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Performance evaluation of microservices communication with REST, GraphQL, and gRPC

Muhammad Niswar, Reza Arisandy Safruddin, Anugrayani Bustamin, Iqra Aswad

***Abstract*—Microservice architecture has become the design paradigm for creating scalable and maintainable software systems. Selecting the proper communication protocol in microservices is critical to achieving optimal system performance. This study compares the performance of three commonly used API protocols: REST, GraphQL, and gRPC, in microservices architecture. In this study, we established three microservices implemented in three containers and each microservice contained a Redis and MySQL database. We evaluated the performance of these API protocols using two key performance metrics: response time and CPU Utilization. This study performs two distinct data retrieval: fetching flat data and fetching nested data, with a number of requests ranging from 100 to 500 requests. The experimental results indicate that gRPC has a faster response time, followed by REST and GraphQL. Moreover, GraphQL shows higher CPU Utilization compared to gRPC and REST. The experimental results provide insight for developers and architects seeking to optimize their microservices communication protocols for specific use cases and workloads.**

***Keywords*—Microservices, API, gRPC, REST, GraphQL.**

I. Introduction

SOFTWARE development using microservices architecture has changed the way we design applications. This architecture advocates breaking down complex applications into smaller, self-contained microservices. Each microservice has specific tasks and can be managed and changed without affecting other components. It allows development teams to focus on specific aspects of the application, improving scalability, faster changes, and better fault isolation [1].

In microservice communication, two commonly used protocols are Representational State Transfer (REST) and GraphQL. REST has been one of the most widely used data exchange methods, which relies on a number of endpoints to access and manipulate data. Although REST remains popular, it comes with certain drawbacks such as over-fetching or under-fetching data, where the retrieved data may exceed or fall short of actual needs. Addressing these drawbacks, GraphQL emerges as an attractive alternative. GraphQL allows clients to specify the data they needed [2] [3], overcoming REST's inefficiency problem and giving application developers more control.

In addition to REST and GraphQL, another data exchange method gaining attention today is Remote Procedure Call (gRPC). gRPC offers an efficient and versatile approach to communication among distributed services. Unlike the REST and GraphQL methods that utilize the HTTP/1 protocol, gRPC employs the HTTP/2 protocol and supports streaming data. gRPC simplifies remote procedure calls (RPC) across various programming languages, delivering enhanced performance and speed in microservice communication [4].

In this research, we aim to evaluate and compare the performance of REST, gRPC, and GraphQL for data exchange within a microservice system under both fetching flat data and nested data. Our study includes a performance analysis with key performance metrics, including Response Time and CPU Utilization. By evaluating these three communication protocols, we aim to assist developers and organizations in making informed decisions when designing and implementing microservices-based systems.

II. Related Work

There have been many studies that compare the performance of REST and GraphQL. Reference [5] describes the performance of the REST and GraphQL in using the Ocelot and Hot Chocolate API gateways in the case of write data and get data. Reference [6] discusses the advantages and disadvantages of the REST and GraphQL. When dealing with data that undergoes frequent changes and needs to be handled efficiently with resource optimization in mind, GraphQL is the preferred choice. Reference [7] describes the REST as the appropriate selection for the data exchange method in situations where data is consistently accessed. Reference [8] [9] focuses on implementing GraphQL in a web application, which shifts from REST to GraphQL. Reference [10] [11] compares REST and GraphQL for API web design, focusing on response times and data sizes. Two NodeJS apps performed CRUD operations on MongoDB. There are no major differences for a few queries or resource removal. GraphQL outperformed REST when displaying data under heavy loads and for small data portions, while REST performed better for large data portions. Reference [12] compared the performance of REST and GraphQL architectural models in three different applications based on metrics like response time and data transfer rate. It found that GraphQL improved performance in most cases, except for workloads above 3,000 requests, where REST performed better. For smaller workloads (100 requests), both REST and GraphQL showed similar performance. Reference

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[13] compares REST and GraphQL for data communication in web applications. An experiment was conducted to assess the performance of both approaches when requesting nested objects. The results indicate that GraphQL outperformed REST in most scenarios. Reference [14] assesses these benefits in practice by migrating seven systems from standard REST-based APIs to GraphQL. The key finding is that GraphQL can significantly reduce the size of JSON documents returned by REST APIs, with a reduction of 94%.

In addition to studies on the performance of REST and GraphQL, there are several studies that discuss the performance of gRPC. Reference [15] explains microservices and gRPC, covering their workings, implementations, limitations, and applications. It relies on reliable online sources to demonstrate a microservice with gRPC servers. Reference [16] delves into microservices architecture and its communication methods, primarily REST API and gRPC. It evaluates the pros and cons of both approaches and conducts a comparative analysis. It presents a decision-making framework for organizations to determine if adopting gRPC offers substantial benefits over REST for their architecture. Reference [17] explores the potential of gRPC for improving content delivery in Kentico Kontent, a widely used Content Management System. The study aims to evaluate gRPC using the Goal Question Metric (GQM) methodology. The findings indicate that gRPC performs exceptionally well in scenarios involving mobile or IoT applications as clients. Reference [18] discusses load balancing challenges in gRPC microservices within Kubernetes using Go. Reference [19] proposes a solution for building gRPC services using NodeJS as independent modules or components. Reference [20] focuses on analyzing emerging technologies for cross-process communication between Linux and Android-based platforms using the gRPC framework. The study involves developing applications in various object-oriented programming languages to perform remote procedure calls between a single-board computer and a smartphone. The performance of computational offloading for algorithms in each platform is evaluated through data analysis. Our study focuses on the performance comparison of REST, GraphQL, and gRPC in microservice environments to provide valuable insights into their respective advantages and drawbacks. We aim to reveal which communication protocols operate efficiently across various scenarios and workloads.

III. API Protocols

Application Programming Interface (API) protocols are sets of rules, conventions, and standards that facilitate communication and interaction between diverse software programs and systems. These protocols define the structure and format of requests and responses, as well as the methods and rules for communication. The API acts as a bridge that allows developers to integrate functionality. The most commonly used API protocols are REST, GraphQL, and gRPC.

A. Representational State Transfer (REST)

REST is an API development architecture that provides client-server-based communication over the HTTP protocol. REST was first introduced by Roy Fielding in 2000 as his doctoral dissertation at the University of California [21]. REST uses the HTTP/1.1 protocol to send data from clients to servers. In systems that use REST, each service usually has a certain endpoint so that it can interact between services and exchange data. In REST, there are several methods that can be used including GET, POST, PUT, and DELETE. The REST supports several formats for presenting data, such as JSON and XML. JSON is used more often because of its simplicity and efficiency. Fig. 1 shows the REST communication model.

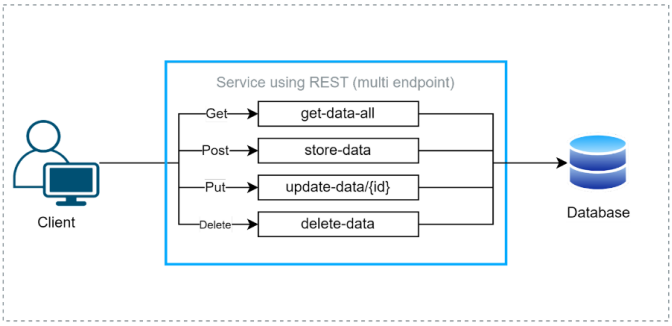


Fig. 1. REST Model

B. GraphQL

GraphQL, a query language for APIs, was created by Facebook and used in communication between clients and servers [22]. The client requests data as needed with a query so the server can return a response according to the query request from the client. GraphQL offers an alternative solution to REST and allows developers to request specific data in a more efficient and flexible format. The background of the development of GraphQl was to meet Facebook's needs in handling complex data and to overcome the problems in the REST, such as over-fetching or under-fetching data. One of the main advantages of GraphQL is its flexibility. With GraphQL, clients can request multiple data sources in a single request, reducing the requests needed to retrieve the desired data. In addition, clients can validate their query requests by using clearly defined types before sending them to the server. Fig. 2 shows the GraphQL communication model.

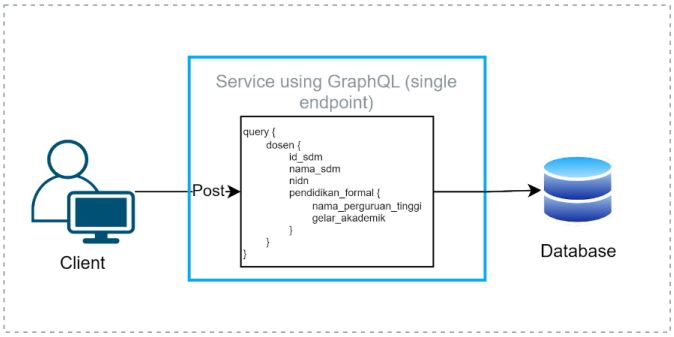


Fig. 2. GraphQL Model

C. gRPC

Google Remote Procedure Call (gRPC) [23] is an open-source, high-performance framework for building efficient, distributed systems and microservices. It was developed by Google and designed to enable communication between applications and services in a way that is both language-agnostic and platform-independent. The gRPC allows applications to define their service methods and data structures using Protocol Buffers (protobufs), a language-neutral interface definition language. Based on these definitions, it generates client and server code in multiple programming languages. Clients and servers can then communicate using HTTP/2, benefiting from features like bidirectional streaming, multiplexing, and efficient serialization. It is a high-performance framework for building efficient and language-agnostic distributed systems, microservices, and APIs. Fig. 3 shows the gRPC communication model.

Fig. 3. gRPC Model

IV. System Design

In this study, we have developed microservices using Go (golang), with the study case of Integrated Education Information System in the Ministry of Education and Culture Indonesia, known as SISTER. It is an integrated information system used to manage and streamline various educational data and processes, including student data, teacher/lecturer information, school management, and other related aspects of the education system in Indonesia. This system aims to improve the efficiency and effectiveness of educational management and administration.

Our study utilizes Hasanuddin University's SISTER data, specifically lecturer data and lecturer's educational background. This research aims to assess the performance of REST, gRPC, and GraphQL. Our proposed service architecture consists of three services implemented in three containers including authentication services, fetching lecturer profile service (Flat Data), and fetching lecturer profile with educational background service (Nested Data). Each service contained a Redis and MySQL database. Fig. 4 shows the architecture of our system.

The evaluation comprises two distinct data retrieval, i.e., fetching flat data and nested data. Fetching flat data refers to JSON structures where all the data is organized at the same level, typically using simple key-value pairs. On the other hand, fetching nested data refers to JSON structures where data is organized hierarchically, with one or more items containing other items as properties or elements.

This study utilizes Redis and MySQL as Database Management Systems (DBMS), with MySQL as the long-term storage solution and Redis as the in-memory storage system. Being an in-memory database, Redis excels in read-heavy operations and is ideal for our use cases demanding low-latency data access. Initially, we imported the SISTER data, available at http://sister.unhas.ac.id/ws.php/1.0 into the MySQL database. This imported data includes lecturer profile data totaling 2,221 entries and lecturer profiles with educational backgrounds, which amounts to 6,197 entries. Subsequently, Redis exported the SISTER data from the MySQL database. The service fetches data from Redis rather than directly from the MySQL database in the data retrieval process. In cases where Redis lacks the required data, the service retrieves it from the MySQL database and caches it within Redis. During testing, data retrieval occurs from Redis. Fig. 5 illustrates the data fetching process within the services.

Fig. 6 shows that JSON represents flat data. It includes a single object within an array, with several key-value pairs. Fig. 7 shows that JSON represents nested data within the "pendidikanformal" array to represent the lecturer's educational backgrounds.

V. Performance Evaluation and Result

Performance evaluation has been conducted to assess the impact of data fetching load on response time and CPU performance. This evaluation aims to evaluate the data exchange with REST, gRPC, and GraphQL to determine the most suitable approach for both flat data and nested data cases. We used Apache JMeter for API load testing. The Apache JMeter application is open source software designed to conduct load test on functional capabilities and assess performance [24].

A. Concurrent Requests Evaluation

In concurrent requests evaluation, multiple clients initiate requests concurrently, ranging from 100 to 500 requests, to assess response times and CPU utilization under these simultaneous load conditions. This approach allows us to gauge how the system performs when subjected to varying levels of concurrent user activity. Response time measurements were conducted for both the fetching flat data and nested data. Each evaluation was carried out over ten iterations. The average response time (aveRT) can be calculated using Eq. 1 :

$$aveRT = \frac{1}{n}\sum_{i=1}^{n} t_{(resp)} - t_{(req)} \tag{1}$$

In Eq. 1, n represents the number of requests, i represents the request number, $t_{(req)}$ is the timestamp when the request is sent and $t_{(resp)}$ is the timestamp when the response is received. The equation calculates the average time interval required for the client to receive a response from the sent request.

Fig. 8 shows the average response time for fetching flat data. For REST, the average response times increase as the number of requests increases, ranging from 1,113.33 ms for 100 requests to 4,009.83 ms for 500 requests. gRPC offers significantly lower response times, with averages ranging from 233.84 ms for 100 requests to 2,606.59 ms for 500 requests. On the other hand, GraphQL shows the highest response times, with averages increasing from 3,852.07 ms for 100 requests to

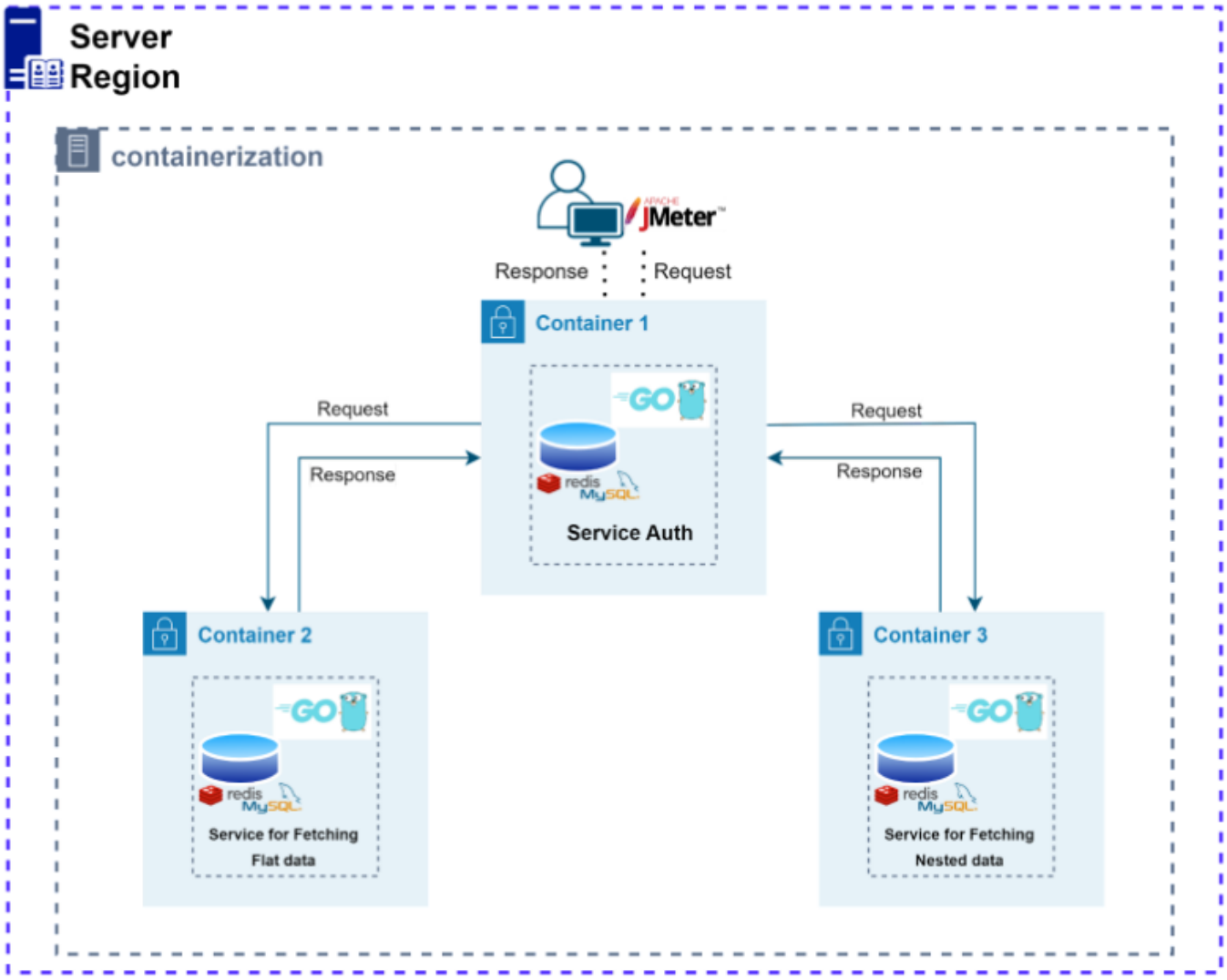


Fig. 4. System Architecture

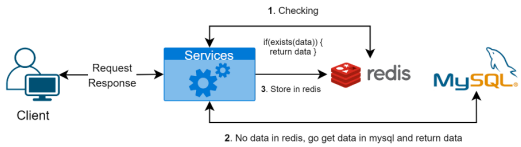


Fig. 5. Data Fetching Process


```
Response Flat Data
Return [
      {
        "id_sdm": "b2f68ea2-06c0-4a72-ac4f-cf8e3e3dd4dd",
        "nama_sdm": "Employee Name",
        "nidn": 2233443322,
        "nip": 190010101900101000,
        "nama_status_aktif": "Active",
        "nama_status_pegawai": "PNS",
        "jenis_sdm": "Lecturer"
      }
  ]
```

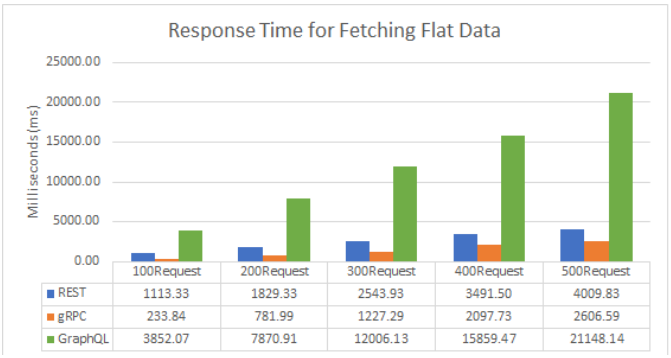

Fig. 6. JSON for Fetching Flat Data


```
Response Nested Data
Return [
      {
        "id_sdm": "b2f68ea2-06c0-4a72-ac4f-cf8e3e3dd4dd",
        "nama_sdm": "Employee Name",
        "nidn": 2233443322,
        "nip": 190010101900101000,
        "nama_status_aktif": "Active",
        "nama_status_pegawai": "PNS",
        "jenis_sdm": "Lecturer",
        "pendidikan_formal": [
          {
            "id": "00000000-0000-0000-0000-000000000000",
            "jenjang_pendidikan": "S1",
            "gelar_akademik": "S.T",
            "bidang_studi": "Informatics Engineering",
            "nama_perguruan_tinggi": "James Cook University",
            "tahun_lulus": 2023
          }
        ]
      }
  ]
```


Fig. 7. JSON for Fetching Nested Data

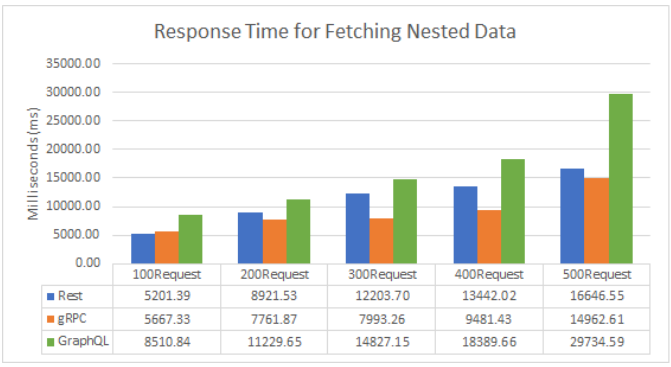
21,148.14 ms for 500 requests. In summary, gRPC provides the fastest response times, followed by REST, while GraphQL lags with substantially higher response times, particularly as the request volume increases.

Fig. 9 shows the average response time for fetching nested data. For REST, as the number of requests increased from 100 to 500, the average response times grew from 5,201.39 ms to 16,646.55 ms. In the case of gRPC, the response times also increased with more requests, ranging from 5,667.33 ms to



	100Request	200Request	300Request	400Request	500Request
REST	1113.33	1829.33	2543.93	3491.50	4009.83
gRPC	233.84	781.99	1227.29	2097.73	2606.59
GraphQL	3852.07	7870.91	12006.13	15859.47	21148.14

Fig. 8. Average response time for Fetching Flat Data

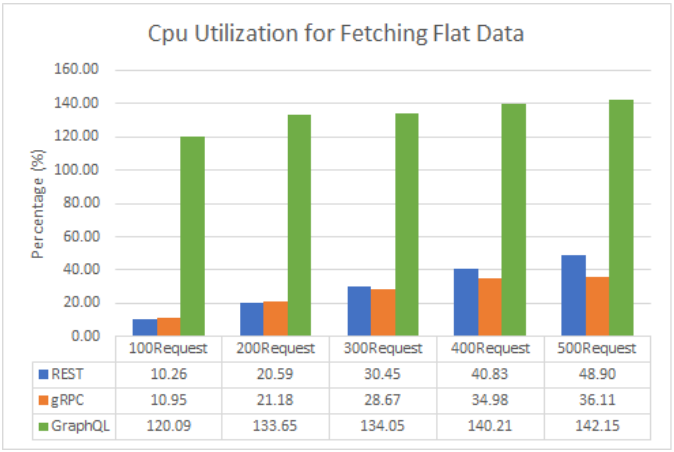


	100Request	200Request	300Request	400Request	500Request
Rest	5201.39	8921.53	12203.70	13442.02	16646.55
gRPC	5667.33	7761.87	7993.26	9481.43	14962.61
GraphQL	8510.84	11229.65	14827.15	18389.66	29734.59

Fig. 9. Average response time for Fetching Nested Data

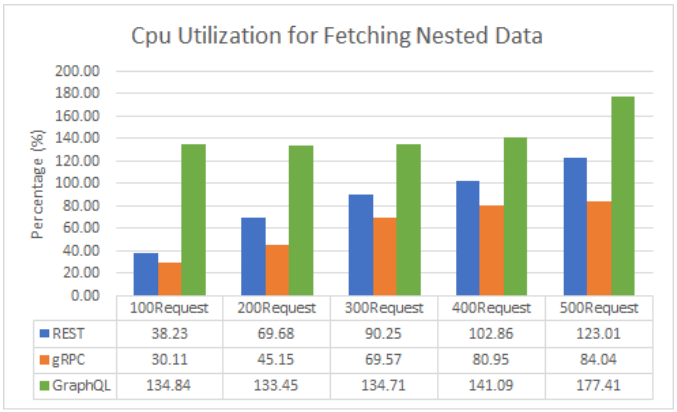
14,962.61 ms. GraphQL showed the highest response times, averaging 8510.84 ms to 29,734.59 ms as the number of requests increased. Overall, REST had the lowest response times, followed by gRPC, while GraphQL exhibited the slowest response times, particularly with a larger number of requests.

We also measured CPU utilization to assess the impact of data fetching load on CPU performance. We aim to gauge how the act of fetching data, whether it involves retrieving flat or nested data, influences the CPU utilization. We examine CPU performance across a range of scenarios, each involving a varying number of data retrieval requests, spanning from 100 to 500 requests.



	100Request	200Request	300Request	400Request	500Request
REST	10.26	20.59	30.45	40.83	48.90
gRPC	10.95	21.18	28.67	34.98	36.11
GraphQL	120.09	133.65	134.05	140.21	142.15

Fig. 10. Average CPU Utilization for Fetching Flat Data



	100Request	200Request	300Request	400Request	500Request
REST	38.23	69.68	90.25	102.86	123.01
gRPC	30.11	45.15	69.57	80.95	84.04
GraphQL	134.84	133.45	134.71	141.09	177.41

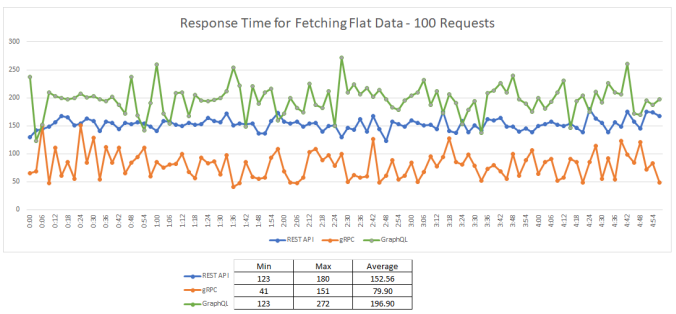
Fig. 11. Average CPU Utilization for Fetching Nested Data

Fig. 10 shows the average CPU utilization for fetching flat data. For REST requests, as the number of requests increased from 100 to 500, CPU utilization gradually increased from 10.26% to 48.90%. With gRPC requests, CPU utilization also increased with the number of requests, going from 10.95% to 36.11%. However, for GraphQL requests, CPU utilization exhibited a different trend, starting remarkably high at 120.09% for 100 requests and gradually increasing to 142.15% for 500 requests. These figures highlight the varying CPU resource demands of different data request protocols. GraphQL was notably more resource-intensive than REST and gRPC, showing increased linear CPU utilization with increasing request loads.

Fig. 11 shows the average CPU utilization for fetching nested data. For REST, CPU utilization increased from 38.23% at 100 requests to 123.01% at 500 requests. gRPC had lower CPU utilization, starting at 30.11% and reaching 84.04% at 500 requests. In contrast, GraphQL showed significantly higher CPU utilization, exceeding 100% even at 100 requests and peaking at 177.41% at 500 requests, suggesting higher processing demands for GraphQL queries than REST and gRPC as the request load increased.

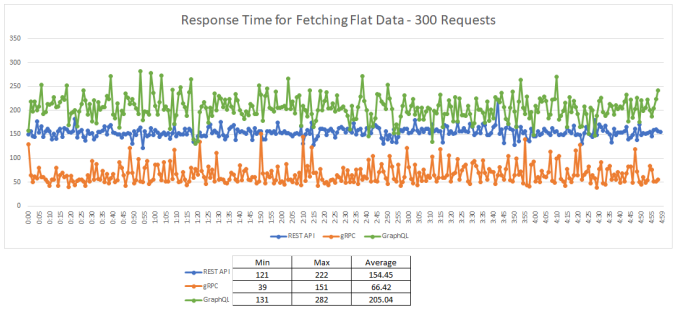
B. Consecutive Requests Evaluation

In the consecutive request evaluation, clients initiate requests consecutively for five minutes with a varying number of requests, from 100-500 requests, to measure response time and CPU utilization during the test.



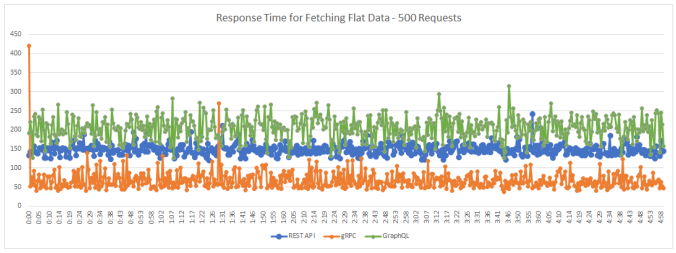
	Min	Max	Average
REST API	123	180	152.56
gRPC	41	151	79.90
GraphQL	123	272	196.90

Fig. 12. Response time during five minutes for Fetching Flat Data (100 requests)



	Min	Max	Average
REST API	121	222	154.45
gRPC	39	151	66.42
GraphQL	131	282	205.04

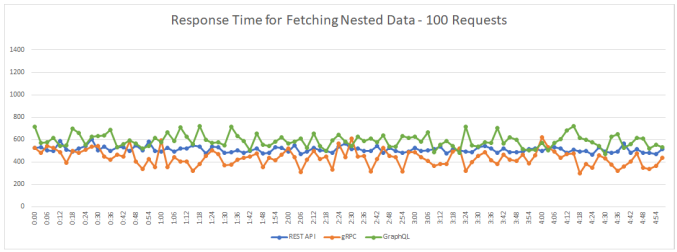
Fig. 13. Response time during five minutes for Fetching Flat Data (300 requests)



	Min	Max	Average
REST API	121	243	149.68
gRPC	37	420	67.75
GraphQL	126	315	204.35

Fig. 14. Response time during five minutes for Fetching Flat Data (500 requests)

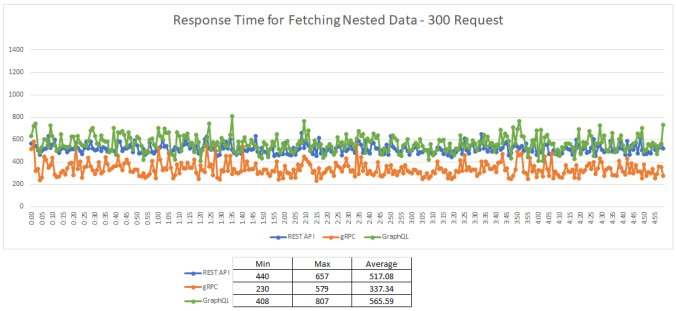
Fig. 12, 13, and 14 show that the response time of gRPC is faster than REST and GraphQL during five minute measurements for fetching flat data. For 100 requests, gRPC has an average response time of 79.9 ms, while REST and GraphQL have higher averages of 152.56 ms and 196.9 ms, respectively. As the number of requests increases to 300 and 500, gRPC maintains its speed advantage with average response times of 66.42 ms and 67.75 ms, compared to REST's averages of 154.45 ms and 149.68 ms and GraphQL's averages of 205.04 ms and 204.35 ms, demonstrating its efficiency in handling data retrieval operations.



	Min	Max	Average
REST API	465	604	510.47
gRPC	297	618	437.03
GraphQL	469	722	589.25

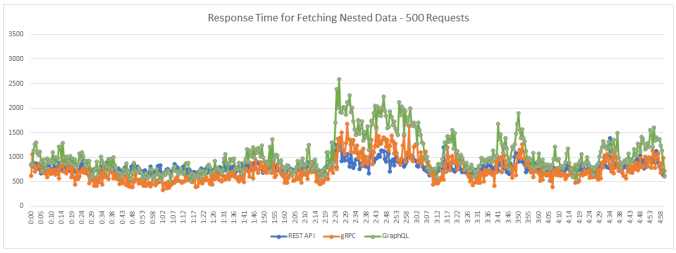
Fig. 15. Response time during five minutes for Fetching Nested Data (100 requests)

Fig. 15, 16, and 17 show that the response time of gRPC is faster than REST and GraphQL during five- minute measurements for fetching nested data. For 100 requests, gRPC performed the fastest, with an average response time of 437.03 ms, followed by REST at 510.47 ms and GraphQL at 589.25 ms. When the number of requests increased to 300, gRPC remained the fastest with 337.34 ms, while REST and GraphQL showed slight increases in response times. However, when the number of requests further increased to 500, GraphQL had the highest average response time at 1,035.46 ms, while gRPC and REST had response times of 748.22 ms and 798.41 ms, respectively, with gRPC being the fastest. We also measured the CPU utilization for five minutes for each data fetching scenario with a different number of requests (100, 300, and 500 Requests).



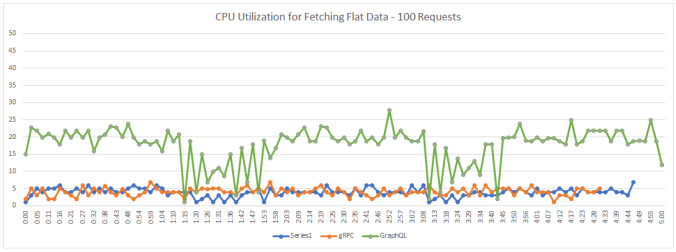
	Min	Max	Average
REST API	440	657	517.08
gRPC	230	579	337.34
GraphQL	408	807	565.59

Fig. 16. Response time during five minutes for Fetching Nested Data (300 requests)



	Min	Max	Average
REST API	622	1394	798.41
gRPC	329	1683	748.22
GraphQL	516	2585	1035.46

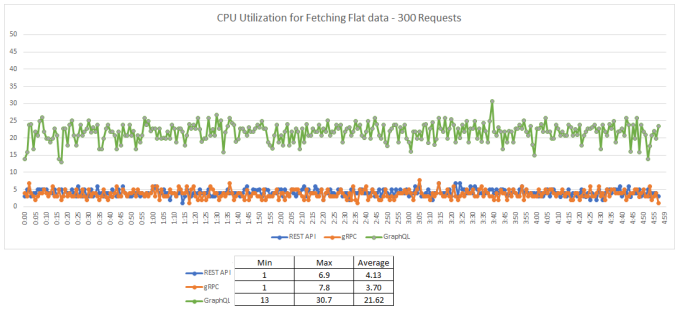
Fig. 17. Response time during five minutes for Fetching Nested Data (500 requests)



	Min	Max	Average
REST API	1	6.9	3.87
gRPC	1	6.9	4.09
GraphQL	1	27.7	17.63

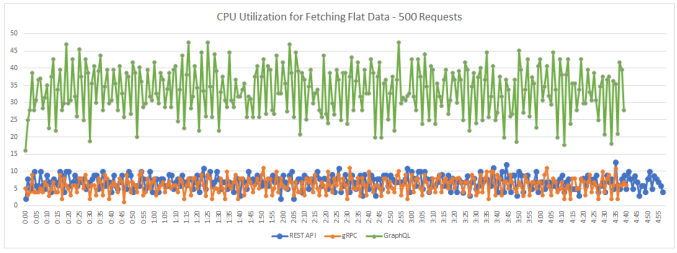
Fig. 18. CPU Utilization during five minutes for Fetching Flat Data (100 requests)

Fig. 18, 19, and 20 show the CPU utilization of three API protocols during five minutes measurement for fetching flat data. With 100 requests, REST had the lowest CPU utilization at 3.87%, gRPC was slightly higher at 4.09%, and GraphQL had the highest utilization at 17.63%. As the request count increased to 300, REST's CPU utilization increased to 4.13%,



	Min	Max	Average
REST API	1	6.9	4.13
gRPC	1	7.8	3.70
GraphQL	13	30.7	21.62

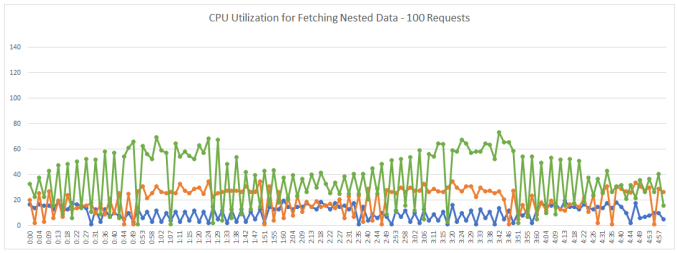
Fig. 19. CPU Utilization during five minutes for Fetching Flat Data (300 requests)



	Min	Max	Average
REST API	2	12.7	6.95
gRPC	1	10.9	5.98
GraphQL	16	47.5	33.53

Fig. 20. CPU Utilization during five minutes for Fetching Flat Data (500 requests)

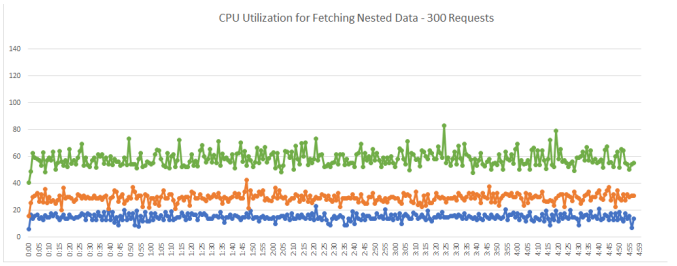
gRPC decreased to 3.70%, and GraphQL spiked to 21.62%. At 500 requests, REST's CPU utilization increased to 6.95%, gRPC to 5.98%, and GraphQL had the highest CPU utilization at 33.53%. These results suggest that GraphQL places a heavier load on the CPU as the number of requests grows compared to REST and gRPC.



	Min	Max	Average
REST API	1	19.8	10.51
gRPC	1	35	20.84
GraphQL	1	73.3	37.53

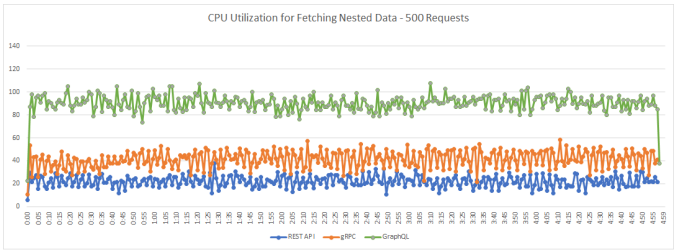
Fig. 21. CPU Utilization during five minutes for Fetching Nested Data (100 requests)

Fig. 21, 22, and 23 show the CPU utilization of three API protocols during five minutes measurement for fetching nested data. For 100 requests, REST had the lowest CPU utilization at 3.87%, followed by gRPC at 4.09%, and GraphQL had the highest at 17.63%. As the request load increased to 300 and 500 requests, the CPU utilization also increased across all three protocols. REST maintained the lowest utilization, gRPC in the middle, and GraphQL consistently had the highest CPU utilization, peaking at 33.53% for 500 requests.



	Min	Max	Average
REST API	6	23	15.03
gRPC	15.8	42.6	29.30
GraphQL	40.6	83.2	58.36

Fig. 22. CPU Utilization during five minutes for Fetching Nested Data (300 requests)



	Min	Max	Average
REST API	5.9	37.6	22.15
gRPC	10.9	58.4	41.41
GraphQL	22.5	107.9	90.30

Fig. 23. CPU Utilization during five minutes for Fetching Nested Data (500 requests)

The performance evaluation shows that gRPC outperformed REST and GraphQL in terms of response time and CPU utilization. This superiority can be attributed to gRPC's adoption of the HTTP/2 protocol, a departure from REST and GraphQL, which rely on the HTTP/1 protocol. The efficient handling of data exchange provided by the HTTP/2 protocol is a significant factor contributing to gRPC's enhanced performance in comparison to its counterparts.

VI. Conclusion

Microservice architecture is now the prevailing framework for developing software systems that are both scalable and easy to maintain. The selection of the proper communication protocol within microservices is essential for attaining the best possible system performance. This research evaluates the performance of API protocols: REST, gRPC, and GraphQL in a microservices-based system using Redis and MySQL as databases. Two distinct data retrieval were examined: fetching flat data and nested data. Based on the evaluation of response time and CPU utilization for fetching flat and nested data scenarios, gRPC outperforms REST and GraphQL. This advantage can be attributed to gRPC's utilization of the HTTP/2 protocol, which contrasts REST and GraphQL, relying on the HTTP/1 protocol. The HTTP/2 protocol is the latest version of the HTTP protocol designed for client-server communication. One of its key features is multiplexing, which enables multiple requests and responses to be efficiently managed over a single connection. This feature proves especially beneficial in gRPC, where numerous remote procedure call (RPC) requests can be executed concurrently on a single gRPC channel. The

study offers valuable insights for selecting API protocols in microservices architectures.

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