Solving virtual network resources allocation's problem using Constraint Satisfaction Problem model

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***Abstract*—We define virtualization as a set of techniques to run multiple operating systems on the same physical machine (physical node) sharing its resources. This technology have a huge success because it improves safety, reliability and flexibility environments. Basically, several studies in the field have been made by different teams. However, the allocation of physical resources remains an open problem in the field of network virtualization. We identified this problem as a graph matching problemand its resolution consists to express it like a Constraint Satisfaction Problem (CSP)what we did. We formulate resources allocation problem in CSP model including QoS requirements and energy saving and to our Knowledge no work before used CSP approach and combine Qos and Green aspects to allocate resources.**

***Index Terms*—Virtual networks, resources allocation, Constraint satisfaction Problem (CSP), Choco.**

I. Introduction

Virtualization has revolutionized the concept of network, new technology like Cloud computing and virtual network have strengthened the concept of virtual server: this concept is several servers which are logical entities installed on physical machines. The power of data centers can place thousands of virtual servers, they can migrate based on criteria that may be the performance, power consumption, cost and other numerous parameters. Today networks are also at the stage of virtualization on a physical router several virtual routers can be installed. These can also migrate virtual routers (transferring from physical node to another) based on criteria specific to networks: cost, power, reliability, congestion control, and other. This notion of virtual routers simply extends to all network equipment such as switches, MPLS Label Switch Routers, box, gateways, SIP servers, PBXs, etc.

Network virtualization must provide a feeling of freedom of movement at all levels. Each virtual network must be free to implement its own topology, routing functionality, as well as its control protocols customized independently of the underlying physical network and other virtual networks coexisting. Several lines of research exist for the field of network virtualization, interfacing and usability for administrators to use virtual networks, signaling and initiation systems. It is true that when creating a new virtual network or adding a node to an existing network has an effect on the convergence of network that includes the time to instantiate the node or network, adding to it time updating of routing tables. Resource discovery and topology, the physical infrastructure provider must be able to identify and have the most current information possible to the condition of its infrastructure and physical resources consumed by the network instantiated. Admission control, monitoring, operation, security, privacy, interoperability, addressing all aspects are being processed.

Basically, several studies in the field have been made by different teams [1][2][3][4][5][6]. However, the allocation of physical resources remains an open problem in the field of network virtualization [7], precisely optimizing the allocation of resources provided by the physical network and the allocation of the bandwidth without violating these constraints. It is finding the right balance between the needs of the customer, the constraints network status (in terms of latency, architecture, quality of service, etc.).

Therefore, even if various constraints and architectures (topology) make this problem very complex, it allows us to propose a more optimal solution. Several studies in the field have not taken into account all the properties of the allowance (discussed later), some focus on the knowledge of virtual requests in advance, others were made with a centralized manner.

Our research aims to develop a solution for the dynamic allocation of resources by modeling as a constraint satisfaction problem. We present in section-2 the related work focusing on resources allocation problem, in section-3 we discuss and present our CSP model, its implementation is described in section-4, the implementation was made of library Choco-java, this library provides several classes for scheduling constraint satisfaction problems, followed by the results and a general conclusion

II. Related Works

In a network virtualization environment, a number of virtual networks coexist on the same physical network. Each virtual network is composed of a subset of the resources of the underlying physical network. A physical network (also called network substrate) is owned and operated by an infrastructure provider (InP) whose goal is to make a profit from the resources of the network by leasing its customers (service providers (SP) or suppliers of virtual networks (VNPs). A virtual network consists of a set of virtual nodes, each hosted on a physical node, and a set of virtual links, each set in the physical path or a set of physical links. Virtual networks that share the same physical network are completely isolated from each other, they can be used to provide end-to-end without the need for application protocols or tools unified control. [7] The architecture of virtual networks has several characteristics as:

- Coexistence: many virtual networks (possibly from different SP) coexist on the same physical infrastructure.
- Recursion: also known as nesting, refers to the possibility that a virtual network which can be implemented on another virtual network creating a hierarchy in the network virtualization environment;
- Inheritance: virtual networks in the upper levels of the hierarchy of recurrent competition (children) could inherit the properties of virtual networks in the lower lev-els (their parents).
- Revisitation: one physical node (link) can be used to host more than one virtual node (virtual link) belong to the same virtual network.

All these characteristics met to to assure flexibility, (i)each virtual network is independent of the underlying physical infrastructure, (ii) manageability: Each virtual network can be managed independently with the ability to provide network administration tools for one or more VLANs. (iii) stability and convergence: the scope of any configuration errors in the underlying physical infrastructure should be limited in order to affect a minimum number of virtual networks on top of the physical infrastructure and (iv) heterogeneity: not only the underlying physical infrastructure could be composed of heterogeneous technologies (like optical and wireless networks), the virtual layer should be too.

A. *Resources allocation problem*

Creating a virtual network requires allocation of physical resources to its nodes and links in accordance with a number of properties. We represent a virtual network and physical network by respectively two graphs, and we consider the allocation problem like a problem of mapping the virtual network over physical resources.

Several mapping algorithms have already been proposed to allocate physical resources efficiently, we present them later in the document, the paper [2] is for us the opening of the field, it defines the foundation of virtual network instanciations, but it also provides a model of resource allocation problem. Thus, several later works inspired by this model and its results. Indeed, [2] proposes rules for instantiating a virtual network. However, the process of creating virtual networks begins after making virtualization of physical resources. Therefore, a group of virtual resources is created and represented by a virtual layer that implements the abstraction of physical available resources. This virtual network will be subject to three interrelated steps:

- Resources description
- Resource Discovery
- Provisioning resources

The main objective is clear, the instanciation of the virtual network must be economical in terms of physical resources. Resource allocation must be done with the idea of optimizing these resources. Notion of boundary nodes and links has been introduced for the assignment of a Maximal number of allocated resources. No process for selecting limits have been proven to date. Maximizing gain (services) generated by instantiating the virtual network in line with the Trade Policy Provider. Functions must also take into account the overhead of CPU and bandwidth of nodes used to not create a supplementary traffic overload. These objectives do not take into account the flexibility and reliability of links

We remind that assignment of physical network nodes for the virtual network without violation of bandwidth constraints is a NP-problem defined in [2]. So the problem is very complex and an efficient and scalable solution for instantiating nodes optimally must be found.

B. *Solution classification*

In our research, we identified several algorithms that we classify as follows:

1) **Centralized approach**: a central entity is responsible for mapping virtual networks to the physical network. It must maintain updated physical network information's (resources) to make appropriate decisions to allocate resources. This approach could suffer from scalability problems. In addition, the communication between the central entity and the other nodes in the physical network (updated information on resources available) will generate extensive network overload.
2) **Distributed approach**:to cope with the problems of the centralized approach, the process of ressources allocation can be distributed over the entire or part of the physical nodes in InP. In general, each physical node involved in the allocation of resources used his local knowledge to this effect. Communication protocols and cooperation are needed to coordinate the process.
   In addition of centralized and distributed approach, [2] [3] present two other ones:
3) **Static approach**: (without reconfiguration) does not allow any change in the assignment of resources during the lifetime of the virtual network.
4) **Dynamic approach**: (with reconfiguration): adaptive, it can change the allocation of resources in dependence applications, Qos and virtual network performance.

To our knowledge, there are around a little more than 25 algorithms for resource allocation in virtual networks they are centralized, distributed with or without re-configuration; and we cannot describe everyone of them, it's why we use a table presented in Figure 1 [Survey] to describes their approach and requirements.

To resume this section, the fundamental problem of virtual networks instanciation are the optimization of resources allocation offered by the network in accordance with physical constraints as well as compliance with the specifications imposed by the "Service Level Agreement" (SLA), including the Quality of Service (QoS). Complexity is added when the environmental aspect is taken into account. Indeed, the ability to save energy can be integrated into the algorithm as additional constraint. Whatever the context, any proposed

Work	Approaches / techniques	Entities / Business roles	Requirements	Splitting
Zhu et al. [31]	- Heuristic	- Substrate network provider - Virtual network	- Topology	- Virtual network
Chowdhury et al. [13]	- Exact formulation - Heuristic	- Infrastructure provider - Service provider	- Topology - CPU - Bandwidth - Node location	———
Lu et al. [34]	- Exact formulation - Heuristic	- Substrate network - Virtual network	- Topology - Traffic - Node location	———
Yu et al. [36]	- Heuristic	- Physical network - Virtual network	- Topology	- Virtual links
Botero et al. [37]	- Heuristic	- Physical network - Virtual network	- Bandwidth	———
Wei et al. [38]	- Multi-commodity flow - Traffic prediction	- Virtual network provider	- Bandwidth	———
Fiedler et al. [39]	- Overbooking - Service Level Agreement	- Network virtualization environment - Users	- Bandwidth	———
Szeto et al. [40]	- Multi-commodity flow (maximum-concurrent flow)	- Physical network - Virtual network	- Bandwidth	- Virtual links
Razzaq et al. [42]	- Heuristic	- Substrate network - Virtual network	- Topology - Node capacity (undefined) - Link capacity (undefined) - Link capacity (undefined)	- Virtual links
Razzaq et al. [42]	- Heuristic	- Substrate network - Virtual network	- Topology - Node capacity (undefined) - Link capacity (undefined) - Link capacity (undefined)	- Virtual links
Zhou et al. [44]	- Game theory	- Service provider - Infrastructure provider	- Bandwidth	———
Lischka et al. [45]	- Graph theory (subgraph isomorphism detection)	- Physical network - Virtual network	- Topology - CPU - Bandwidth	———
Houidi et al. [23]	- Exact formulation - Exact resolution - Heuristic	- Virtual Network Provider - Infrastructure Provider	- Node cost (undefined) - Link cost (undefined)	- Virtual network
Houidi et al. [22]	- Heuristic - Multi-agent	- Substrate network - Virtual network	- Unlimited substrate network resources	- Virtual network
Chowdhury et al. [16]	- Policy-based	- Infrastructure Provider - Service Provider	- Topology - Node location	———
Houidi et al. [29]	- Multi-agent	- Infrastructure Provider - Virtual Network Provider	- Node cost (undefined) - link cost (undefined)	———
Botero et al. [50]	- Exact formulation - Heuristic	- Substrate Network - Virtual Network	- CPU - Bandwidth	———
Wang et al. [51]	- Game theory	- Physical Infrastructure - Service Provider	- Bandwidth	———
Marquezan et al. [54]	- Heuristic - Self-organization	- Virtual managers (one in each physical node)	- Interruption time - Storage capacity	———
Butt et al. [18]	- Heuristic	- Substrate network - Virtual network	- CPU - Bandwidth	———
Bienkowski et al. [56]	- Algorithmic (online and offline)	- End user - Service provider - Infrastructure provider	- Latency - Bandwidth	———
He et al. [57]	- Congestion control - Routing protocol - Traffic engineering	- Substrate network - Virtual network	- Bandwidth	- Virtual links
Rahman et al. [17]	- Exact formulation - Heuristic	- Virtual Network - Substrate network	- Bandwidth	- Virtual links
Yeow et al. [59]	- Opportunistic redundancy pooling	- Physical infrastructure - Virtual Infrastructure - Virtual network	- Topology	———

Figure 1: Summary of resources allocation algorithms

allocation must be able to support the desired traffic (required one).

III. Model and Architecture

Methods for solving a problem of graph matching can be divided into two classes [8] **the exact methods** and **approximate methods**. (i)The exact method assumes that a sub-graph exists and the task is to find it but in some situations where the data is altered, a perfect match can not be found.(ii) The approximate method finds a solution optimizing an matching objective function. In our study the different algorithms that are based on these methods (Ullmann, Nauty, Schmidt and Druffel) does not correspond perfectly to our problem. Indeed, the matching network must consider the capacity of nodes and links.

A. Matching graph

We model the physical network as weighted indirect graph $G^s = (N^s, L^s, A_N^s, A_L^s)$,$N^s and L^s$ respectively represent set of nodes and links of the physical network, each node has properties A_N^s that we have identified as the CPU and the memory capacity, it is the same for links A_L^s whose main property is the ability in terms of bandwidth. We also take account of the existing roads between all nodes of the physical network and represent a matrix called P^s. The instantiation of the virtual network is characterized by a query that is also modeled by a weighted undirected graph, $G^v = (N^v, L^v, C_N^v, C_L^v)$, the pair ,$N^v and L^v$ represents the logical topology of the virtual network. The virtual network is characterized by constraints on virtual nodes and links that constitute C_N^v, C_L^v modelize respectively constraints of virtual node N and virtual link L

physical resources allocation to the virtual network is the matching of G^V on a part of G^S, respecting the constraints of the virtual network: $f : G^V \rightarrow (N', P', R_N, R_L)$ The global allocation function which is an application for starting domain G^V, and arrival domain which consists of:

- $N' \subset N$: the set of allocated nodes
- $P' \subset S$: the set of paths, a path can be composed of multiple links,
- R_n, R_L: respectively the allocated resources of nodes and links.

the assignment problem of nodes and links are dependent and must be treated simultaneously:

- Nodes assignment: $f^N(N^V, C_N^v) \rightarrow (N', R_n)$
- Assignment links: $f^L(L^V, C_L^v) \rightarrow (P', R_L)$

Symbol	comment
N^s	Set of physical nodes
L^s	set fo physical links
A_N^s	physical node properties
A_L^s	Physical link properties
N^v	Set of virtual nodes
L^v	Set of virtual links

Table I: Model's symbols

allocate a large number of virtual links to a physical link because it's can be disturbed (cut, bottleneck,...) or a router that would have a high number of instantiated virtual machines are not appreciated it can be decreased its performances, this is the business experiences that guide us in the use of some useful parameters that may be to the nodes and / or links in order:

- To improve the performance of the physical network by passing the virtual networks that are mapped above,
- Reduce the rate of packet loss, lowering the packet collision due to cross traffic flow in several physical links

It is necessary to have a load sharing over the entire substrate (physical) network.

Our work want to be specific to take care about the Quality of service and economy of energy, for this goals, we identify two functions of utility depending about the SLA, it's why we model The service level agreement (SLA) and develop provider utility and client utility.

B. Service Level Agreement

SLA is a contract between a service provider, in this case a physical network provider and a client (virtual network) [9]. The contract specifies what services the provider must provide to the customer and penalties if the service is not provided. However, customer expectations in most market studies emphasize requirements [9] [10] as reliable measurement of quality of service (QoS), provision of the expected quality of service and optimizing the use of resources.

Client	Provider
Carrier Service Provider	Carrier Service Provider
Internet Service Provider	Carrier Service Provider
Enterprise/ operator	Internet Service Provider
User	Internet Service Provider

Table II: Interaction between SLA's Actors

In the field of virtualization an SLA can be produced between different protagonists, table II shows the possible interactions between these actors for the implementation of a virtualization service. For example a Carrier Service Provider who has a very huge physical infrastructure can provide to an ISP or an operator's his physical infrastructure to instantiate virtual networks on demand, the ISP or operator can then about to propose this service (network virtualization) to its customers.

The operational implementation of SLA in network technologies is reflected in the adequacy of the various parameters that are customized for client needs, these parameters are presented in table III

P	Parameters	type
P1	Packet lost	Nonfunctional
P2	Delay	Nonfunctional
P3	jitter	Nonfunctional
P4	Bandwidth	Functional
P5	CPU and Memory	Functional
P6	Topology	Functional
P7	Availability	Nonfunctional
P7	Admission Control	Functional

Table III: SLA's Parameters

We identify two types of parameters, functional and nonfunctional. Indeed, some properties such as topology and functional resources are representative of the needs and constraints that must be strictly respected, conversely non-functional properties correspond to those on QoS and availability.

A contract must take into account two aspects, the customer and supplier satisfaction, a utility function must be set up, for this purpose we use a classification of services and its correspondence with the SLA, we have adapted the proposed correspondence [9] to our needs, the following figure shows that:

	Packet lost	delay	jitter	Bandwidth	CPU memory	Topology	Availability	Admission Control
Voice	=	++	++	+	=	=	+	++
Videophone	=	++	+	++	=	=	+	++
Telephony	=	=	0	0	=	=	+	++
Multimedia	+	++	0	++	=	=	+	++
VOD	=	++	0	++	=	+	+	++
VPN	Depends about the encapsulated data				=	++	++	++
Real Time Data	++	++	0	+	=	=	+	++
Data (web, mail , e-Commerce)	++	+	0	0	=	=	+	++
Streaming	++	=	0	0	=	=	+	++

++	Very High Performance	=	Performance Best Effort
+	High performance	0	indifferent

Figure 2: Mapping SLA Services

We classify services, a client needs to match one or more classes, our solution calculates the most optimal allocation based on the objective function that will be defined, The supplier shall implement all the relevant parameters of the SLA constraints. So the resources allocation considers these conditions. From there we decompose the problem into two sub-problems.

C. Client utility

The client expresses his needs in the SLA, in our SLA model his needs are expressed by several properties defined for several distinct services, the main task is to choose an allocation that meets the needs of the customer to the best of these properties, how we can differentiate between an allocation and another? How do I know which one is more appropriate? We decided to base our decisions on **multi-criteria** techniques.

The multi-criteria analysis or, more accurately, multi-criteria decision-making methods are relatively new techniques and are growing. [11] Support that multi-criteria decision as an alternative to traditional optimization methods based on the definition of a single function. The interest of MCDA is to consider a set of criteria from different types (expressed in different units), without necessarily transform it. By the way they integrate any type of criteria, these procedures seem better afford to move to a judicious compromise rather than optimum often obsolete.

Example: the delay parameter and its importance for VoIP service and streaming service, it is clear that delay is critical for VOIP service, but at the same time it is less important for the Streaming considered as a average important criterion. According to [8][9] we have ordered the non-functional parameters according to their importance by service and the result is presented in table VI. this helps us to make a weight over each parameter by service to respond and offer the needed Qos.

Our model will allow us to compare between two proposed allocations, it takes into account the functional aspects that

Services Parameter	packet lost	Delay	Jitter	Availability
VOIP	3	1	2	4
Videophone	3	1	2	4
Telephony	3	2	4	1
Multimedia	2	1	4	3
VOD	3	1	4	2
VPN	3	1	4	2
Real time data	2	1	4	3
Streaming	1	3	4	2

Table IV: Importance of SLA's parameter by service

are expressed in the SLA, as well as non-functional (which are related to QOS)and express précisely the client's needs.

D. Provider Utility

The interest of the physical network provider is the monetary gain it can get in instantiating a virtual network. We identify two types of gains, one relating to the SLA and trade agreements between him and the client, the other to the economic aspects of energy that induces budgetary savings.

a) SLA's gain: We have previously discussed and modeled trade relations between Client and Provider, it express the gains generated by the satisfaction of customer needs from the SLA, the allocation of resources which are deployed to answer to non-functional customers needs in terms of quality of service engenders a gain, it is subject to the ability of the operator to provide this quality for a certain part of times.

b) Energy saving: Today on each computer entity (hardware), a provider should take into account the costs associated with its use, so the ecology and earnings can reach a common goal, Our model take into consideration the energy saving and express this aspect putting the physical node in standby if we don't really need to instanciate virtual node over it, carrying about the Qos. it's means when we can choose to instaciate a virtual node over two physical nodes, we will instaciate it on the already used one.

IV. Implementation and Test

A. Implementation

A constraint is simply a logical relation among several unknowns (or variables), each taking a value in a given field.The algorithm "backtrack" is a blind search of the solution by experiment sets of variable assignments to find a solution. The complexity of the backtracking algorithm depends on the number of solutions to trying, for a CSP the complexity evolved on an exponential manner depending about the number of variables and the size of their respective fields.

The implementation is based on the constraints defined with the CSP, the language of programming "Choco" allows us to express the graph for each network separately and the QoS constraints that characterizes each one, taking account the functional and non-functional characteristics of each network expressed in SLA, our program gives us the the most optimal solution to resources allocation because it is based on **Choco Solver**.

For the implementation of our project, we have developed the CSP module. First, we express the characteristics of virtual networks in form of CSP. The CSP must take into account several points such as:

- First time, Satisfying the functional constraints.
- Guaranteeing non-functional parameters so that possible
- To save energy provider by allocating virtual networks to physical networks with nodes already instantiate and pause the rest of the nodes,

Our solution is a centralized solution, so our CSP is aware of all of the physical network resources allocated or not, a cluster is set up with all the necessary information. We define two types of constraints, Capacity-Constraint and Projection-Constraint which represent respectively the functional and non-functional constraints.

Previously, figure 2 presents different types of QoS, depending on the service provided by its virtual network, we propose a clear and simple method to express this difference and the importance of the order of the main non-functional parameters that must take into account a possible solution to provide the most optimal allocation, for this, each parameter has a weight, weight differs from the service and its corresponding SLA.

For saving energy, We joined a global score function which is equal to the score of each parameter multiplied by its weight.

c) Functional Scoring: The score of the functional parameters is a global value that is equal to the number of physical routers allocated whatever service or settings multiplied by their weight

d) Non Functional Scoring: The score of the Non Functional parameters is equal to the sum of the individual scores for each non-functional parameter multiplied by the value of its weight

In conclusion, the global score is the aggregation of scores (functional and non functional) Thus, to limit the abusive use of physical routers, an objective function has been implemented in order to minimize the global Score.

B. Test and results

we present in this section tests in order to validate our approach beggining by knowing the execution times. The tests were performed on a HP-ProBook 4530s machine with an Intel Core i5-2430M CPU 2.40 GH processor with a memory of 4 gigabytes and operating system Windows 7 Professional 64-bit. We chose to simulate generic physical routers with the same CPU and memory, but with a different rate on each link, for a virtual router CPU and memory capacity are equal (between virtual routers) but bandwidths are different (for each virtual link). To simplify our graphs, a glossary is established.

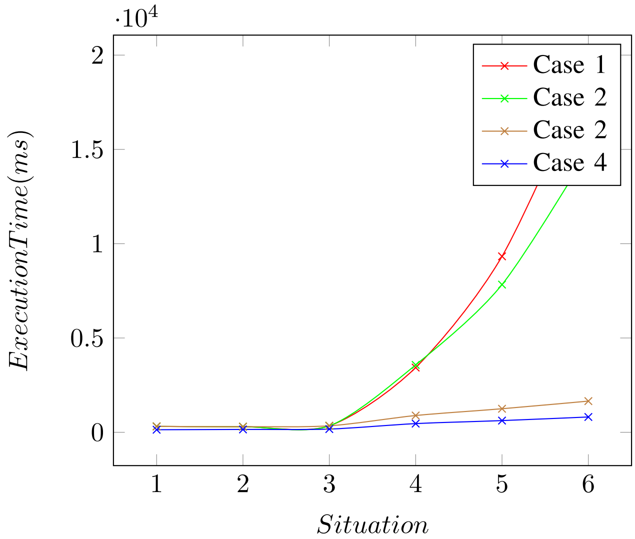
Situation	Applied constraints
S1	CPU
S2	CPU + Memory
S3	CPU + Memory + Bandwidth
S4	Functional + Delay
S5	Functional + Delay + Packet lost
S6	Functional and Non Functional

Table V: Glossary

Execution time

we varied the number of constraints that the CSP had dealt with the following conditions:

1) Case 1: The weight value of service (parameter) equal to that of a VOIP network.
2) Case 2: The weight value of service equal to 1 for all non-functional parameters.
3) Case 3: The weight value of service equal to 0 for all non-functional parameters.
4) Case 4: The weight value of service equal to 0 for all parameters (not functional).



This figure allows us to have a clear view of the differences between the running time. So it is obvious that the greatest value is that of case 1, which is when our constraints is applied to the maximum for response to QoS needed by the virtual network instantiate service, this increases the time resolution because of increase of the search space.

The combination exposure of the solution and all set of research leads us to believe that our solution does not happen to scale, but on one hand, some research areas are inaccessible because the constraints are not respected (in effect as a step violates a constraint, the algorithm operates without a back-track down to the sub-tree), and the other heuristic exploration strategies can be used to obtain better results.

we are in the process of testing the performance of the solution and first results are encouraging and promising

V. Conclusion

In this project, we realized a solution based CSP whose function is the dynamic allocation of resources in virtual networks with the possibility of reconfiguration. We identified the problem as a problem of graph matching. One of the methods of resolutions combination problems is to express it in CSP. We used this mathematical tool to formulate the resource allocation problem, the QoS requirements and energy

The separation of the resource allocation problem into two parts, one including severe constraints represented by the functional parameters and the other expressing the QoS with less severe constraints but respecting the SLA allowed us having encouraging results that are optimal due to their solving by a CSP solver (Choco).

The code optimization and the use of multiple features Choco has resulted in a shorter execution time, ergonomics program and restricted our search set. It remains to find solutions to the problem of links assigning, trying to implement a load balancing between virtual links (possibly machines) according to the SLA established by the provider.

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