also facilitated by means of blockchain based schemes. Khan et al. [5] have proposed a model deploying hyperledger fabric for facilitating automated payment mechanisms for electric vehicle charging. The model is superior in its functionality by providing higher level of security and transparency, improved throughput and reduced latency of transactions. The work could further be enhanced by deploying crypto currencies for charging payment process and machine learning

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approaches for better evaluation and prediction. Distribution of charging load among stations is managed in a fair manner by means of blockchain based mechanisms. Jin et al [16] have proposed a novel trading mechanism that considers multiple factors of concerns to determine the charging demands. Smart contracts based on ethereum platform ensure right allocation ensuring fairness while preserving transparency and security. Further optimization is performed to achieve better performance. However, the work has not modeled process of coordination optimization and interaction amongst different energy sources. Energy exchange market is revamped by deploying blockchain at different levels. Liu et al [17] have developed a distributed system for energy exchange by deploying advanced blockchain architecture. This facilitates secure energy exchange among peers in real-time without the intervention of competent central authority. The work can further consider exhaustive set of factors of the system to devise a more accurate utility function. Variety of optimization approaches can be explored. Methods for sharing charging credits are also realized by means of blockchain based approach. Firoozjaei et al. [15] have proposed a model called EV Chain that ensures trust and distributed operations along with privacy preservation during the process of charge credit sharing. Their model maintains data at two levels and makes uses of additional header in block to handle credit sharing. Several entities are involved in the process of electric vehicle charging makes it ultimately complex, which leads to possibility of active and passive attacks on the data being exchanged. This may end up in compromise of information confidentiality and integrity. Antoun et al. [31] have presented in detail various security concerns associated with the deployment of charging infrastructures. The blockchain based reputation schemes suffer from inefficient storage, sluggish query and retrieval concerns. Multichain based models emerged as solution for the aforesaid problem. However, the information obtained from this set up, involving different data stored over different blockchains faces the problem of unreliability. He et al [1] proposed a cross chain based model which employs merkel proof to validate the authenticity of information. While computing the reputation, the model employs multiple counting bloom filters to aid filtration of non-real time information. Further, the reliability of the information is ensured by deploying hash mutexes during the write operations across chains. The work can be further investigated in terms of reducing the resource consumption. One of the possible means of achieving the same is to enable only the transfer of results across blockchains so as to minimize the utility of the resources. A Novel ethereum based charging management framework was proposed by Zhengtang et al. [3]. In their work, a custom solidity smart contract is used for governing the charging process. The model ensures accountability of the transactions taking place in a network of untrusted peers. Mechanisms for achieving high speed and reduced cost operations were proposed and verified over a real time scenario of private charging facility. The mobile and web applications enable simplified operations with highest level of ease to use. The work can be further enhanced by focusing on minimization of transaction costs, light weight consensus schemes. Investigations may be carried out so as to evaluate scalability, the robustness of the system in variety of threat conditions. Secure models for energy trading is well facilitated by means of blockchains. Atif et al [9] proposed a novel model with smart contracts for transaction among peers. The initial phse involves registration and after successful completion of the same, the authentication process will take place. This enable only legitimate entities to take part in transacting thereby ensuring security. The solution also overcomes the problem of single point of failure and tampering. The work can be further investigated by deploying machine learning concepts for the prediction of charging and discharging and artificial intelligence techniques for improvising the process of penalty on malicious participants. Selection of electric vehicle charging station has been found to be effective when blockchain based approaches are employed. Danish et al. [13] proposed a model that employs blockchain based protocol for selecting the charging station. The model offers high level of security and privacy by means of smart contracts and trusted reservation. The scheme enforces penalties for misbehaviors of participating entities and thereby

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ensures trust and availability. The process for achieving full privacy preservation can further be investigated in conjunction with the other capabilities of the model. Powerful blockchain based approaches aid the navigation of charging piles in realtime. Guo et al. [22] have designed blockchain based framework that employs incentive-based reputation mechanism. The honest behavior and historical behavior of the electric vehicles are taken in consideration in the process of calculating reputation. Their approach facilitates reliable and timely information exchange on road conditions amongst users. Explorations on complete mitigation of all types of attacks, synchronization of transaction across chains and other interoperation aspects can be carried out further. Deployment of blockchain along with existing data stores for dealing with data mutation and tampering have been investigated in the past. Javed et al. [24] have proposed blockchain aided scheme for P2P vehicle charging. The scheme ensures reliable and timely exchange of messages and uses for four components for computing total charging cost. Location based privacy preservation is also implemented in the model.

3.2 Cryptography Aided Block Chain Based Approaches

The data exchanged over untrusted environment of internet of electric vehicles is often prone to the attacks. The data can be tapped by the attackers to find the behavior of the legitimate user. Mere anonymity of the communication will not suffice to deal with the tracking intentions of the adversary. Almuhaideb et al. [28] have proposed a novel ECQV based approach for authentication. Their model provides better security and privacy by means of implicit certificates. Compliance of the novel approach with other algorithms can be studied in details and the mechanism for advanced authentication pertaining to excess energy selling entities can be investigated further. ECC based approaches facilitates additional reliability and integrity to the charging based transactions. Chen and Zhang [23] proposed a novel electricity trading scheme using ECC based digital signature in conjunction with blockchain for higher level of security. Further a byzantine algorithm for fault tolerance is applied to ensure consistency of data as well as to enhance the throughput. Yet mechanism for strict punitive action against malicious entities for complete stability of the system is not dealt with in this work Energy trading between charging station to vehicle and vehicle to vehicle is also aided by means of novel blockchain based mechanisms. Baza et al. [21] proposed a model for secure and privacy preserving trading amongst the aforesaid cases. An efficient blockchain based payment method is also encompassed in their scheme. Further the operations are secured against Sybil and denial of service attacks. Security of energy trading has been improved by means of employing blockchain models. Wang et al. [6] have proposed permissioned blockchain architecture for enhancing security in the process of energy trading. A novel architecture for private charging pile sharing network is proposed and a protocol for private charging pile sharing is developed based on the reputation and BLS signature. The model is found to improve the quality of experience and also found to be effective against wide range of security attacks. The aspect of discharging may be considered to enhance the investigation. [31-35]

3.3 Optimization Aided Block Chain Based Approaches

Two-layer model for the process of charge and discharge trading was proposed by Li and Hu [30]. The objective of minimizing the load variance under various constraints was solved by mixed integer programming. Further a novel algorithm and decentralized model for electricity trading was proposed using consortium blockchain. Their model implemented on hyperledger fabric reveals better security and privacy. Further, various types of incentives can be considered for creation of advanced system model. Blockchain approach has emerged as only viable means for effective charging management. Amrit et al. [34] have proposed a decentralized model for charging management of electric vehicles by taking into account both the system and user perspectives. An iterative consensus algorithm is implemented to facilitate the above objective. The scheme enables higher level of user satisfaction in addition to meeting the charging needs of the vehicles. Consortium blockchains have alleviated the problems of lack of coordination

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among energy companies. Zhengtang et al. [11] have proposed a novel model for EV charging that involves wide range of energy companies to provide hassle free charging for users. Their custom smart contract facilitates balancing the charging operation thereby ensures fair profit gain across network of companies. A mixed Integer programming model was developed along with a robust search algorithm for aiding the operations of the smart contract so as to provide better performance. The notion of preference and explicit tokens were not studied in the model. The mechanism of cross chain and novel incentive schemes may be explored for better performance. Charging management process not only involves coordination with suppliers and customers but also requires a secure payment method. Erdin et al. [12] proposed a bitcoin based approach for facilitating payment involved in electric vehicle charging. A payment network in parallel to main ledger is built with appropriate signatures and security permissions so as to reduce the transaction charges of bitcoin. An optimization model is built for the network of charging stations by considering various constraints. The process of registration is not completely focused in the model. Better insights can be obtained by evaluating the heuristics in case of massive network formation.

3.4 Other Hybrid Approaches

Fog computing is used in conjunction with blockchain in the scheme proposed by Li et al. [4]. A novel consortium blockchain model is designed and employed across fog nodes. The custom services are provided locally by the fog nodes with reduced delay and latency. Further, the authentication process along with smart contract and blockchain setup enables greater level of security and privacy during the process of electric vehicle charging. Sun et al. [29] have designed a novel model in which consortium blockchain is deployed in conjunction with fog computing to facilitate secure energy trading. In their work the byzantine fault tolerance algorithm is enhanced to provide a more efficient consensus algorithm. Their scheme is less resource intensive and ensures better privacy protection. However, mechanisms for automatic processing of the transactions can be implemented using smart contract as an extension of the model. Lightning networks are used along with blockchain to enable fool proof security in electric vehicle charge management process. Huang et al. [7] proposed a security model involving integration of lighting network, custom smart contracts and blockchain. The model defines distinct phases of authentication, scheduling and charging in addition to the initial registration phases for enhancing the security of the energy trading between the charging piles and electric vehicles. Several procedures for achieving trusted EV charging coordination without a central arbiter have been proposed in the past. Ping et al. [10] proposed a two phase process for electric vehicle charging. The initial phase deals with the process of evaluating the total charging demands and ensures if the same is met. The second phase deals with the process of fair allocation among entities. The model also employs a privacy protection algorithm thus providing a trusted fully autonomous coordination. Blockchain based solutions have also come up to deal with the problem of obtaining optimal charging schedule whilst achieving zonal energy balance in vehicular energy networks. Wang et al. [14] have proposed a novel blockchain model using advanced ledgers and cryptocurrencies for realizing a secure incentive mechanism. A reputation-based consensus protocol is deployed and local trust and credibility are exploited for the process. Optimizations can be considered at multiple levels to obtain better modeling of real time scenario.

4. Comparison of Approaches

This section provides a comparison of the popular technologies and approaches used for electric vehicle charging management. In majority of the works, combination of computing approaches such as blockchain, cryptography, and optimization was used to carry out operations such as charging coordination and energy trading. In certain works, novel consensus algorithms and new smart contracts were designed so as to facilitate effective charge management. New protocols and platforms for electric vehicle charging management were proposed in some of the works. Their model provides better security and privacy by means of implicit certificates. Compliance of the novel Table 1 shows the combination of technologies involved in each of the works proposed by the author for achieving effective charging management.

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Table 1 Combination of Technologies

Author	Techniques Involved			
	Blockchain	Cryptography	Optimization	Others
10, 14		×	×	✓
11,12		×		×
18,19,20,32,33		×	×	×
5		×	×	×
6	✓		×	×
7, 29	✓	×	×	
16,17		×	×	×
23			×	×
30,34	✓	×		×
15, 31		×	×	×
1,3,13,22,24		×	×	×
4		×	×	
21,28	✓	✓	×	×

5. Challenges

This section discusses the common challenges faced in the real-world while implementing the approaches. Blockchain based electric vehicle charging management solutions are still in the stage of development and hence their protocols suffer from several issues. The capacity of these solutions to handle huge volume of data, scalability of the solution, throughput concerns, possibility of privacy leaks, transaction loads, massive resource requirements, legal and regulatory concerns are commonly observed challenges in real time implementations. The major concern associated with cryptography-based schemes is that, they are computationally complex and highly resource intensive.

Conclusion and Future Directions

Electric vehicles have come up as a transformative technology that enables transportation with less pollution. Electric vehicle charge management is one of the most critical aspects that ensure success of this technology. Several researches have been carried out in the past on this subject. Computing techniques such as cryptography and blockchain facilitates effective management of electric vehicle charging, that involves a highly untrusted environment. This review covers in detail the various approaches for electric vehicle charging and the associated characteristics. Further, this paper discusses in detail various computing based techniques employed in the process of electric vehicle charging management. Finally, the review provides various challenges encountered in the real-world implementation. One of the directions for future work is to study the potential of electric vehicle charging management solutions in handling massive real time data. Effective mechanisms for reducing the storage requirements may be proposed based on the study. Yet another direction of investigation is to review the existing consensus and incentive mechanisms used and formulate better and more efficient approaches. Also studies can be carried out to identify the potential bottlenecks associated with the adaptability of electric vehicle charging management solution in a particular region. Thus, a context-based assessment might provide more valuable insights.

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