Simulating Africa's Internet Topology

Willie Macharia
mchwil006@myuct.ac.za
Department of Computer Science
University of Cape Town
Cape Town, South Africa

ABSTRACT

In Africa, internet connectivity has increased in the last decade. In turn, this has led to rapid change of the continent's internet topology. As more devices get connected to the internet, the structure of the internet topology keeps changing. Over the years, various topology mapping models have been used to map the internet topology at IP level, router level and AS level. This literature review focuses on research that has been done on mapping internet topology, state of internet topology in Africa, simulating network topologies and simulating Africa internet topology. We start by broadly looking at research that has been on mapping internet topology by paying attention to various topology discovery techniques which have been developed over the years. After this, we look at the research that has been done on mapping Africa's Internet Topology. We then pay attention to research that has been done on simulating network topologies. Finally, we look closely to the work that has be done on simulating Africa's internet topology. Through this review, we comment on the findings that we gather from past research, with an aim of creating a suitable way to simulate Africa's internet topology.

CCS CONCEPTS

• **Networks → Overlay and other logical network structures**.

KEYWORDS

ISP Peering,IXP,Network Measurements,Internet Topology

1 INTRODUCTION

Internet topology is the structure in which autonomous systems (ASes), routers and devices(hosts) are interconnected to each other [23]. Mapping this topology is important as it provides a visual representation of how interconnection in the internet looks like. Topology discovery techniques are used to collect internet measurements from different internet measuring tools. Data collected from these techniques is used for network visualization [12]. These techniques are grouped into two: passive techniques and active techniques. Passive techniques involves using BGP routing tables to obtain data on how various autonomous systems interact with each other [12]. The data obtained is used mainly to map network topology at AS-level and router level[31]. Active techniques involve sending traffic to selected network destinations with an aim to obtain topological data. Through exploitation of protocols such as SNMP and ICMP, responses obtained from the destinations are analysed to obtain topology characteristics such as routing path and the round-trip-time (RTTs) of the traffic[12].

Peering[26], as used in internet topology, is defined as business relationship where ISPs provides interconnection to each othersinternet traffic. Various ISPs seek peering relationships for two reasons: peering decrease internet end to end latency[26] and decreases operational costs of purchasing traffic transit[26].

Various ISPs are governed by different interconnection policies that are both internal and external. External policies are determined by internet regulators while internal policies are determined by the ISP. For effective peering to done, these policies need to be considered.

It is important to simulate internet topology as various peering and routing scenarios are explored to better understand how internet performance can be improved[28]. Prior to simulating the topology, internet topology mapping is done. The topology graphs obtained from this mapping are then used for simulation [28]. Simulating a network topology requires the initial topology needs to be generated from the real data. Thereafter, various network components such as nodes and links are removed or added to better understand the topology [22]. Internet topology mapped at AS-level or router-level consists of nodes as either ASes or routers and links which are the interconnections between the ASes or routers [22]. Some nodes represent IXPs(Internet Exchange Points) which are locations where various ISPs and CDNs(Content Delivery Networks) connect with each other[22].

Recent work on Africa's internet topology has shown that most internet traffic in the continent follows circuitous paths which affects internet performance in the continent [22] . In 2014, Gupta *et al*[21] also showed that 67% of the traffic detours through Europe which increase the latency of the internet traffic. Local peering amongst ISPs in Africa still remains low, which is one of the factors that contributes to high internet latency. According to Chavula *et al* [9], increasing local African peering will improve internet performance as latency will decrease. Hence, it is important to use African's internet topology to simulate various peering scenarios which can be done amongst various ASes in Africa. The simulation will also aid in studying how various interconnection policies can be amended or formulated to improve internet performance in Africa.

2 INTERNET TOPOLOGY DISCOVERY

Since 1998, when CAIDA(Center for Advanced Internet Data Analysis) was formed, research on internet topology has intensified due to explosive growth of internet [24]. Internet topology can be mapped in four different levels namely AS level, router level, Point of presence(PoP) level and IP level [12]. At AS level, every AS is represented as a node on the internet graph [12]. At router level, a node represents a single router on the internet graph, while at IP level, every node represents an IP address of either hosts or routers [12]. Many researchers have referred to router level and PoP level as the same level since PoP is a cluster formed by resolving routers aliases [12]. Due to the nature of our study, in this literature review, we pay attention to mapping internet topology at AS level and router level.

A node on AS logical topology represents an AS, IXP or a CDN(Content Delivery Network) [12]. A connection/link between the nodes in the graph represents either a peering link between ASes or an access link between customer network and AS[12]. Peering link is a link where two ASes agree to exchange traffic in between while access link is where one AS pays another AS to carry traffic [12]. This is shown well in figure 1 where the access link is the link between the customer AS and provider AS and peering link is the link between ISP B and ISP C.

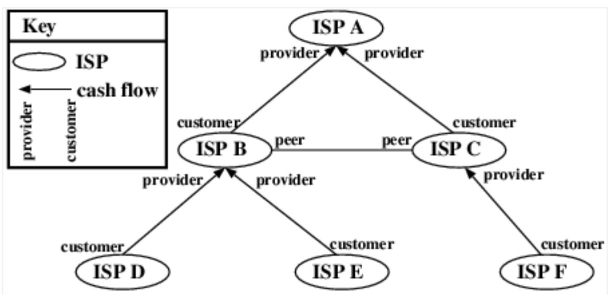

Figure 1: An image showing how IXPs and ASes connect in the internet. Source[3]

Data required to map internet topology at AS-level is obtained from BGP routing tables or Internet Routing registries that maintain the WHOIS database with data from their respective regions [12]. According to Donnet *et al*[12], BGP is an inter-domain and a path vector protocol in which routing decisions are made based on reachability of the advertised AS paths and expressed network policies. BGP data can be collected from BGP archives such as Oregon RouteViews[7] and RIPE RIS(Reseaux IP Europeans Routing Information Service) [8]. These archives collect BGP route information through a set of route collectors known as BGP monitors or vantage points. Even though many studies on mapping Internet topology at AS-Level relied on passive collection of BGP data, efforts have been made to use active probing to collect AS topology data. This is because passive collection of BGP data has various limitations such as BGP does not reveal public or private exchange points(IXPs) within the infrastructure or short-term AS path variation. It does not reflect how traffic actually traverses toward a destination network since it only provides one perspective of how traffic flows from a router to destination.

According to Daigle[11], the WHOIS databases stores AS peering information useful for network operators. These databases are manually maintained by the regional internet registries: AFRINIC, ARIN, APNIC, LACNIC, and RIPE NCC. According to Mahadevan *et al* [25], some of these WHOIS databases contain some inaccurate information, sometimes due to lack of timely updates from the registered networks. In fact, a graph generated from WHOIS data is likely to reflect unintentional or intentional over-reporting of peering relationships amongst some ISPs since some ISPs have been reported to do so, to increase their importance in the internet hierarchy [25]. Registries whose public WHOIS database have been found to cointain current topological information, are RIPE and APNIC. RIPE database contains European Internet infrastructure data while APNIC database contains Asian Internet infrastructure data [25]. Due to this, data obtained from WHOIS database cannot be relied upon to accurately map the internet topology.

Due to these limitations offered by data derived from BGP routing tables and WHOIS databases, efforts to collect AS topology data through active probing have gained traction recently. Active probing involves sending traffic data onto a network to sample its topology data. This has been done by organizations such as CAIDA and RIPE Atlas platform.

CAIDA uses various internet measurement tools to get topology data [3]. One of its popular tool is skitter which collects forward IP paths and round trip times to over half a million destinations[3]. CAIDA has over 171 monitors located all over the world to monitor destinations of which only 11 monitors have been deployed in Africa. These monitors store data about the destinations and can be publicly accessed via CAIDA web tool. This data can be accessed through CAIDA ITDK(Internet Topology Data Kit). The IPv4 routed /24 topology dataset is used to map the topology at AS-level since it contains information on ASes adjacencies[3]. However, CAIDA keeps adding more monitors around the world and it becomes difficult to distinguish if the change of the data is due to evolution of the internet topology or increase in monitors around the globe. If more monitors get added, more data is collected which means that the internet topology changes. When more ISPs,hosts and routers get connected to the internet, the internet topology changes. Hence, CAIDA data is not enough to measure and monitor internet topology.

According to Bradley *et al*[24], active probing has been found advantageous compared to reading data from BGP tables and WHOIS tables. Some of the advantages include [24]:

- Active probing covers more lateral connectivity compared to BGP tables.
- Active probing provides a richer model of internet topology.
- Active probing can be used to measure load balancing in the internet unlike BGP tables.

Recently, it has been suggested [25] that using data from multiple sources could improve accuracy of mapping internet topology [25]. For example, Mahadevan *et al* [25] used data from three sources namely BGP,WHOIS and from CAIDA skitter tool. By combining the data from these sources, a more unbiased structure of data was obtained. However, the inaccuracies from these sources could also make the data more inaccurate. WHOIS databases from developing countries have been noted to be so inaccurate [25]. CAIDA also uses this data from these databases to infer names of various ASes present in various regions. If CAIDA does an active probing and uses inaccurate reference from WHOIS database, then the resulting map is inaccurate. Hence, an effective way to collect accurate and available data to map internet topology is needed.

3 STATE OF AFRICA'S INTERNET TOPOLOGY

Africa's internet ecosystem has a membership of 54 developing countries. Recently, there has been a high rate of internet connectivity which in turn demands study of its internet topology. Currently, Africa's internet ecosystem is faced by two big problems: existence of a small number of ISPs operates in each country; the ISP market is dominated by one or two ISPs[16].

By March 2020, the data from African IXP Association[1] showed that the continent had 45 IXPs. However, these IXPS are only in 33 countries, leaving the rest with no single IXP. Though recent studies have shown the importance of IXPs in improving internet performance in an ecosystem [20], many African ISPs have not peered amongst each other in their local IXPs [21]. With this problem at hand, many researchers have tried to map the African internet topology to try and understand this problem better.

3.1 Research on Africa's Internet Topology

Recent studies have focused on mapping the internet topology of African Research Educational Networks(ARENs) and others topology of various ISPs present in Africa. These studies have been useful in tracking progress of the state of internet topology in the continent.

Fanou *et al* [14] used 214 RIPE Atlas probes and took active measurements from 32 African countries, covering 90 ASes present in these countries. The results indicated that it was important to have a large and diversified set of vantage points before drawing conclusions on the state of interdomain routing in Africa which is basically continent Internet topology. This is because transit habits of various ISPs in Africa depend on the official language of the country, monetary region and business profile of the region. For example; Orange was found to be the most dominant ISP in West Africa countries which mostly speak French and it was present in France IXP. Orange was not found to be present in English speaking countries. These results clearly show that to make conclusions on the state of Africa's internet topology, internet measurements need to be taken from a broad range of vantage points[14].

Gupta *et al* [21] used BGP routing information from RouteViews,Packet Clearing House and Hurricane Electric to infer peering relationships between various ASes at each IXP [21]. The data showed that many ASes were not present in local African IXPs, and those ASes that were present at local IXPs, many of them did not have peering relationships amongst them. For example, Liquid Telecom has presence in both Kenya and South Africa. Liquid Telecom connects with JINX(Johannesburg Internet Exchange) but does not peer at KINX(Kenya Internet Exchange). This forces its South African users to reach many Kenyan networks via LINX(London Internet Exchange). This means that internet traffic follows a circuitous path to reach Kenya and vice-versa. Due to economies of scale, many African's ISPs prefer to connect at LINX due to high availability of other ISPs at LINX. Due to the circuitous path of internet traffic in Africa, internet performance in the continent is characterized with high latency. This could be reduced if more peering links are added in local IXPs and more local cache for various CDNs[21].

Gilmore *et al* [19] mapped the African Internet topology both at As-level and router-level. Using traceroute utility to collect router data from the internet, a BGP feed and an IP to AS mapping was used to create an AS-level topology graph. Walrus, CAIDA visualization tool was used to generate the graph. The graph generated from this work showed that internet traffic that originated from the South African Tertiary Education Network did not make use of the African Internet infrastructure outside South Africa. On the graph, South Africa had most of the links probes because the trace-routes were sent from South Africa. The graph also showed that most of the intra-Africa internet traffic was detouring through Europe before getting to destination [19]. When international links were removed from the graph, some routers on the graph showed no connection with one another. This means that some ISPs in Africa only depended on Europe IXPs to exchange their traffic. At AS-level, the graph showed that some countries had one ISP that connected at international IXP and the other ISPs in the country had to rely on the one ISP to reach international networks[19].

Chavula *et al* [9] took topology measurements from 5 vantage points targeting 95 academic institutions in Africa. These measurements were used to generate topology maps at both AS-level and Point of Presence(PoP) level. It was found that 75% of the internet traffic from African vantage points to academic institutions, traversed through PoPs in Europe such as Amsterdam, London,Lisbon and Marseille. The observation of the topology at AS-level, showed that many NRENs were interconnected mostly by ISPs that peered at global IXPs in Europe [9]. Due to this, the node degree of the African internet topology at AS-level was high for the European ASes compared to African ASes [9].

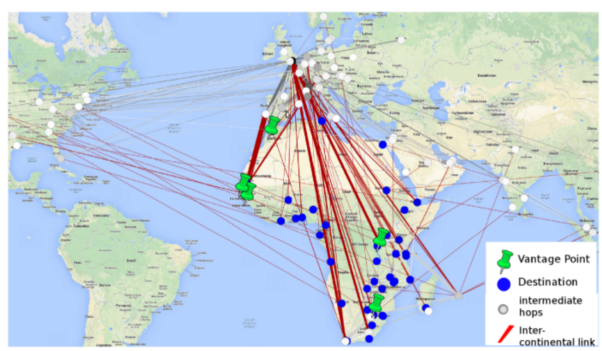

Figure 2: An image showing Africa's Logical Internet Paths Source: [9]

The limitations of the above studies have been inadequate data that covers only some parts of Africa. So far only two studies which have covered above 60% of the African countries. These studies are Fanou *et al* [14] that covered almost 60% of the Africa countries and more recent study, Formoso *et al* which covered 91%. The challenge to collect enough data to study the internet topology in Africa is clear since most of the monitors used by various internet measuring platforms such CAIDA are outside the continent.

4 SIMULATION OF INTERNET TOPOLOGIES

Internet topologies are usually presented in the form of graphs. These graphs are usually referred to as "Internet graphs". From the formal definition of a graph, G(V,E), a graph (G) has both vertices(V) or nodes and edges(E). Similarly, internet graph consists of nodes and edges which represent various components which make up the internet [13, 18]. Simulation of such graph involves adjusting the way the graph looks like by either adjusting the number of nodes or adjusting the number of edges[18]. An internet graph at AS-level consists of nodes that represent either IXPs or ASes and edges represent either a link between an AS and an AS or a link between an AS and an IXP [18].

Motivation to simulate internet topology is to enable the researcher explore various ways in which internet components can be connected to improve internet performance. Internet measurements taken after every simulation will help the researcher to make decisions on which scenarios is internet performance better. These measurements are Round Trip Time(RTT) and end to end latency.

Simulation of internet topology should produce realistic internet graphs [10]. Chen *et al*[10] showed that by combining of various parameters, one may determine how a simulated graph is far from a real graph. Taking two graphs, where one was artificially generated and the other one was mapped from the real data, the graphs were tested against each other in terms of node distribution.

Internet topologies simulators can be grouped into two: web-based simulators and non-web based simulators. Examples of non-web based simulators include NS family simulators. Examples of web-based simulators include QualNet simulator[6], Netsim and IXP Jedi Tool developed by RIPE NCC. In this literature review we review one non-based simulator: NS family simulator. We also review one web-based IXP Jedi Tool. We then compare two to understand which is better than the other.

4.1 Non-web based simulators

Non-web based simulators involve installing the simulators on a machine and performing the simulation. To set up a non-web based internet topology simulator, a tool chain for the internet simulator needs to be installed first[27]. The required simulating test-bed needs to be configured properly by ensuring all libraries and dependencies are well installed[27].
During simulation, firstly, the data needs to be parsed to form the initial topology to simulate. The data can be sourced from internet data providers such as CAIDA or RocketFuel[27]. Secondly, the simulator needs to be configured with all the internet parameters such as link delays, capacities and weights. Finally, the traffic matrix is assigned to the simulator. The matrix consists of how the traffic flows from source and destination.These steps suggest that for one to simulate a network topology, a lot of software plugins are needed. With this problem at hand, [27] created a Fast Network Simulation Setup tool chain(FNSS). FNSS was written in C++ to be a comprehensive library which could simplify setting up a non-web based network simulator[27].

4.1.1 NS Family simulators. NS family simulators are discrete-event network simulation tools[29]. Currently, there are two versions of NS family simulators: ns-3 and ns-2[29]. Both simulators were written in C++ but ns-3, the latest version, has additional python scripts to support its simulation[29]. Network Animator(nam) is an object in ns-2 used for visualization of the simulation output[29]. Major limitation for ns-2 was scalability since it uses sequential simulation which is not sustainable while simulating a large amount of nodes. NS-3 used distributed simulation to try solve the scalability problem. Both simulators, however, require them to be installed on machines for simulations to be done[29].

4.2 Web Based simulators

Web based simulators are simulators which run on the web. These simulators do not require to be installed for simulation to be done as they can be accessed via the web.

4.2.1 IXP Jedi Tool. IXP Jedi Tool is a web tool developed by RIPE NCC used to simulate internet traffic per country[5]. The tool provides visualization of traffic paths between Ripe Atlas probes present in each country. The tool has been developed as web interface[5] also with command-line tools. The tool also provide a public Rest API through its python wrapper called RIPE Atlas Cousteau[4]. This API can be used by developers who would like to extend its functionality to their system. The AS-graph generated by the tool provides a topological view of the probes[5]. Visualization is key during simulation, therefore, this tool can be very useful when simulating internet topology. The tool can be used anytime whenever one has access to the internet.

4.3 Advantage of Web-based simulator over non-web based simulator

A web based simulator can be accessed without requiring installation. Non-web based simulators require installation which can be cumbersome to some users.

4.4 Challenges of Simulating internet topologies

Firstly, configurations of different internet components such as ASes,routers and hosts are governed by different routing policies.These policies get updated every now and then which means that a simulation done today might not work in the future[12]. Secondly, many of the available internet topologies simulators use artificially synthesized internet topologies.This makes it difficult to rely on the results obtained from these simulators to make key recommendations to stakeholders on how to improve the internet performance. For example, when a certain AS is peered with another AS during a network simulation, the results shouldn't be far from what is expected. This challenge demands that a good internet topology simulator should be parsed with real-time topology data to ensure reliable results are obtained after simulation.

5 SIMULATING AFRICA'S INTERNET TOPOLOGY

Recent studies [9, 14, 16, 21] have shown that Africa's internet traffic suffers from high latency due to presence of circuitous paths. These paths are a result of low peering density amongst various ISPs in the continent and lack of local content. The remedy to this problem as [21] recommends, is to localize Africa's intra-continental internet traffic to avoid inter-continental paths. In order to provide evidence for this, simulation of Africa's internet topology is needed to explore various scenarios where various ISPs could be peered at local IXPs.

Currently, most African ISPs are peers at global IXPs mostly in Europe due to economies of scale [21]. Content Delivery Networks deploys their content caches in areas with good internet performance. Therefore improving internet performance in Africa will attract various CDNs to deploy their caches more in Africa. Two questions exist : how should African's ISPs pair to better internet performance? When internet performance improves in Africa, where exactly should CDNs be deployed? It is through simulating Africa's internet topology that a researcher will get better observations to respond to above questions. Through this literature review we look closely at research that has been done to address the above questions.

When exploring possible peering scenarios amongst Africa's ISPs, internet topology is mapped at AS-level. According to work done by Chavula *et al* [17], simulation was carried out where links connecting local ISPs with global IXPs mostly Europe were transferred to local Africa's IXPs. A proxy Africa Internet Exchange was created for the simulation purpose. The results showed that by utilising local IXPs, end to end latency for intra-continent traffic reduced by 50% [17]. This is a huge improvement of internet performance. The limitation of creating a central IXPs is not feasible in Africa due to its geography. For example, it would not be feasible for North Africa ISPs to peer at central African IXP hosted in Central Africa as this would rather increase latency since North Africa countries such as Morrocco are near Europe than Central Europe. Therefore, inclusion of more factors such as geographical position of ISPs when designing IXPs in Africa is needed[16].

Increasing the number of well positioned IXPs in an area improves internet performance in the area. To determine the best suitable location to place an IXP, simulation of internet topology is needed.This allows various locations to be explored and the best location will be determined to be the one where internet performance is best. Fanou *et al* [16] used a more inclusive strategy to simulate Africa's Internet topology to determine the best locations to deploy Africa IXPs. Fanou *et al* took geographical, submarine cable deployment, terrestrial fibre deployment and social-economic data of African countries to create matrices which were used to simulate Africa's internet topology. Fanou *et al* [16] results suggested the creation of various regional IXPs where CDNs could deploy their caches could improve internet performance. The study also showed that internet traffic routed via the regional IXPs had an RTT less than the median of normal RTT [16].

In pursuit of making data on current internet traffic statistics, Africa Route Data Analyzer(ARDA) [2, 15], was created. ARDA is an open source web platform created by AFRINIC to provide a common IXP data collection in Africa[2]. A user can be able to see the traffic statics at three different views: IXP-view, National-view and regional view. ARDA has been developed using two-process architecture. These processes are :

- **Data collection and storage process.** This process involves data collection from different data sources such as geolocation databases such as OIM and BGP routing tables sources such as Route Views collectors. Both IPv4 and IPv6 daily and historical snapshots are taken[15].
- **Data analysis,computation and visualization process.** The data is analysed in the following metrics
  - The growth and business potential of the IXP is analysed[15].
  - How interconnection development is progressing in Africa is also analysed.
  - The IXP view metric structure.

6 DISCUSSION

Throughout the review, we have reviewed research that has been done on internet topology discovery, state of Africa's internet topology and simulating Africa's internet topology. From the review the following observations can be made:

Collection of adequate and accurate data to map Africa's internet topology still remains a big challenge. Most of the organizations which provide data for internet topology mapping, hosts very few monitors in Africa. For example, CAIDA hosts their monitors only in 11 countries out of 54 African countries [3]. This means that the data obtained can not be used to study a large area of the continent. AFRINIC WHOIS database which contains data on various ASes in Africa has been noted to contain some inaccurate information[25]. This has led to many studies that have been conducted on Africa's internet to cover and comment only on a small portion of Africa's internet. Therefore,a good method to collect internet data in Africa is needed to allow accurate mapping of Africa's internet topology which will be effective during simulation. Simulating an accurate internet topology means reliable results are obtained from the simulation.

The current platforms used to simulate network topologies such as ns-3 simulators [25] are mainly designed to simulate artificially synthesised network topologies. A gap still remains on getting an effective platform that can be used to simulate real time internet topology. Such a platform should be web-based such that it can gather real-time topology data from endpoints of data providers and generate a topology graph. The topology obtained can be simulated later for reliable results. Such a simulation will ensure that properties of graphs such as node distribution and edge density can be used to study and explore effects of peering amongst various ASes in Africa. We have also discovered that, a web-based platform is better than a non-web based platform due to its accessibility without installation.

Peering amongst Africa's ISPs in local IXPs still remains poor[21]. Despite the ISPs being aware that local peering could improve internet performance, many African ISPs have resolved to peer in international IXPs such as Europe due to economies of scale[14]. This means that if an interconnection policy which makes ISPs to incur low costs, then many ISPs will peer locally. These interconnection policies could vary from tax incentives to status incentives. Through simulation, these policies could modelled into a matrix to determine which policy incentives the ISPs most.

Throughout our review we note very little research that has been done on simulating Africa's internet topology. The three level architecture of internet topology discovery used and proposed by YU *et al*[30] can be exploited to develop an effective way to simulate Africa's internet topology. The three step process made of three subsystems: data storage subsystem, topology generating subsystem and topology visualization subsystem. This process can be exploited to add a simulation phase where Africa's data is used to simulate its internet topology [30].

7 CONCLUSIONS

Throughout this review, we have analysed different techniques that researchers have used to map and simulate internet topologies. We have also looked at this in the African context in order to develop a good strategy, to follow when designing an effective way to simulate Africa's internet topology.

The review has also revealed some of the challenges that other researchers have experienced and which we need to understand and think about when designing our simulation. The big challenge, which is getting accurate data to map the internet topology, still remains unsolved.

The need to simulate Africa's internet topology is evident since many researchers have recommended that local peering amongst African ISPs will solve the high end-end latency that most intra-continental traffic experiences. Through simulation, possible scenarios of peering amongst ISPs will be tested to obtain their internet performance.

Peering of ISPs amongst African countries is affected by various factors such as language spoken in the country, geographical position of the country and various social-economic factors.Therefore, for an effective simulation, these factors need to be considered too for best results to be obtained.

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