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Predicate-Based RDF Indexing Using Hadoop MapReduce for Storage Optimization and Efficient Semantic Data Retrieval

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ABSTRACT: Resource Description Framework (RDF) is widely used for Semantic Web applications and graph-based data management [1][10]. Traditional RDF storage generates redundancy due to repeated predicate representation, increasing storage requirements and affecting retrieval performance. This paper proposes a Predicate-Based RDF Indexing approach using Hadoop MapReduce to optimize RDF storage and improve retrieval efficiency [2][3]. The movie dataset was transformed into RDF format and processed using Hadoop Streaming with Python-based mapper and reducer implementations. Experimental results demonstrate a reduction in RDF storage from 7.09 MB to 5.02 MB, achieving approximately 29.26% storage optimization while maintaining accessibility and scalability.

KEYWORDS: RDF, Hadoop MapReduce, Predicate Indexing, Semantic Web, Storage Optimization

I. INTRODUCTION

The rapid growth of large-scale web data and Semantic Web applications has increased the need for efficient data representation and storage techniques. Resource Description Framework (RDF) is one of the most widely used models for representing semantic information in the form of subject-predicate-object triples [1][16]. RDF provides flexibility and interoperability for semantic applications; however, it generates large amounts of redundant data because predicates are repeatedly stored for multiple entities.

Traditional RDF storage methods may lead to increased storage requirements and reduced retrieval efficiency when handling large datasets [5]. Efficient indexing mechanisms are therefore necessary to improve RDF storage management and query performance [6].

Distributed computing frameworks such as Hadoop MapReduce provide scalability and parallel processing capabilities for handling large-scale datasets [2][3]. This research proposes a Predicate-Based RDF Indexing technique using Hadoop MapReduce for improving RDF organization and storage optimization.

II. LITERATURE SURVEY

Several researchers have investigated RDF storage optimization techniques and semantic data processing methods. Dean and Ghemawat introduced the MapReduce programming model for distributed processing of large datasets [2]. White discussed Hadoop architecture and distributed processing mechanisms for big data applications [3].

Weiss et al. proposed Hexastore indexing for RDF storage and demonstrated improved retrieval performance using semantic indexing techniques [5]. Wilkinson et al. developed Jena2 for efficient RDF storage and retrieval [6]. Harth and Decker presented optimized indexing structures for RDF storage and query processing to improve retrieval efficiency [13].



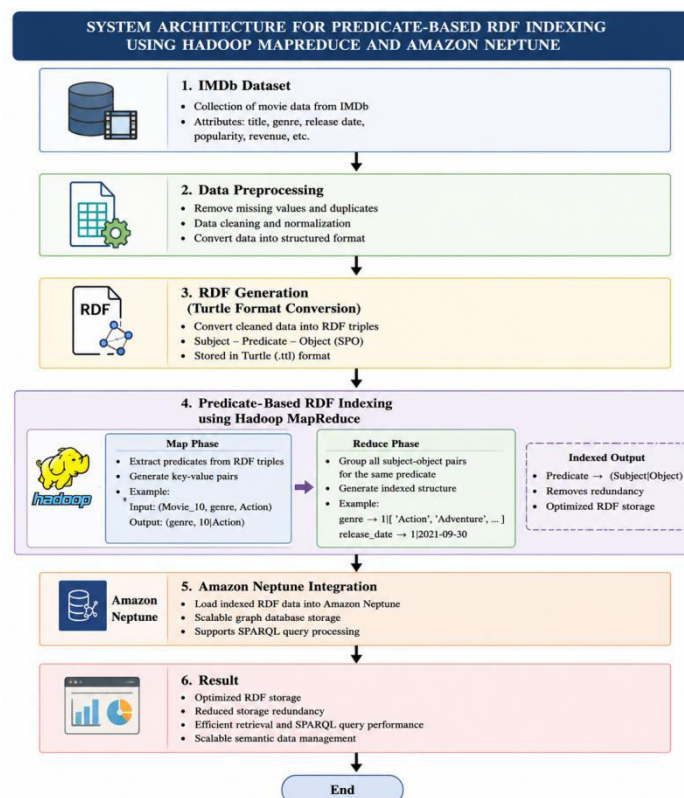
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Berners-Lee et al. introduced the Semantic Web framework and discussed semantic interoperability among heterogeneous systems [10]. Cyganiak et al. further explained RDF concepts and data representation models used in semantic systems [16].

Urbani et al. proposed scalable distributed reasoning techniques using MapReduce for semantic data processing [19]. Zou et al. introduced graph-based query processing approaches for RDF datasets and SPARQL execution [20]. Recent graph database systems such as Amazon Neptune support RDF storage and SPARQL query execution [8]. The literature indicates that RDF optimization techniques focusing on indexing mechanisms can improve data organization, scalability, query efficiency, and distributed semantic data management [13][21][23].

III. SYSTEM ARCHITECTURE



IV. METHODOLOGY / APPROACH

The proposed methodology consists of multiple processing stages:

Step 1: RDF Dataset Generation

The movie dataset was cleaned and transformed into RDF format using Turtle (.ttl) representation [1][16].

Dataset:

movie_cleaned.ttl

```

C:\hadoop-3.3.6\bin>dir movie_cleaned.ttl
Volume in drive C has no label.
Volume Serial Number is 0212-9658

Directory of C:\hadoop-3.3.6\bin

04-03-2026 18:23          7,089,511 movie_cleaned.ttl
               1 File(s)          7,089,511 bytes
                0 Dir(s) 124,944,502,784 bytes free
  
```

Step 2: Mapper Phase

The mapper extracts RDF predicates and generates intermediate key-value pairs.



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Input Triple:

(Movie_10, genre, Action)

Mapper Output:

(genre,10|Action)

```
Administrator: Command Prompt
ns1:release_date "2020-07-02" ;

C:\hadoop-3.3.6\bin>type movie_cleaned.ttl | python mapper_predicate.py | more
genre 1|['Science Fiction', 'Action', 'Adventure']
id 1|5.88489e+05
original_language 1|en
original_title 1|Venom: Let There Be Carnage
overview 1|After finding a host body in investigative reporter Eddie Brock, the alien symbiote must face a new enemy, Carnage, the alter ego of serial killer Cletus
Kasady.
popularity 1|5.401308e+03
release_date 1|2021-09-30
revenue 1|4.24e+08
runtime 1|9.7e+01
tagline 1|Not Available
vote_average 1|6.8e+00
vote_count 1|1.736e+03
genre 10|['Action', 'Thriller']
id 10|7.68449e+05
original_language 10|en
original_title 10|American Badger
overview 10|A seemingly cold-blooded hitman is assigned to befriend a call girl, but all hell breaks loose when he is assigned to kill her.
popularity 10|1.148822e+03
release_date 10|2021-03-05
revenue 10|0e+00
runtime 10|8.8e+01
tagline 10|Justice Before Redemption
vote_average 10|6.3e+00
vote_count 10|1.4e+01
genre 100|['Action', 'Crime', 'Drama', 'Thriller']
id 100|5.39885e+05
original_language 100|en
original_title 100|Ava
overview 100|A black ops assassin is forced to fight for her own survival after a job goes dangerously wrong.
popularity 100|3.02664e+02
release_date 100|2020-07-02
revenue 100|2.987741e+06
runtime 100|9.6e+01
tagline 100|Kill. Or be killed.
vote_average 100|5.7e+00
vote_count 100|1.785e+03
genre 100|['Adventure', 'Family', 'Action', 'Adventure', 'Comedy']
```

Step 3: Reducer Phase

The reducer groups all subject-object pairs associated with the same predicate.

Reducer Output:

genre $\rightarrow$ 1[['Science Fiction', 'Action', 'Adventure']]

release date → 1|2021-09-30

original title $\rightarrow$ 1|Venom: Let There Be Carnage

Step 4: Predicate Index Generation

Final Structure:

Predicate $\rightarrow$ (Subject|Object)

```

Administrator: Command Prompt - more predicate_index.txt
BrokenPipeError: [Errno 32] Broken pipe
[output file]
The pipe is being closed.

C:\Hadoop-3.3.6\bin\more-predicate_index.txt
gene -> 10['Action', 'Thriller', 1001['Action', 'Thriller', 1001['Adventure', 'Family', 'Comedy', 'Thriller', 1000['Animation', 'Family', 'Adventure', 'Romance', 1001['Drama', 1002['Animation', 'Drama', 'Fantasy', 1003['Animation', 'Drama', 'Fantasy', 1004['Adventure', 'Family', 'Comedy', 'Thriller', 1005['Action', 'Science Fiction', 'Drama', 1006['Drama', 1007['Animation', 'Comedy', 'Family', 'Fantasy', 1008['Action', 'Adventure', 'Science Fiction', 'Fantasy', 1009['Family', 'Animation', 'Comedy', 1010['Action', 'Thriller', 1011['Animation', 'Family', 'Fantasy', 'Comedy', 'Music', 'Adventure', 1012['Action', 'Thriller', 1013['Action', 'Thriller', 1014['Horror', 'Fantasy', 'Action', 1015['Science Fiction', 'Action', 'Thriller', 1016['Drama', 1017['Action', 'Drama', 'Thriller', 1018['Drama', 'Crime', 1019['Action', 'Horror', 'Thriller', 'Adventure', 'Mystery', 1020['Comedy', 'Romance', 1021['Drama', 1022['Action', 'Comedy', 'Crime', 1024['Crime', 'Comedy', 'Action', 'Adventure', 1025['Drama', 'History', 'Family', 1026['Crime', 'Drama', 'Thriller', 'Action', 1027['Comedy', 'Drama', 'Family', 'Fantasy', 'Science Fiction', 1028['Family', 'Animation', 'Comedy', 'Fantasy', 1029['Action', 'Crime', 1030['Comedy', 'Animation', 'Family', 'Fantasy', 'Adventure', 1031['Action', 'Comedy', 'Romance', 'Drama', 1032['Family', 'Music', 'Adventure', 'Fantasy', 1033['Horror', 'Drama', 'Mystery', 1035['Family', 'Animation', 'Fantasy', 'Action', 'Adventure', 1036['Family', 'Animation', 'Romance', 'Fantasy', 1037['Drama', 'History', 'Adventure', 1038['Action', 'Comedy', 'Family', 'Adventure', 1039['Family', 'Fantasy', 'Adventure', 'Comedy', 1040['Action', 'Fantasy', 'Adventure', 1040['Animation', 'Family', 'Science Fiction', 'Horror', 1042['Action', 'Adventure', 'Thriller', 1043['Thriller', 1044['Comedy', 'Romance', 1045['Action', 'Thriller', 'Drama', 1046['Thriller', 'Drama', 1047['War', 'Action', 'History', 'Thriller', 'Drama', 1048['Family', 'Animation', 1049['Adventure', 'Animation', 'Drama', 'Family', 1050['Action', 1050['Comedy', 'Fantasy', 1051['Romance', 'Comedy', 1052['Drama', 1053['Family', 'Drama', 1054['Fantasy', 'Action', 'Horror', 1055['Animation', 'Family', 'Adventure', 'Fantasy', 1056['Drama', 1057['Family', 'Adventure', 'Comedy', 'Animation', 1058['Animation', 'Comedy', 'Family', 1059['Action', 'Thriller', 'Drama', 'Horror', 1060['Drama', 'Thriller', 1061['Action', 'Adventure', 'Thriller', 1062['Family', 'Music', 'Adventure', 'Fantasy', 1063['Comedy', 'Drama', 'Romance', 1063['Science Fiction', 'Action', 'Adventure', 1064['Action', 'Science Fiction', 'Thriller', 1065['Action', 'Adventure', 'Fantasy', 1066['Horror', 'Thriller', 'Action', 1067['Animation', 'Family', 'Adventure', 1068['Action', 'Animation', 'Comedy', 1069['Animation', 'Action', 'War', 'Fantasy', 1070['Comedy', 1070['Action', 1071['Mystery', 'Thriller', 'Drama', 1072['Family', 'Animation', 'Comedy', 'Action', 'Adventure', 1073['Science Fiction', 'Action', 'Adventure', 1074['Adventure', 'Drama', 'Action', 1075['Adventure', 'Action', 'Comedy', 'Fantasy', 1076['Science Fiction', 'Action', 'Adventure', 'Thriller', 1077['Action', 'Crime', 'Drama', 'Thriller', 1078['Adventure', 'Fantasy', 'Drama', 1079['Drama', 1080['Horror', 'Action', 1080['Science Fiction', 'Adventure', 'Fantasy', 1081['Animation', 'Action', 'Adventure', 'Fantasy', 1082['Science Fiction', 'Thriller', 'Horror', 1083['Animation', 'Action', 'Fantasy', 'Science Fiction', 'Romance', 1084['History', 'Action', 'Adventure', 'Fantasy', 'Comedy', 'Music', 1085['Action', 'Crime', 1086['Action', 'Crime', 1087['Action', 'Crime', 1088['Animation', 'Mystery', 1089['Drama', 'Crime', 1090['Action', 'Thriller', 1090['Action', 'Adventure', 'Western', 1091['Action', 'Adventure', 'Fantasy', 1092['Fantasy', 'Action', 'Adventure', 'Animation', 'Comedy', 'Family', 1093['Comedy', 'Drama', 'Romance', 1094['Drama', 'Fantasy', 'Romance', 1095['Romance', 'Drama', 1096['Comedy', 'Romance', 1097['Action', 'Adventure', 'Fantasy', 'Science Fiction', 1098['Drama', 'Crime', 1099['Drama', 'Action', 'Thriller', 1100['Animation', 'Comedy', 'Family', 1101['Animation', 'Comedy', 'Family', 1100['Animation', 'Family', 'Comedy', 'Adventure', 1101['Adventure', 'Fantasy', 1102['Romance', 'Drama', 'Thriller', 1103['Family', 'TV Movie', 'Music', 'Adventure', 'Fantasy', 1104['Drama', 1105['Horror', 1106['Drama', 'Thriller', 'Mystery', 1107['Drama', 'Adventure', 'Action', 1108['Animation', 'Family', 'Adventure', 'Comedy', 1109['Drama', 1110['Animation', 'Science Fiction', 'Family', 'Comedy', 1110['Drama', 'Action', 'History', 1111['Comedy', 1111['Action', 'Adventure', 'Comedy', 'Drama', 'Romance', 1112['Action', 'Adventure', 'Fantasy', 'Science Fiction', 1121['Animation', 'Family', 'Adventure', 'Fantasy', 'Comedy', 1120['Fantasy', 'Action', 'Thriller', 1121['Action', 'Thriller', 'Adventure', 1122['Action', 'Fantasy', 'Science Fiction', 1123['Adventure', 'Animation', 'Action', 1124['Comedy', 'Family', 'Fantasy', 'Romance', 1125['Animation', 'Action', 'Family', 'Science Fiction', 1126['Animation', 1127['Comedy', 'Horror', 1128['Drama', 'Romance', 1129['Action', 'Comedy', 'Mystery', 'Crime', 1130['Comedy', 1130['Horror', 1131['Horror', 1132['Animation', 'Family', 'Fantasy', 'Adventure', 'Drama', 1133['Drama', 'Documentary', 1134['Drama', 'History', 'Thriller', 'Crime', 1135['Comedy', 1136['Fantasy', 'Animation', 'Adventure', 1137['Science Fiction',

```



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Step 5: Amazon Neptune Integration

The optimized indexed RDF output can further be integrated into Amazon Neptune for scalable graph storage and SPARQL query processing [8].

V. RESULTS & DISCUSSION

The proposed system was implemented using Hadoop Streaming with Python-based mapper and reducer components [9][21].

Experimental Environment

Operating System: Windows

Hadoop Version: 3.3.6

Programming Language: Python

Processing Framework: Hadoop Streaming

RDF Format: Turtle (.ttl)

Dataset Name:

movie_cleaned.ttl

Experimental Results

Map Progress: 100%

Reduce Progress: 100%

Job Status: Successfully Completed

Generated Output File:

predicate_index.txt

Sample Generated Output:

genre → 1|['Science Fiction','Action','Adventure']

release_date → 1|2021-09-30

original_title → 1|Venom: Let There Be Carnage

Storage Optimization Analysis

```
Administrator: Command Prompt
Family'], 1141[['Animation', 'Comedy', 'Family', 'Adventure'], 1142[['Drama', 'Horror'], 1143[['Action', 'Drama', 'Mystery', 'Thriller', 'Crime'], 1144[['Drama', 'Romance'], 1145[['Horror', 'Thriller'], 1146[['Action', 'Adventure', 'Thriller', 'War'], 1147[['Comedy', 'Fantasy'], 1148[['Drama'], 1149[['Action', 'Crime', 'Thriller'], 115[['Family', 'Music', 'Adventure', 'Animation', 'Fantasy'], 1150[['Thriller', 'TV Movie'], 1151[['Fantasy', 'Adventure', 'Animation', 'Family'], 1152[['Action'], 1153[['Drama', 'Romance', 'Thriller'], 1154[['Adventure', 'Family', 'Drama'], 1155[['Science Fiction', 'Action', 'Adventure'], 1156[['Drama'], 1157[['Action', 'Adventure', 'Fantasy'], 1158[['
C:\hadoop-3.3.6\bin>dir movie_cleaned.ttl
Volume in drive C has no label.
Volume Serial Number is 0212-9658

Directory of C:\hadoop-3.3.6\bin

04-03-2026  18:23                7,089,511 movie_cleaned.ttl
               1 File(s)              7,089,511 bytes
               0 Dir(s) 124,928,761,856 bytes free

C:\hadoop-3.3.6\bin>dir predicate_index.txt
Volume in drive C has no label.
Volume Serial Number is 0212-9658

Directory of C:\hadoop-3.3.6\bin

06-06-2026  10:39                5,015,193 predicate_index.txt
               1 File(s)              5,015,193 bytes
               0 Dir(s) 124,929,185,920 bytes free

C:\hadoop-3.3.6\bin>
```

Parameter	Value
Original RDF Size	7.09 MB
Indexed Output Size	5.02 MB
Storage Saved	2.07 MB
Percentage Reduction	29.26%

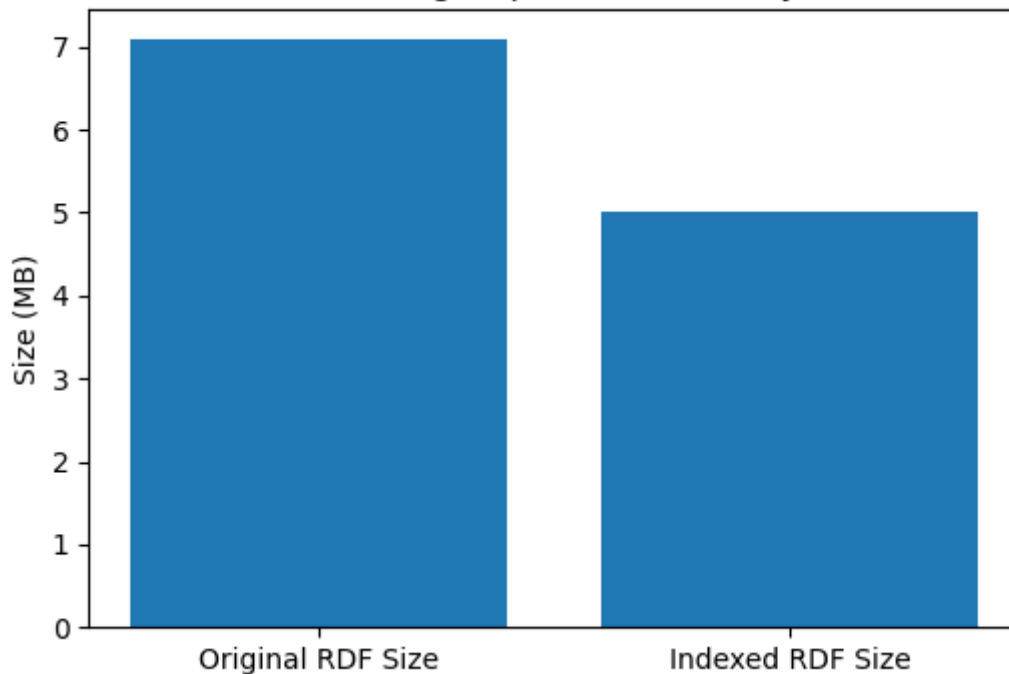
RDF Storage Optimization Analysis



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RDF Storage Optimization Analysis



Analysis:

The graph illustrates the comparison between the original RDF dataset size and the predicate-indexed RDF output size. The original RDF dataset occupied 7.09 MB, while the optimized indexed structure required only 5.02 MB. The proposed Predicate-Based RDF Indexing technique achieved approximately 29.26% storage optimization, indicating reduced redundancy and improved storage efficiency. The obtained results demonstrate that the proposed approach effectively organizes RDF entities and supports scalable semantic data management[8].

VI. CONCLUSION

This paper presented a Predicate-Based RDF Indexing technique using Hadoop MapReduce for RDF storage optimization and efficient semantic data management. The proposed approach grouped RDF entities according to predicates and generated an indexed structure that reduced repeated RDF storage. Experimental results demonstrated a reduction in storage requirements from 7.09 MB to 5.02 MB, achieving approximately 29.26% storage optimization. The obtained results indicate improved RDF organization, reduced redundancy, and enhanced storage efficiency. Furthermore, the proposed framework can support scalable semantic retrieval and graph-based processing through Amazon Neptune integration [8].

VII. FUTURE WORK

Future enhancements may include implementation of advanced RDF indexing techniques to further improve storage optimization and query performance. The proposed framework can also be extended for real-time RDF processing, larger datasets, and complete integration with Amazon Neptune for scalable semantic graph analysis.

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