# Performance analysis of self-learning forwarding algorithms for Vehicle-to-Vehicle networks on Named Data Networking (NDN)


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***Abstract*—Vehicle Ad-Hoc Network (VANET) is a special network that provides wireless communication for moving vehicles and other infrastructure to reduce accident rates and collect various information related to the vehicle environment that is useful as a support for driver navigation to improve the safety of drivers and vehicle passengers. The network architecture currently being developed, namely Named Data Networking (NDN) implemented in VANET is an innovative technology to meet future information needs. The self-learning forwarding algorithm is one of the forwarding strategies whose working mechanism avoids running routing protocols, the network can learn routes by itself after broadcasting packets of Interest Base on successful data packet retrieval routes. Self-learning forwarding algorithm based on broadcast is used in VANET networks on NDN which can enable networks to adapt to changing environments and enable mobility of vehicle nodes without using a routing mechanism on NDN networks, thereby reducing computation time and speeding up the information exchange process.**



***Index Terms*—VANET, NDN, Forwarding Strategy, Self-learning Forwarding**


## I. Introduction

Named Data Networking (NDN) is a future Internet network architecture that is being developed, which can then transform the network viewpoint that was previously host-centric on the current IP network architectures into data-centric. If, on an IP network, each device must know where the IP address of the data content provider is and must reach that address, then on the NDN, the user does not have to know the address of the data content provider, but rather any device that is close to the user and has the content requested by the user can send it directly to the user. This can be because on NDN, each router has a Content Store (CS) that uses a caching algorithm mechanism to store duplicate data from the manufacturer or so-called server in the IP network architecture, as well as a forwarding algorithm for data delivery and forwarding mechanisms that enable NDN to speed up information exchange efficiently. This NDN network paradigm can provide many benefits, ranging from support for mobility to low-cost configuration. The traditional Internet architecture, TCP/IP, provides applications with a stable end-to-end connection between client and server to transmit information. However, in a vehicle environment such as VANET, these connections are unstable due to vehicle mobility, resulting in a change in location for the client, the server, or both [1]. To address this situation, Named Data Networking has been proposed as a new architecture for supporting mobility and data retrieval that is expected to support VANET networks with fast mobility characteristics in vehicle environments.

Broadcast-based self-learning forwarding is a mechanism for forwarding data packets in network design. Self-learning forwarding broadcasts the first interest package with unknown tracks across the network. When, and if, the data package results from the return delivery response, an entry routing table will be created on the Forwarding Information-Based (FIB) section for the destination, so that the upcoming package only needs to be sent unicast [2]. In general, NDN forwarding strategies use the routing protocol to forward packets on the network. However, the forwarding approach involves additional maintenance, configuration, and application complexity. To avoid running routing protocols, self-learning forwarding algorithms are used in the network so that it can learn the route on its own after broadcasting interest packages based on a successful data package pick-up route.

In this study, we evaluate the effectiveness of self-learning forwarding and contrast the outcomes with those of other established NDN forwarding techniques. Our analysis concentrates on each scheme's success rate, throughput, and data retrieval time. ndnSIM, the NDN simulator, as well as detailed simulations and measurements were used to compare self-learning forwarding to other forwarding techniques. In comparison to alternative forwarding systems, the findings collected demonstrate that self-learning forwarding on the grid-map vehicle path design has the best success rate, throughput values, and retrieval time values.

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## II. Related Work

Ahmed et al. [3] created a propagation technique for VNDN based on controlled data packets to reduce data flooding by employing hop counters in interest packs and Time-To-Live (TTL) in data packs. Broadcast interest in the network can result in flooding that influences the incidence of overhead. On VNDN, each vehicle has a hop counter that records the number of hops passed by the interest package. The TTL parameter is used to restrict the number of copies of the data package that can be made. To regulate broadcast storm data for VNDN, Ahmad et al. [4] presented controlled data and interest evaluation techniques. The first value, which represents the number of hops and is part of the interest package, and the second, which is the limit of data spread and is part of the data package, are new fields that the author defines. To prevent additional copies of the data or content, this field is used. Unfortunately, the mobility on the alternative route is not taken into account in this work. Similar to this, Amadeo et al. [5] based on their earlier work proposed a similar design, the Content-Centric Vehicular Network. To lessen package conflicts, the system combines a straightforward counter-based broadcast strategy with a transmission time regulator. In the expansion of this work, the manufacturer sends a single-hop beacon message including metadata about the new component, and the vehicle broadcasts an emergency message to a one-hop neighbor. Instead of treating a beacon as unwelcome information and discarding it, a neighbor who gets one generates a temporary PIT entry to store the input piece of data. [6] The mobility of the intermediary node on the reverse track, which can have a negative effect on the network's performance, is not taken into account in this work.

Boukercheet al. [7] suggested integrating interest-based link stability into the content request protocol in VNDN to lessen the interest broadcast storm. The stability of the anticipated links between vehicles is taken into account by this forwarding mechanism at various points while determining the priority level of each neighbor. The main goal of choosing a stable connection is to make sure that the best path is chosen, allowing data packets to go along the same path in the opposite direction from that in which the interest package is transmitted. Previously, Liang et al. [8] developed self-learning forwarding for the Edge network using the NDN architecture, which can analyze all network routes and identify network routes with multiple routes. When first suggested, self-learning has several restrictions. One of these is the fact that forwarding self-learning can only learn one path, therefore whenever interest arises, interest flooding is transmitted, which may cause network overhead. The development of self-learning forwarding for MANET networks has also been studied, and this involves balancing the methods of flooding and self-learning when creating the NDN baseline in MANET [9].

## III. Named Data Networking (NDN)

Unlike the Internet Protocol (IP) network design, which provides identification to the host, NDN is a network architecture that gives identity to the content. In NDN, there are two types of packages: data packages and interest packages. Interest packets are packets that users send to the network with the data name as their identity, not the source or destination address, as in the IP. A data package is a packet in a network that contains information from a manufacturer or router device. Three key components, the Content Store (CS), Forwarding Information Base (FIB), and Pending Interest Table (PIT), are included in each NDN router [10]. With the exception that the IP buffer will be destroyed after the requested package is successfully sent to the destination, the Content Store (CS) on the NDN architecture is comparable to the buffer memory on the IP network architecture. Each package stored in CS will be effectively used in NDN, as it can be reused if the consumer makes the same content request as the previous consumer [10]. Interest packages are sent via the Forwarding Information Base (FIB) protocol to the device that already stores content data. Data can come from various sources thanks to the FIB mechanism in NDN. FIB on IP, however, only receives data from devices in the IP routing table [10]. By recording routes so that information from other manufacturers or routers can be returned to consumers, the Pending Interest Table (PIT) serves to maintain the trace of interest sent from the consumer, router, or manufacturer. Data will be provided to consumers using tracking after the requested information is found, and the tracking will then be removed from the track.

## IV. Comparison of Forwarding on IP and NDN

Messages containing data information service requests are sent to a specific server as an IP address in the IP network architecture to meet user requests for data information. This request will be forwarded through the network router until it reaches the IP address of the target server. The request process from user to server and the response from server to user will repeat if the other user asks for the same information [10]. Users can access information from a network rather than just from a particular server when using an NDN-based network design. The network determines which device responds to user requests, so other router devices in the network that store the content in question can also receive content requests from the user and not just from a specific server. Each node of the router in NDN has a CS that acts as a data storage device. The content requested by the user will be stored in the CS so that it can be sent back to other users who make the same request with them. In an IP network, the routing mechanism's task is to identify routes that packages can take to move from one address to another, after which routing data is stored in a routing table. When a package reaches the router node, the routing table path information will be used to determine how to proceed with the package. As for the NDN network architecture, routing has a function in determining the best path at the beginning of the formation of tables on the FIB section, and the function of the forwarding mechanism is to set the mechanism of sending packets from the node to another node according to the data in the FIB table. At NDN, when other consumers process the same requests as previous consumers, content requests will be served by the router node that has a copy of the data cached at CS. The study analyzed the performance of self-learning forwarding algorithms on NDN-based VANET or VANET-NDN networks by comparing several other forwarding strategies such as broadcast, access, and NCC.

1) Each required package is forwarded via the forwarding broadcast or multicast technique used in ndnSIM to all the interfaces listed by the FIB entries available on the NDN router. [11].
2) When the forwarding access strategy delivers the first package of interest, multicast is used. The used next hop is noted when a data package is given to the consumer and is then used as the chosen next hop to deliver the desired next packet. It will be broadcasted again if the delivery is unsuccessful. [11].
3) The default strategy CCNx, sometimes referred to as the NCC strategy as used in the NFD, was the forwarding strategy that was initially used in the ICN. In this approach, the NDN router forwarded the interest package it had received on one side while it awaited the return of the data package. The face will be remembered as the ”best” face and used to pursue future interests with the same name if the item arrives within a specific prediction period established by the strategy [12].

### A. *Broadcast-Based Self-Learning Forwarding*

Broadcast-based self-learning allows the network to adapt to the environment and allows to support cellular networks with rapid change of position where self-Learning forwarding algorithms can run without using routing mechanisms in the NDN network [2]. In broadcast-based self-learning forwarding, interest flooding uses up network bandwidth and causes extra CPU activity on the end-host that gets interest but lacks content. Reducing flooding is the key to cutting costs in overhead. According to this goal, only customers have the power to ignite the interest flood. Any interest with an unknown path or one where a previously researched path has failed should begin flooding. If users want to flood the network with interest, they must identify it as ”discovery,” otherwise it will be marked as ”non-discovering.” The addition of this tag enables customers to control the frequency of flooding. When the NFD receives interest that is already familiar with the work path, the interest will be retagged as ”non-discovery” and will proceed down the known path through the unicast to prevent wasteful flooding. The initial prefix announcement used to construct the FIB entry will be attached to the data package when it returns to the same forwarder, enabling the new downstream node to discover the manufacturer’s prefix. [2]. The self-learning forwarding algorithm can be illustrated in Figure 1 [2]. When a consumer sends an interest plan, the first interest plan (the previously unsolicited package) will be broadcast to the network. (see black arrow). When the desired package arrives at manufacturer 1, the data package is returned to the path opposite the interest package’s arrival path. (see green arrow). The forwarding mechanism on the network will make FIB entries of the data packets that have

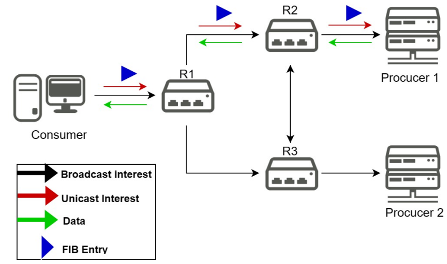


Fig. 1. Broadcast-based self-learning in NDN.

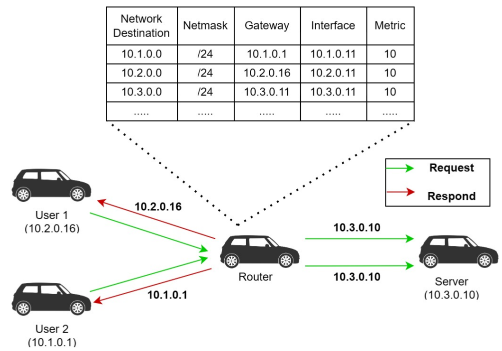


Fig. 2. VANET Architecture on IP Networks.

been successfully returned to the consumer at node producer 1 (blue triangle), so that the interest that will be requested later on the day will be sent unicast via the route. (see red arrow). The main advantages of this mechanism are comfort, adaptability and mobility. [2].

## V. VANET on IP Network Architecture and NDN

Vehicular Ad-Hoc Network (VANET) is an ad-hoc mobile network on a vehicle where the vehicle is used as a cellular node limited to the road topology [1]. The process of data transmission on the VANET architecture uses the IP network architecture depending on the routing table, and the link update process due to the rapid change of vehicle location becomes an obstacle to the use of this architecture given that IP is a host-centric network, where the transmission of data is focused on the IP address so that it only requires the transfer of data on the destination IP address and the source IP address specified.Figure 2 is a picture of the VANET architecture on the IP network [1]. Whereas in VANET architecture using NDN network architecture, the process of data transmission can be carried out by any network device that has the content requested by the consumer, unlike IP that focuses on routing tables between source and destination addresses, NDN has a stateful nature to the mechanism of its transmission. So it can speed up the process of data exchange that is not dependent on routing tables. Figure 3 is an image of the VANET architecture on the NDN network. [1].

## VI. Simulation and Analysis

Changing the environment or column used by the vehicle to know the impact of changes in the network environment in

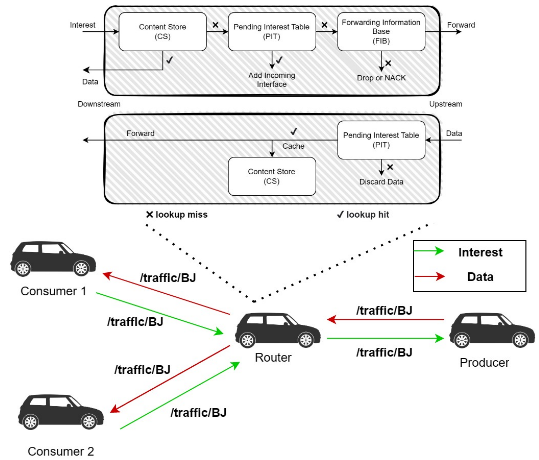


Fig. 3. VANET Architecture on NDN Networks.

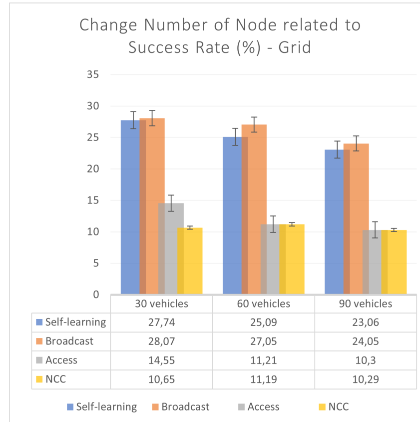


Fig. 4. Results of Changes in the Number of Nodes to the Success Rate in Grid Design.

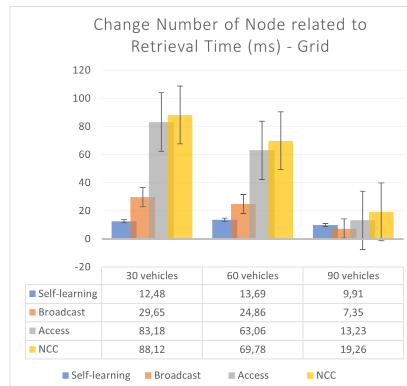


Fig. 5. Results of Changes in the Number of Nodes to the Retrieval Time in Grid Design.

mountainous areas and toll roads on the forwarding process on VANET-NDN Performance testing is carried out using ndnSIM and SUMO software on the NDN4IVC Framework. Data collection is done by calculating the parameters used: success rate, retrieval time, and throughput, from the obtained data through the designed simulation process.

### A. *Simulation Design Vehicle Path with Grid Map*

Road planning with grid maps is a simulation of VANET-NDN that is carried out in rural areas or mountains where there is a distance between one road and another road because there are barriers in the form of plantations, residential areas, or residential housing.

TABLE I
FIRST SCENARIO SIMULATION PARAMETERS

| Parameter | Value |
|---|---|
| Number of Node | 30; 60; 90 nodes |
| Number of RSU | 2 nodes |
| Strategy Forwarding | Broadcast; Self-Learning; Access; NCC |
| Distance between Vehicles | 10 meter |
| Interest Interval | 1000 ms |

*1) Changes the Number of Nodes to the Success Rate value:* Figure 4 shows that the number of vehicle nodes can affect the success rate value of each forwarding strategy used, i.e., if the number of vehicle nodes increases, then the success rate value decreases. Subsequently, broadcast forwarding has the greatest success rate of other forwarding strategies, as the broadcast forwarding strategy broadcasts the packages requested for the first time to all interfaces in the FIB and then sets a single route to obtain data packets from the packets requested by the consumer.Access and NCC forwarding strategies have lower success rates compared to broadcast and self-learning. The forwarding access strategy performs multicast on the delivery of its first interest package. When a data package is sent to the consumer, the next-hop used is recorded and then used as the selected next-hop to send the next package, so focus on the nearest next-hop or hop only, as node position changes very quickly in the VANET-NDN network.

*2) Changes the number of nodes to the Retrieval Time:* From Table 5, it is seen that the number of vehicle nodes can affect the retrieval time value of each redirecting strategy used, i.e., if the vehicle number of nodes increases, then the value of the retrieval time decreases. This happens because the pickup time is influenced by the number of packets stored in the cache. The more data packets that are stored in the cache, the lower the value of the take-off time. It can then be seen that self-learning has the shortest retrieval time value of all forwarding strategies because the self-learning strategy broadcasts the desired packets to all interfaces in the FIB for the first time and then assigns a single route to obtain the packet data from those interests, which can reduce the computational time to broadcast the packets of interest to all the interfacing available in the FIB that will be available after the NDN routing is run.

*3) Changes in the number of nodes to the Throughput:* Figure 6 shows that the number of vehicle nodes can affect the throughput value of each forwarding strategy used, i.e., as the number of vehicle nodes increases, so does the value of

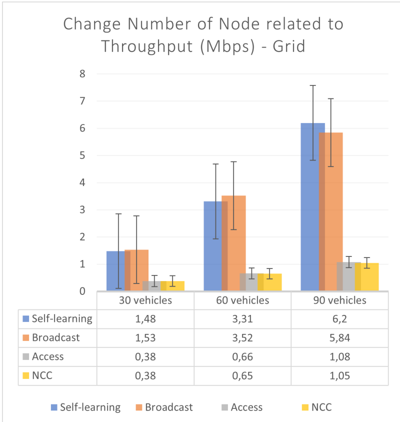


Fig. 6. Results of Changes in the Number of Nodes to the Throughput in Grid Design.

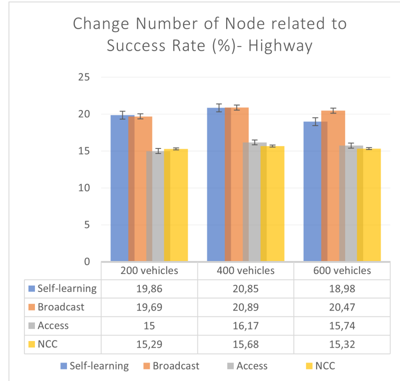


Fig. 7. Results of Changes in the Number of Nodes to the Success Rate in Highway Design.

throughput.This is because the throughput value is influenced by the number of packets running on the network. So the more data packets that are requested, the greater the value of the throughput. It is seen from the graph that self-learning has the largest throughput value of other forwarding strategies when the number of vehicle nodes is 90, which indicates that the forwarding strategy can adjust the number of nodes in the network. This is because, in addition to being able to find the interface available in the network, self-learning forwarding can also minimize delivery time because it does not rely on the running NDN router. Access and NCC forwarding strategies have smaller throughput values compared to broadcast and self-learning. The forwarding access strategy focuses on the nearest next-hop interface after multicast transmission, while the NCC is focused on the lowest occurring latency, so it is inefficient for networks with a rapid rate of position change, such as VANET-NDN networks.

### *B. Simulation Highway Vehicle Track Design*

Vehicle route planning with highway is a VANET-NDN simulation that is done on a straight road without obstacles like on a toll road.

TABLE II
SECOND SCENARIO SIMULATION PARAMETERS

| Parameter | Value |
|---|---|
| Number of Node | 200; 400; 600 nodes |
| Number of RSU | 2 nodes |
| Strategy Forwarding | Broadcast; Self-Learning; Access; NCC |
| Distance between Vehicles | 10 meter |
| Interest Interval | 1000 ms |

*1) Changes the Number of Nodes to the Success Rate value:* From Figure 7, it is seen that in scenarios using road vehicle line design, the number of vehicle nodes does not significantly affect the Success Rate value of any forwarding strategy used. This is because the road design is not hindered by the environment, as in conditions such as grid design, and there is a stable distance between vehicles when using road design. Thus, it can be seen that the self-learning forwarding strategy has the highest success rate value on 200 nodes when compared to other forwarding strategies because it can adjust the number of nodes in the network. Self-learning forwarding can also minimize delivery time because it does not rely on the running NDN router.However, it can be seen that for the number of nodes (400 and 600 nodes), broadcast forwarding strategy has the highest success rate value of other forwarding strategies. This is due to broadcast continuously broadcasting interest packages to ensure all interfaces in FIB entries are available or not, as well as from the help of routing protocols. Access and NCC forwarding strategies have smaller throughput values compared to broadcast and self-learning. The Forwarding Access strategy focuses on the next-hop interface nearest after multicast transmission, while the NCC is focused on the lowest occurring latency, so it is inefficient for networks with rapid position change speeds such as VANET-NDN networks.

*2) Changes the number of nodes to the Retrieval Time:* It is seen from the chart in Figure 8 that self-learning has the greatest retrieval time value of all forwarding strategies because self-learning broadcasts interest packages for the first time to all interfaces in the FIB, then sets a single route to obtain the package data from the interest package requested by the consumer. This can reduce the computational time to broadcast interest packs to all the interfacing available in the FIB that will be available after the NDN routing runs. However, it can also be controlled because the movement of the vehicle nodes is faster on the toll road than the route with the design of the grid. The car's tendency to move rapidly with not much changing distance makes self-learning algorithms weak because they don't rely on running NDN routing.

*3) Changes in the number of nodes to the Throughput:* It is seen from the chart in Figure 9 that self-learning has the greatest retrieval time value of all forwarding strategies because self-learning broadcasts interest packages for the first time to all interfaces in the FIB, then sets a single route to obtain the package data from the interest package requested

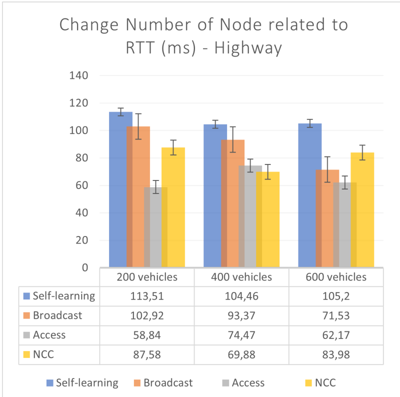


Fig. 8. Results of Changes in the Number of Nodes to the Retrieval Time in Highway Design.

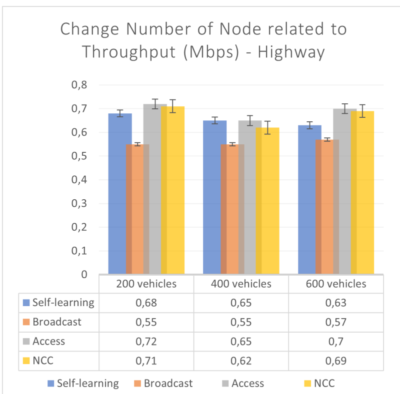


Fig. 9. Results of Changes in the Number of Nodes to the Throughput in Highway Design.

by the consumer. This can reduce the computational time to broadcast interest packs to all the interfacing available in the FIB that will be available after the NDN routing runs. However, it can also be controlled because the movement of the vehicle nodes is faster on the toll road than the route with the design of the grid. The car's tendency to move rapidly with not much changing distance makes self-learning algorithms weak because they don't rely on running NDN routing.

## VII. Conclusion

From the results and data analysis carried out in connection with the performance analysis of the self-learning forwarding strategy on the VANET-NDN network, it appears that in the first scenario using a grid-map vehicle route design, the number of nodes affects the value of the success rate and retrieval time of each forwarding strategy. used, that is, the more vehicle nodes, the smaller the value of the success rate and retrieval time. This is because the success rate and retrieval time values decrease as the number of nodes increases, the network load increases, and the position and distance of the vehicle changes rapidly, causing the success rate to decrease and the retrieval time value to decrease. The amount of data cached on the network affects the retrieval time; the more data cached on the network, the smaller the value of the retrieval time. So, in the first scenario using a grid-map vehicle route design, the self-learning forwarding strategy has the best success rate and throughput value as well as the best retrieval time value compared to other forwarding strategies. This is because the self-learning forwarding strategy, in addition to being able to find available interfaces on the network, can also minimize delivery time because it does not depend on running an NDN router.

In the second scenario using the road vehicle path design, the number of vehicle nodes does not significantly affect the success rate and throughput value of each forwarding strategy used. While the number of vehicle nodes affects the value of the retrieval time, the more nodes, the smaller the value. Retrieval time is affected by the amount of data stored on the network, so the more data cached on the network, the shorter it is. Meanwhile, the success rate and throughput values are not too influential because the toll road design is not hindered by environmental conditions such as grid design, and the distance between vehicles is stable on the lane with the toll road design.

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