Intelligent Eco Networking (IEN) II: A Knowledge-Driven Future Internet Infrastructure for Value-Oriented Ecosystem

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***Abstract*—Intelligent Eco Networking (IEN) is intent on evolving the IP-based network architecture into a Knowledge-Driven Future Internet Infrastructure based on hierarchical heterogeneous networks composed of virtualized and configurable devices, taking the valuable contents as first-class e ntity, d riven by knowledge intelligence, integrating the decentralized consensus trust preservation, to establish a value-oriented social ecosystem. To counter with the complicated but inefficient m echanisms of IP, a tokenized fine-grained a llocation m echanism i s proposed, taking comprehensive consideration of storage, computing and networking, bringing about a collaborative and mutually beneficial v alue-interconnection. K nowledge-Driven S cheme (KDS), as the guideline of IEN's establishment, illustrates the way to extract knowledge from the network, the value consensus of Blockchain, and the feedback control of Federated Learning, making economy-based distributed commerce feasible.**

Keywords*—internet architecture, blockchain, ICN, value-oriented ecosystem, distributed commerce

I. Introduction

With the emerging need on diverse network hierarchies, research on networks in various gradation gain a great deal of attention, including research on fundamental structure and protocol of networks, knowledge networks taking Knowledge Graph as an archetype, social networks centered on social behavior and so forth. However, traditional network architecture, such as TCP/IP, drives difficulties for adapting the fast-developing demand of upper networks' continually springing up [1]. Several flaws in the long-established base network seem unrecoverable, including:

- The organizational structure becomes rigid, resulting in insufficient capability.
- Inferior competence of perception on contents in the network leads to more and more serious redundancy.
- Quality of Service (QoS) is exclusively confined to *Best Effort Only*.

Quantity of devices and connections in networks are in explosive growth, especially in the scene of "Internet of Things" (IoT) [2], bring about the necessity for management of numerous nodes. Long-established formidable computing power furnished by centralization, confronted by the dispersed nodes, have been brought to its knees, with distributed computing being more and more significant. Nevertheless, designed for communication network as its core, the traditional IP network is inadequate to satisfy the need for content distribution. Furthermore, the traditional network cannot gain a perception of knowledge in the contents, drawing forth that redundant data keep transmitting without any cost. Confined to the network structure and perception ability mentioned above, present networks offer QoS of *Best Effort Only*, lacking in supplying differentiated features for diverse networks.

As a frontier research field of future networks, Named Data Networking (NDN) [3] is capable of many new demands of the Internet which are not satisfied by the traditional network as mentioned above. Owing to the natural trait of NDN, taking contents as the core instead of hosts, better performance can be achieved to fulfill the need of contents distribution which becomes vigorous in the present Internet. Hence, there are more and more researches focusing on applying NDN to new emerging network paradigms, such as NDN employed for IoT [4], NDN to sustain edge computing [5] [6] and so forth. Although it's impossible to supplant the traditional network by NDN directly, the paradigm of NDN offers great insight into the gradual evolution of the future network. However, NDN is aimed to implement the additional features of Network Layer, still lacking in direct sustainment to upper application. As for the reason, native NDN cannot perceive the knowledge in the network, which is feasible because NDN can capture semantic of contents in Network Layer. Accordingly, based on the structure of NDN, if we seek in utilization of knowledge in network and analyze the value flow behind the network transmission, we can realize a network system driven by value, avoiding the transmission of worthless data without spending, and avoiding the low-value data's taking up the resources of high-value data.

Different implications of value can be inferred by different participants, so it's of great significance to build up a consensus of value over different objects, where Blockchain

[7] technology provides reliable support. Through establishing Blockchain of value over multiple participants, it's practicable to implement an economy-based multiparty network ecosystem. Analyzing the value flow in the network and fulfilling consensus of value applying to Blockchain [8], we can see a profound vision of the economy-based network. But automation of management and allocation of the network can be further made happen, by Artificial Intelligence (AI) [9] which attracts a great deal of attention over the past several years. Due to the dispersion of network nodes, how to utilize distributed AI becomes much important, and Federated Learning [10] rising in recent years furnishes us a good solution.

Based on the above, we can tell the research background and purpose of Intelligent Eco Networking (IEN) [11]. As the evolution of NDN, IEN analyzes the knowledge to gain insight into the value flow in the network, and Blockchain will be applied to realize value consensus. Last but not least, IEN applies AI, represented by Federated Learning, to achieve automated management and allocation of value flow.

In this paper, much effort is put in to bring forward a Knowledge-Driven Scheme (KDS) and demonstrate the superiority and feasibility of IEN. Based on the basic of NDN as a Network Layer protocol, we deduce the value flow in the network, employ Blockchain to fulfill the feature of multiparty value consensus and take advantage of Federated Learning for distributed and automated network management. Our main contributions of this paper can be summarized as follows.

- As research on the development of the future network, in this paper, we give a brief but broad description and analyzation of traditional network. And a series of approaches to address the issues are proposed.
- A Knowledge-Driven Scheme is brought forward, which establishes a profound blueprint of future network, consisting of NDN, Blockchain and Federated Learning.
- To our knowledge, this is the first try to give an illustration of using economic knowledge in the network, which inspects the value of contents through analyzing the balance of data.

This paper is organized as follows. Section 2 offers an overview of several pieces of research aiming at the flaws of the traditional network, including NDN, Blockchain, Federated Learning, and Knowledge Defined Network. In Section 3, we formally bring forward the Knowledge-Driven Scheme, containing the key ideas and organizational structure of KDS, which tells the way to integrate NDN, Blockchain, Federated Learning, and the inherent Knowledge. Section 4 illustrates KDS, where differentiated QoS can be realized between the contents of various value. We conclude the superiority of KDS in Section 5, and raise the open issues of IEN.

II. Related Work

In this section, we make a brief but broad introduction of related works for establishing the KDS, including NDN, Blockchain, Federated Learning, and Knowledge Defined Network.

A. Named Data Networking (NDN)

The tradition IP network architecture is rooted in the ideology of host-centric transmitting behavior in the network. As mentioned in the previous section, this kind of paradigm centered in communication is incapable of content distribution, which becomes more and more common in network nowadays. Thus, the methodology of Information-Centric Network (ICN) [12], centered in content, comes into being and separates the contents from the hosts. And based on the idea of ICN, there emerge many network stacks of new kinds, in which NDN is the most representative one.

Named Data Networking (NDN) [3] is a brand-new kind of network driven by consumers, suggesting that clients acquire data by the way of pulling. Two types of data packages are set in NDN, including *Interest* and *Data*. Content consumers send *Interest* packages to the network, and if the corresponding *Data* packages are cached in forwarders, it will return in the path of the *Interest*. Otherwise, the *Interest* will be kept forwarding until arrived at the content providers. Hence, each network node in NDN needs to sustain three data structures. The first is the Forwarding Information Table (FIB), where appropriate forwarding interfaces are stored. The second is the Pending Interest Table (PIT), recording the *Interest* packages which have been forwarded but not been satisfied. The third is the Content Storage (CS), caching *Data* packages. Owing to the trait of content-centric, separation between data and control can be achieved in NDN. Though more robust computing power is needed in each node of NDN, it can better fulfill the demand of the modern network.

B. Knowledge-Defined Networking (KDN)

Even in the traditional network, researches are conducted on how to fuse AI into the control of the network, and there comes Knowledge-Defined Networking (KDN) [13]. What KDN mainly pay attention to is joining AI to the control plane of Software-Defined Networking (SDN) [14], but it's still restricted in the skeleton of the traditional network. However, the paradigm of knowledge-driven offers us a profound insight into the revolution of the future network. No matter how the network is constructed, what is transmitted indeed is the knowledge we need, and lots of knowledge of the network are implicated in the transmission as well. From the perspective of knowledge-driven to inspect the network, not only can we foresee the inherent characters of the network, but also, we can take advantage of knowledge to optimize the structure and management of the network.

C. Blockchain

Once we jump out of the limitations of the traditional architecture and broaden the horizons, we can see the intent of consensus in the network. As a proverb says, *love is in the eye of the beholder*. The implications of value may be different among various participants. Multiparty value consensus is of great significance, and thankfully, Blockchain rising in recent years provides us a marvelous solution, which is bound to play a decisive role in the revolution of the future network.

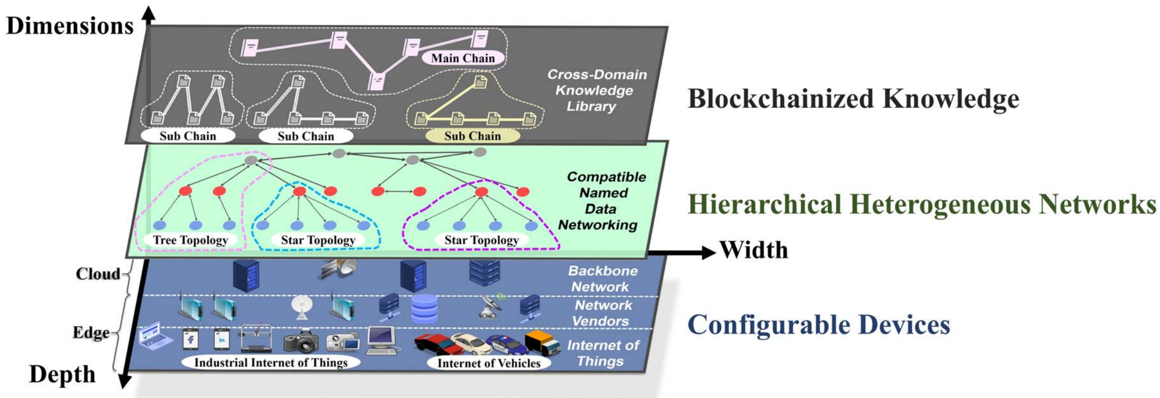

Fig. 1. Infrastructures of Knowledge-Driven Scheme.

And some researches like BlockNDN [15] have started off to remedy the shorts of networks by Blockchain. A bitcoin-like Blockchain system was established in BlockNDN, enabling support for multicast and the hierarchies of status, and the weak-connectivity phenomenon was enhanced while the broadcast overhead was decreased.

D. Federated Learning

Since the automation of network management and resources allocation is expected to be realized in large-scale and wide-dispersed nodes, we must think about the AI methodology implemented in distributed environments, such as Federated Learning [10]. Traditional machine learning methods run in a single node or a powerful data center, while Federated Learning is the latest research on the collaborative training of models over numerous dispersed nodes. Two issues are mainly considered in Federated Learning: the first is how to synchronize the models when training, while the second is how to ensure the privacy of clients. As the representative of distributed machine learning methods, Federated Learning avoids depending on powerful nodes or data centers and completes the training of models through the interaction of multiple nodes. Therefore, Federated Learning is suitable for modern networks composed of dispersing nodes.

III. Knowledge-Driven Scheme

In this section, we describe the proposed Knowledge Driven Scheme (KDS) in IEN consisting of three hierarchies of infrastructure (Fig. 1): Configurable Devices, Hierarchical Heterogeneous Networks and Blockchainized Knowledge.

A. Key Ideas

Conceptually, IEN is to implement a robust infrastructure of Network Layer, furnishing distributed computing, transmission, and storage. As a framework of Network Layer, IEN relies on the basic characteristic of NDN, including naming, data-centric security, routing, forwarding, and in-network storage. This makes up for deficiencies of the traditional network on content distribution and effectively props up the distributed framework of the upper level. Acting as an intelligent networking infrastructure of the future, IEN focuses on the knowledge of data and intelligence scrutinized from the knowledge. Via the inspection of knowledge from the network, perception of value over content is made feasible, thereby comes the fine-grained optimization and regulation of network. Two key challenges must be addressed in IEN: how to perceive and authenticate the value of content, how to optimize the network according to the value? Regarding the first challenge, Blockchain technology is employed in IEN. Blockchain offers adequate sustain for perception and consensus of value and brings about distributed trust and tokenized incentive mechanism. As for the second challenge, we need an intelligent optimizing scheme, which Federated Learning can achieve practicably in distributed environments.

The ways to address the challenges above are set by the scrutinization of knowledge. Knowledge-Driven Scheme (KDS) is the primary method of IEN, which implies to assess the knowledge from the running of network and in turn, utilize distributed AI to optimize the structure and regulation of network. Benefited from the NDN framework adopted by IEN, semantic perception is made possible. Through the analysis of knowledge from the content's behavior and the content itself, we can extract the economic value implicated by the content [16] and further use economic theories to conduct macro-control. In simple terms, as for worthless content (e.g. anomalous data), we can filter it. For valuable content, quantitative analysis can be carried out to provide differentiated QoS. For example, high QoS priority may be furnished to instant messaging, while lower QoS priority may be provided to download, which is not possible in traditional Network Layer.

B. Infrastructures and Framework

Infrastructures of IEN includes the devices, the networks and the knowledge. Generally speaking, infrastructures in IEN consist of three hierarchies, as Fig. 1. The bottom one is composed of the network function configurable devices, including users' terminals, routers, switches, servers and so forth. Devices' constructing networks together make up the second layer: diverse sort of heterogeneous networks with a compatible protocol of NDN. The uppermost one is knowledge we can acquire from devices and networks, where we

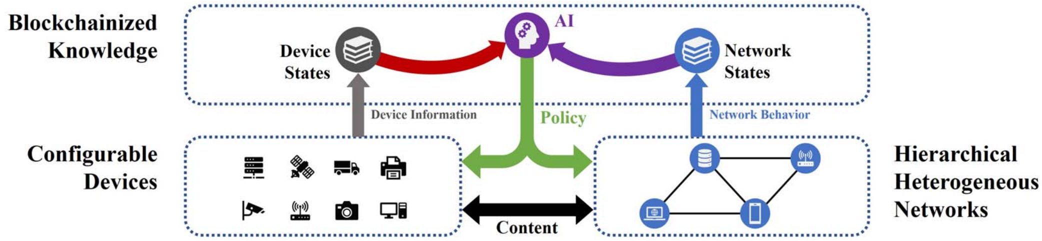

Fig. 2. Logic of Knowledge-Driven Scheme.

extract knowledge to make economy-based methods and trust management based on Blockchain come true. The detail of the infrastructures will be illustrated in this section.

1) Configurable Devices: As we can see in Fig. 1, routers and switches to form the network are regarded as configurable devices, but also devices interacting with the real world are seen as parts of it, including but not limited to cameras, printers, and computers. This reflects the original intention of IEN to realize the interconnection of everything. Nevertheless, as the expression Configurable Devices suggesting, the infrastructures are bound to be equipped with definable characteristic. Only if the devices with this feature are used, we can implement a physical abstraction layer, which provides unified interfaces for the heterogeneous devices. The physical abstraction layer is downward compatible with multiple protocols of Physical Layer, (e.g. 5G, Wi-Fi, Bluetooth), and furnishes hardware-independent call methods for upper applications, satisfying the access to devices of different performance and consumption.

It should be noted that though the devices may differ in computing powers and network locations, each node is treated equally, meaning that each of them is able and obligated to run the basic batch tasks. An important idea of IEN is shown here: no matter how the computing powers of devices are, they are needed to offer resources with the distributed framework, combined with the thought of Fog Computing. Thanks to the abstract physical layer and equality over multiple nodes, configurable devices can support upper applications well, and therefore we can further build the heterogeneous networks based on NDN.

2) Hierarchical Heterogeneous Networks: Although the traditional network has been found to have many challenges confronted by the new emerging demands, it is not practicable to replace it in the short term due to its long history. Thus, constructing the heterogeneous networks to be compatible with the traditional network is imperative. NDN can be compatible with the traditional network as mentioned above, while NDN can better accord the needs of content distribution and semantic perception as well. Consequently, NDN should be employed as the basic protocol of the heterogeneous networks without suspense.

The superiority of adopting NDN to found the heterogeneous networks can be illustrated from two aspects: the costs and the benefits. In term of the building costs, owing to the utilization of configurable devices, construction of NDN will be better supported, though slightly higher resources may cost. From the perspective of benefits from enhancing the network performance, the in-network cache is deployed in NDN, which means the faster response of requests. As for data transmission, it's beneficial for content-centric NDN to conduct semantic analysis and security proof.

It's crucial to note that networks are not only the devices and the connections among them, but also the content transmitted between devices. With no exaggeration, networks are born to satisfy content interflowing. Therefore, the analysis of content and the behavior of them can uncover the network.

3) Blockchainized Knowledge: The highest infrastructure is the knowledge in the networks, implying the knowledge from the semantic of content and the knowledge implicated by the behavior of content. Knowledge Layer has to grab real-time network data. Extraction and analysis of knowledge in the network are the features the Knowledge Layer ought to provide as well. The first employment of the knowledge is to draw out the value implicated in the networks. Because abundant semantic information is involved in the packages of NDN, we can first resolve them to pick up information including popularity, matching relationship, redundancy and so on. After that, statistical models can contribute to analyzing their value, which combines with Federated Learning. Finally, network regulation and resources allocation can be achieved by the economic model. The second adoption of knowledge is trust management, which embodies two levels of trust: the trust of data themselves using encryption to protect and the consensus of value. The usage of knowledge mentioned above is rooted in Blockchain, which provides consensus and synchronization of knowledge. As IEN is bound to function a wide range of needs, cross-domain knowledge library will be built, containing one main chain to sustain global knowledge and multiple sub chain to enable quick local response.

4) Framework: Three points above illustrate the implication of each infrastructure, but they are not set up individually. The operational logic of three layers in our framework is brought forward as Fig. 2. When devices are going to exchange information, they will be connected through the heterogeneous networks. Heterogeneous networks composed of configurable devices fulfill the various basic features of networks, while knowledge is combined with Artificial Intelligent Methods and states of devices and networks to scrutinize the real-time network information and then, in turn, helps to optimize the network by delivering policy.

IV. Illustration of Knowledge-Driven Scheme

This section presents an illustration of Knowledge Driven Scheme, for the sake of conducting feasibility provement on KDS, telling how to differentiate the value of data.

There exist two types of packages evaluation methods: the evaluation in Network Layer and the evaluation in Application Layer. The ways implemented in Network Layer are too close to the underlying architecture, failing in perceiving content and address the redundancy, while the approaches in Application Layer cause excessive overhead, risks on privacy and limited capability. In the light of KDS, we propose a method value assessment on data in NDN. According to the names of each Interest and Data, balances of requests are analyzed to obtain knowledge, distinguishing the values of data. The values are set as the lead of processing priority. By the means of inspection of knowledge in networks, settling the problem of assessment on data in Network Layer, it can not only sense the application layer's demand for data, but also reduce redundancy, and avoid direct detection of data, so as to reduce computing overhead, protect privacy, and expand the scope of utilization.

A. Implementation Scenario

By the way of distributed computing, the design proposed in this section runs on various routers with NDN as the protocol stack. The correspondence between the illustration and the framework is described in Fig. 3. The Configurable Devices mainly include packages transmission devices such as routers. They are born with NDN-based protocol stack, programmable and definable computing power, and runs the IoT operating system represented by OpenWRT. Heterogeneous Networks comprise networks of diverse typologies and forms (e.g. Wi-Fi, Ethernet of *Star* Topology or *Fat-Tree* Topology). Knowledge primarily refers to the value of packages, as reflected in the demand for the content. It should be noted that as an illustration, only a part of the objects is indicated as examples of the framework. Configurable Devices can include devices other than routers. The same applies to Heterogeneous Networks and Knowledge.

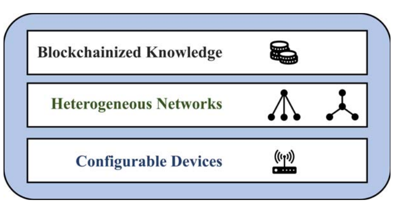

Fig. 3. Correspondence between the Illustration and the Framework.

B. Content and Index

Specific field *Index Length* will be added in the original-designed Interest and Data packages of NDN, for the sake of analyzation on the content of the network, as shown in Fig. 4. Thanks to the one-to-one correspondence between the Interest and Data, when content fragmentation occurs, multiple fragments can be considered as the same content. *Index Length* is aimed to indicate the length of the prefix in names which signify the same content. Taking Table I as an example, if a package is named */ucla/videos/demo.mpg/1/3*, with *Index Length* set as 3, the package with the prefix of */ucla/videos/demo.mpg* will be treat as the same content. And the prefix of a certain length is called the index of the content, presuming that the Interest asking for a content and the Data to return the content are marked with the same index.

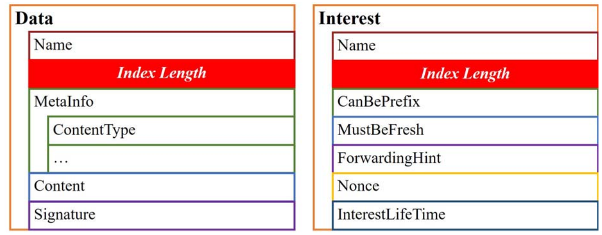

Fig. 4. Specific field *Index Length* added in the packages.

TABLE I
Name and Index

Name	*Index Length*	Index
/ucla/videos/demo.mpg/1/3	3	*/ucla/videos/demo.mpg*
...	...	...

C. Processing and Evaluation Mechanism

The evaluation will be performed on the index of packages only, not involving the content itself. Since merely the knowledge, which means the demand for data here, is taken into account, the privacy and availability can be guaranteed, while effectively reducing the redundancy and the computational overhead of packages analysis.

1) Calculate Content Demands Based on Balance: Because of the trait that Data retrace by the way of Interest, the actual demand for content can be evaluated based on the balance between them. Firstly, we define Δ as the absolute difference of transmission between the two types of packages, calculated by the equation:

$$\Delta = |T_C - T_{C^*}| \tag{1}$$

T_C represents the amount of Interest requesting content C, while T_{C^*} represents the amount of Data in response to the Interest. And we can further compute the content symmetry coefficient ξ by the equation:

$$\xi = \frac{1}{\Delta + 1} \tag{2}$$

According to the transmitting proportion of content in the time slice and the content symmetry coefficient, the demand for content can be represented by D_C:

$$D_C = \xi \times \frac{T_C + T_{C^*}}{\Sigma T_i} \tag{3}$$

The calculation is performed in cycles, and the algorithm is shown in Algorithm 1. Due to the symmetry relationship between Interest and Data, if there is an imbalance between them, it can be understood as the repeated transmission of data, or even a network attack.

Algorithm 1 Calculate the Demand of Content C

Input:

The name of content C, N_C;

The set of packages in a period, P;

Output:

The amount of all packages, T_P;

The amount of Interest named C, T_C;

The amount of Data named C, T_{C^*};

The demand for content C, D_C;

$T_P = 0$, $T_C = 0$, $T_{C^*} = 0$;
for p in P **do**
  $T_P + +$; // Count the amount of all packages
  if p.type is Interest and p.name is N_C **then**
    $T_C + +$; // Count the amount of Interest named C
  else if p.type is Data and p.name is N_C **then**
    $T_{C^*} + +$; // Count the amount of Data named C
  end if
end for
$\Delta = math.abs(T_C - T_{C^*})$
$\xi = 1/(\Delta + 1)$
$D_C = \xi * (T_C + T_{C^*})/T_P$

2) Analyze Value of Data: Therefore, by analyzing the balance between Interest and Data, if the symmetric relationship between them is satisfied, the demand for the transmitted content can be proved to be large. Otherwise, the worse the balance, the smaller the demand is. We normalize the demand for different content, obtain the demand D'_C corresponding to the content, and analyze the value of different packages V_C.

$$V_C = D'_C \tag{4}$$

Via the Algorithm 1, an illustration of KDS is given, in which the knowledge from network gets extracted, while here it specifically refers to the demand of content. The value of data could differentiate the priority of processing, and the practicability and superiority of KDS are proved. It should be noted that Blockchain plays a significant role in this illustration, as the synchronization and consensus of content demands and value must be well clarified among multiple nodes.

V. Conclusion and Open Issues

The new demands springing up cannot be satisfied by the long-established network, while ICN represented by NDN is capable of them but still lacking in taking advantage of semantic information in the network. In this paper, we bring forward a Knowledge-Driven Scheme. Based on NDN, we make perception of the content of the networks and pick up the knowledge to analyze the value of them. And with this assistance of Federated Learning, according to the value, we can optimize the structure, features and resources allocation of the network. Blockchain will be used to achieve value consensus and trust management.

Multiple open issues need to be discussed to push the development of IEN. Firstly, it's a problem on how to realize a gradual evolution of semantic control mode, with a guarantee of compatible with the traditional network to acknowledge valued data. Secondly, how to choose wise economic models to regulate value and provide the basic measurement and evaluation for the complex multi-objective decision-making? Moreover, while IEN furnishes a big platform for future network, what we need is to make diversified QoS guarantee mechanism come true and establish a predictable, multi-objective hierarchical equilibrium coordination mechanism.

Acknowledgment

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