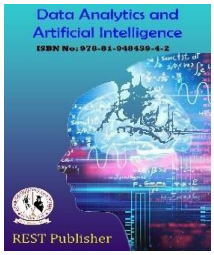
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Comparative Performance Evaluation of Computing System Architectures Using Grey Relational Analysis: A Multi-Criteria Decision-Making Approach

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Abstract: *Modern computing systems include decentralized, networked, distributed, multi-node, and federated systems. Evaluating the performance of these computing systems on various parameters is very important to choose the most effective system for practical application. It enables us to understand the relative advantages and disadvantages of different computing systems. It will aid us in choosing an appropriate computing system based on its performance. The methodology involves the application of grey relational analysis in analyzing data, deviation sequence, and coefficient values. The results obtained show that networked systems have the highest rating, followed by federated systems and distributed computing architecture. Multi-node and decentralized computing systems have comparatively poor ratings. It is concluded that networked systems perform efficiently and hence can be chosen as the best one. The significance of multi-criteria decision-making techniques can be understood from this study.*

Keywords: *Grey Relational Analysis, Computing Architecture, Multi-Criteria Decision Making.*

1. INTRODUCTION

Consensus-based approach combined with failure detection is designed to identify and mark observable misbehaviors by generated suspicions. A Peer Review algorithm creates a secure journal for each node, logging messages sent and received, as well as application input/output values. In distributed systems, failures can be due to hardware or software problems or a result of malicious attacks targeting nodes. The benefits of Peer Review can be proved via practical implementation in various decentralized systems. Net Bet provides an opportunity to have a common workspace regardless of time and place, thus offering means for research in distributed systems and networking. Net Bet successfully solves problems regarding reliability of distributed systems built with unstable commodity hardware; however, more improvement is needed in this aspect. Access to root for nodes makes experimentation with kernel changes or raw sockets possible. Batch processing can provide an opportunity to study problem space exhaustively in a very efficient way. A standard single-node experiment takes around 135 seconds, of which most of the time is used for rebooting. Message-passing approach is often used in building distributed systems, which rely on communication between processes through exchange of data over the network. Decentralized systems tend to be deployed in data centers composed of thousands of computers that run a large number of applications. In the case of Coda system, weak consistency model is enough; but other systems can reap great benefits from using distributed transactions, for example, Sinfonia. With the growth of decentralized systems, there is a tendency towards automating the management processes via decentralized management facilities. They provide both negative and positive authentication services and inconsistency detection capabilities. Policy-based management becomes increasingly important in managing complex and large-scale systems; however, development of lower-level policies from high-level descriptions turns out to be a very complicated problem similar to software synthesis. Operating system issues can be viewed from the perspective of distributed computing to come up with new solutions and angles on them. In these systems, the lengthy RPCs may be minimized through the use of more compact representations for the higher-level procedures, minimizing

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the RPCs down to one. This way, communication becomes an executable transfer only. Despite similarities between decentralized systems and aggregate systems, algebraic analysis methods can still be used. Research indicates that the behavior of these systems can be described through mathematical relations based on polynomials and sub-modules. The behaviors of the systems tend to be expressed in terms of functions comprising exponential parts obtained from the roots of polynomials. Physical time plays an important part in influencing the semantics of decentralized computing systems. Many ways have been developed for addressing their characteristics including different evaluation mechanisms. Examples include systems like Ode, which excel at events, but their language and use can be confusing. As the starting point for analysis, several replication techniques in distributed and database systems can be analyzed using abstract protocols. Specifications of problems in distributed systems are normally categorized as either security or liveness requirements. Replication in distributed systems can occur in either deterministic or non-deterministic ways. In decentralized systems, there is normally greater emphasis on ordering. With the increase in size and complexity of decentralized systems, there has been an increased requirement for automated management. This is because in an organization involving large number of components, it is not practical to define the individual policies for each component. It is important to find a balance among simplicity, security, and flexibility when implementing decentralized systems. This can be achieved by using language-based approaches that decouple components as suggested in Koenig. In addition, globally unique random numbers are used in distributed systems to distinguish nodes. Future distributed systems should pay due attention to securing the systems to ensure that they remain reliable. There has been much progress made in the area of workstations; however, there is still room for improvement through the evaluation of their use cases in the WAN environment, comparison of unified information servers against single information servers, and identification of diverse user access methods. Blockchain technology may be considered revolutionary in terms of creating secure transactions that do not depend on any third-party entity, but operate in a trustless way. The core principle of blockchain technology involves keeping the data stored in multiple nodes in a distributed way by means of blocks connected one to another. The consensus algorithms, such as proof-of-work and proof-of-stake, are responsible for ensuring the validity of the transactions and reaching an agreement. The applications of blockchain are numerous since it can be used both in finance and other spheres were transaction transparency and data integrity matter greatly. Apart from cryptocurrencies, such as Bitcoin and Ethereum, it may be applied to trace products in the supply chain or securely store medical data of patients. Still, some issues, including scalability issues, require further attention.

2. MATERIALS AND METHODS

Alternatives

- **Decentralized Computing Systems:** Decentralized computing systems are described as the type of computing system wherein the computations take place in an independent manner by several independent nodes rather than by the use of a central node or central authority. Such types of computing systems find application across various sectors, starting from the blockchain sector to cloud computing.
- **Networked Computing Systems:** Networked computing systems are referred to as those computing devices or computers which are interconnected via a network. This network allows data transmission and hence, enables communication between computing devices. There are many types of networked computing systems available, such as the internet, LANs, enterprise computing systems, and IoT.
- **Distributed Computing Systems:** The distributed computing systems are defined as multiple computing devices which cooperate in order to execute complex computations. They work by splitting up workloads and executing them simultaneously in a parallel fashion. Grid computing systems, cluster computing systems, and cloud computing belong to distributed computing systems.
- **Multi-Node Computing Systems:** Multi-node computing systems are known to comprise several computing devices which work together in collaboration with each other. Such multi-node computing systems share their computing and storage resources amongst them. These multi-node computing systems have wide-ranging use cases.
- **Federated Systems:** A federated system entails an arrangement whereby multiple independent subsystems interact together in order to attain common goals yet maintain their independence. The federation enables data sharing across several geographic areas securely. Federated systems are useful in application scenarios like healthcare data integration, organizational interactions, and federated learning.

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Evaluation Parameters

- **Availability:** Availability indicates the ability of the system to function and be accessed whenever it is required. Availability becomes critical in such areas as healthcare, financial services, and e-commerce, where any outage would lead to severe effects. An outage will have such effects as reduced productivity, financial losses, and diminished consumer confidence. There are various strategies used in improving the availability of a system, including redundancy and failure transfer.
- **Response Time:** Response time refers to the period that elapses from the moment a user requests services to the point when the system responds. Response time is crucial in determining the performance of systems. Fast response time ensures improved performance, whereas poor response times reduce system performance. Efficient response time is achieved through improvements in algorithms, reducing network delays, and improved hardware performance.
- **Cost:** Cost is an economic metric that includes expenses required for system implementation and operation, which include installation costs, licensing fees, maintenance fees, power consumption, and upgrading cost.
- **Speed:** This is dependent on the computational ability of the computer and other related variables such as the speed at which the data can be transferred. Improvement of speed can be accomplished through better hardware, improved software, or even parallel computing.
- **Storage Capacity:** The storage capacity is the amount of data that the system can store efficiently. It becomes very essential nowadays when large amounts of data are being generated each day. Proper storage would allow efficient access and appropriate protection of data.

GRA

The Gray relational analysis (GRA) model has experienced many developments from models that depend on proximity to evaluate similarity to more sophisticated models that take into account proximity and similarity. To conduct an extensive evaluation of similarity, current GRA models utilize both absolute and relative Gray relational coefficient indicators. In cases where there is a need to evaluate absolute variations in data series and the rate of variation from the original point of departure, the synthetic GRA model becomes useful. The synthetic coefficient (u) is estimated by weighting the two associated concepts proportionally. The latest development in GRA is the estimation of sequence distances that involve up to three ranks. This development has increased the discriminating ability of GRA. Tang Yaoguo developed a model that integrates the conventional real number sequence GRA model to the interval number sequence GRA model. The model uses the idea of intervals to estimate distances. This innovation reduces the complications involved in Gray relational analysis of multidimensional data from categorical integral models to multiple integrals. This represents the idea of generalization of the Gray relational analysis model. This paradigm of group-wise rotation provides a possibility for independent rotation of the kernel set used for rotation, which results in a reduction of the number of total parameters when compared to the existing state-of-the-art methods. This new architecture permits effective adaptation and implementation in the contemporary convolutional networks, providing less loss of features and increased performance. In order to study the effect of structural parameters, an elimination experiment was carried out with respect to the number of groups in the GRA structure. The results show that the group-wise rotation concept can effectively capture the oriented object by means of the kernels' independent rotation, which increases directional sensitivity. In the realm of decision making under conditions of uncertainty, the SVPNS-MADM model, or a MADM technique based on GRA in single-valued pentapartitioning neutrosophic sets (SVPNS), was introduced. The definition of Hamming distance for SVPNS is developed as a result of the neutrosophication process of the GRA methodology. Pentapartitioned neutrosophic sets are a potent mathematical apparatus that can be applied in situations of uncertainty and randomness. For instance, Mondal and Pramanik applied the neutrosophic GRA based decision making tool under the SVNS environment towards material selection during the process of construction, more specifically to determine optimal clay bricks. In order to aid these decision-making processes, the notion of PNS was introduced by Mallik and Pramanik. Detailed explanation and numerical illustration of the SVPNS-MADM technique is discussed in section 5 while section 6 discusses the concluding observations and future perspectives. The application of the GRA method turns out to be both flexible and pragmatic in dealing with multiple uncertainties. The approach does not make use of large-scale data base as well as rigid classification procedure. The determination of the criterion weight through GRA aids in formulating effective optimization models using fuzzy data for decision making purposes. On the other hand, the use of GRA technique has aided in improving the valuation of used cars through modeling using artificial neural network models.

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3. RESULTS AND DISCUSSION

TABLE 1. Distributed System

	availability	response time	cost	speed	storage capacity
Decentralized Systems	35.0	57.0	27.0	58.0	45.0
Networked Systems	65.0	67.0	75.0	54.0	84.0
Distributed Computing Architectures	25.0	42.0	67.0	27.0	29.0
Multi-node Systems	35.0	53.0	67.0	51.0	61.0
Federated Systems	47.0	64.0	81.0	35.0	85.0

Networked Systems demonstrate high availability (65.0), high response time (67.0), and high storage capabilities (84.0); however, their price is comparatively higher (75.0). Federated Systems possess a high rate of storage (85.0) and response time (64.0) but have a higher price than others (81.0). Multi-node Systems are efficient in terms of all characteristics. Decentralized Systems have medium and consistent rates, whereas Distributed Computing Architectures have low speed and storage.

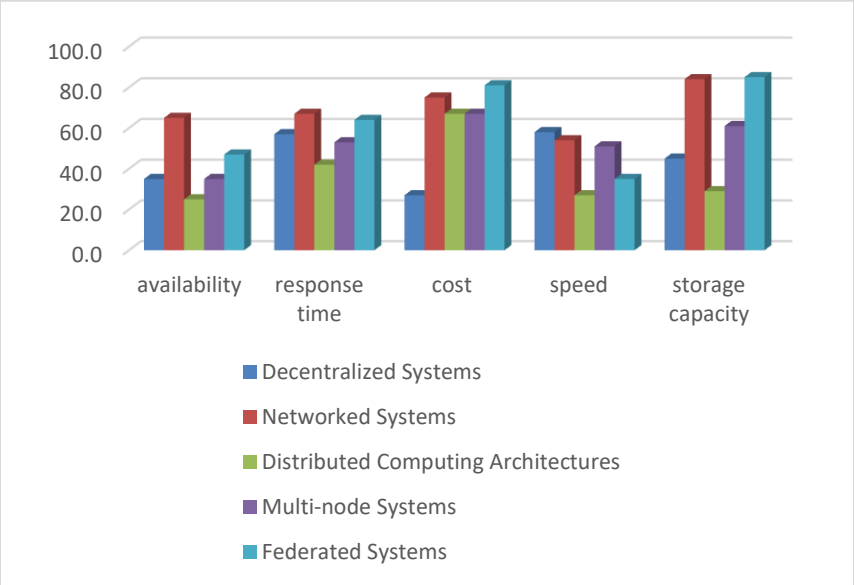


FIGURE 1. Comparative Analysis of Performance of Computer Architectures on Key Performance Indicators

The Figure below provides a comparison between five computer architectures – Decentralized Architecture, Networked Architecture, Distributed Computing Architecture, Multi-node Architecture, and Federated Architecture – on five key performance indicators such as availability, response time, cost, speed, and storage capacity. Networked and Federated Architectures have generally shown better performance in all these areas, especially in terms of cost and storage capacity. On the other hand, the Decentralized and Distributed Computing Architectures have relatively low-performance numbers.

TABLE 2. Normalized Data

Normalized Data					
	availability	response time	cost	speed	storage capacity
Decentralized Systems	0.2500	0.6000	0.3292	0.0000	0.7143
Networked Systems	1.0000	1.0000	0.9255	0.1290	0.0179
Distribute Computing Architectures	0.0000	0.0000	0.8261	1.0000	1.0000
Multi-node Systems	0.2500	0.4400	0.8261	0.2258	0.4286
Federated Systems	0.5500	0.8800	1.0000	0.7419	0.0000

The normalized data highlights the comparative performance of different systems across key criteria. Networked Systems excel in availability and response time, showing high efficiency, but perform poorly in storage capacity. Distributed Computing Architectures achieve the best results in speed and storage, though they lack availability and

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responsiveness. Federated Systems demonstrate strong cost efficiency and good overall performance except in storage. Multi-node and Decentralized Systems maintain moderate, balanced performance without extreme strengths or weaknesses.

TABLE 3. Deviation sequence

Deviation sequence					
	availability	response time	cost	speed	storage capacity
Decentralized Systems	0.7500	0.4000	0.6708	1.0000	0.2857
Networked Systems	0.0000	0.0000	0.0745	0.8710	0.9821
Distributed Computing Architectures	1.0000	1.0000	0.1739	0.0000	0.0000
Multi-node Systems	0.7500	0.5600	0.1739	0.7742	0.5714
Federated Systems	0.4500	0.1200	0.0000	0.2581	1.0000

The deviation values represent the extent to which each architecture deviates from the perfect performance for each criterion. The Distributed Computing Architecture demonstrates high deviation for availability and response time, while there is zero deviation for speed and storage, meaning that the architecture is highly proficient in these two categories. The Networked System architecture presents low deviation values for availability and response time, indicating consistency, but high deviation for storage. The Federated System architecture performs excellently in cost and response time but presents maximum deviation values for storage.

TABLE 4. Grey relation coefficient

Grey relation coefficient					
	availability	response time	cost	speed	storage capacity
Decentralized Systems	0.4000	0.5556	0.3333	0.3333	0.6364
Networked Systems	1.0000	1.0000	0.8182	0.3647	0.3373
Distributed Computing Architectures	0.3333	0.3333	0.6585	1.0000	1.0000
Multi-node Systems	0.4000	0.4717	0.6585	0.3924	0.4667
Federated Systems	0.5263	0.8065	1.0000	0.6596	0.3333

The Grey Relation Coefficient scores represent the degree of association of each system with the ideal solution. Networked Systems have the greatest performance on issues of availability and responsiveness, with Grey Relation Coefficients being one, and they maintain efficiency in terms of cost. Distributed Computing Architectures perform well with regards to speed and storage capabilities as they have the maximum possible Grey Relation Coefficients indicating their supremacy when it comes to high-performance computing. Federated Systems have the highest ranking with respect to cost and significant responsiveness.

TABLE 5. GRG

	GRG
Decentralized Systems	0.4517
Networked Systems	0.7040
Distributed Computing Architectures	0.6650
Multi-node Systems	0.4779
Federated Systems	0.6651

The Grey Relational Grade (GRG) is an index value that measures the overall performance of each alternative through the summing up of all indices. The Networked System has the highest GRG value (0.7040) compared to other alternatives, showing that it is the best performer overall. The Federated Systems (0.6651) and Distributed Computing Architecture (0.6650) almost have identical performance values but are not as good as those for the topmost performer.

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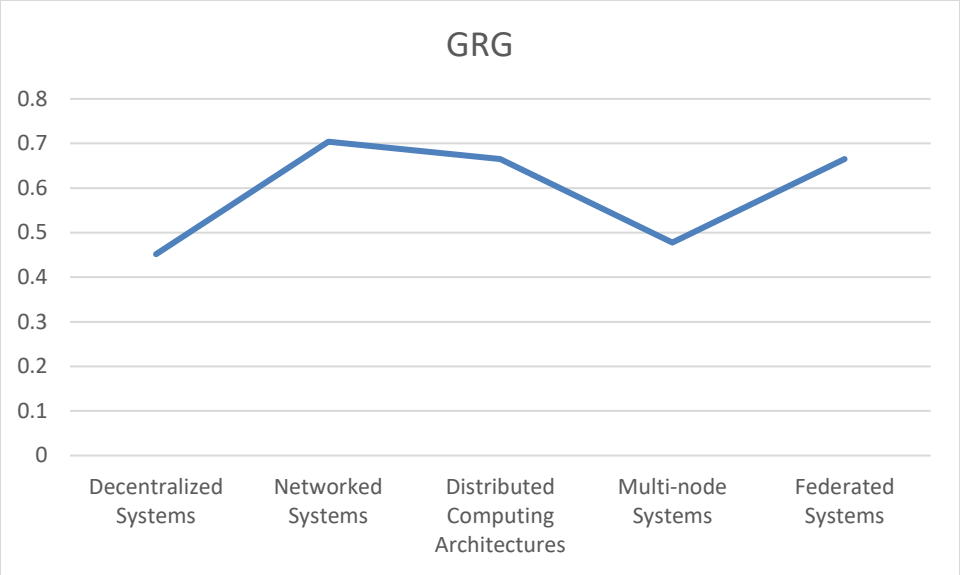


FIGURE 2. Grey Relational Grade (GRG) Scores Across Computing System Architectures

Grey Relational Grade (GRG) is determined for five categories of architecture of computing systems, namely Decentralized Systems, Networked Systems, Distributed Computing Architecture, Multi-node Systems, and Federated Systems. The highest value of GRG for Networked Systems was recorded to be around 0.71, while Distributed Computing Architectures and Federated Systems exhibited moderate GRG values of around 0.66. However, Decentralized Systems and Multi-node Systems exhibited poor GRG values of around 0.45 and 0.48 respectively.

TABLE 6. Rank

	Rank
Decentralized Systems	5
Networked Systems	1
Distributed Computing Architectures	3
Multi-node Systems	4
Federated Systems	2

The outcomes from the ranking show quite clearly what the preference is for the efficiency that these systems provide. Networked Systems rank first because they display the greatest efficiency. Federated Systems rank second and third are Distributed Computing Architectures. Multi-node Systems rank fourth and have average efficiency, whereas Decentralized Systems come in fifth and thus rank lowest among all the systems.

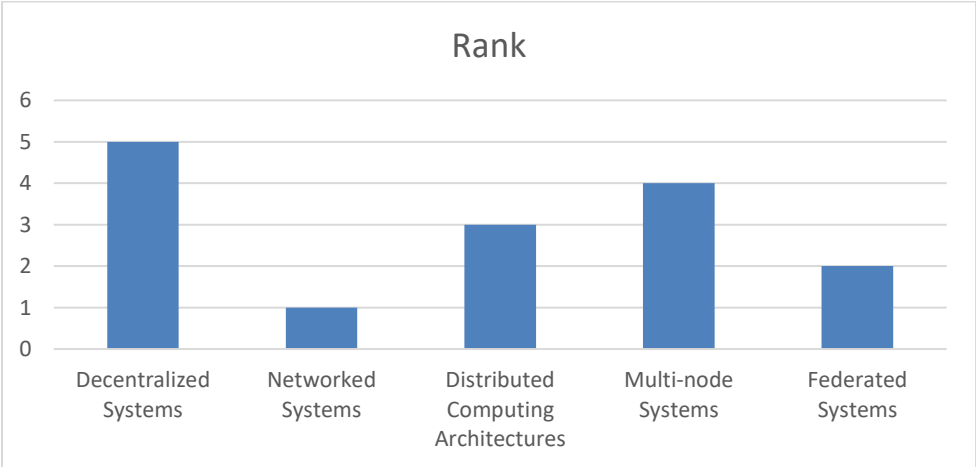


FIGURE 3. Performance Ranking of Computing System Architectures Based on Grey Relational Analysis

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The above figure shows the ranks arrived at from GRG method among five architectures. The first rank means that the system architecture is more effective compared to others under consideration while the fifth rank implies the worst system architecture. Networked Systems was found to be the best architecture while Federated Systems took the second-best architecture position while Distributed Computing Architectures came third.

4. CONCLUSION

The comparative analysis of the five computing system architectures under study involved the assessment and evaluation of their performance along five critical parameters namely availability, response time, cost, speed, and storage capacity. The GRA technique was used in measuring the relative performances of the systems in question by calculating the Grey Relational Grades (GRGs) of each architecture. According to the experiment results, there was a marked difference in the performances of the architectures being studied. Coming second on the performance list were Federated Systems with impressive GRGs, showing their strength especially in cost and storage capacity. On the other hand, Distributed Computing Architecture scored a moderately good performance due to balanced performance levels on all parameters under study. Multi-node Systems and Decentralized Systems lagged behind in terms of performance levels with Rank 4 and Rank 5 respectively, as indicated by their relatively poor GRG values. This shows that the two architectures did not perform well compared to the rest.

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