
**UNIVERSITI PUTRA MALAYSIA**

# *NETWORK BANDWIDTH UTILIZATION BASED ON COLLABORATIVE WEB CACHING USING MACHINE LEARNING ALGORITHMS IN PEERTO-PEER SYSTEMS FOR MEDIA WEB OBJECTS*

**WAHEED YASIN MOHAMMED**

**FSKTM 2018 65**

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**By**

**WAHEED YASIN MOHAMMED**


**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy**

**May 2018**


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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**May 2018**

**Chairman: Professor Hamidah Binti Ibrahim, PhD**
**Faculty: Computer Science and Information Technology**

Web caching plays a key role in delivering web items to end users in World Wide Web (WWW). Many benefits can be gathered from caching such as improving the hit rates, alleviating loads on origin servers, and reducing network traffic.

Cache size is considered as a limitation of web caching. Furthermore, retrieving the same media object from the origin server many times consumes the network bandwidth. On the other hand, full caching for media objects is not a practical solution and consumes cache storage in keeping few media objects because of its limited capacity. Moreover, traditional web caching policies such as Least Recently Used (LRU) and Least Frequently Used (LFU) suffer from caching pollution (i.e. media objects that are stored in the cache are not frequently visited, which negatively affects on the performance of web proxy caching). This problem has been addressed in the works of Ali et al. (2012a), Ali et al. (2012b), Julian et al. (2014), and Julian and Sagayaraj (2015). For example, the average improvement of Hit Ratio (HR) in the works of Ali et al. (2012a) and Ali et al. (2012b) achieved by NB-LRU approach over LRU increased by 7.68%. In terms of Byte Hit Ratio (BHR), the average improvement achieved by NB-LRU, NB-LFU approaches over LRU and LFU are 11.65%, 2.88%, respectively. On the other hand, they do not consider the advantages that can be given by applying these approaches in peer-to-peer systems.

In this work, intelligent collaborative web caching approaches based on C4.5 decision tree and Naïve Bayes (NB) supervised machine learning algorithms are presented. The proposed approaches take the advantage of structured peer-to-peer systems where peers' caches contents are shared in order to enhance the performance of the web caching policy.



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The performance of the proposed approaches is evaluated by running simulations on a two datasets that are collected from YemenNet which is the Internet Service Provider (ISP) in Yemen, and IRCache network which is used as a source for dataset in many researches. The results demonstrate that the new proposed approaches improve the performance of LFU and LRU traditional web caching policies in terms of HR, BHR, and Cost Throughput (CT), the results are compared with the most relevant and state-of-the-art web proxy caching policies.



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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PENGGUNAAN JALUR LEBAR RANGKAIAN BERDASARKAN KERJASAMA *WEB CACHING* MENGGUNAKAN ALGORITMA PEMBELAJARAN MESIN DALAM SISTEM *PEER-TO-PEER* UNTUK OBJEK WEB MEDIA**

Oleh

**WAHEED YASIN MOHAMMED**

**Mei 2018**

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*Web caching* memainkan peranan yang penting dalam menghantar item Web kepada pengguna akhir di *World Wide Web (WWW)*. Banyak kebaikan boleh diperolehi daripada *caching* seperti meningkatkan kadar hit, mengurangkan beban kepada pelayan asal, dan mengurangkan trafik rangkaian.

Saiz *cache* dianggap sebagai kekangan bagi *Web caching*. Tambahan pula, mencapai objek media yang sama dari pelayan asal beberapa kali mengambil sejumlah rangkaian jalur lebar. Sebaliknya, *caching* objek media secara keseluruhan bukan jalan penyelesaian yang praktikal dan mengambil storan *cache* dalam menyimpan beberapa objek media disebabkan kekurangan kapasiti. Tambahan pula, polisi *Web caching* tradisional seperti *Least Recently Used (LRU)* dan *Least Frequently Used (LFU)* mengalami pencemaran *caching* (iaitu objek media yang disimpan di dalam *cache* tidak selalunya dilawati dengan kerap yang memberi kesan negatif kepada prestasi *Web Proxy Caching*). Masalah ini telah ditangani dalam karya-karya Ali et al. (2012a), Ali et al. (2012b), Julian et al. (2014), dan Julian and Sagayaraj (2015). Contohnya, peningkatan purata *Hit Ratio (HR)* dalam karya-karya Ali et al. (2012a) dan Ali et al. (2012b) yang dicapai oleh pendekatan *NB-LRU* terhadap *LRU* meningkat sebanyak 7.68%. Dari segi Nisbah *Byte Hit Ratio (BHR)*, peningkatan purata yang dicapai oleh *NB-LRU*, pendekatan *NB-LFU* terhadap *LRU* dan *LFU* masing-masing adalah 11.65%, 2.88%. Sebaliknya, mereka mengabaikan kelebihan yang boleh diberikan dengan menggunakan pendekatan ini dalam sistem *peer-to-peer*.

Di dalam kerja ini, pendekatan *Web caching* kerjasama cerdas berdasarkan pepohon keputusan *C4.5* dan algoritma pembelajaran mesin terselia *Naïve Bayes (NB)* dibentangkan. Pendekatan yang dicadangkan mengambil peluang yang ada di dalam



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struktur sistem *peer-to-peer*, di mana kandungan *cache peer* dikongsi bagi meningkatkan prestasi polisi *Web caching*.

Prestasi bagi pendekatan yang dicadangkan dinilai dengan simulasi ke atas set data yang dikumpul dari rangkaian YemenNet dan IRCache. Keputusan menunjukkan bahawa pendekatan baharu yang dicadangkan meningkatkan prestasi dasar cache web tradisional LFU dan LRU dari segi *Hit Ratio (HR)*, *Byte Hit Ratio (BHR)* dan *Cost Throughput (CT)*. Tambahan pula hasil dibandingkan dengan polisi *Web proxy caching* yang paling relevan dan *state-of-the-art*.



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I certify that a Thesis Examination Committee has met on 4 May 2018 to conduct the final examination of Waheed Yasin Mohammed on his thesis entitled "Network Bandwidth Utilization Based on Collaborative Web Caching using Machine Learning Algorithms in Peer-to-Peer Systems for Media Web Objects" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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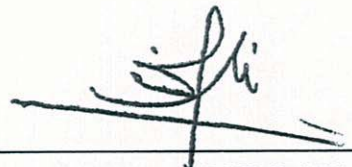

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ABC | Artificial Bee Colony |
| ACHP | Average Cache Hit Probability |
| AODE | Averaged One-Dependence Estimators |
| AP | Access Point |
| APS | Adaptive Path Selection |
| BHR | Byte Hit Ratio |
| BPNN | Back Propagation Neural Network |
| BSR | Bandwidth to Space Ratio |
| CART | Classification and Regression Trees |
| CBC | Content-Based Centrality |
| CBR | Case-Based Reasoning |
| CCN | Content Centric Network |
| CCR | Correct Classification Rate |
| CDN | Content Delivery/Distribution Network |
| CR | Communication Rate |
| CT | Cost Throughput |
| CPU | Central Processing Unit |
| DA | Dynamic Aging |
| DDoS | Distributed Denial of Service |
| DDSB | Data Distribution Service Bridge |
| DHT | Distributed Hash Table |
| DWT | Discrete wavelet transform |
| ECHO | Efficient Complex Query over DHT |
| EPC | Evolved Packet Core |
| FIFO | First In First Out |
| GA | Genetic Algorithm |
| GDS | Greedy Dual Size |
| GDSF | Greedy Dual Size Frequency |
| GFRT-Chord | Grouped Flexible Routing Tables Chord |
| HR | Hit Ratio |
| HRR | Hop Reduction Ratio |
| HTML | HyperText Markup Language |
| HTTP | Hypertext Transfer Protocol |
| IC-C4.5 | Intelligent Collaborative C4.5 |
| IC-C4.5-LFU | Intelligent Collaborative C4.5 Least Frequently Used |
| IC-C4.5-LRU | Intelligent Collaborative C4.5 Least Recently Used |
| ICN | Information Centric Networking |
| IC-NB | Intelligent Collaborative NB |
| IC-NB-LFU | Intelligent Collaborative Naïve Bayes Least Frequently Used |
| IC-NB-LRU | Intelligent Collaborative Naïve Bayes Least Recently Used |
| IP | Internet Protocol |
| ISO | International Organization for Standardization |
| ISP | Internet Service Provider |
| LAN | Local Area Network |
| LFU | Least Frequently Used |
| LRU | Least Recently Used |
| LTE | Long-Term Evolution |



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| | |
|---|---|
| M-DART | Multipath Dynamic Address Routing |
| MANET | Mobile Ad hoc Network |
| MARS | Multivariate Adaptive Regression Splines |
| MDC | Multiple Description Coding |
| MLP | Multilayer Perceptron |
| mSCTP | Mobile Stream Control Transmission Protocol |
| NB | Naïve Bayes |
| NNPCR | Neural Network Proxy Cache Replacement |
| OSI | Open System Interconnection model |
| POD | Peer Connection over Data |
| PRISM | Portal Infrastructure for Media objects caching Media |
| PSO | Particle Swarm Optimization |
| PST | Path Selectivity Table |
| QoE | Quality of Experience |
| QoS | Quality of Service |
| RF | Random Forest |
| RAM | Random Access Memory |
| RAN | Radio Access Network |
| RAND | Random |
| SIEMS | Security Information Event Management System |
| SPRON | Scalable Private Reappearing Overlay Network |
| SVM | Support Vector Machine |
| TN | TreeNet |
| TANB | Tree Augmented Naive Bayes |
| UDN | Ultra Dense Network |
| URL | Uniform Resource Locator |
| VCR | Video Cassette Recording |
| VFDT | Very Fast Decision Tree |
| WAN | Wide Area Network |
| WebRTC | Web Real Time Communication |
| WORM | Write-Once-Read-Many |
| WWW | World Wide Web |
| WS-Chord | Web Service-Chord |

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# CHAPTER 1

# INTRODUCTION

## 1.1 Overview

Web caching is a technique where local copies of a web page are stored in places close to the end-users. Web caching plays a key role in delivering web items to end users in World Wide Web (WWW). Web caches are used to improve the performance of the WWW. Many benefits can be gathered from caching such as improving the hit rates, alleviating loads on origin servers, and reducing network traffic.

Caching replacement policies is the core of web caching which is the procedure that has to be taken when the cache is full while there are web objects that have to be cached. Thus, it is common that a web caching policy is defined according to the cache replacement algorithm. The web object is divided into two types, namely: text object and media object. This work focuses on media objects because of their huge sizes compared to text objects. In this work, the term object and the term item are used interchangeably.

Collaborative caching offers an efficient utilization of cache storage of neighbour peers that are joining a network by sharing web objects. Furthermore, collaborative caching reduces the latency that is required to answer a query, because the query is answered from a neighbour cache rather than fetching it from the origin server. Also, collaborative caching increases Hit Ratio (HR) and Byte Hit Ratio (BHR) (Hara et al., 2010).

Many challenges have to be considered when collaborative caching is applied in the system such as the cache replacement decision that must to be taken when there is no enough space for new coming objects. This replacement is based on entry time, location, expiration time of the objects in peers' caches, frequency, and last access. Furthermore, patterns of user requests, heterogeneous cache sizes, and network topology are other challenges of collaborative caching (Xiuhua et al., 2017).

The collaborative approaches that are presented in this work are based on machine learning that provide algorithms to deal with information from data, where humans are not able to deal with because of its complexity level or the size of data to be treated per time unit. Furthermore, the proposed collaborative approaches share information about peers caches' contents in order to enhance the traditional web caching policies that are Least Recently Used (LRU) and Least Frequently Used (LFU). Many variants of LRU and LFU have been presented in the literature (Podlipnig, 2003) such as SVM-LRU, NB-LRU, (Ali et al., 2012a; Ali et al., 2012b), LFU-Aging and LFU-DA (ElAarag,



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2013; Zink & Shenoy, 2005). However, these approaches do not consider the contents of neighbours' caches.

In this work, two supervised machine learning algorithms are implemented, namely: the C4.5 decision tree and Naïve Bayes (NB) supervised machine learning algorithms because they are popular supervised machine learning algorithms that have been applied successfully in many domains such as medical, military, forecasting, modelling, control, and computer science (Ali et al., 2011; Sulaiman et al., 2008; Darwiche, 2010; de Melo & Sanchez, 2008; Goubanova & King, 2008). Moreover, NB and C4.5 machine learning algorithms are considered simple classifiers because of the independent assumptions among features. Also, they are more effective compared to other more sophisticated classifiers. In this work, NB and C4.5 classifiers are incorporated effectively with traditional web caching policies. More details are presented in Section 4.3.

A peer-to-peer system is a system in which interconnected peers share resources amongst each other without the use of a centralized administrative system. There are two different ways for configuring a peer-to-peer system that are structured peer-to-peer systems and unstructured peer-to-peer systems.

Many challenges have to be taken into account when a peer-to-peer system has to be applied. For example, the communication overhead between peers, searching mechanism, and the impact of peer's joining/leaving the overly network (Guoqiang et al., 2014). Furthermore, the Quality of Service (QoS) of the cached objects in terms of the delay which is taken to answer the query from peers' caches has to be considered. Moreover, updating and maintaining the cached objects in peers is considered as a challenge of caching in peer-to-peer system. Also, if a problem happened in a signal power, it might lead to packet loss or errors.
Mobility is one of the common characteristics in peer-to-peer system, where a peer can move at any time during its joining the overly network. This movement might cause unpredictable results. This issue has been addressed in (Elfaki et al., 2014).

## 1.2 Problem Statement

Utilizing the bandwidth of a network is considered as an important aim for network administrators (Jelenković & Radovanović, 2009). Caching policies such as LRU and LFU play a key role in utilizing the network bandwidth by delivering web items to end users in WWW. However, these caching policies have some limitations such as making a cache replacement decision by a node without depending on other nodes, which results in many nodes cache the same data that means wastes the cache storage in caching duplicated web items.

Recent studies show that media objects are the dominant form of the traffic on the Internet. For example, YouTube and Netflix consume 20-30% of the traffic on the



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Internet (Pouya et al., 2016). Thus, a cache size has to be considered when caching is required. Furthermore, retrieving the same media object from the origin server many times consumes the network bandwidth (Kyounghwan et al., 2004; Radhamani et al., 2010; Shoushou et al., 2015; Xiuhua et al., 2017), which might lead to the following:

- More delays for web users due to the increase in traffic on the Internet (Kumar & Norris, 2008; Kumar, 2009).
- Push network administrators to extend network uplinks (outgoing communication links) at a rate which is out of proportion to the subscribers' growth, or push them to increase the cache storage size, which costs a lot of money (Abhari et al., 2006). These extensions of bandwidth and cache size are immediately consumed without reaching the expected improvement of network performance, which results in web user dissatisfaction.

Moreover, traditional web caching policies such as Least Recently Used (LRU) and Least Frequently Used (LFU) suffer from caching pollution (i.e. media objects that are stored in the cache are not frequently visited) which negatively affects on the performance of web proxy caching (Arlitt et al., 2000; Cherkasova & Ciardo, 2001; Karlsson, 2005; Koskela et al., 2003). Many variants of traditional web caching policies have performed investigations on the problem of caching pollution such as Support Vector Machine-Least Recently Used (SVM-LRU), Naïve Bayes-Least Recently Used (NB-LRU), Support Vector Machine-Least Frequently Used (SVM-LFU), Naïve Bayes- Least Frequently Used (NB-LFU), Very Fast Decision Tree-Least Recently Used (VFDT-LRU), Very Fast Decision Tree-Greedy Dual Size Frequency (VFDT-GDSF), Tree Augmented Nave Bayes- Least Recently Used (TANB-LRU), and Tree Augmented Naïve Bayes-Greedy Dual Size Frequency (TANB-GDSF) (Ali et al., 2012a,b; Julian et al., 2014; Julian & Sagayaraj, 2015); however, they do not take into account the contents of neighbours' caches in the network. As a result of that, repeated data in peers' caches that wastes the cache storage. On other hand, in the work of Raghee and Sajeev (2015), the caching pollution in peer-to-peer systems has been addressed where an approach based on C4.5 machine learning algorithm has been presented that is called Intelligent Greedy Dual Size (IGDS).

Collaborative caching is a kind of caching where a cache replacement decision is made by a node depending on other nodes which enables resources utilization by caching web objects and sharing them with other neighbour nodes. Thus, it does not result in caching the same data in nodes' caches, thus wasting the cache storage in caching duplicated media objects.

There are a lot of works that are based on collaborative caching to investigate the above issues such as the work that has been presented in (Elfaki et al., 2014) and the work of Mushtaq & Ahmed(2008). The cache space allocation is the main issue in collaborative caching. Furthermore, in heterogeneous environment, caching multiple bitrate versions of the media objects incurs high overhead in terms of cache storage (Tuyen et al., 2017). However, the policies that are presented in this work take the advantages of collaborative approach and machine learning algorithms as presented in more details in Chapter 4. The performance metrics including HR, BHR, and Cost Throughput (CT) are presented in Section 3.3.



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The problem which is tackled in this work can be divided in two main problems that are: (i) The problem of caching pollution which leads in wasting cache storage in storing infrequent objects. (ii) The problem of wasting network bandwidth in retrieving media objects which leads in insufficient utilizing of network bandwidth. The problem statement is illustrated in Figure 1.1.

## 1.3 Research Objectives

The research objective of this work is as follows:

- To propose collaborative web caching policies that have better performance compared to existing web caching policies in terms of HR, BHR that reduce caching pollution.
- To reduce the network bandwidth consumption by reducing the CT to fetch media objects based on NB and C4.5 supervised machine learning algorithms in peer-to-peer systems. The performance of the proposed approaches are evaluated and compared to the traditional and state-of-the-art web proxy caching policies.

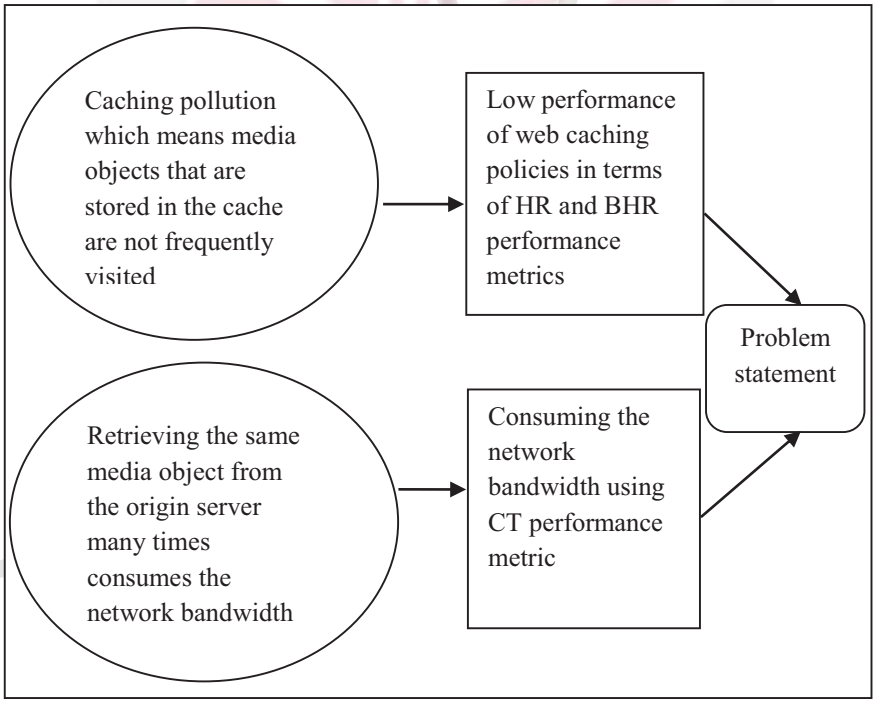


**Figure 1.1: Problem statement**



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## 1.4 Scope of the Research

A web page may include, among other things: texts, images, sounds, videos, data, applications, e-services, and animations. Web pages are normally updated and the problem of data consistency appears, however; media objects follow the principle of Write-Once-Read-Many (WORM) which makes cache consistency issues more resilient than those considered in caching other web objects. The scope of this research is limited to web caching for media objects because they have huge sizes compared to other objects such as text objects. Thus many researches have focused on the media object.

## 1.5 Contribution of the Thesis

This research has made the following contributions:

- It proposes collaborative web caching approaches for LRU and LFU based on C4.5 decision tree and NB supervised machine learning algorithms in order to utilize the network bandwidth by reducing network traffic caused by cache pollution. The proposed approaches are listed below:
    - Intelligent Collaborative Naïve Bayes Least Recently Used (IC-NB-LRU).
    - Intelligent Collaborative Naïve Bayes Least Frequently Used (IC-NB-LFU).
    - Intelligent Collaborative C4.5 Least Recently Used (IC-C4.5-LRU).
    - Intelligent Collaborative C4.5 Least Frequently Used (IC-C4.5-LFU).
- The proposed approaches take the advantages of structured peer-to-peer systems where peers caches' contents are shared using Distributed Hash Table (DHT) in order to enhance the performance of the web caching policy. The proposed approaches are evaluated using simulations.

## 1.6 Thesis Outline

Chapter 1 introduces the research study and the significance of this study. Furthermore, it states the problem that is tackled in this work. Also, this chapter presents the research objectives, scope of the research, contribution of thesis, and thesis outline.
The literature review is presented in Chapter 2 including a background on web caching including benefits of caching, caching limitations, caching stages, and traditional web caching policies. Also, in this chapter, media object caching is presented including media object characteristics, media object systems, and the advantages of caching media object. Also, this chapter introduces peer-to-peer systems, their categories, and collaborative caching based on peer-to-peer systems. Finally, this chapter provides the latest related works of the current state of the art techniques and comment on them.



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Research methodology is a systematic methods analyzed to accomplish the objectives of any research. Thus, in this work, Chapter 3 illustrates the research methodology design. Moreover, it presents the research methodology including the stages that are performed to conduct this work.

Chapter 4 presents the infrastructure of the media object caching in peer-to-peer systems. Furthermore, the proposed collaborative caching approaches using machine learning algorithms in peer-to-peer systems for media objects are presented in Chapter 4. In this work, two supervised machine learning algorithms are adopted namely NB and C4.5 are presented in this chapter.

Chapter 5 illustrates the results and discussion where the proposed approaches are compared to the conventional caching policies namely LRU and LFU caching policies. Furthermore, they are compared to the existing intelligent web caching approaches.

Chapter 6 provides the conclusion of this work by summarizing the findings and contributions of this work. It also provides a specific guidance of the directions of future work suggestions that are recommended in order to follow on from this work.

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