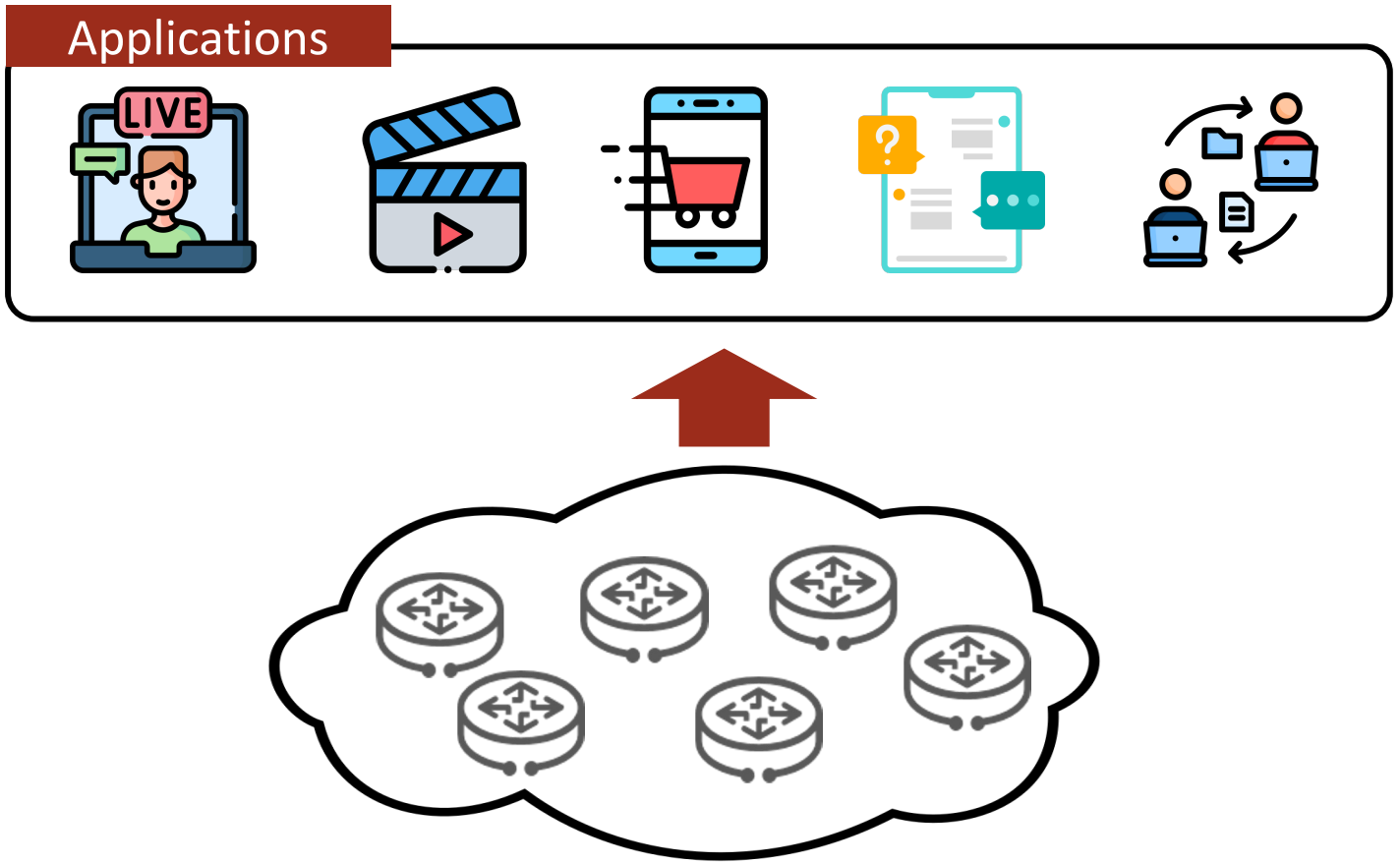
ACM SIGCOMM 2022 Best Paper Award

Software-defined Network Assimilation: Bridging the Last Mile Towards Centralized Network Configuration Management with NAssim

Huangxun Chen[1], Yukai Miao[2,1], Li Chen[3], Haifeng Sun[4], Hong Xu[5], Libin Liu[6], Gong Zhang[1], Wei Wang[7]

[1]Huawei Theory Lab, [2]University of New South Wales, [3]Zhongguancun Laboratory
[4]Beijing University of Posts and Telecommunications, [5]The Chinese University of Hong Kong
[6]Shandong Computer Science Center (National Supercomputer Center in Jinan)
[7]Hong Kong University of Science and Technology (Guangzhou & Hong Kong)



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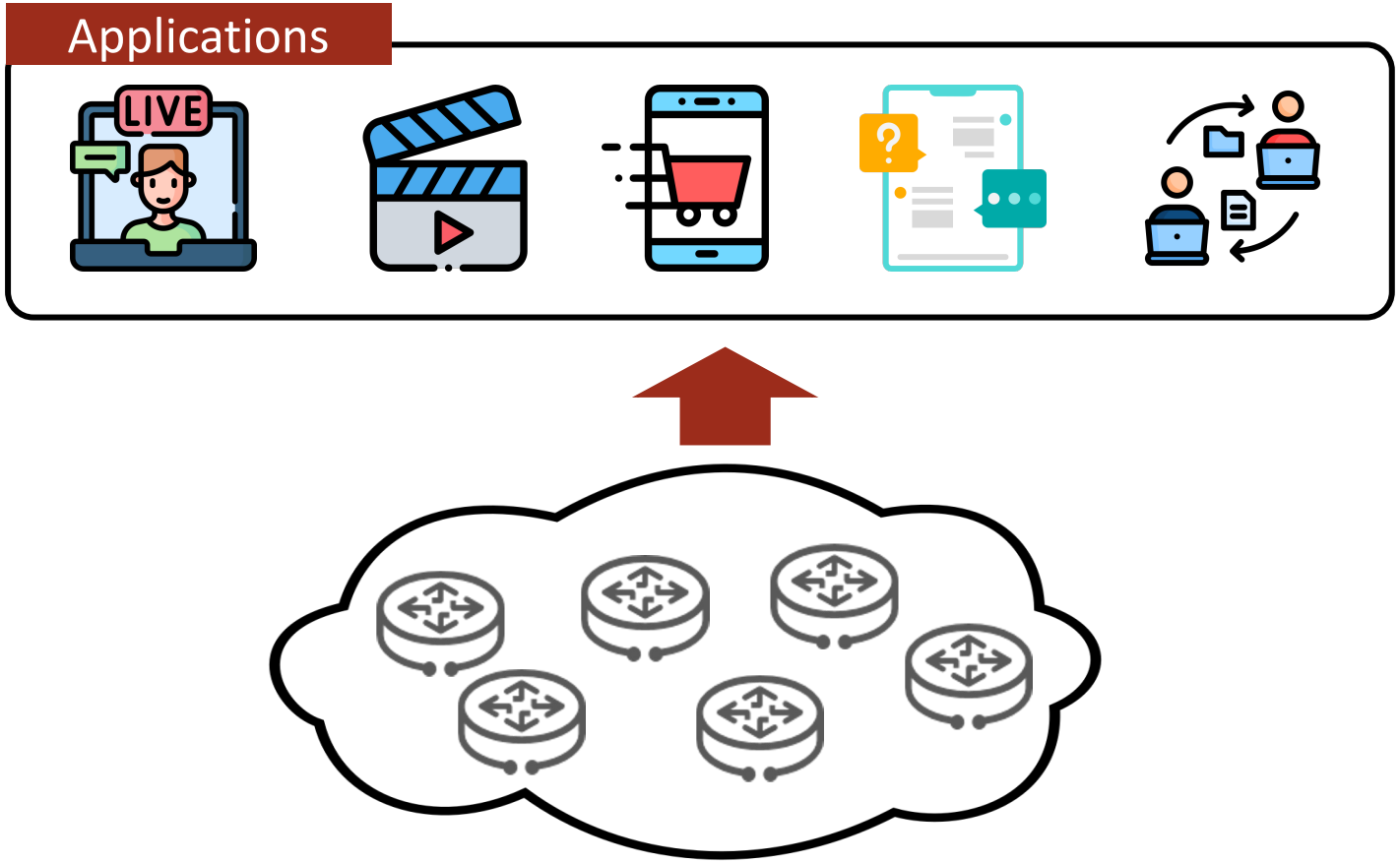

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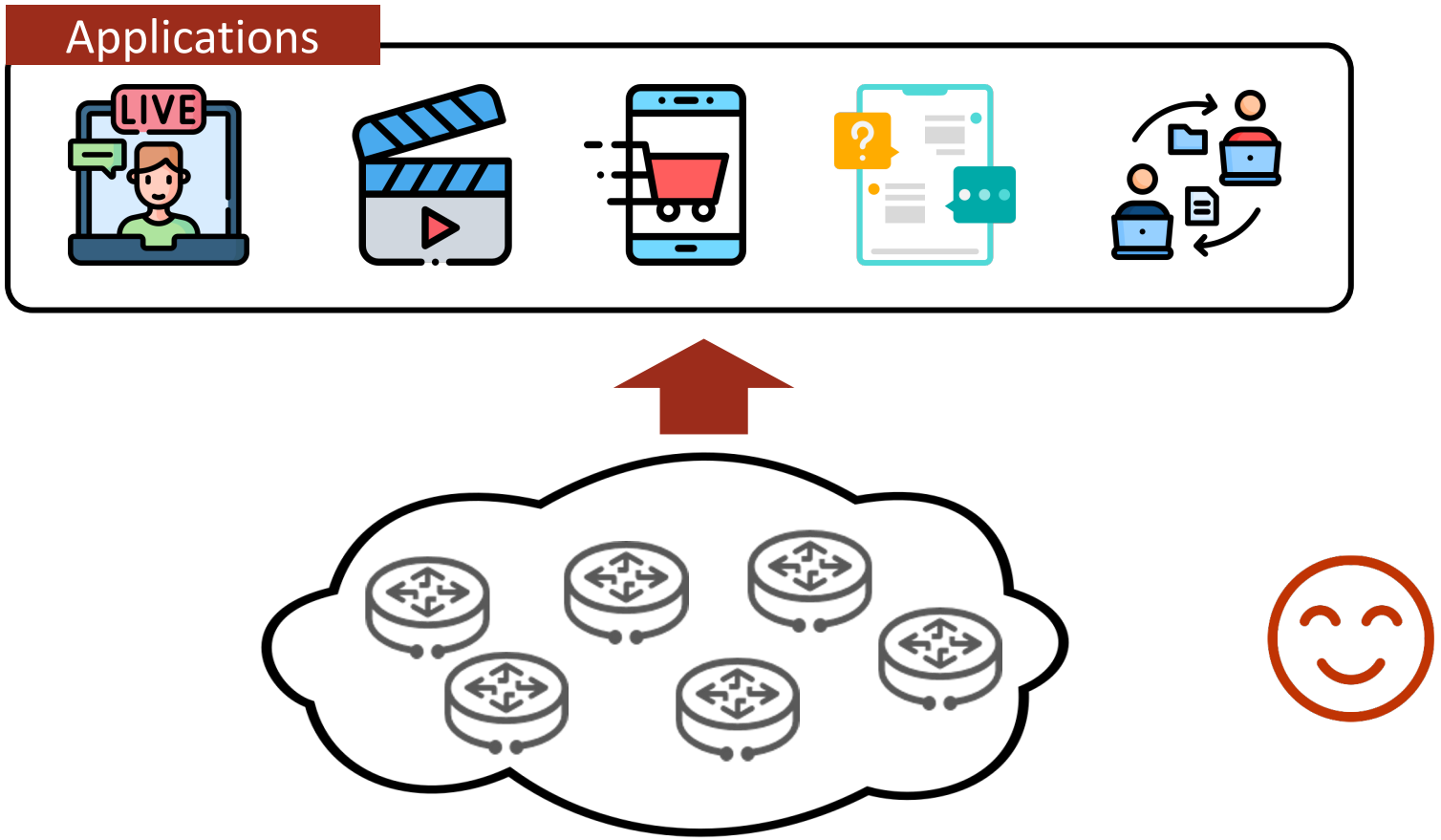

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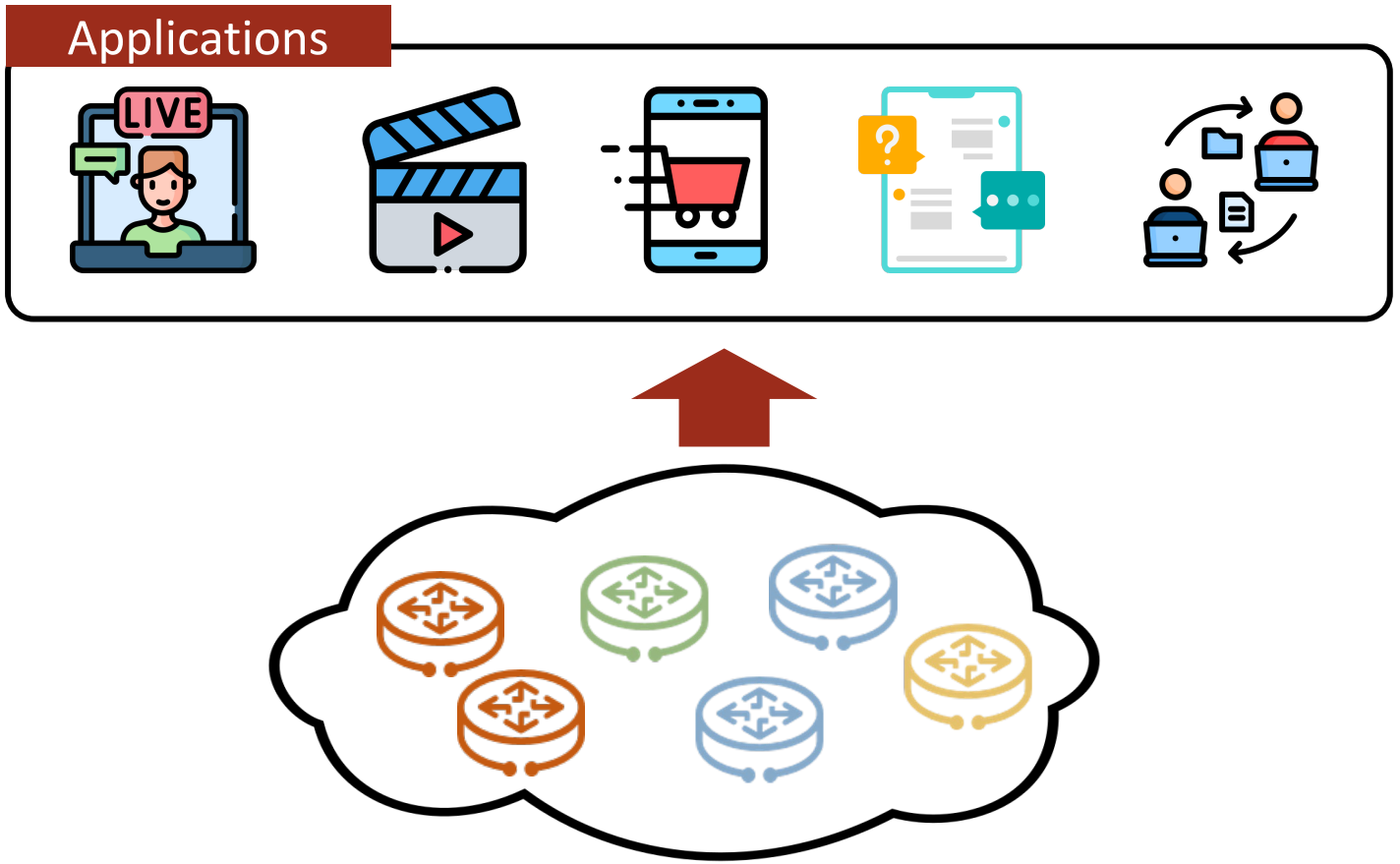

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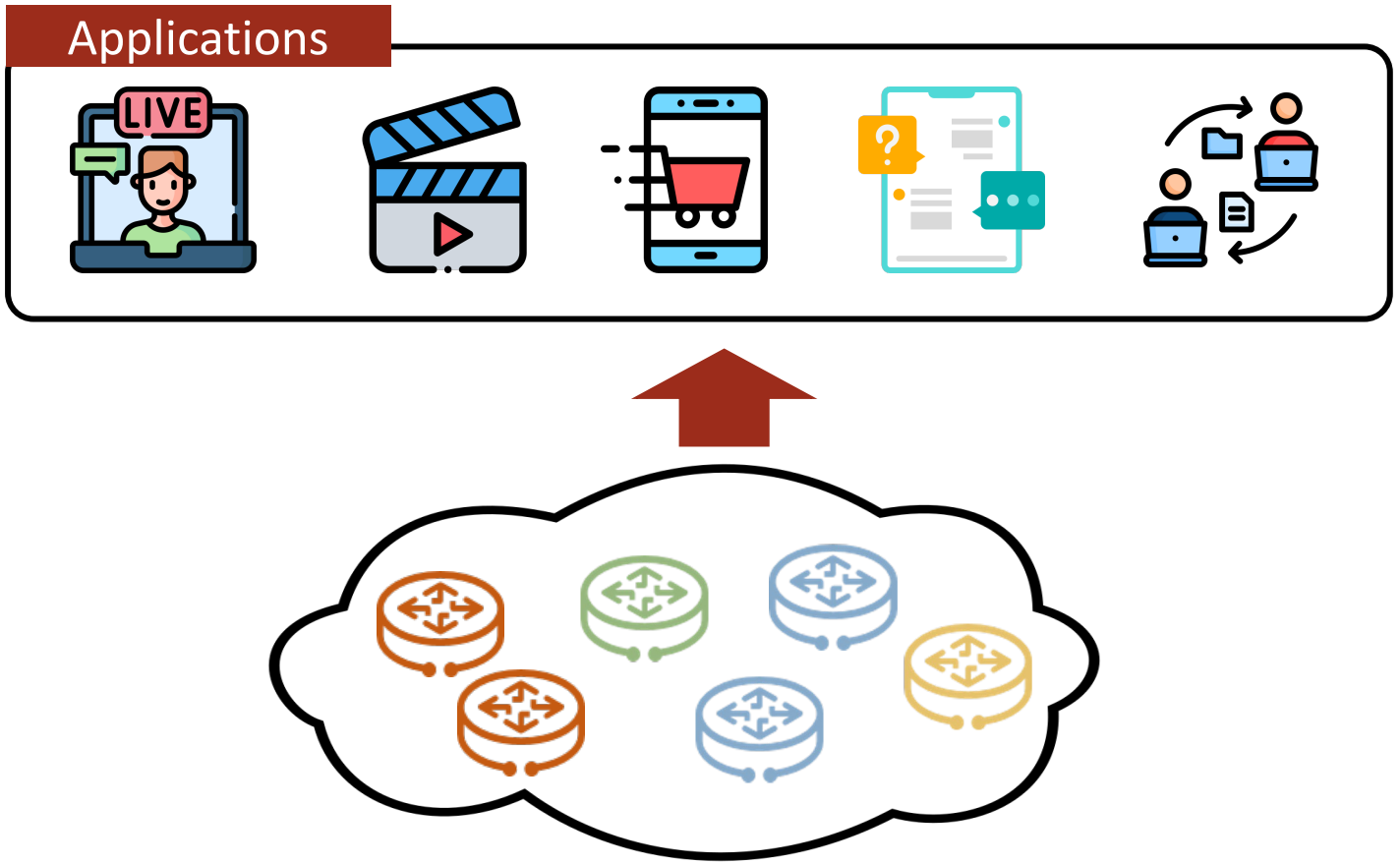

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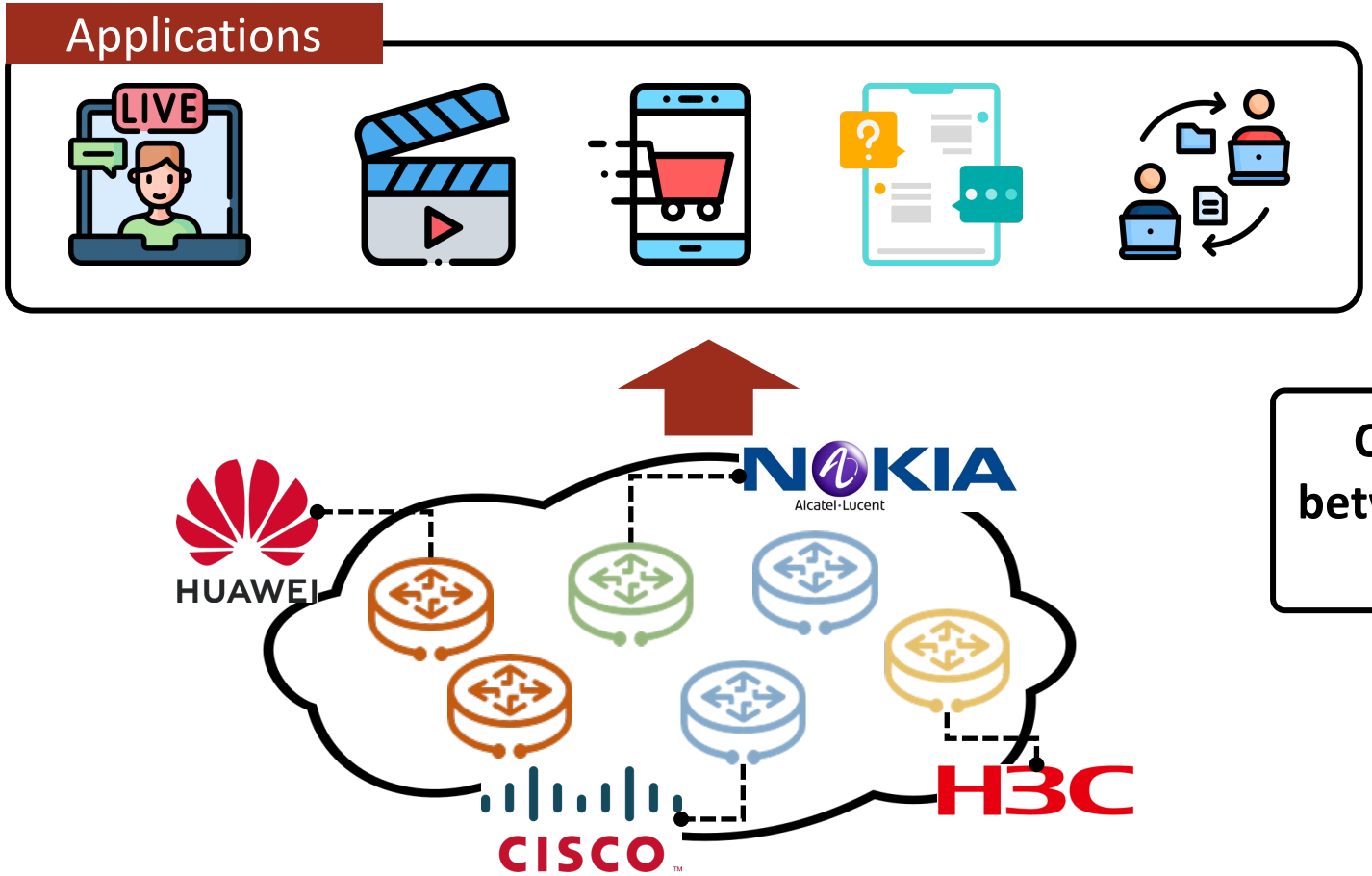

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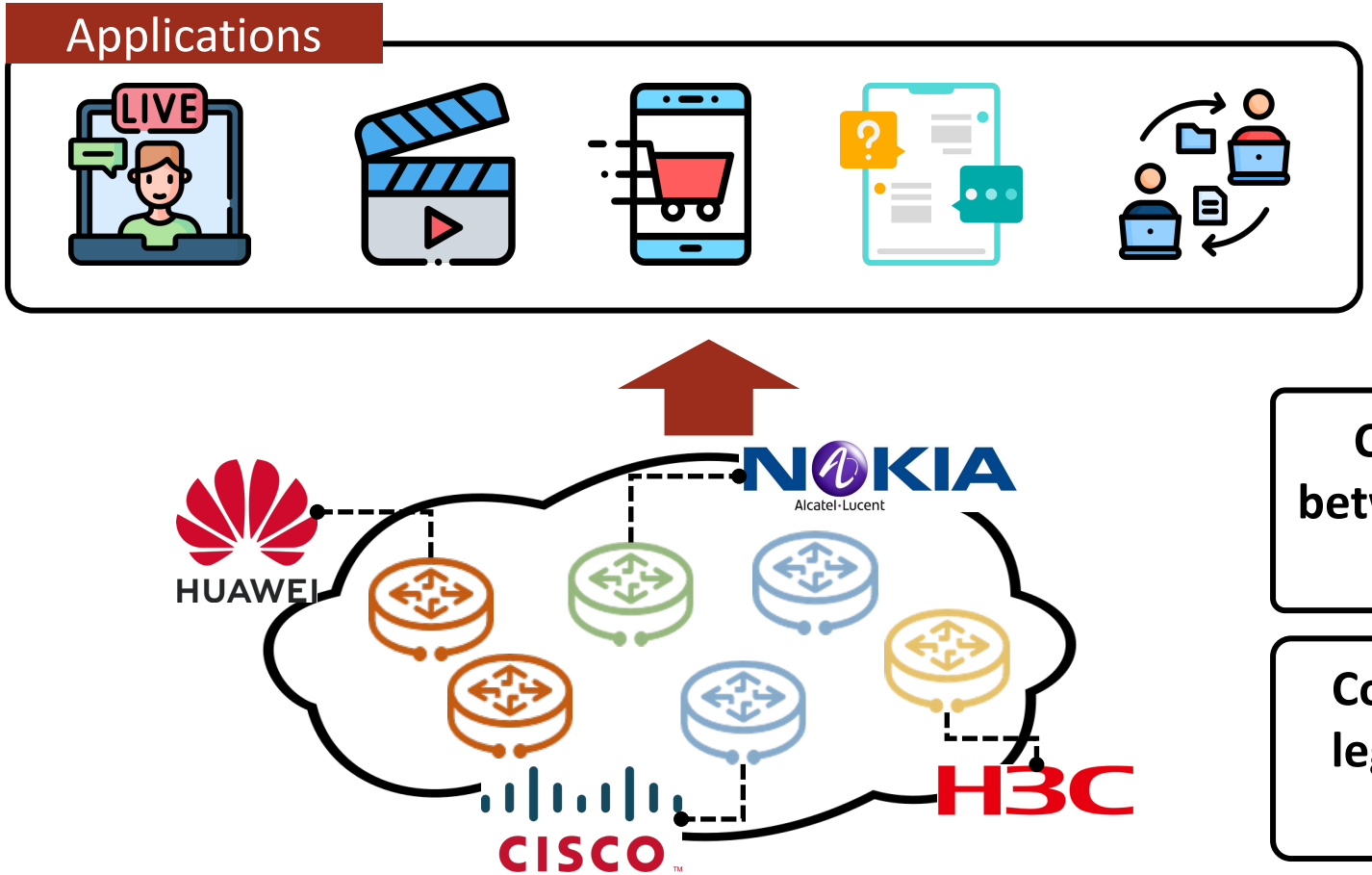

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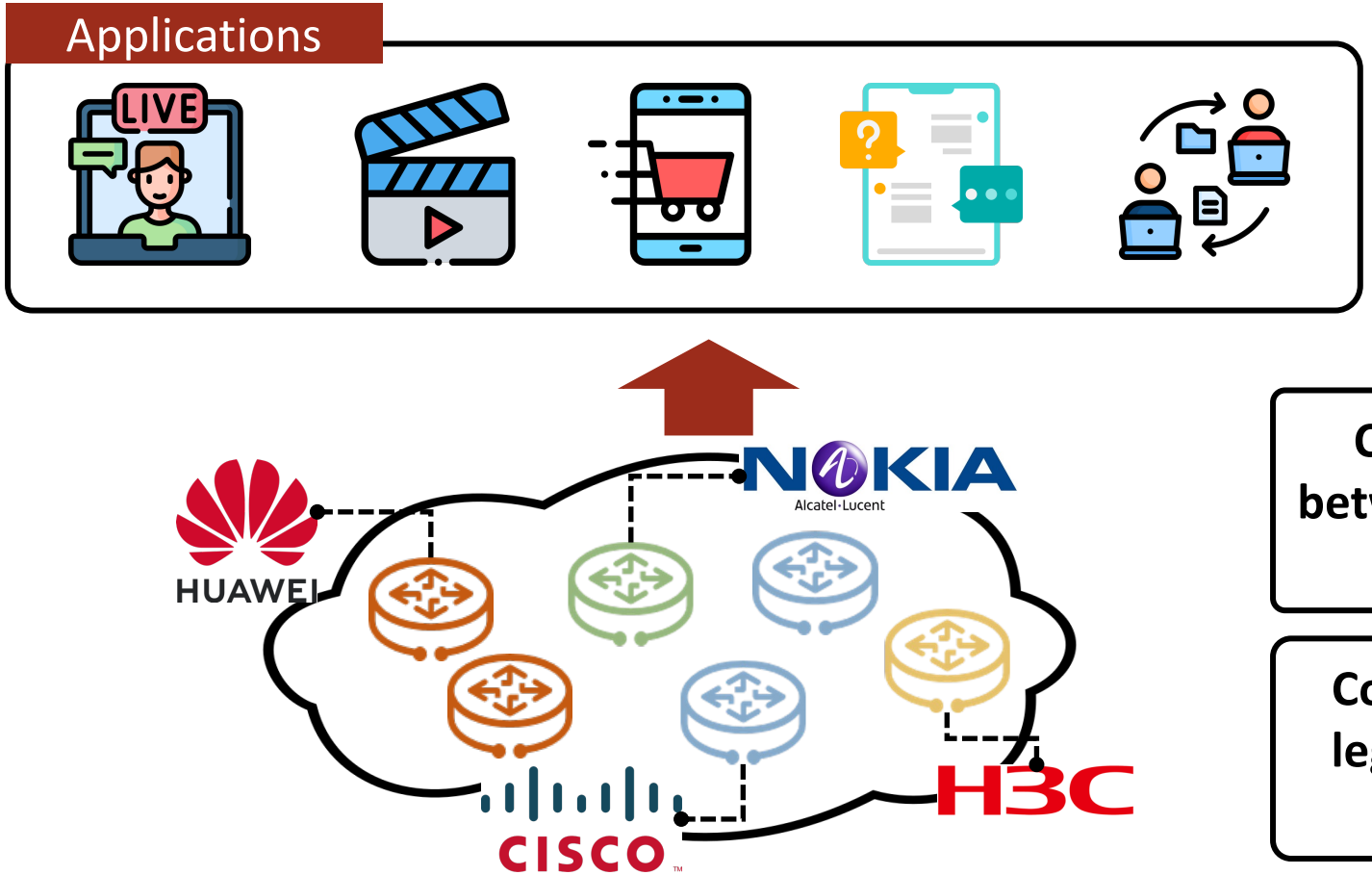

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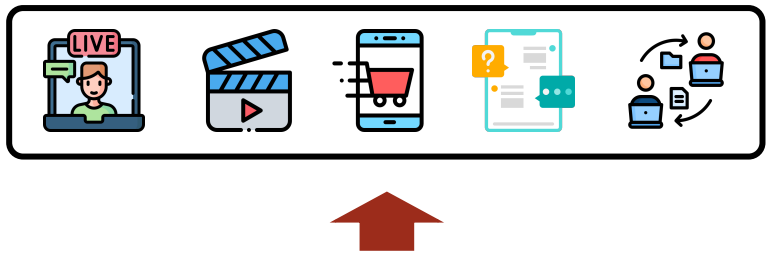

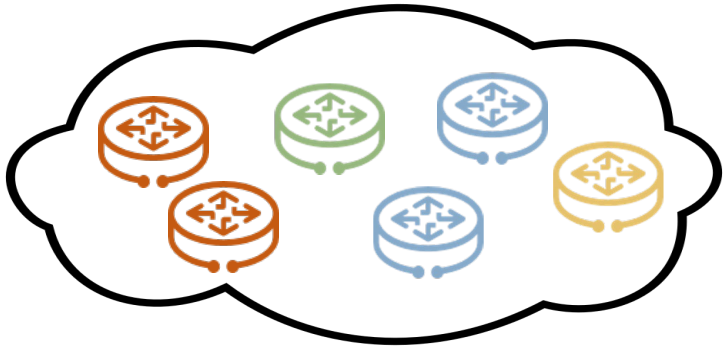

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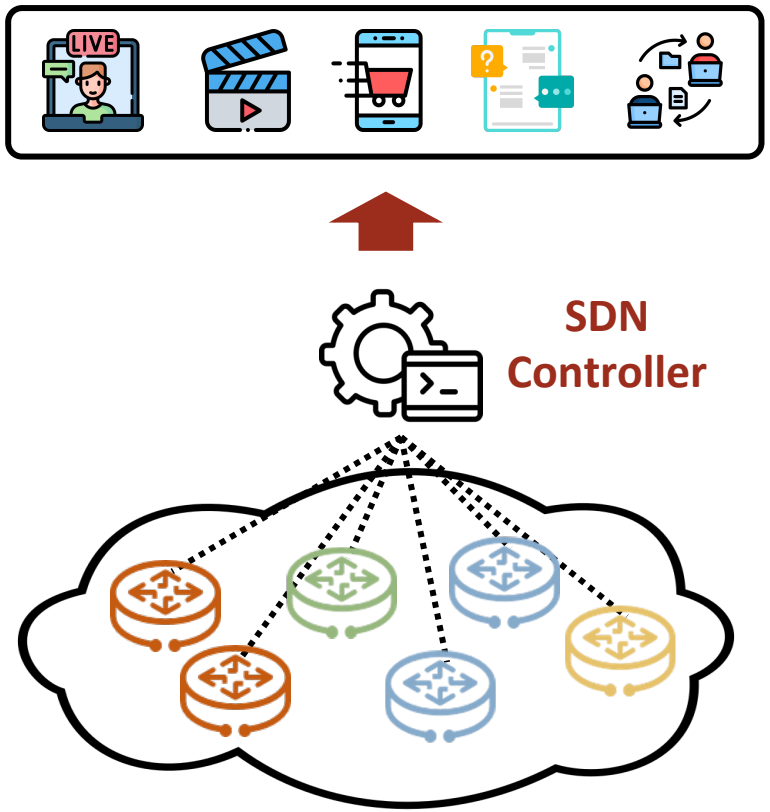

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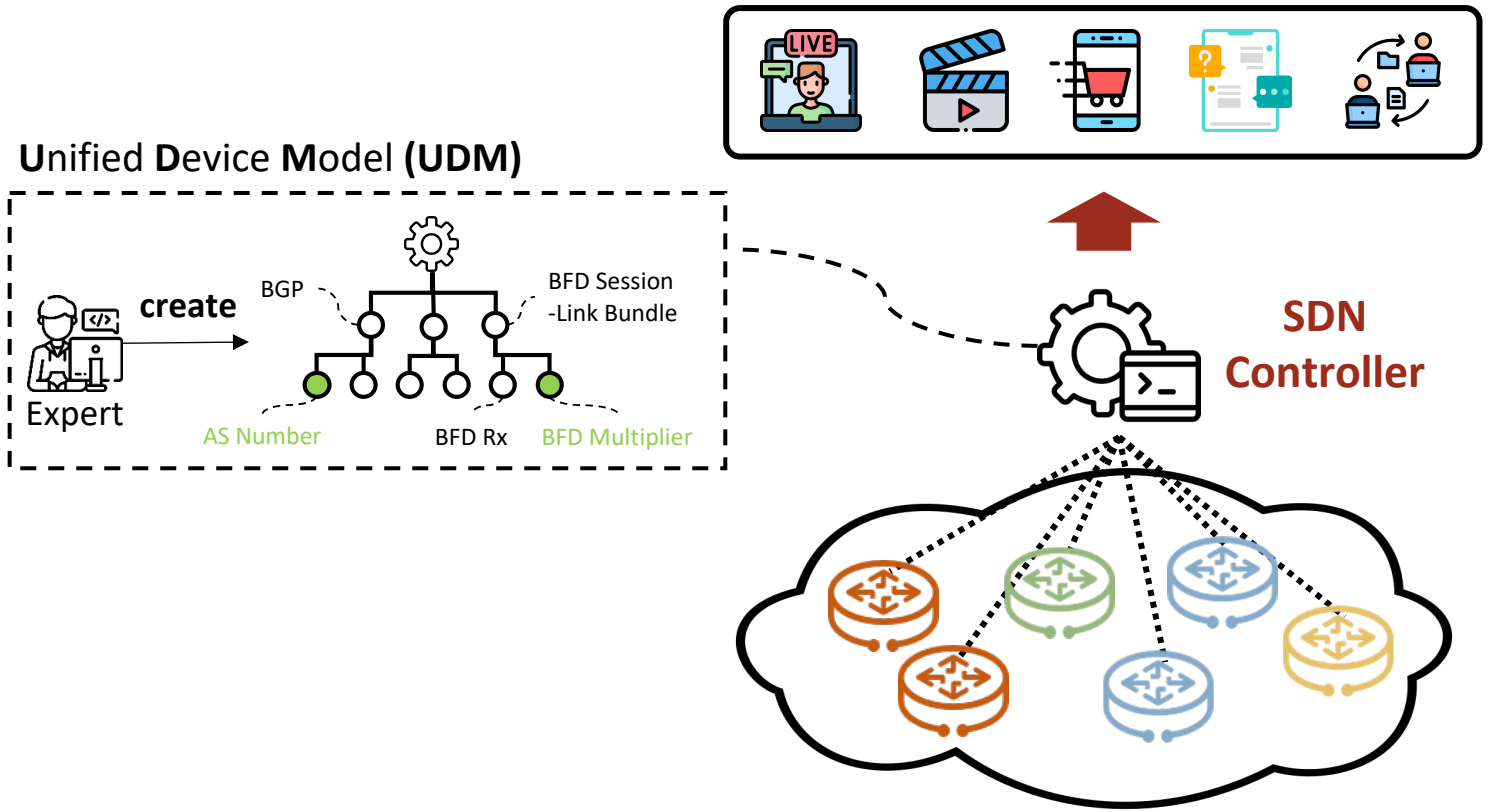

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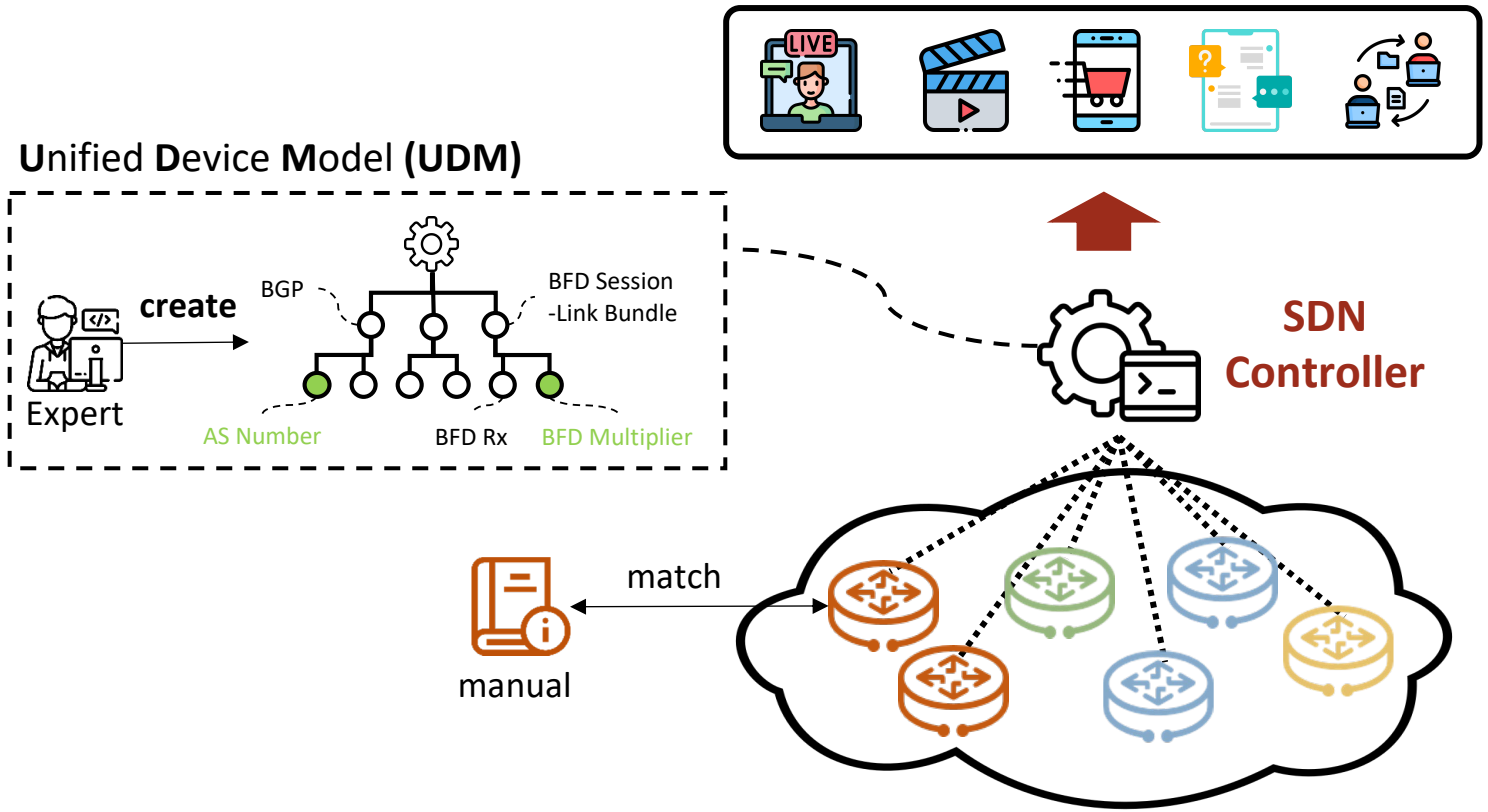

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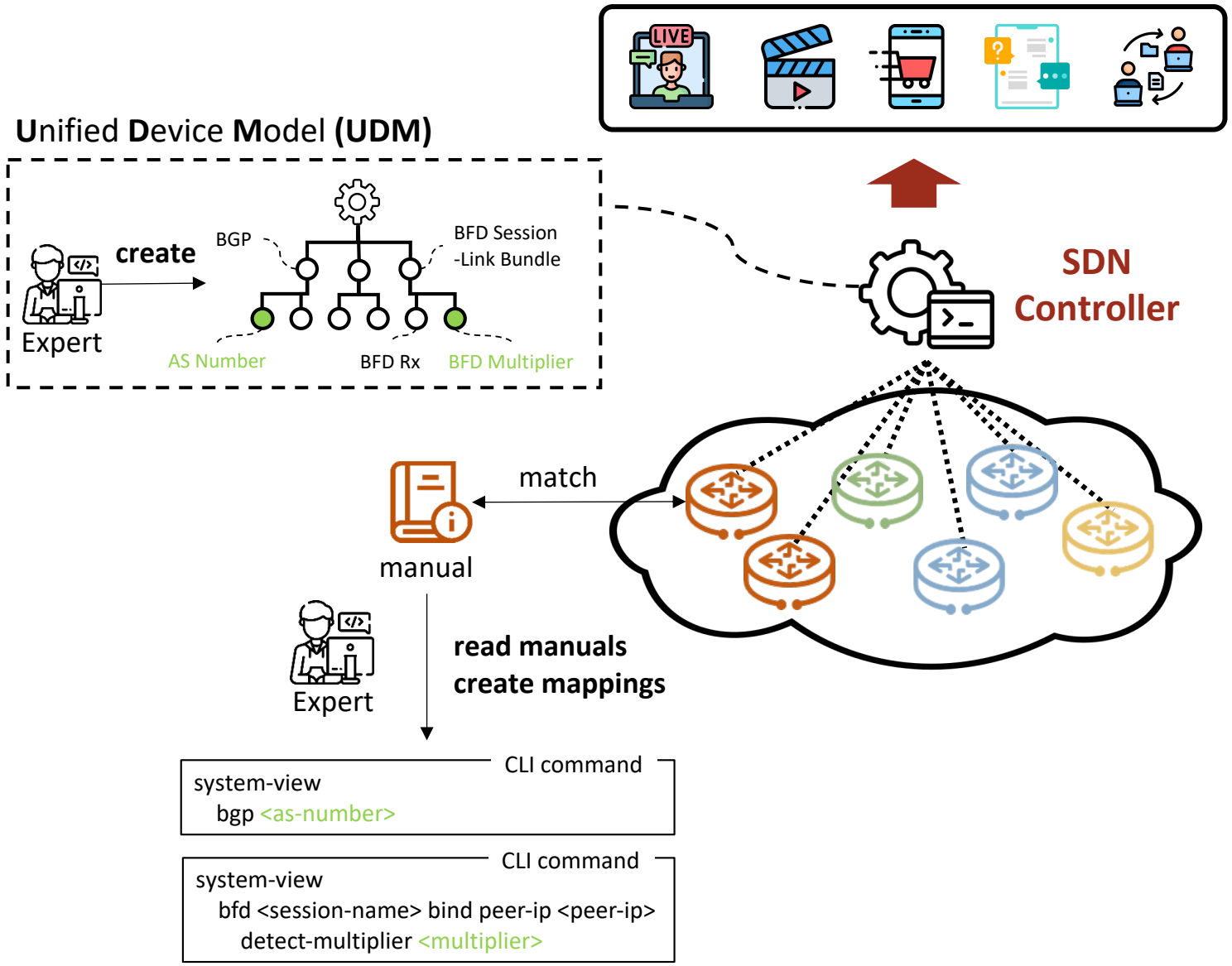

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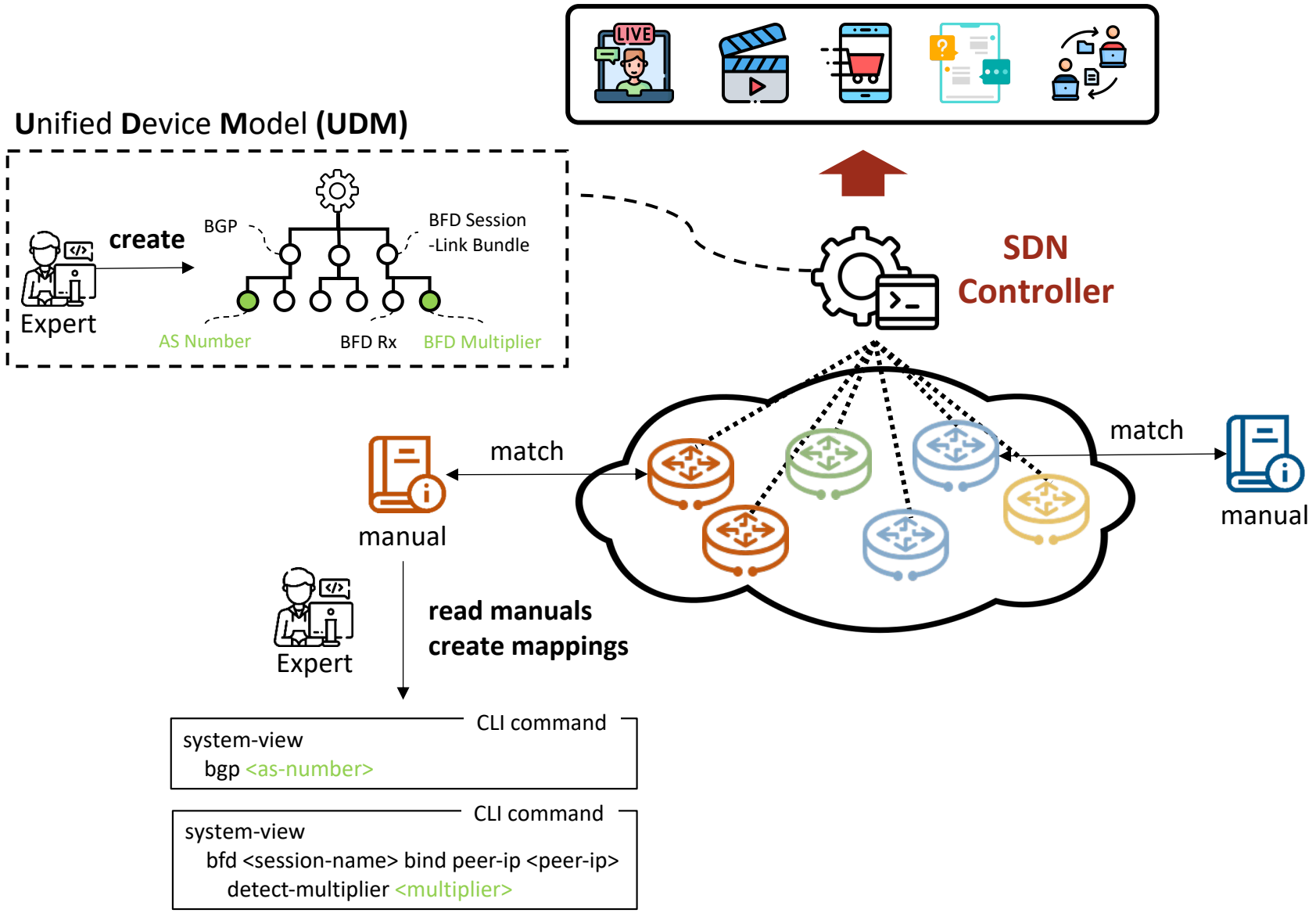

HUAWEI

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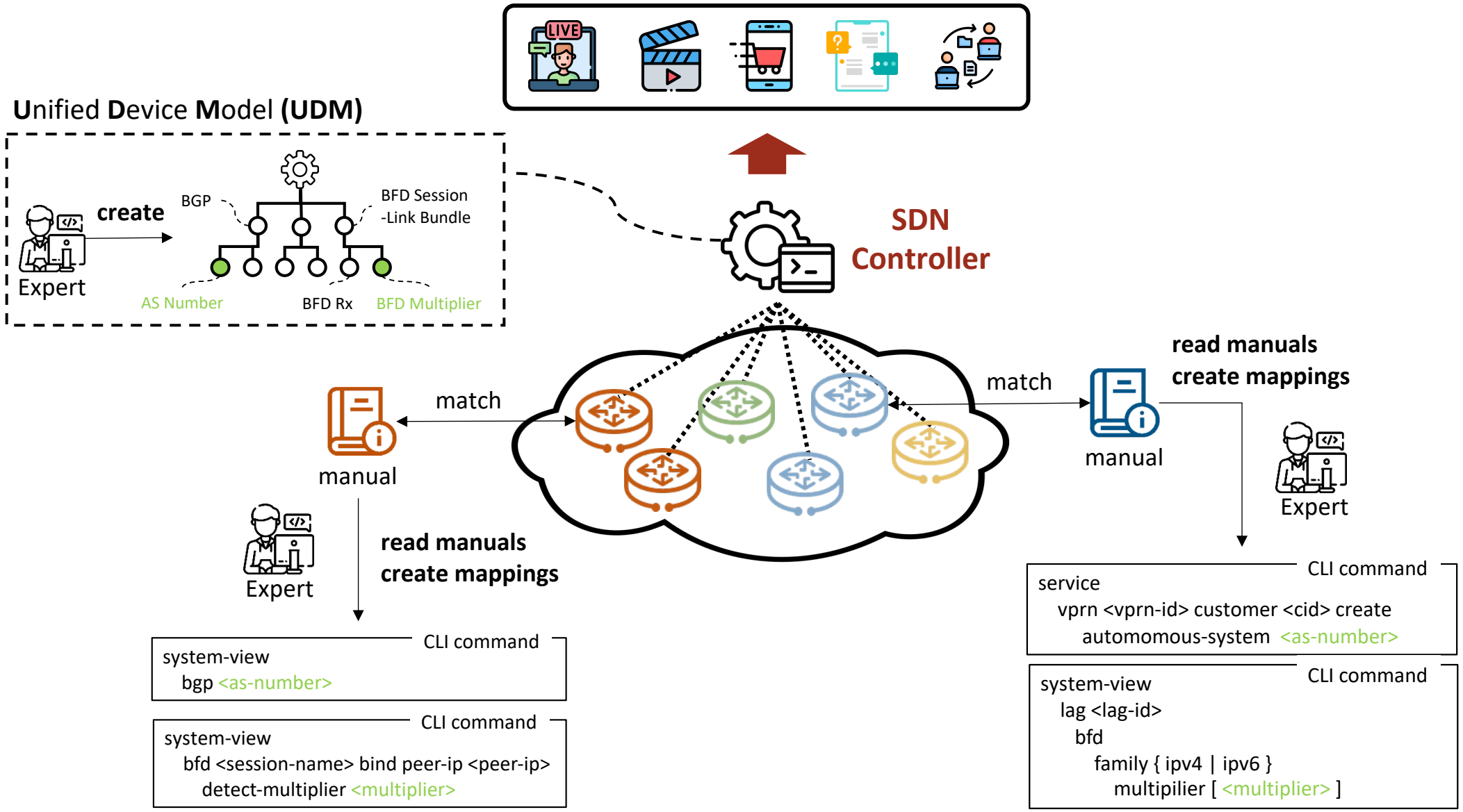

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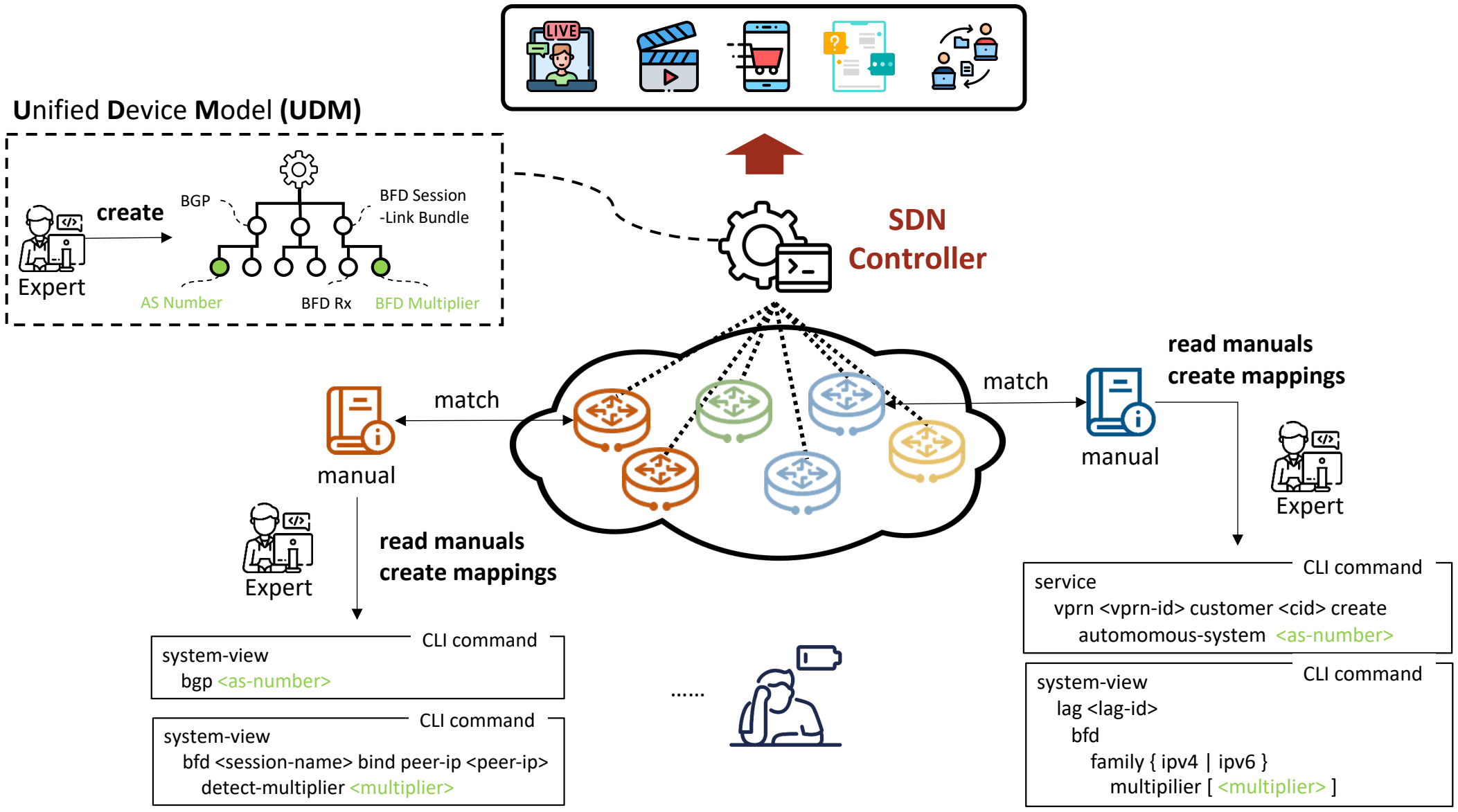
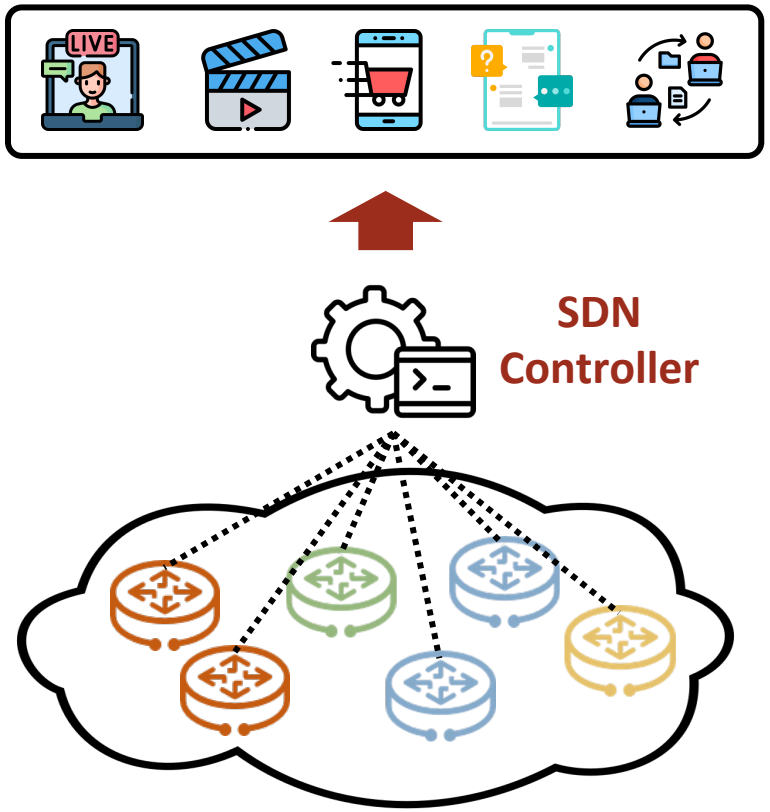


HUAWEI

Current SNA approaches require significant human efforts



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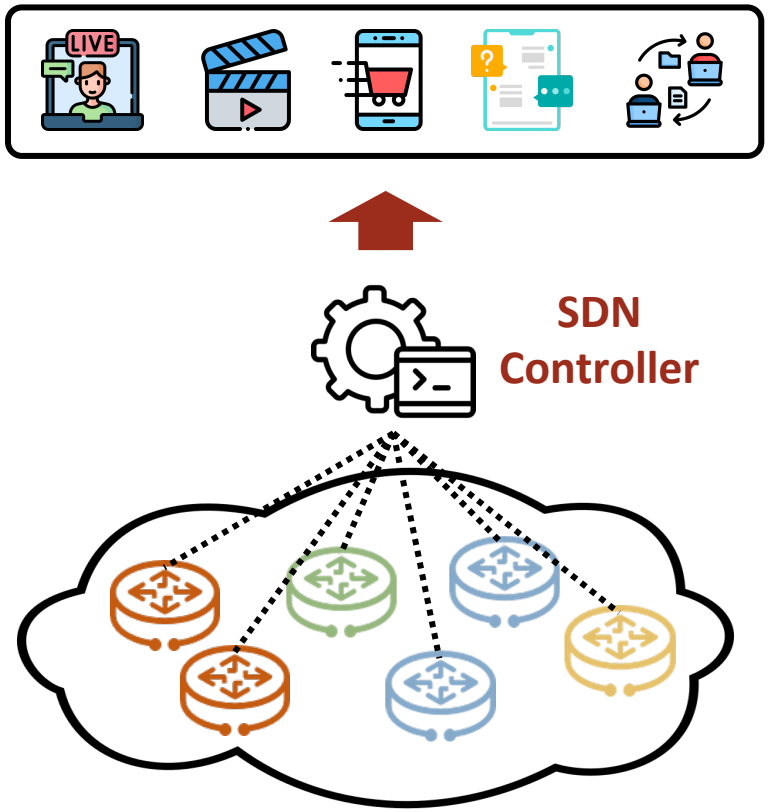

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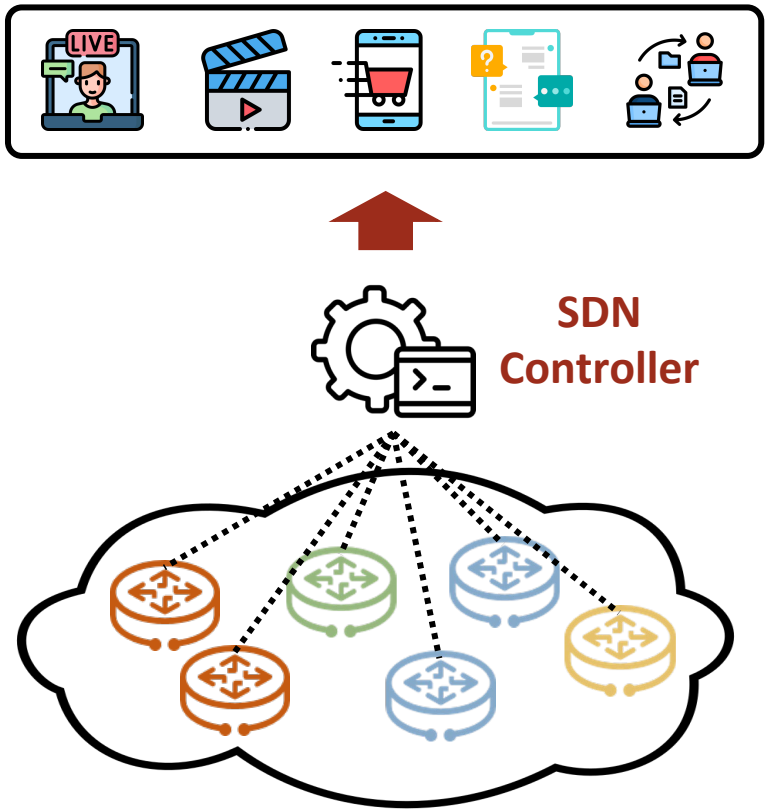
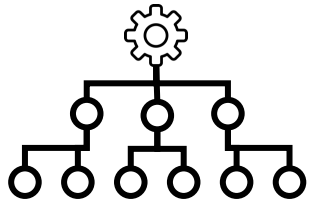


Unified **D**evice **M**odel **(UDM)**



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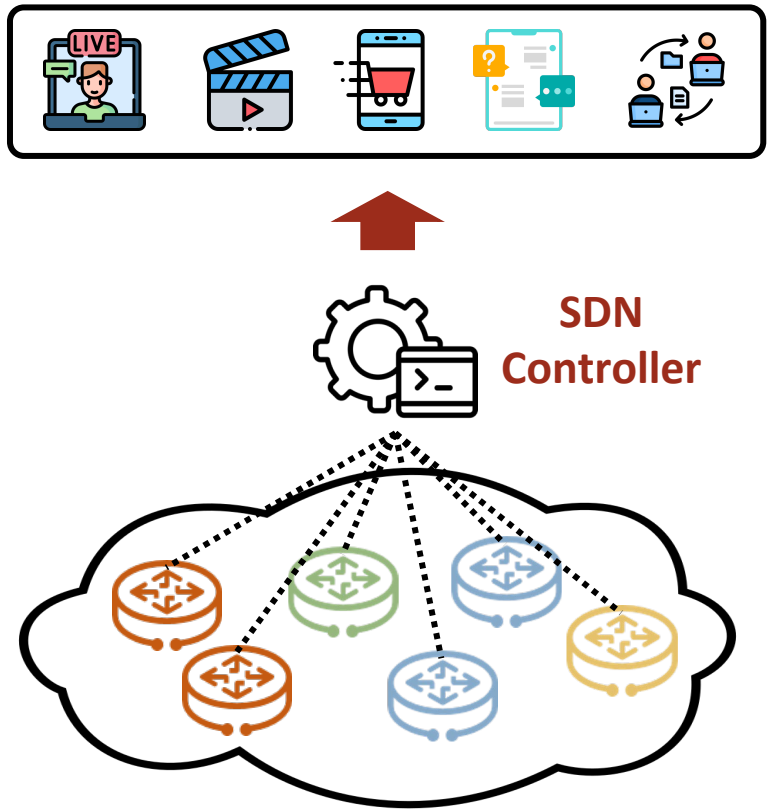

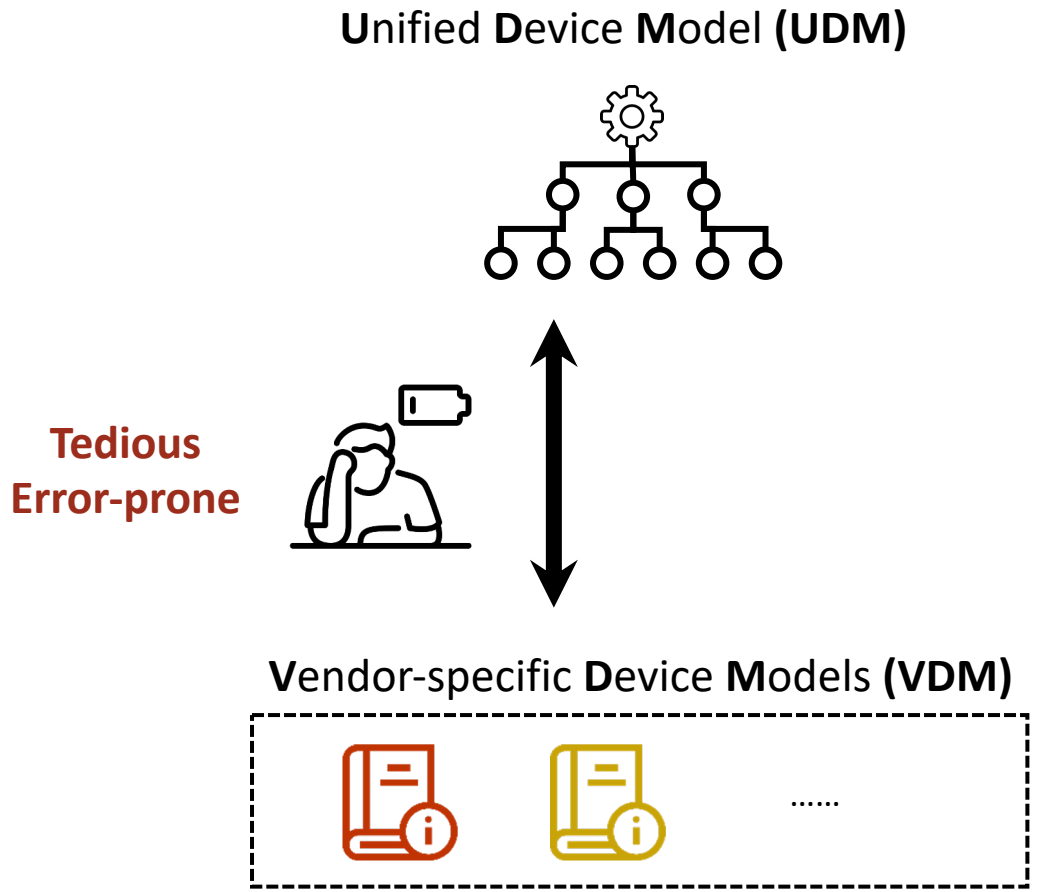

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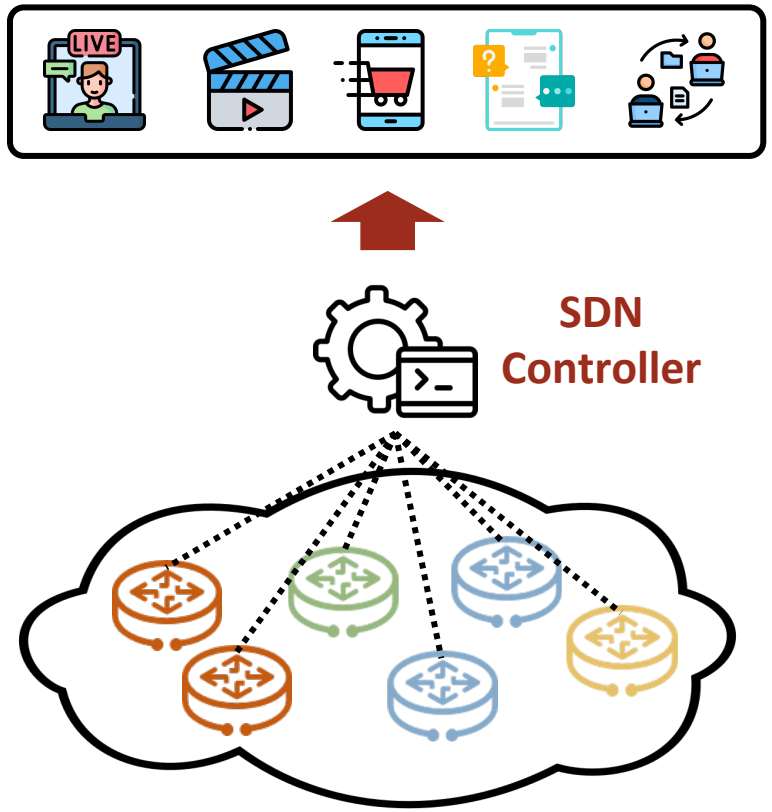

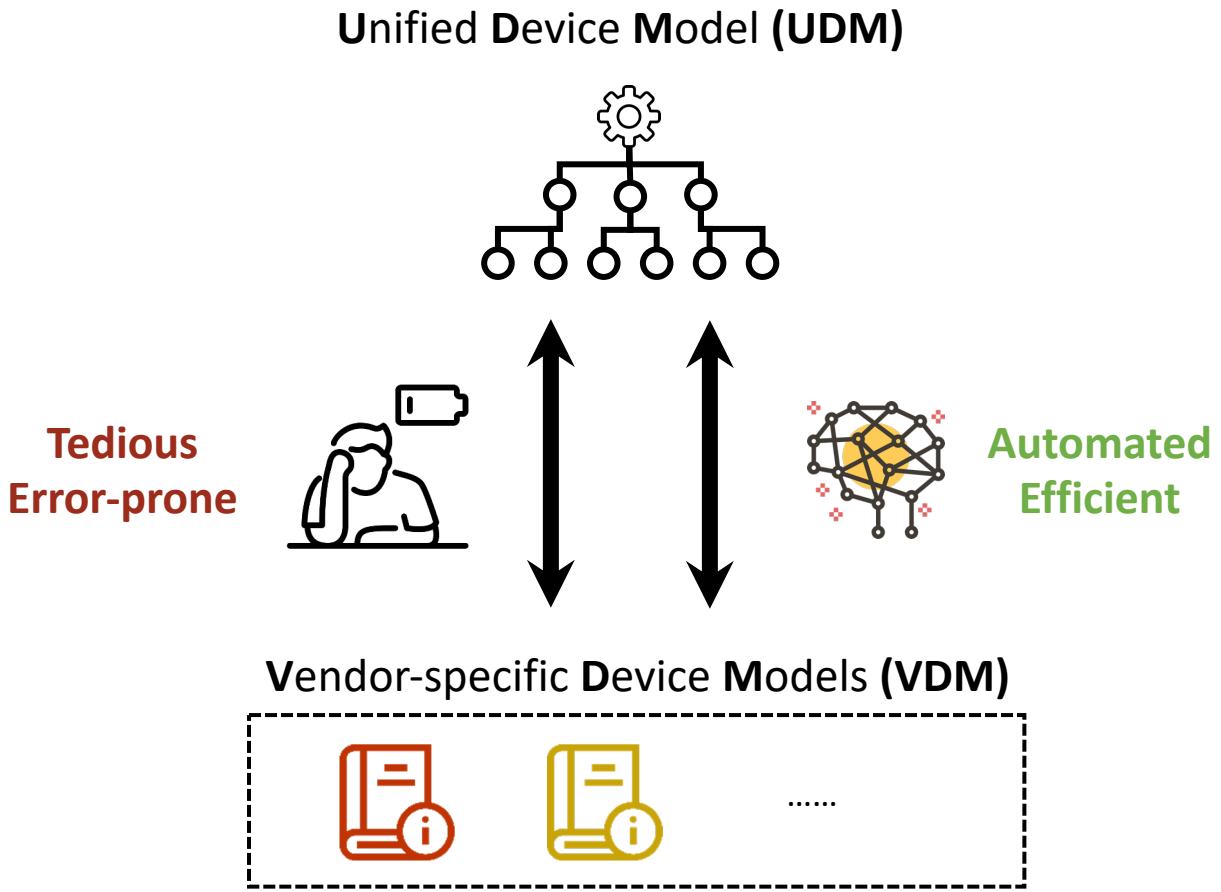

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Basic Insight: Imitating the Practices of NetOps

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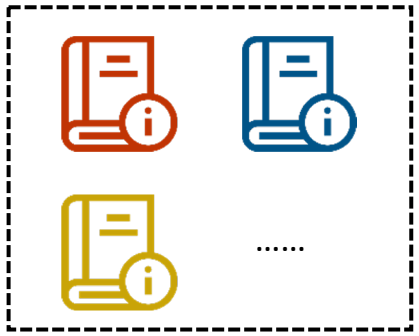

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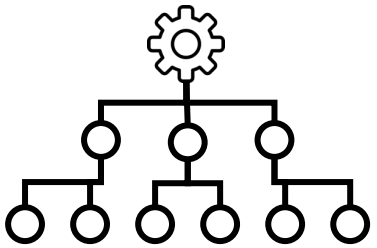

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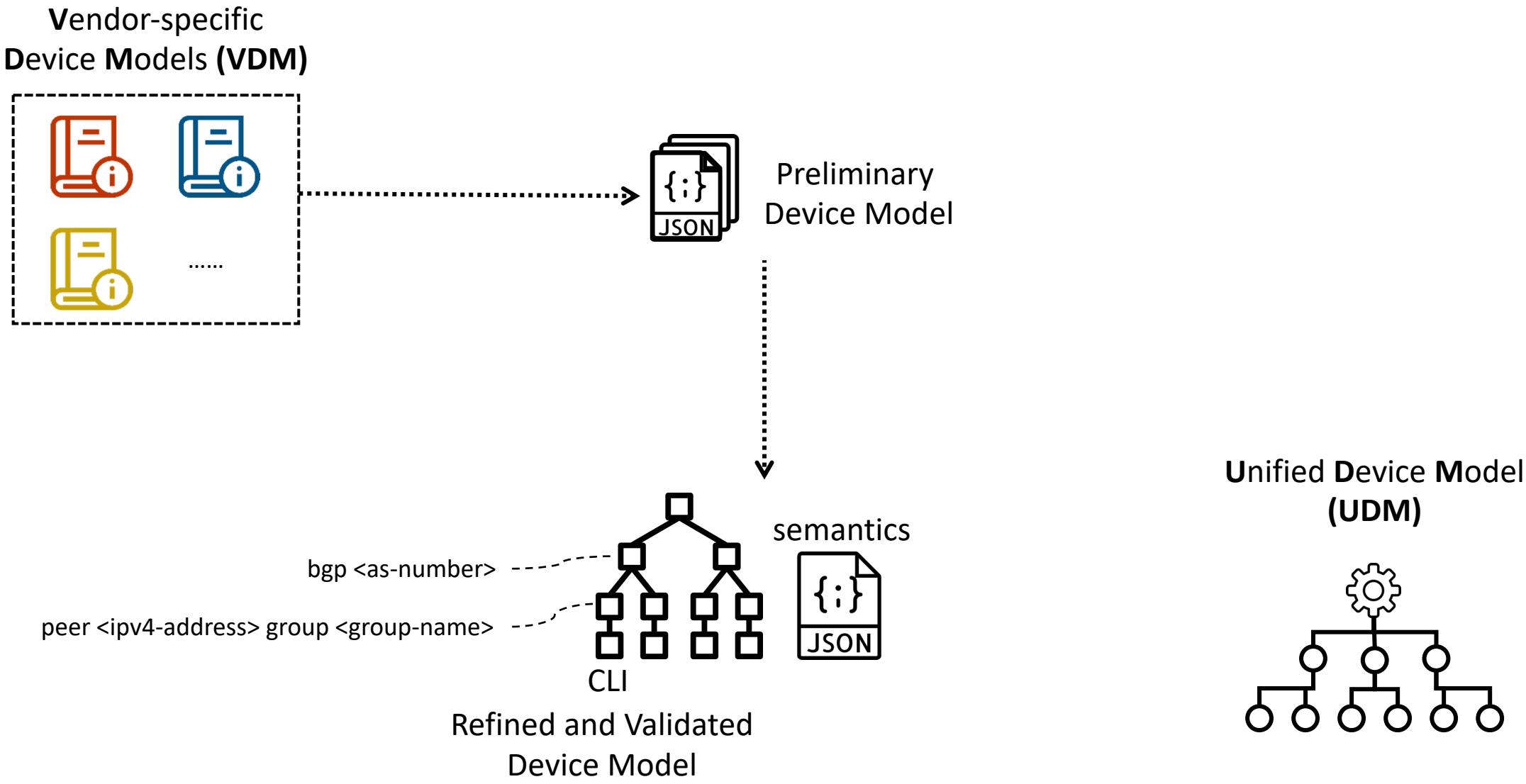

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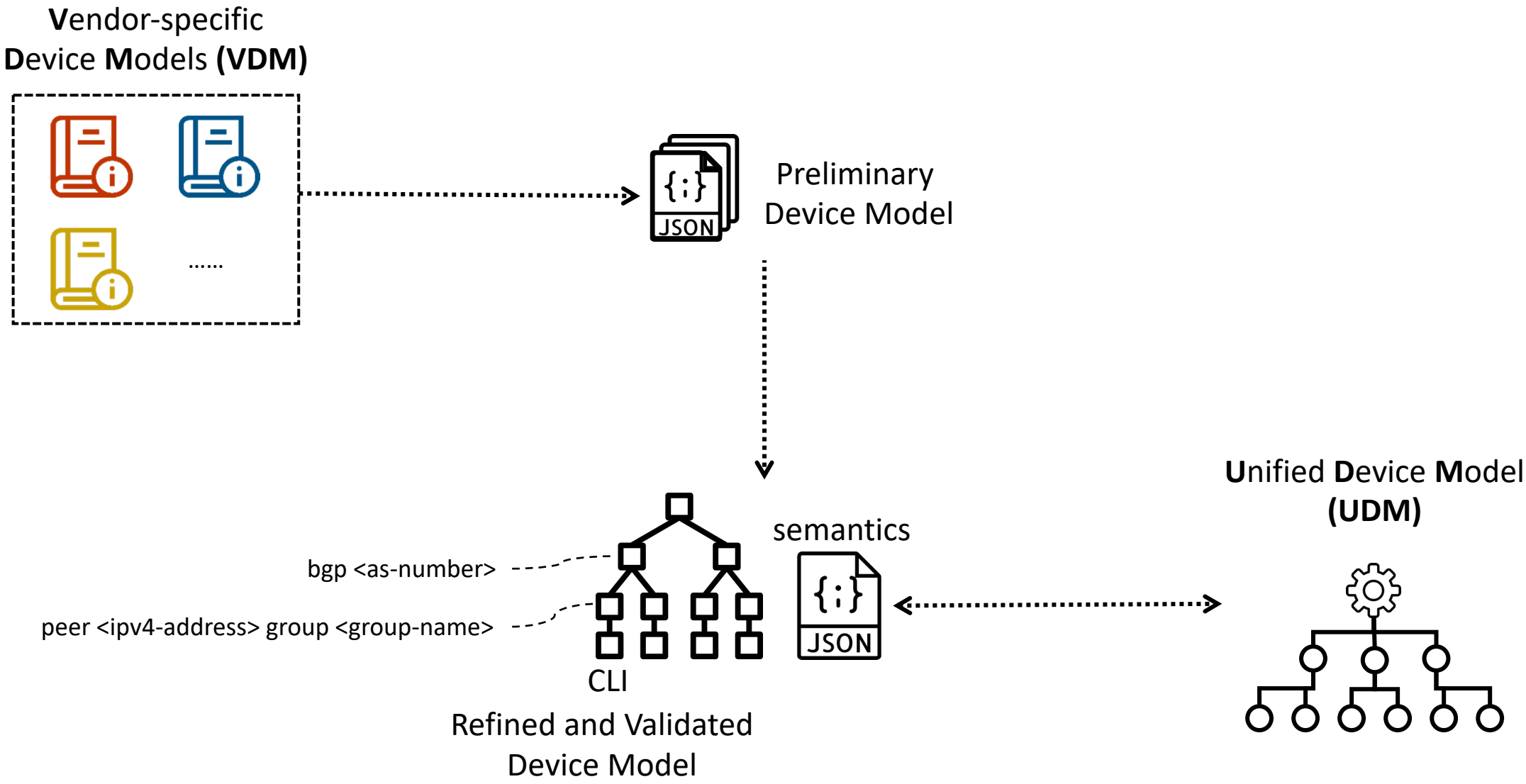

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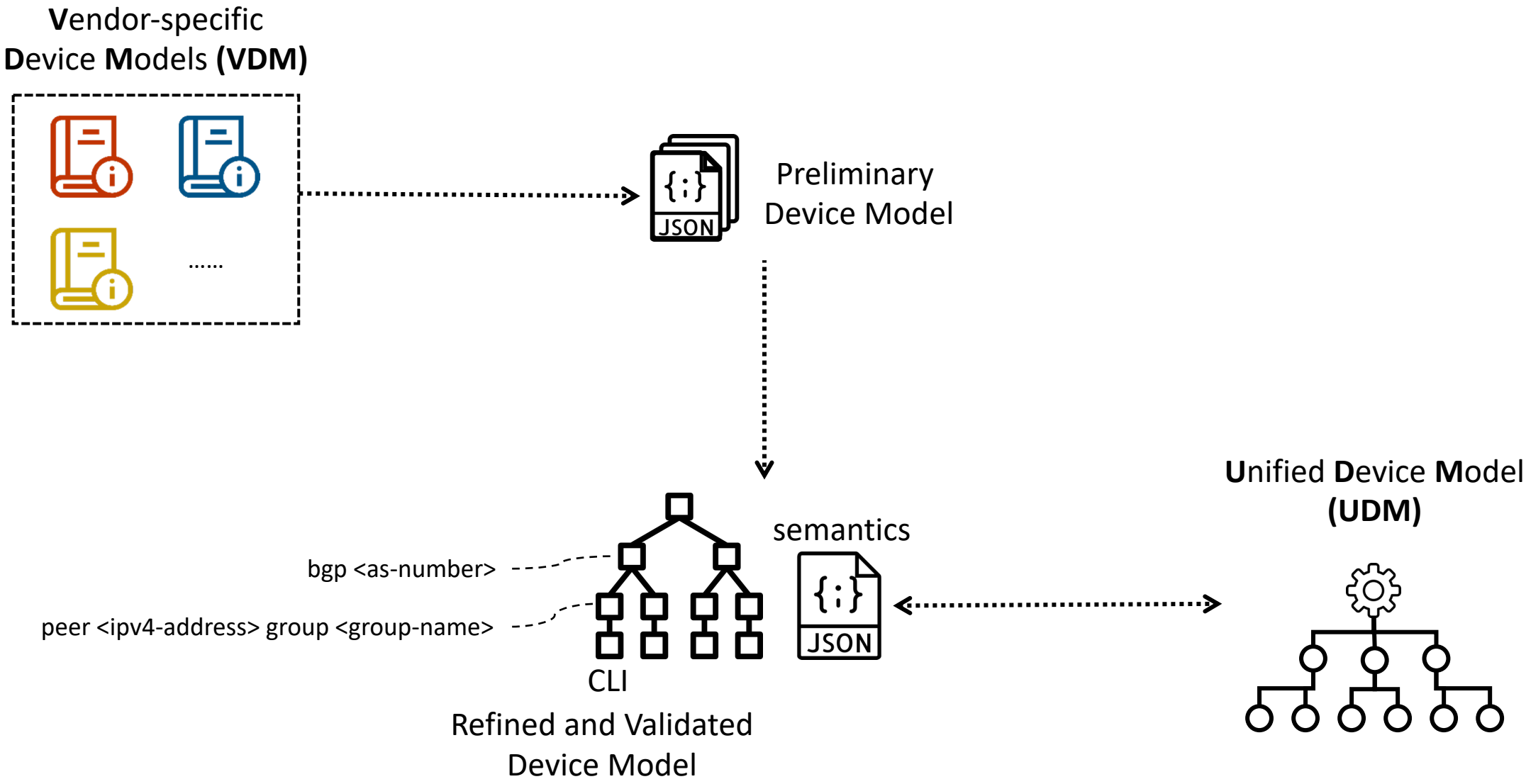

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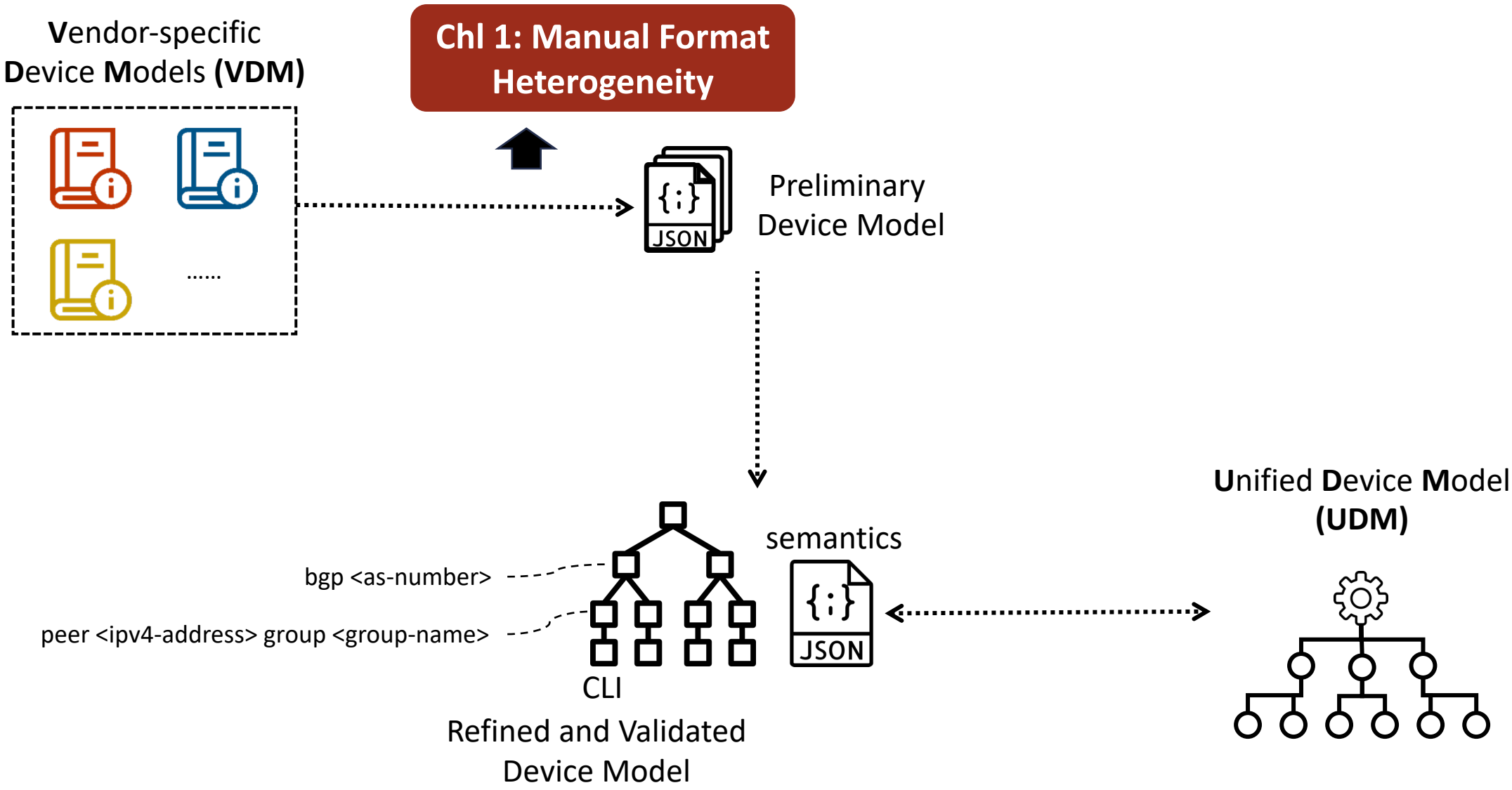

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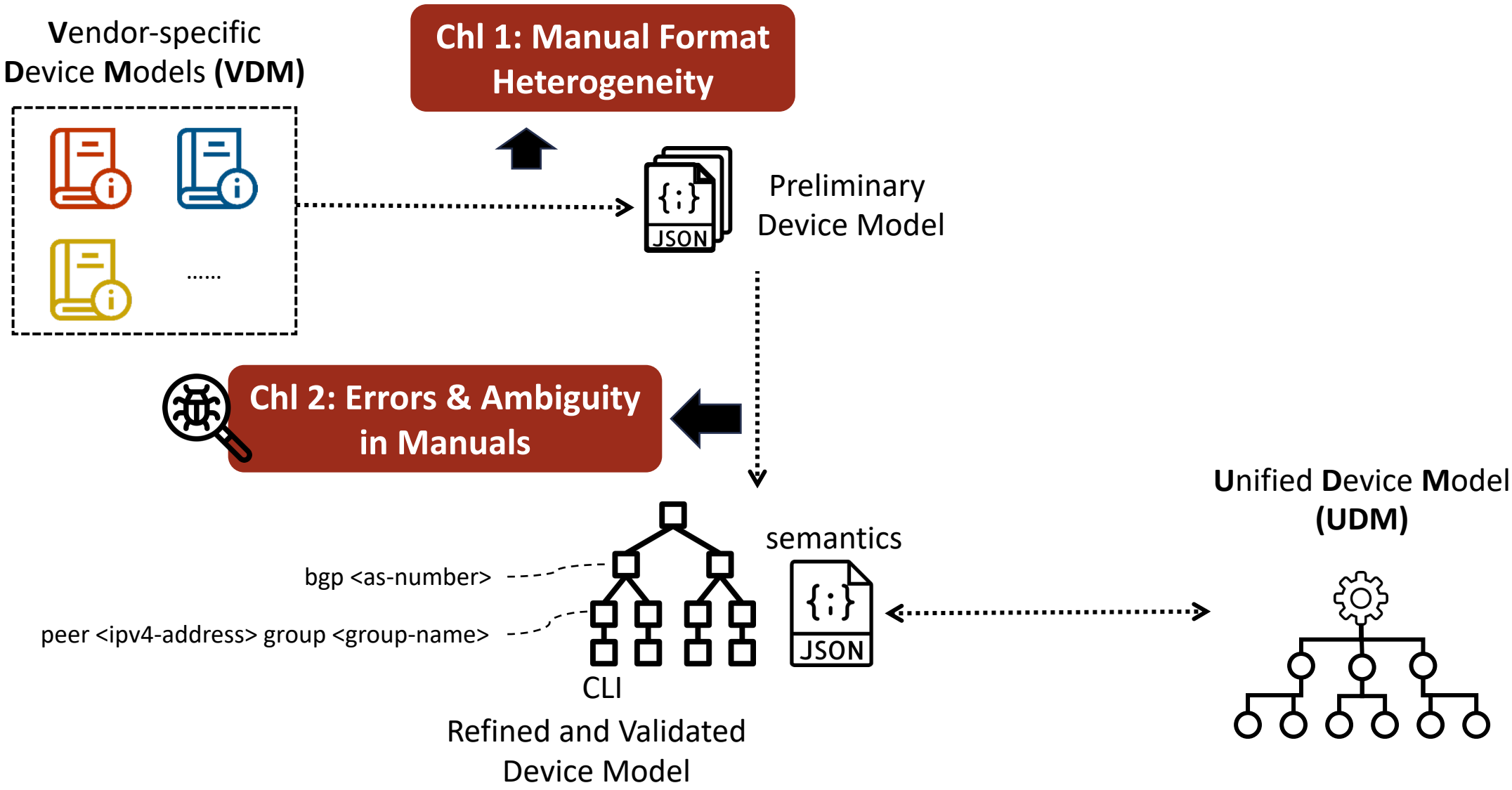

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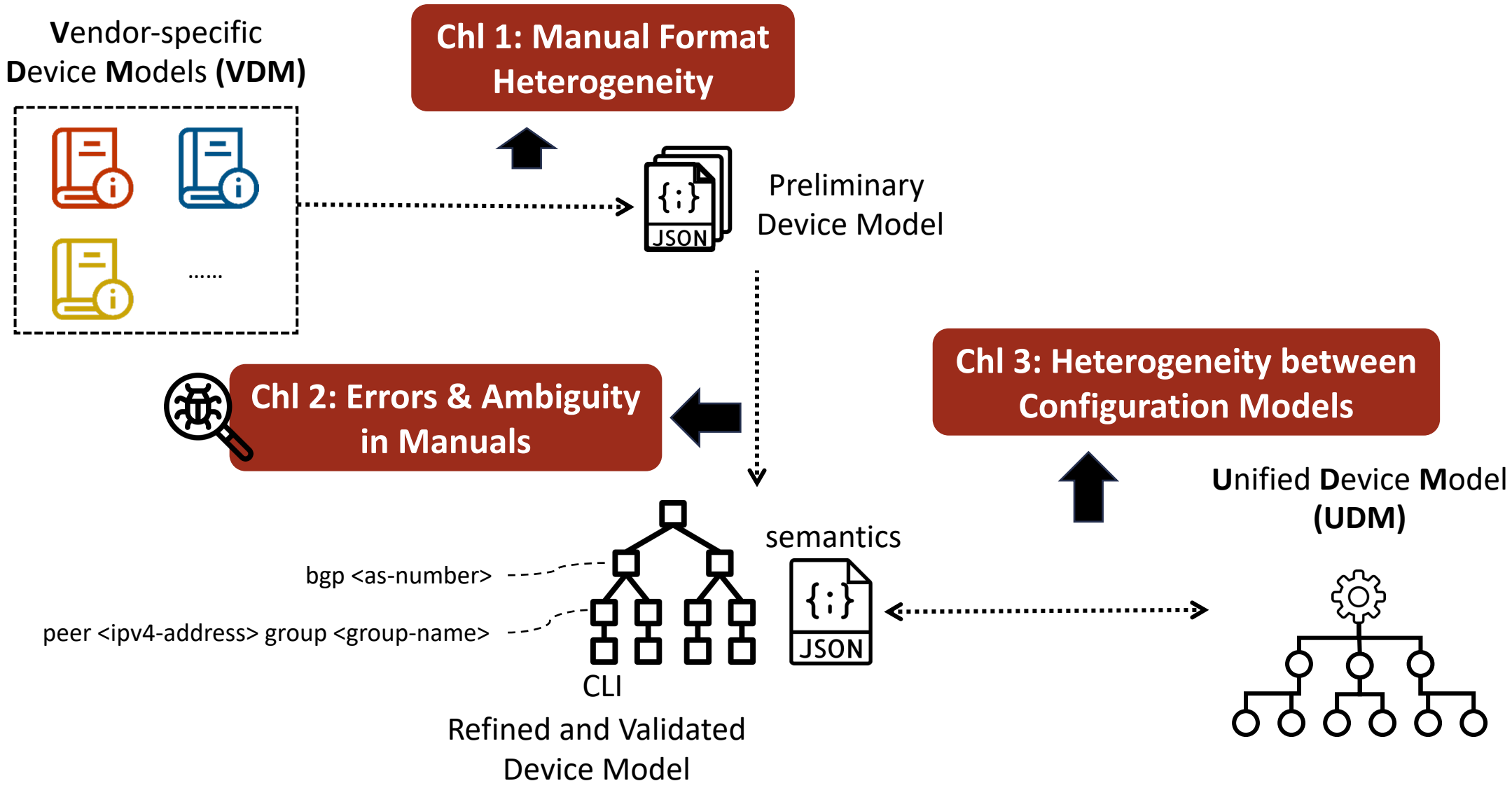

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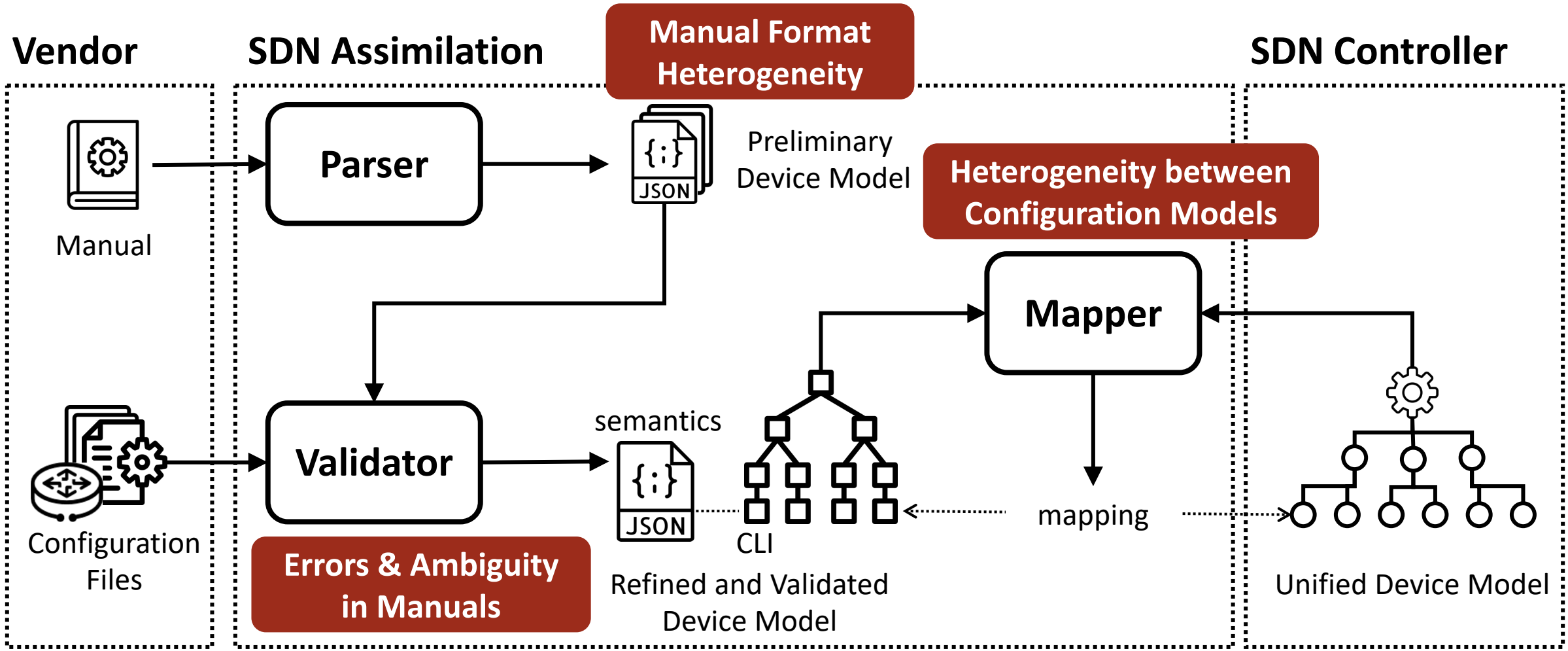
- Dataset: a validated and expert-curated dataset of parsed manual corpus for future research. (https://github.com/AmyWorkspace/nassim)

SDN Network Assimilation (NAssim) in a Nutshell



An Assistant Framework for Bridging the Last Mile Towards Centralized Network Configuration Management

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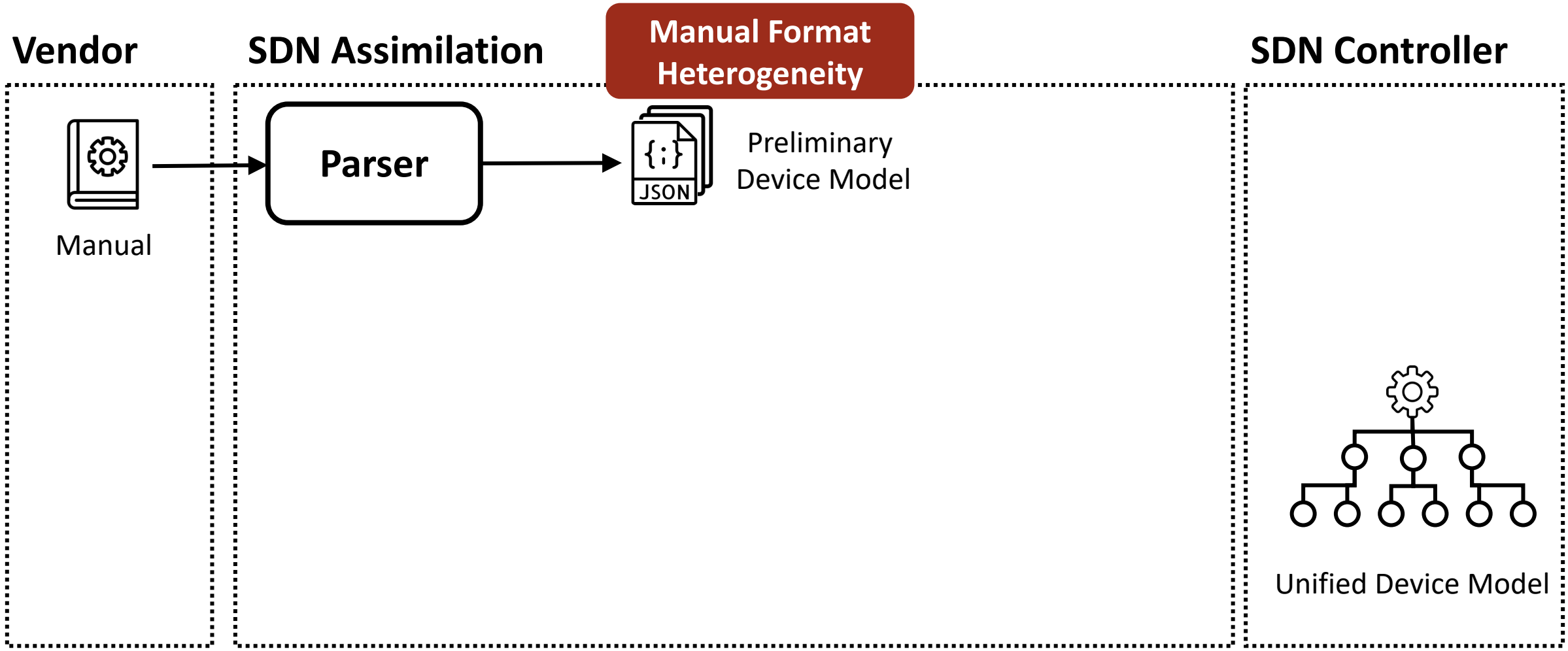

NAssim Parser Framework: Key Insights

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peer as-number (BGP view)

Function

The **peer as-number** command creates a peer and configures an AS number for a specified peer.
The **undo peer as-number** command deletes the AS number of a specified peer.
By default, no BGP peer is configured, and no AS number is specified for a peer.

Format

peer *ipv4-address* **as-number** *as-number*
undo peer *ipv4-address*

Parameters

Parameter	Description	Value
ipv4-address	Specifies the IPv4 address of a peer.	It is in dotted decimal notation.
as-number	Specifies a destination AS number.	For an integral AS number, the value is an integer ranging from 1 to 4294967295. For an AS number in dotted notation, the value is in the format of x.y, where x and y are integers ranging from 1 to 65535 and from 0 to 65535, respectively.

Views

BGP view

Default Level

2: Configuration level

Task Name and Operations

Task Name	Operations
bgp	write

Usage Guidelines

Usage Scenario
The **peer as-number** command is used to create a BGP peer.
Precautions
If a peer does not join any peer group or the peer group to which a peer belongs is not configured with an AS number, deleting the AS number of the peer will reset the peer relationship.
If a peer in a peer group is not configured with an AS number, deleting the AS number of the peer group will interrupt the connection on the peer.
The AS number for external session group cannot be the same as the local AS number.
If you run the **undo peer ipv4-address** command, all configurations related to the peer are deleted. Therefore, exercise caution when running this command.

Example

Set the AS number to 100 for IPv4 peer 10.1.1.1.

```
<HUAWEI> system-view
[~HUAWEI] bgp 100
[*HUAWEI-bgp] peer 10.1.1.1 as-number 100
```

Huawei

redistribute (BGP)

To inject routes from one routing domain into the Border Gateway Protocol (BGP), use the **redistribute** command. To remove the **redistribute** command from the configuration file and restore the system to its default condition in which the software does not redistribute routes, use the **no** form of this command.

redistribute {**direct** | **eigrp** *instance-tag* | **ospf** *instance-tag* | **rip** *instance-tag* | **static**} [**route-map** *map-name*]

no redistribute {{**direct** | **eigrp** *instance-tag* | **ospf** *instance-tag* | **rip** *instance-tag* | **static**} [**route-map** *map-name*]

Syntax Description

direct	Distributes routes that are directly connected on an interface.
eigrp *instance-tag*	Specifies the name of an EIGRP instance. The *instance-tag* can be any case-sensitive, alphanumeric string up to 20 characters.
ospf *instance-tag*	Distributes routes from the OSPF protocol. This protocol is supported in the IPv4 address family. The *instance-tag* can be any case-sensitive, alphanumeric string up to 20 characters.
rip *instance-tag*	Distributes routes from the RIP protocol. The *instance-tag* can be any case-sensitive, alphanumeric string up to 20 characters.
static	Redistributes IP static routes.
route-map *map-name*	(Optional) Specifies the identifier of a configured route map. Use a route map to filter which routes are redistributed into EIGRP.

Command Default

Disabled

Command Modes

Command HistoryAddress family configuration mode
Router configuration mode
Router VRF configuration mode

Release	Modification
5.0(3)N1(1)	This command was introduced.

Usage Guidelines

Use the **redistribute** command to import routes from other routing protocols into BGP. You should always use a route map to filter these routes to ensure that BGP redistributes only the routes that you intend to redistribute.

You must configure a default metric to redistribute routes from another protocol into BGP. You can configure the default metric with the **default-metric** command or with the route map configured with the **redistribute** command.

This command requires the LAN Enterprise Services license.

Examples

This example shows how to redistribute BGP routes into an EIGRP autonomous system:

```
switch(config)# router bgp 64496
switch(config-router) address-family ipv4 unicast
switch(config-router-af)# redistribute eigrp 100
```

Cisco

Related Commands

Command	Description
default-metric (BGP)	Sets the default metrics for routes redistributed into BGP.

ospf cost

Syntax

ospf cost *value*

undo ospf cost

View

Interface view

Parameters

value: Cost for running an OSPF process on an interface, in the range of 1 to 65535.

Description

Use the ospf cost command to configure the OSPF cost on an interface.

Use the undo ospf cost command to restore the default.

By default, the OSPF cost on an interface is 10.

You can use the display ospf brief command to display the OSPF cost information.

Related commands: display ospf brief.

Examples

Specify the OSPF cost on the interface as 33.

```
<Sysname> system-view
System View: return to User View with Ctrl+Z.
[Sysname] interface Vlan-interface 10
[Sysname-Vlan-interface10] ospf cost 33
```

H3C

label-ipv4

Syntax
label-ipv4 send *send-limit* **receive** [**none**]
label-ipv4 send *send-limit*
no label-ipv4

Context
config>router>bgp>add-paths
config>router>bgp>group>add-paths
config>router>bgp>group>neighbor>add-paths

Description
This command is used to configure the add-paths capability for labeled-unicast IPv4 routes. By default, add-paths is not enabled for labeled-unicast IPv4 routes.

The maximum number of labeled-unicast paths per IPv4 prefix to send is the configured *send-limit*, which is a mandatory parameter. The capability to receive multiple labeled-unicast paths per prefix from a peer is configurable using the **receive** keyword, which is optional. If the **receive** keyword is not included in the command, receive capability is enabled by default.

The **no** form of the command disables add-paths support for labeled-unicast IPv4 routes, causing sessions established using add-paths for labeled-unicast IPv4 to go down and come back up without the add-paths capability.

Default
no label-ipv4

Parameters
send-limit— The maximum number of paths per labeled-unicast IPv4 prefix that are allowed to be advertised to add-paths peers. (The actual number of advertised routes may be less.) If the value is none, the router does not negotiate the send capability with respect to label-IPv4 AFI/SAFI.
Values— 1 to 16, none

receive — The router negotiates to receive multiple labeled-unicast routes per IPv4 prefix.

none— The router does not negotiate to receive multiple labeled-unicast routes per IPv4 prefix.

ALU/Nokia

HUAWEI

NAssim Parser Framework: Key Insights

the same concept may have different names

Attribute \ Vendor	Huawei	Cisco	Nokia	H3C
CLIs	<class="sectiontitle">Format	<class="pCE_CmdEnv">	<class="SyntaxHeader">Syntax	<class="Command">Syntax
FuncDef	<class="sectiontitle">Function	<class="pB1_Body1>	<class="DescriptionHeader">Description	<class="Command">Description
ParentViews	<class="sectiontitle">Views	<class=pCRCM_CmdRefCmdModes> Command Modes	<class="ContextHeader">Context	<class="Command">View
ParaDef	<class="sectiontitle">Parameters	<class="pCRSD_CmdRefSynDesc"> Syntax Description	<class="ParametersHeader">Parameters	<class="Command">Parameters
Examples	<class="sectiontitle">Examples	<class="pCRE_CmdRefExample"> Examples	/	<class="Command">Examples

Table 1: Diversity of Device User Manuals: The 'CLIs' field denotes the formal syntax of CLI commands, which are command templates with place-holder parameters and special characters to specify selection or optional branches. The 'ParaDef' field contains the implication and value range of place-holder parameters. The 'FuncDef' field describes the functionality of the complete CLI. The 'ParentViews' field indicates the parent/working views of CLIs, *i.e.*, one CLI may have multiple viable working views. The 'Examples' field shows examples of common snippets, *e.g.*, entering a parent view and issuing an instantiated CLI.

NAssim Parser Framework: Key Insights

the same concept may have different names

Attribute \ Vendor	Huawei	Cisco	Nokia	H3C
CLIs	<class="sectiontitle">Format	<class="pCE_CmdEnv">	<class="SyntaxHeader">Syntax	<class="Command">Syntax
FuncDef	<class="sectiontitle">Function	<class="pB1_Body1>	<class="DescriptionHeader">Description	<class="Command">Description
ParentViews	<class="sectiontitle">Views	<class=pCRCM_CmdRefCmdModes> Command Modes	<class="ContextHeader">Context	<class="Command">View
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Despite diverse styles, all manuals serve the same purpose: show how to configure the devices via CLI.

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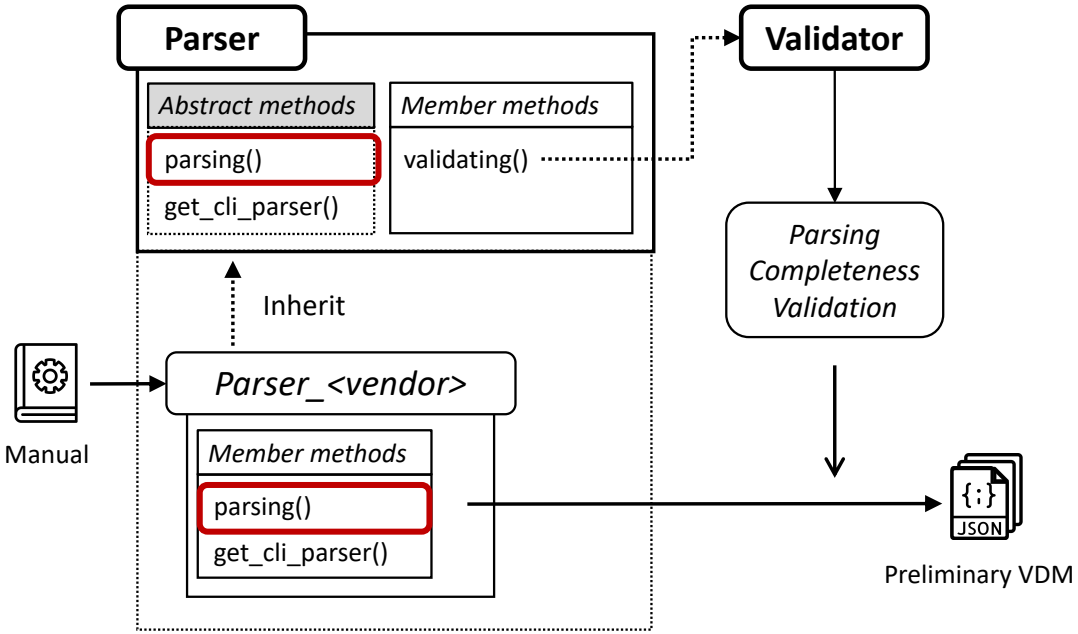
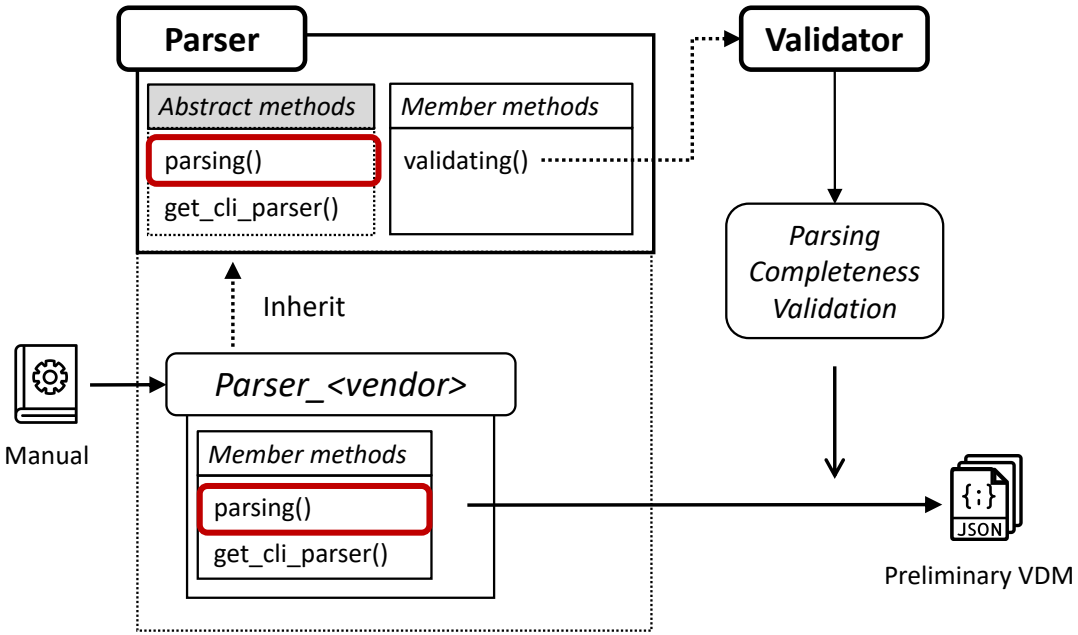
Despite diverse styles, all manuals serve the same purpose: show how to configure the devices via CLI.

NAssim Parser Framework: Design



NAssim Parser Framework: Design



Keys	Type Restriction
CLIs	a list of string (non-empty list)
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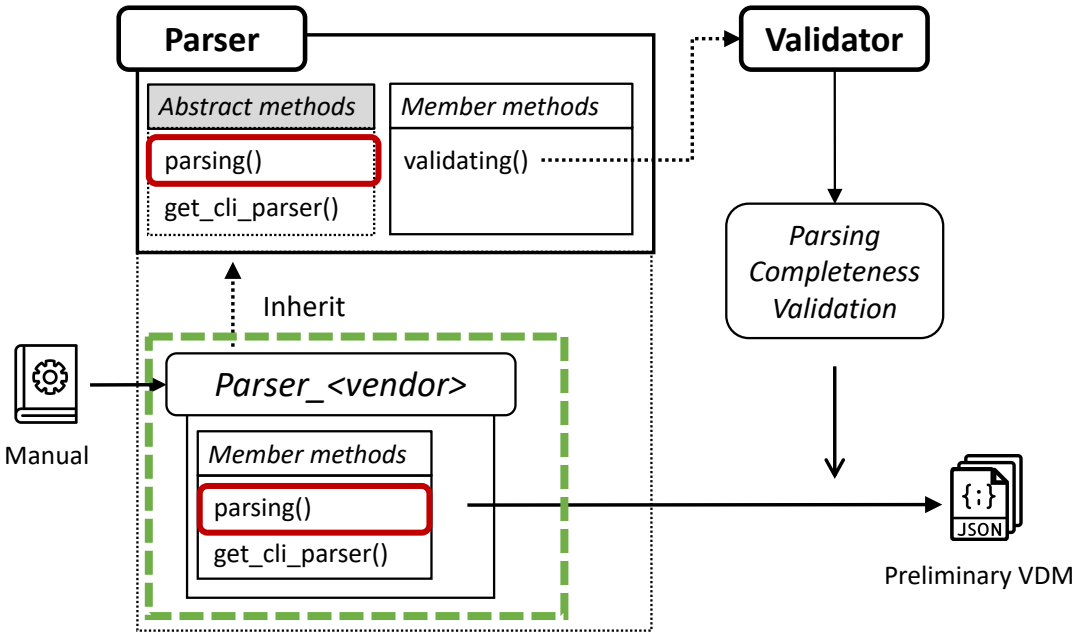
ParentViews	a list of string (non-empty list)
ParaDef	a list of dict (Keys:"Paras" and "Info")
Examples	a list of list

Format Definition of Vendor-Independent Corpus (JSON)

NAssim Parser Framework: Design



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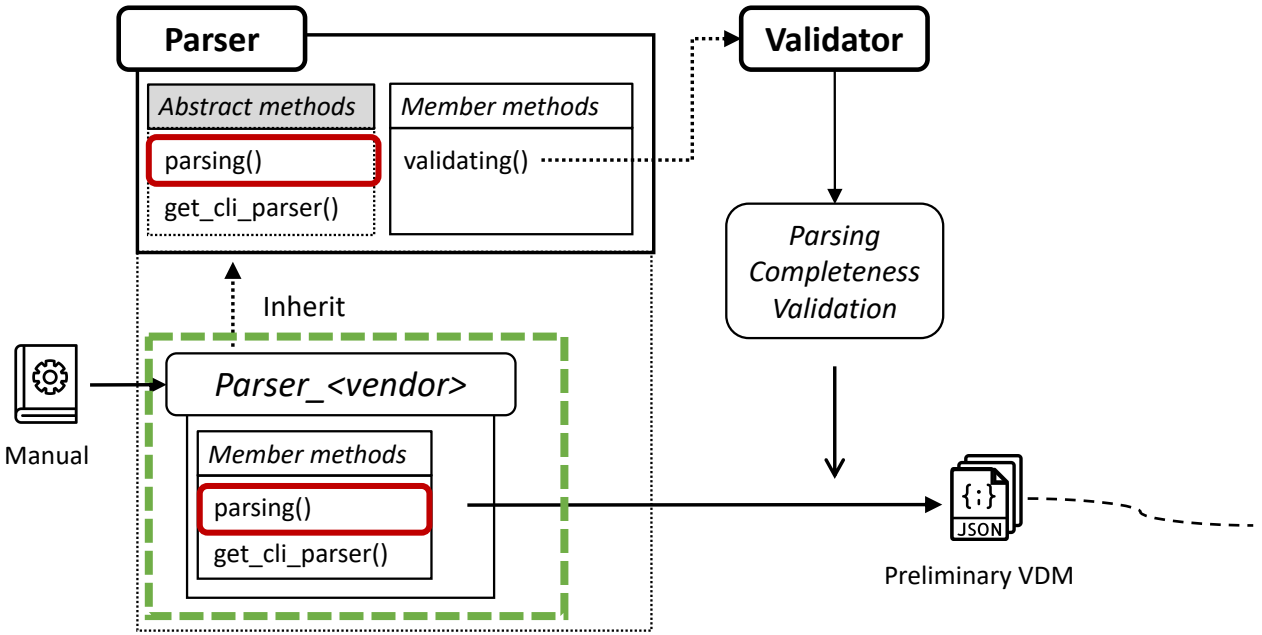

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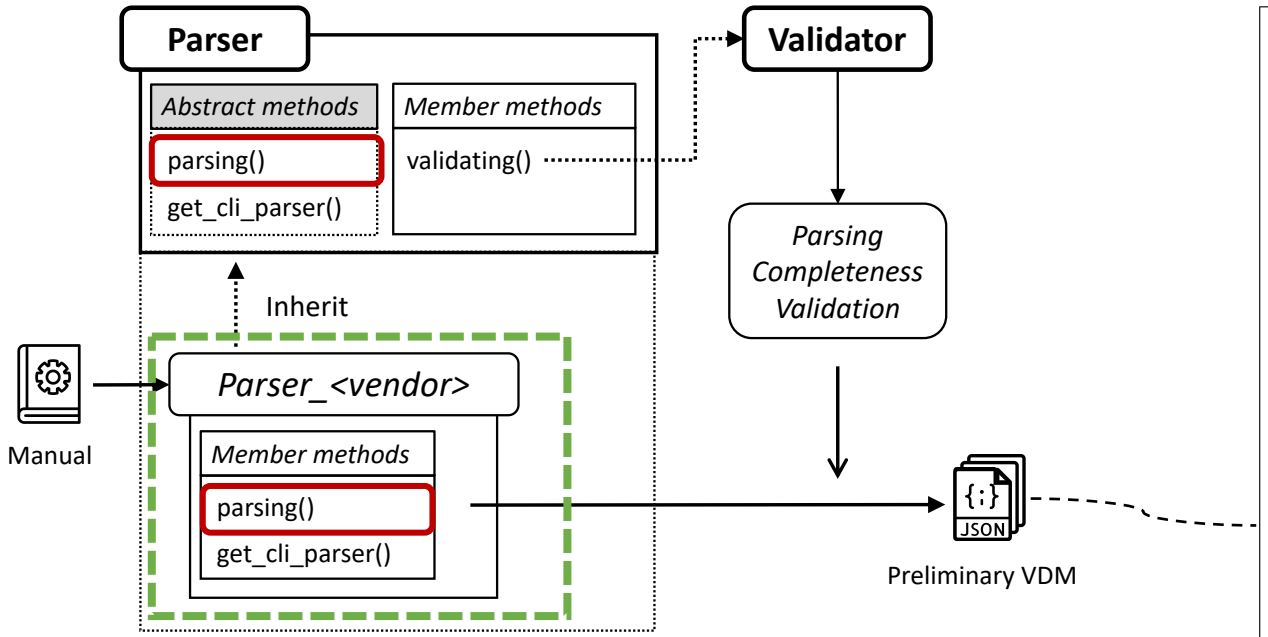

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ParaDef	a list of dict (Keys:"Paras" and "Info")
Examples	a list of list

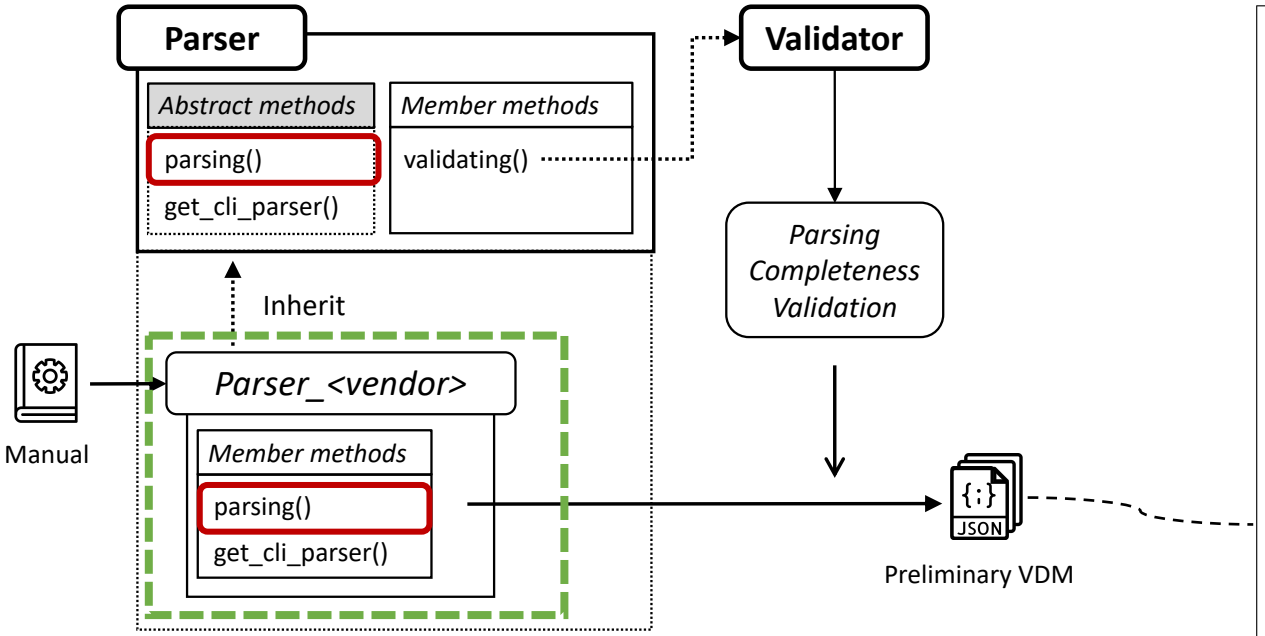
Format Definition of Vendor-Independent Corpus (JSON)

```
{
 "CLIs": [
   "peer <ipv4-address> group <group-name>",
   "undo peer <ipv4-address> group <group-name>"
 ],
 "FuncDef": "The peer group command adds a peer to a peer. The undo peer group
command deletes a peer from a peer group and all configurations of the peer. By default,
no peer group is created",
 "ParentView": ["BGP view"],
 "ParaDef": [
   {"Parameters": "ipv4-address",
    "Info": "Specifies the IPv4 address of a peer. It is in dotted decimal notation."},
   {"Parameters": "group-name",
    "Info": "Specifies the name of a peer group. The name is a string of 1 to 47 case-
sensitive characters, with spaces not supported."}
 ],
 "Examples": [
   ["<HUAWEI> system-view",
    "[~HUAWEI] bgp 100",
    "[*HUAWEI-bgp] group test internal",
    "[*HUAWEI-bgp] peer 10.1.1.1 group test"]
 ]
}

// Extended corpus with distilled ParaType info
{
 "CLIs": [
   "peer <ipv4-address> group <group-name>",
   "undo peer <ipv4-address> group <group-name>"
 ],
 "...": "... ",
 "ParaType": {
     "ipv4-address": [ipv4],
     "group-name": [string, 1, 47]}
}
```

A sample of parsed VDM corpus.

NAssim Parser Framework: Design




```
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 "CLIs": [
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Format Definition of Vendor-Independent Corpus (JSON)

Vendor-independent parsed format captures the commonality of manuals from different vendors, also balancing extendibility and human-readability.


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}
```
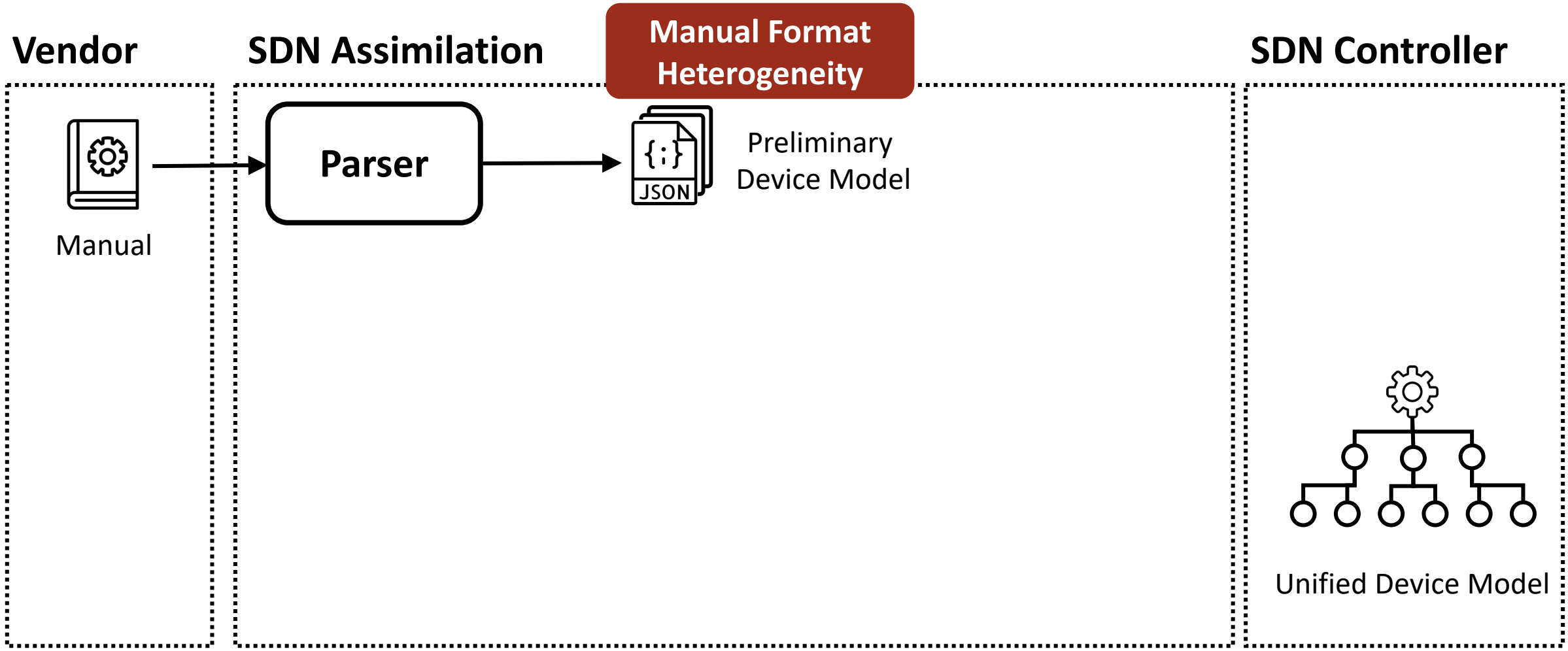


A sample of parsed VDM corpus.

SDN Network Assimilation (NAssim) in a Nutshell



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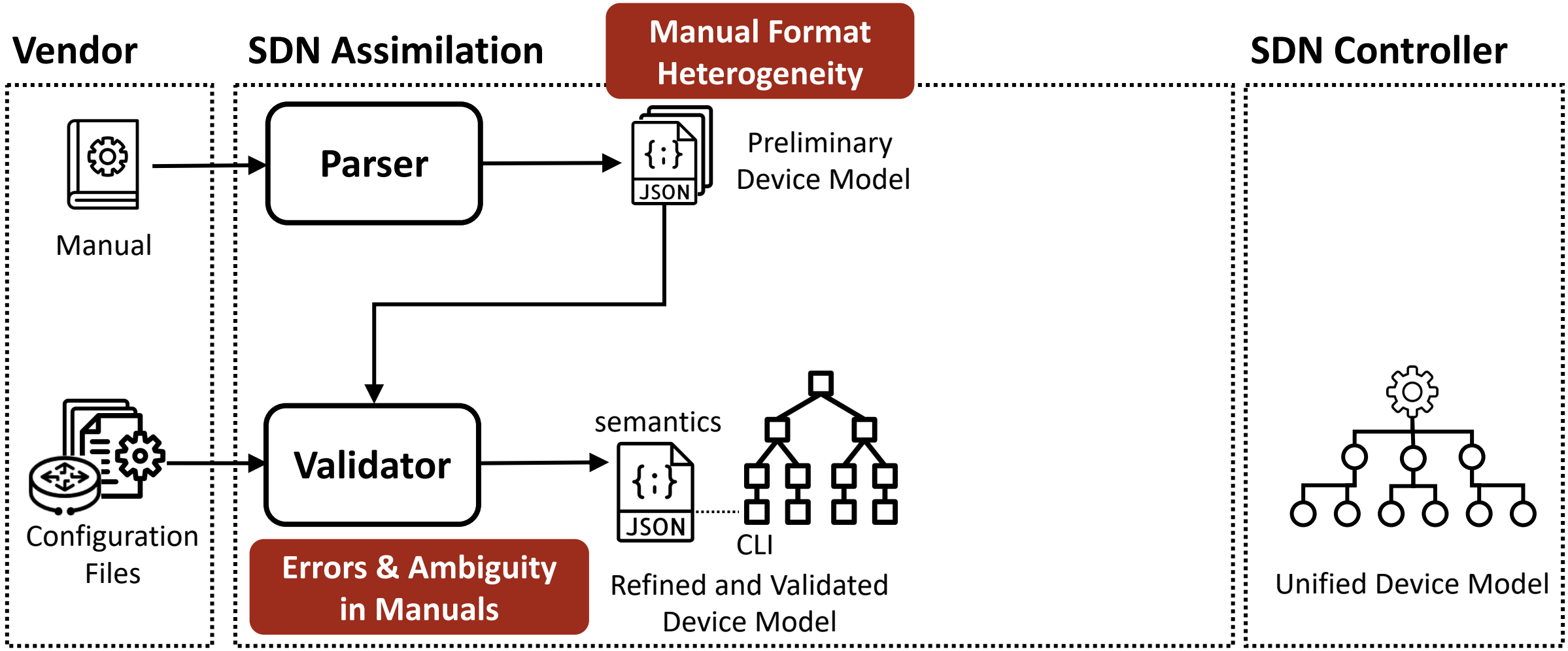

NAssim Validator: Key Insights

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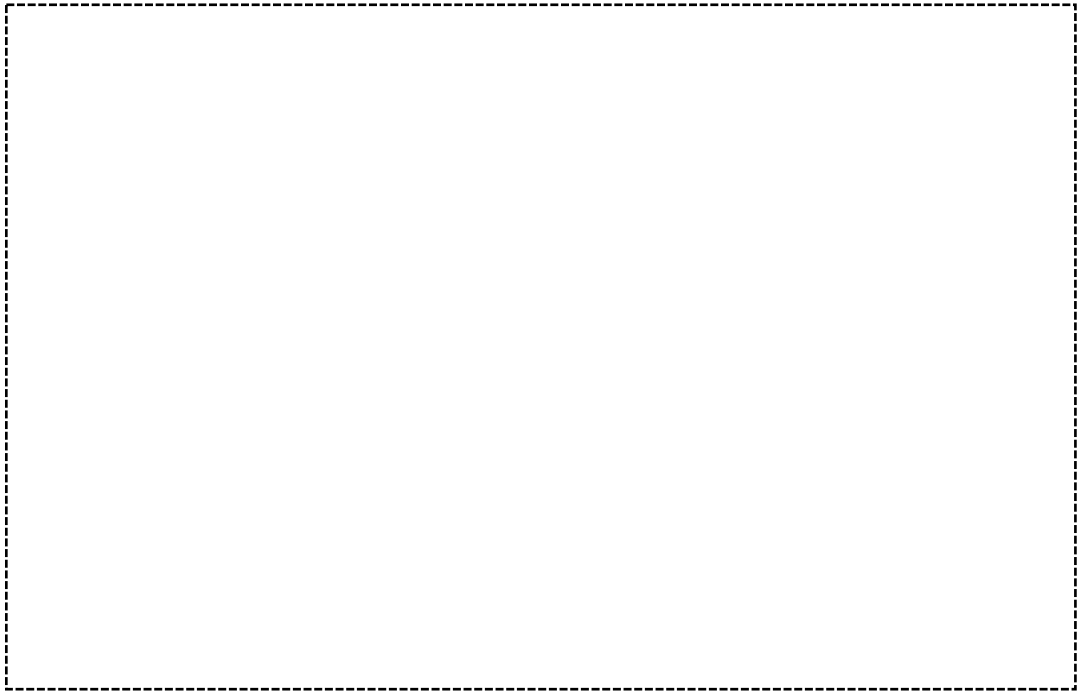
Manuals are not fully reliable. A rigorous validation scheme needs to catch inevitable errors and ambiguities in human-written manuals.

NAssim Validator: Key Insights

Syntactic Ambiguities



An example of ambiguous CLI command template*

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**https://www.cisco.com/c/en/us/td/docs/switches/datacenter/nexus5500/sw/command/reference/unicast/n5500-ucast-cr/n5500-bgp_cmds_n.html*

NAssim Validator: Key Insights

Syntactic Ambiguities

neighbor { <ip-addr> | <ip-prefix/length> } [remote-as { <as-num>
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unpaired left bracket

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Correction Option 1: removing the left bracket

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Hierarchy Ambiguities

An example of ambiguous view

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Hierarchy Ambiguities

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{
 "CLIs": [
  "import-source acl { acl-number | acl-name }",
  "undo import-source"
 ],
  "...": "... ",
 "ParentView": ["VPN instance MSDP view", "MSDP view of a public network instance"],
  "...": "... ",
 "Examples": [
  ["<HUAWEI> system-view",
   "[~HUAWEI] acl number 3101",
   "...",
   "[*HUAWEI-acl4-advance-3101] quit",
   "[*HUAWEI] multicast routing-enable",
   "[*HUAWEI] msdp",
   "[*HUAWEI-msdp] import-source acl 3101"]
 ]
}
```

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NAssim Validator: Key Insights

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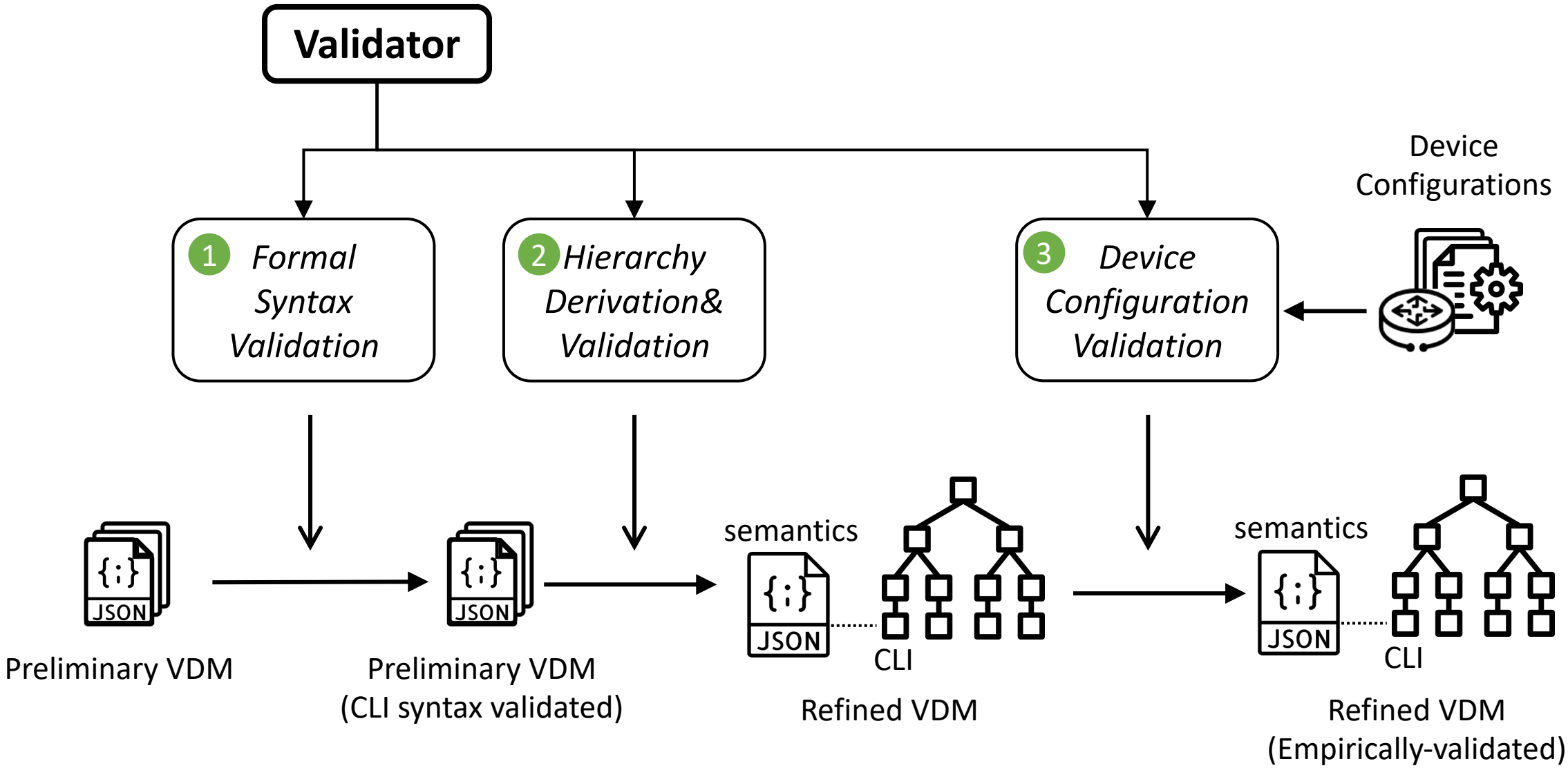
NAssim Validator: Design



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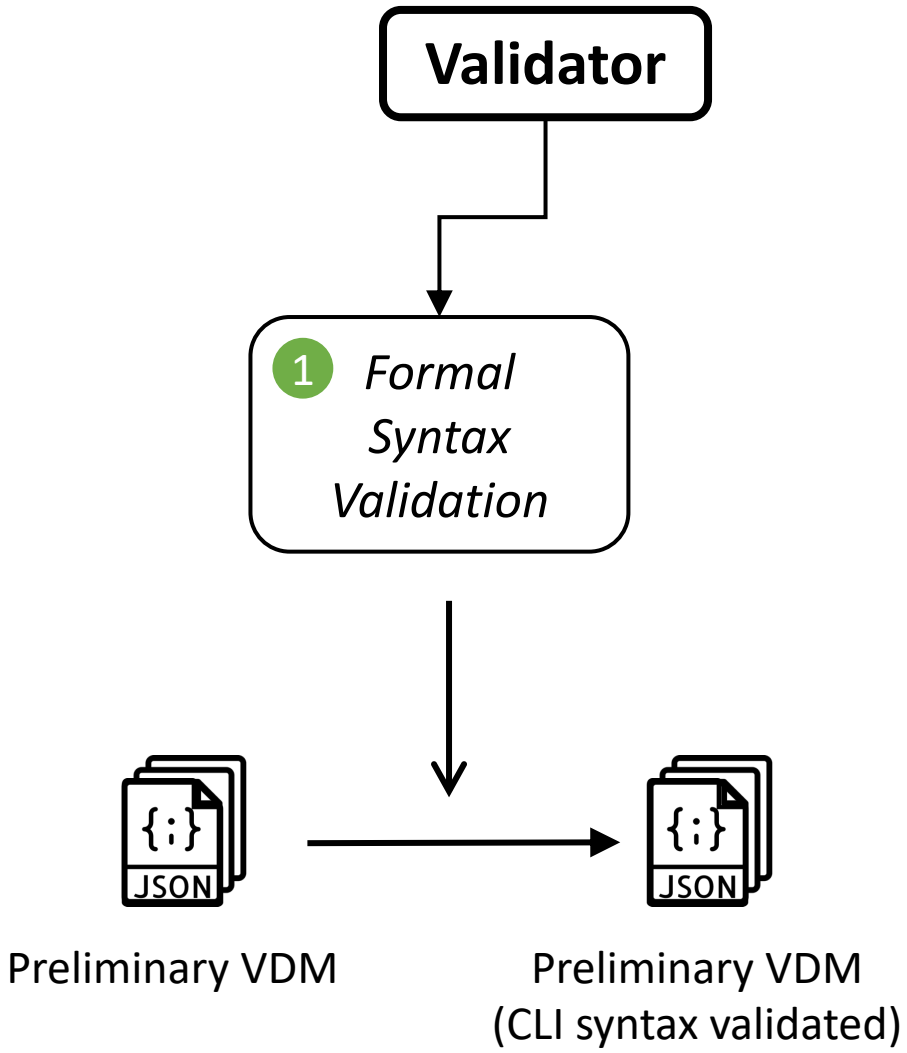

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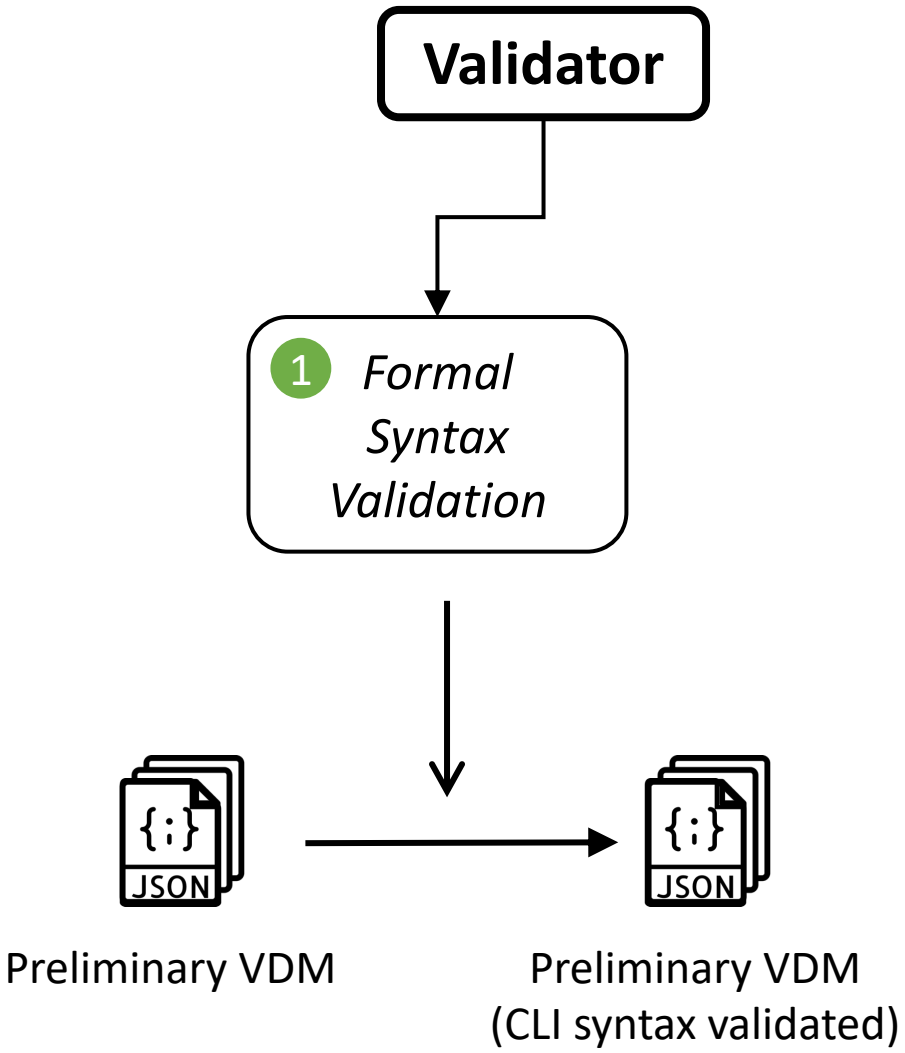


Express command conventions into their equivalent Backus Normal Form (BNF) for formal validation.

Command descriptions use these conventions:

Convention	Description
boldface font	Commands and keywords are in boldface.
italic font	Arguments for which you supply values are in italics.
[ ]	Elements in square brackets are optional.
{x | y | z}	Alternative keywords are grouped in braces and separated by vertical bars.
[x | y | z]	Optional alternative keywords are grouped in brackets and separated by vertical bars.
string	A nonquoted set of characters. Do not use quotation marks around the string or the string will include the quotation marks.

Command convention of Cisco manuals

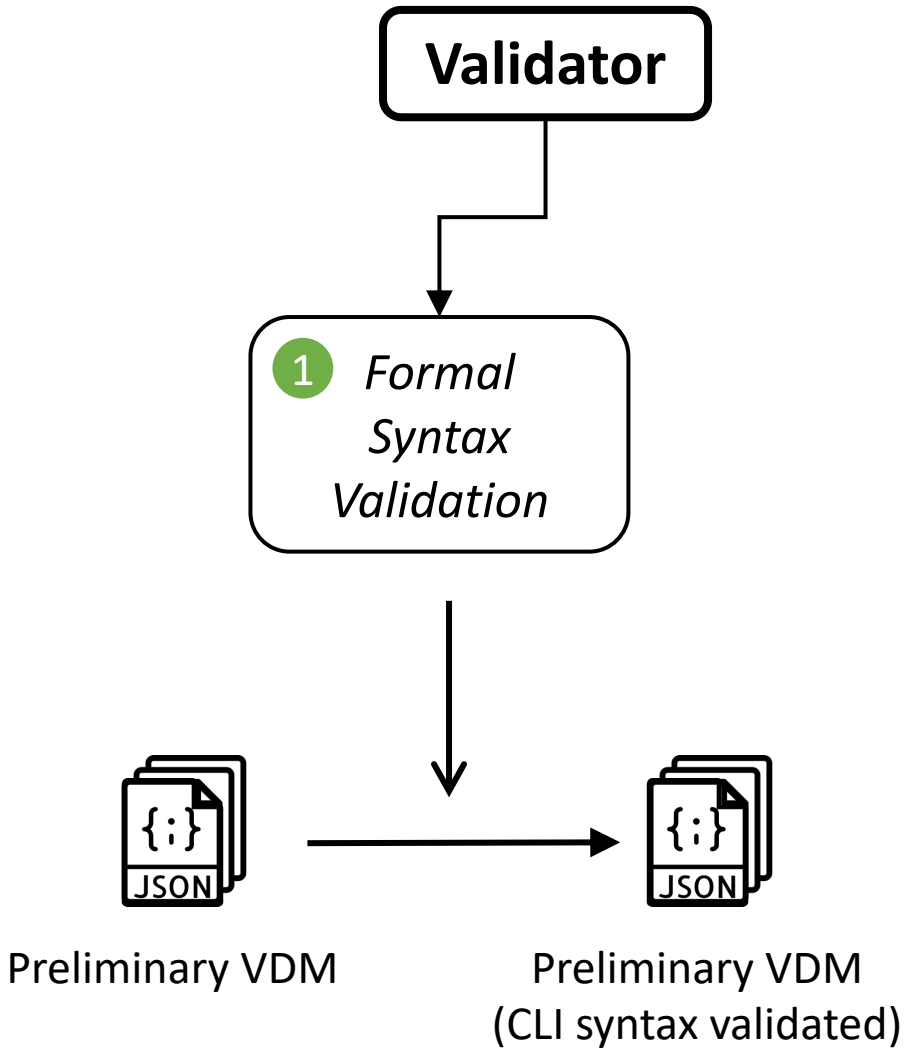
```
import pyparsing as p

# syntax parser for Cisco CLI
word = p.Word(p.printables, exclude_chars='{}[]|#\n').setParseAction(leaf_gen)
ele = p.Forward()
items = ele + p.ZeroOrMore('|' + ele)
select = p.Group('{' + items + '}').setParseAction(select_gen)
option = p.Group('[' + items + ']').setParseAction(option_gen)
ele <<= p.OneOrMore(option ^ select ^ word).setParseAction(ele_gen)

syntax_parser = ele
```

Code snippet for syntax parser generation

NAssim Validator: Design



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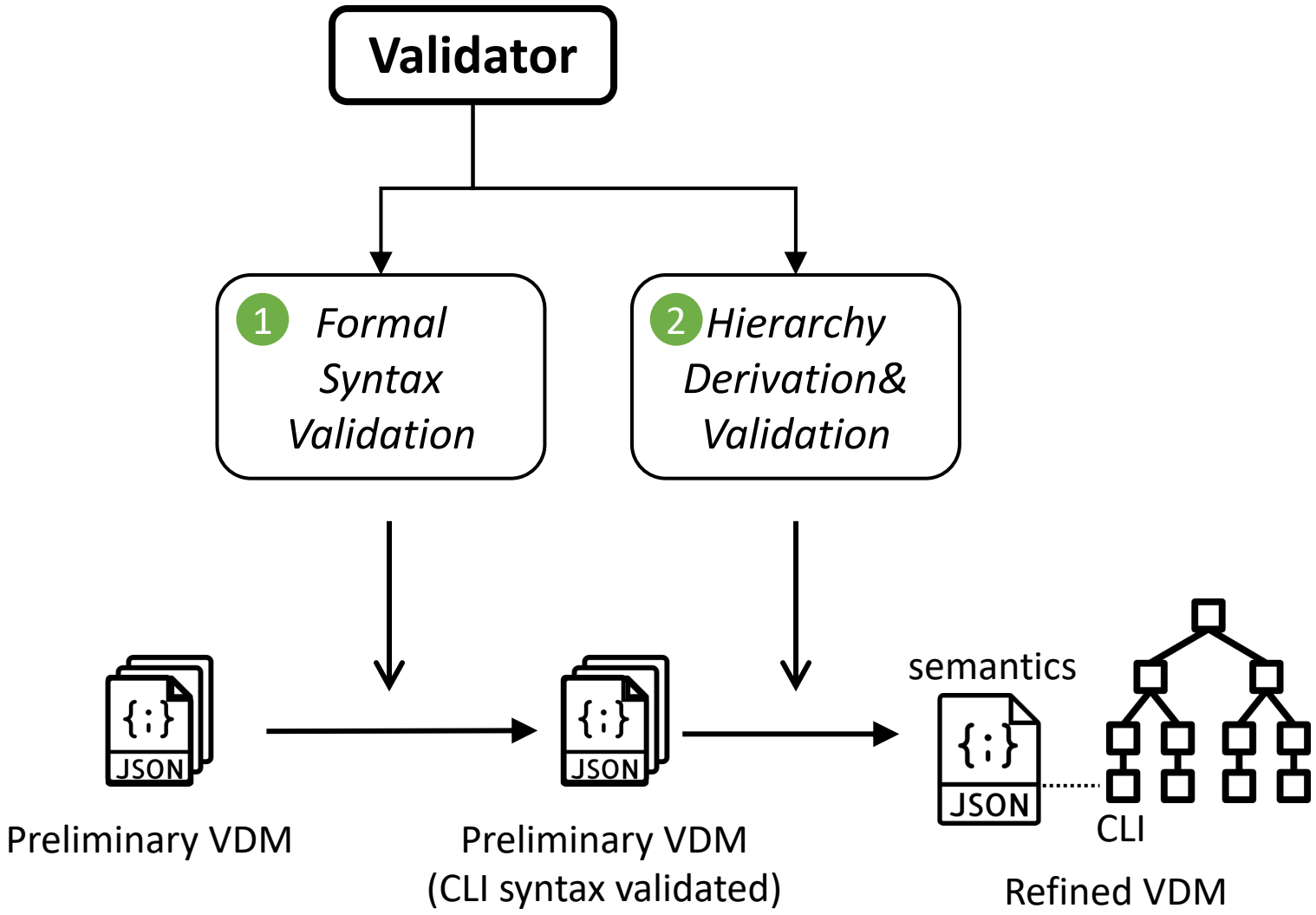

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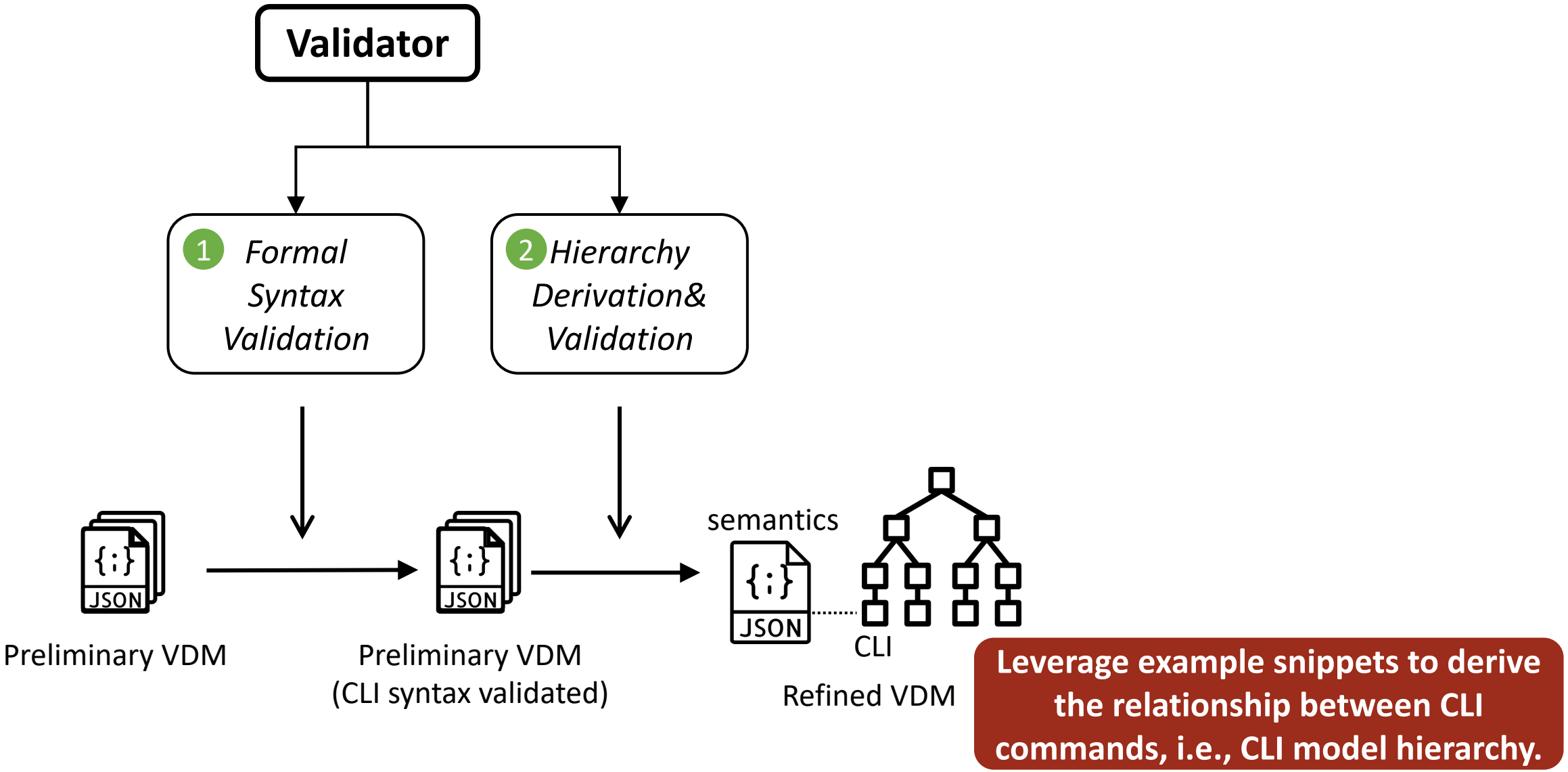
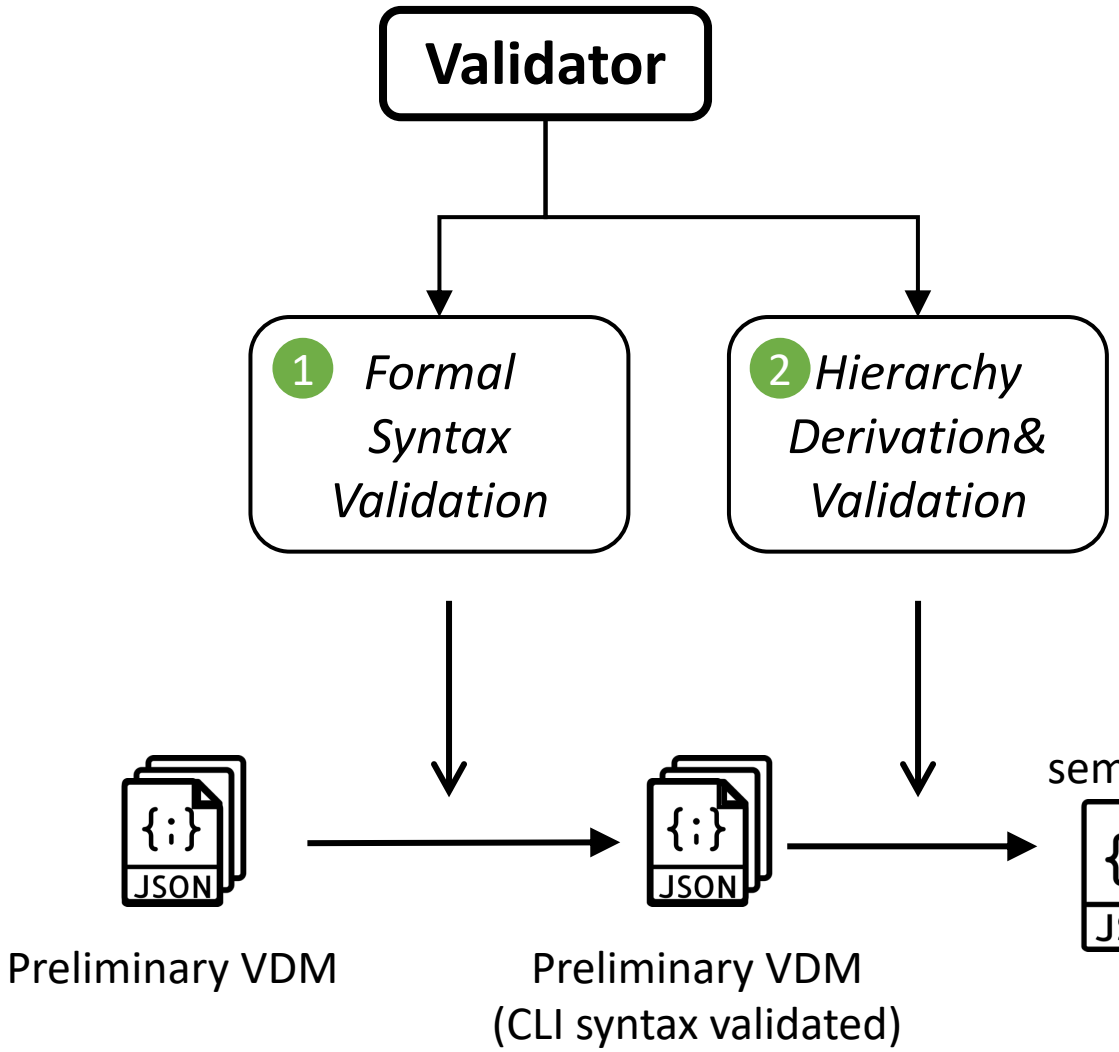


Leverage example snippets to derive the relationship between CLI commands, i.e., CLI model hierarchy.

NAssim Validator: Design




```
{
 "CLIs": [
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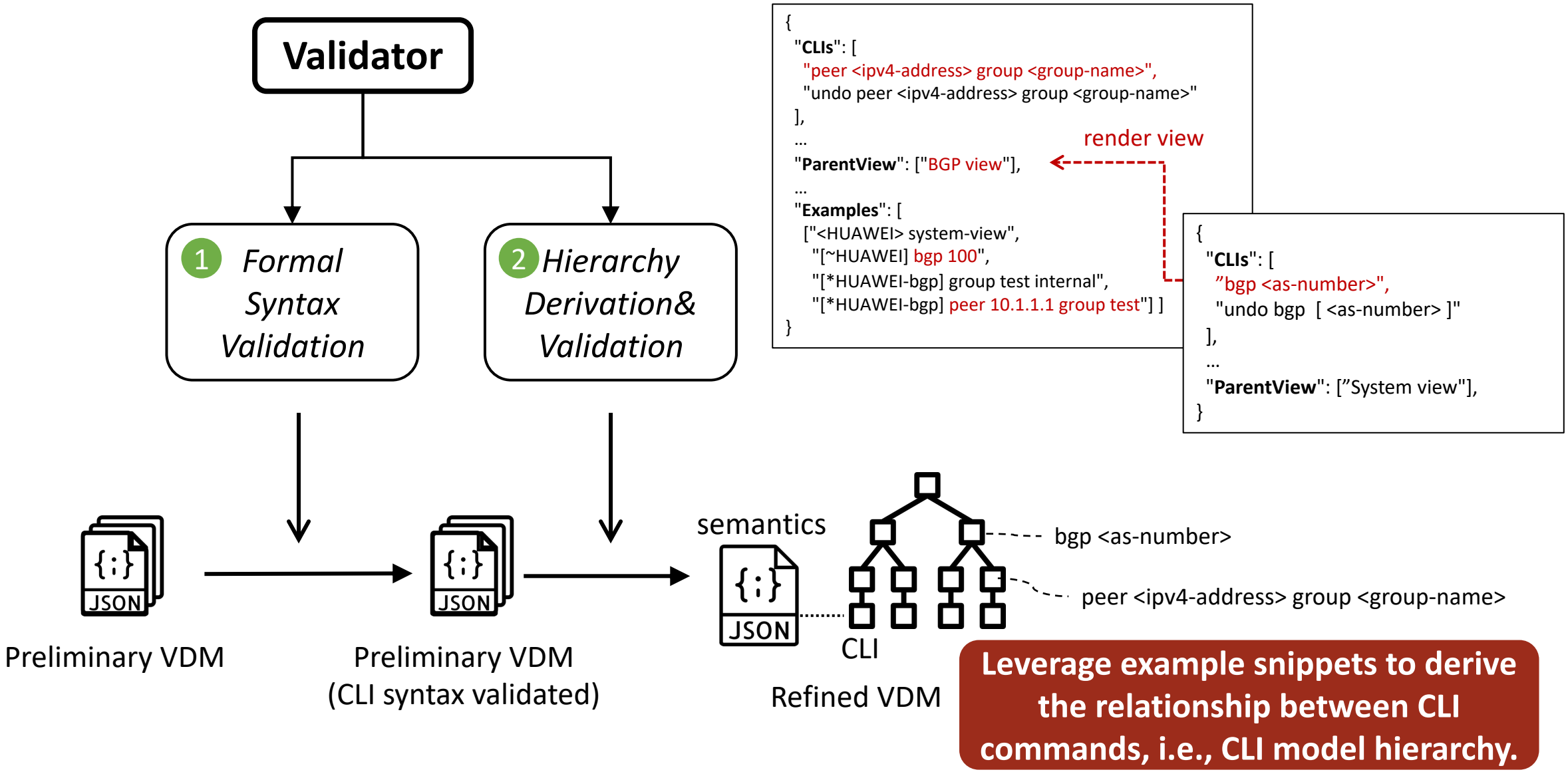
  "undo peer <ipv4-address> group <group-name>"
 ],
 ...
 "ParentView": ["BGP view"],
 ...
 "Examples": [
  ["<HUAWEI> system-view",
   "[~HUAWEI] bgp 100",
   "[*HUAWEI-bgp] group test internal",
   "[*HUAWEI-bgp] peer 10.1.1.1 group test"] ]
}
```

```
{
 "CLIs": [
  ”bgp <as-number>",
  "undo bgp  [ <as-number> ]"
 ],
 ...
 "ParentView": [”System view"],
}
```

Leverage example snippets to derive the relationship between CLI commands, i.e., CLI model hierarchy.

NAssim Validator: Design



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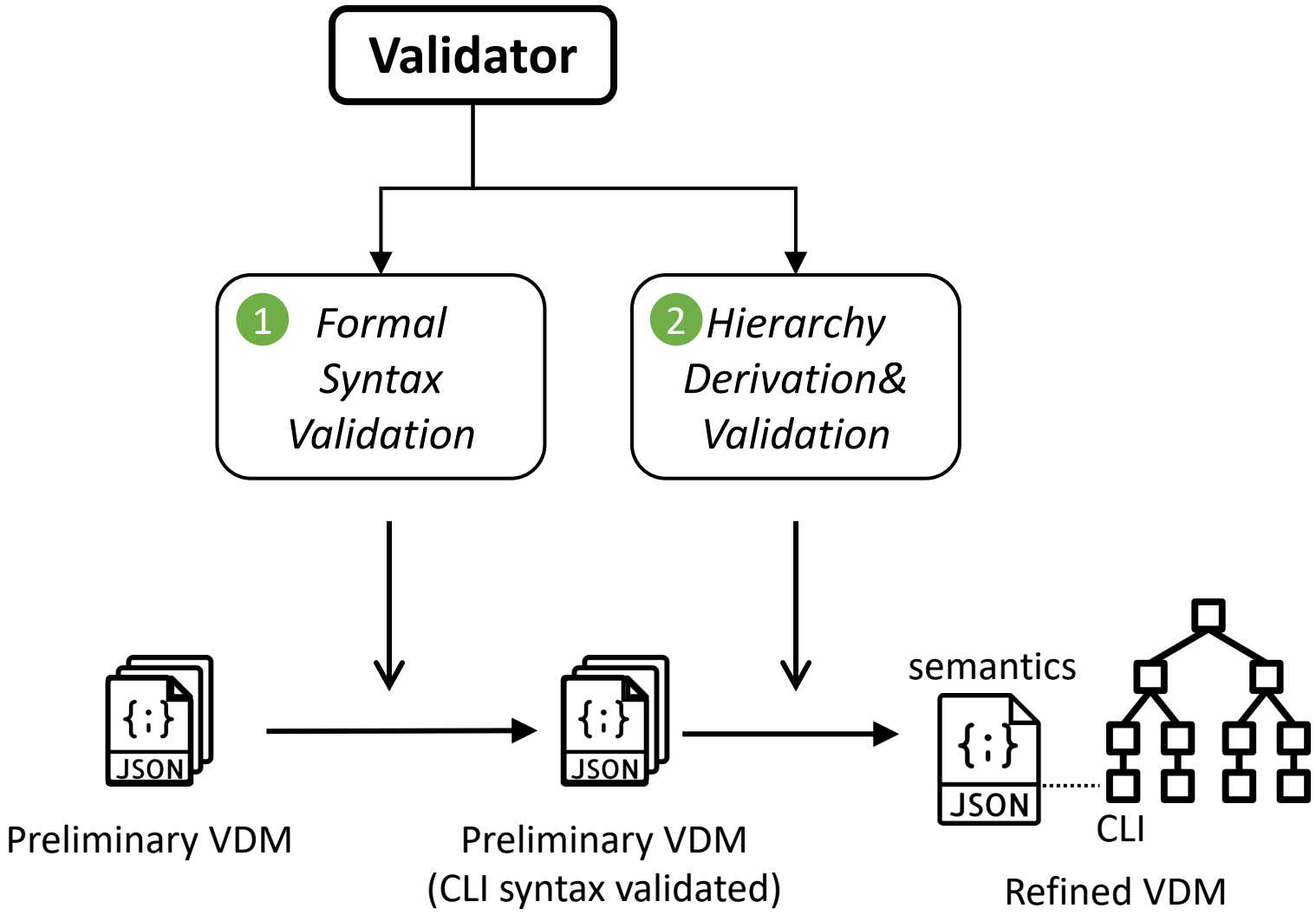

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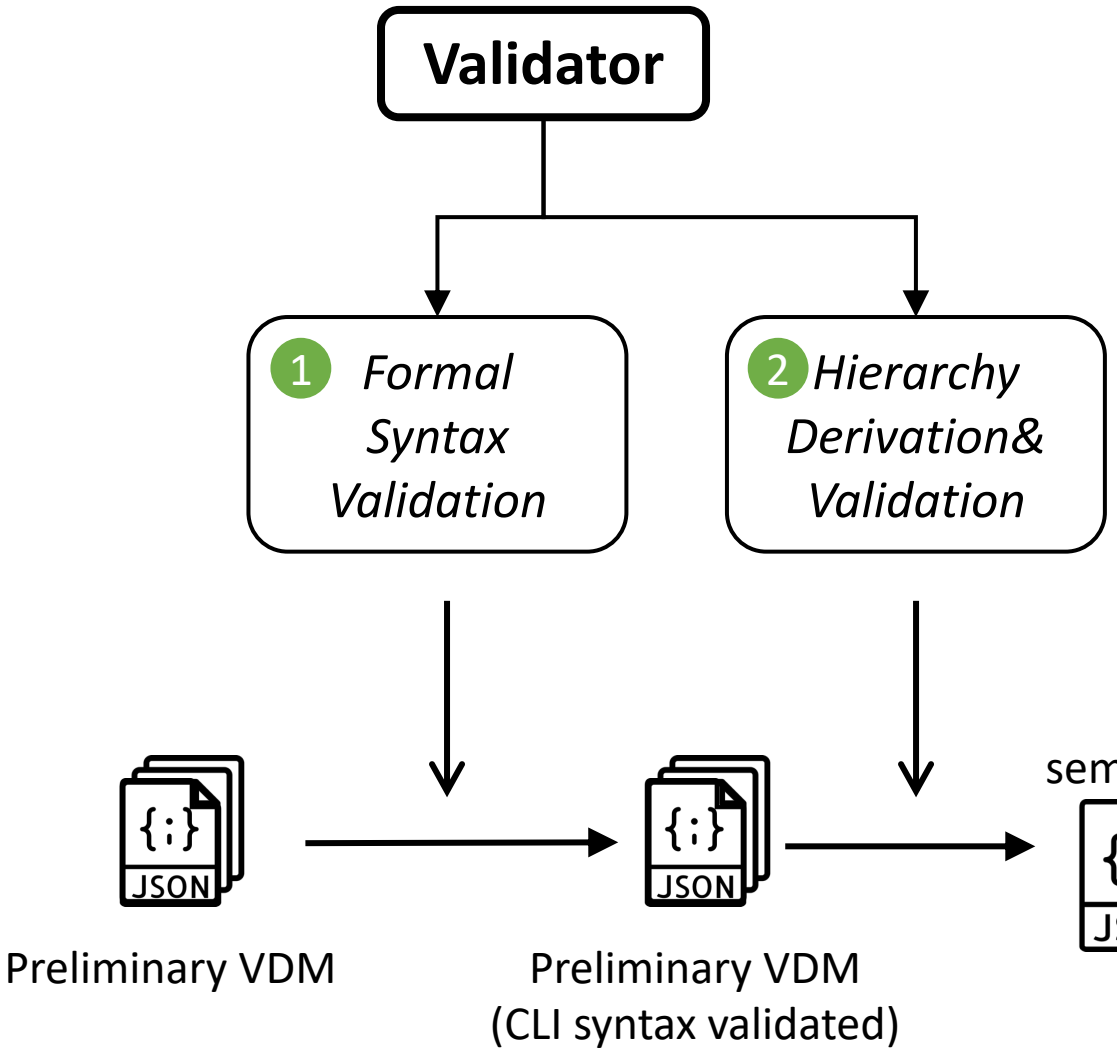


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   "[*HUAWEI-msdp] import-source acl 3101"]
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```


An example ambiguous view not be fully resolved by our hierarchy derivation scheme

Quantify the certainty of the derivation to facilitate expert intervention

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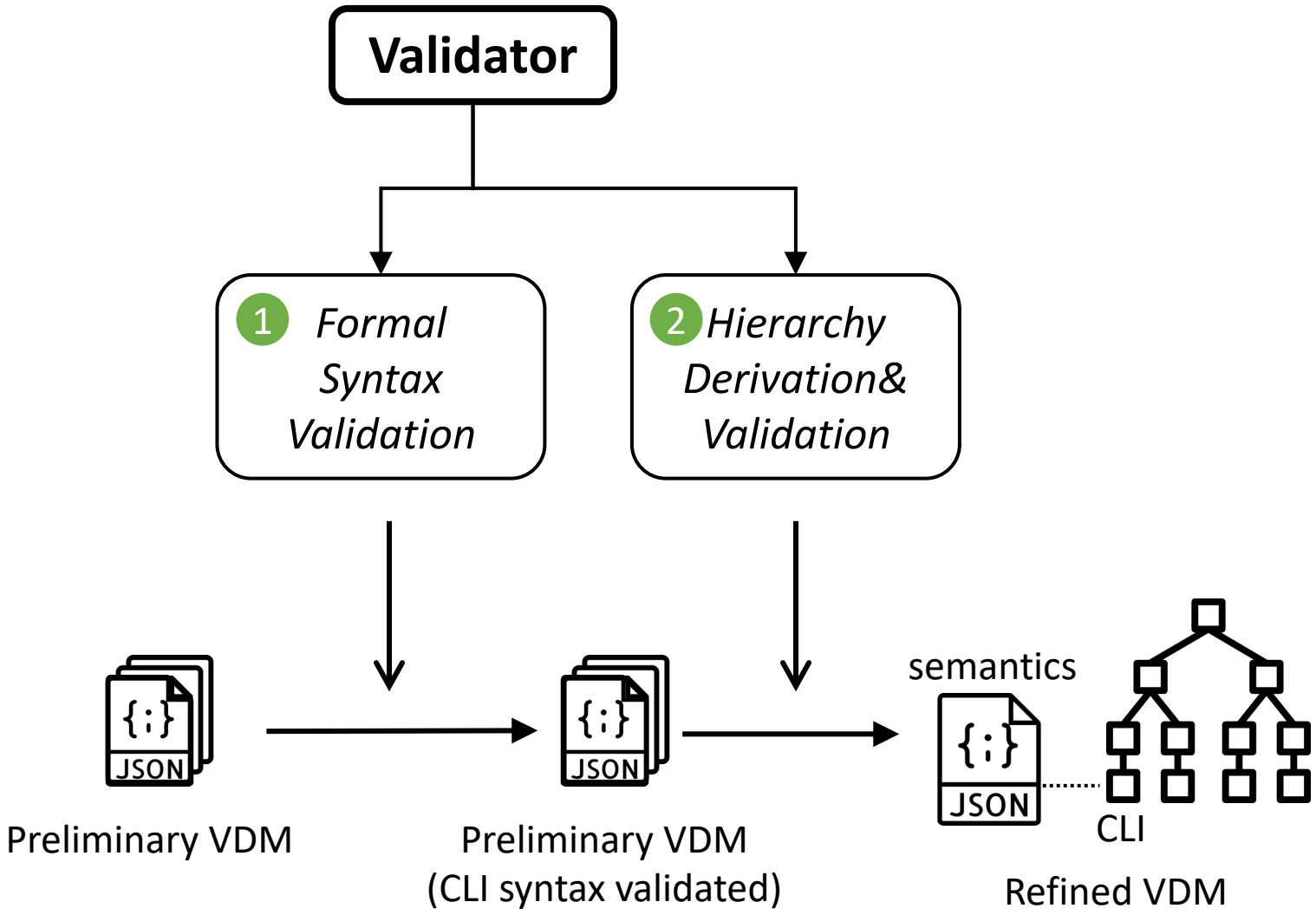

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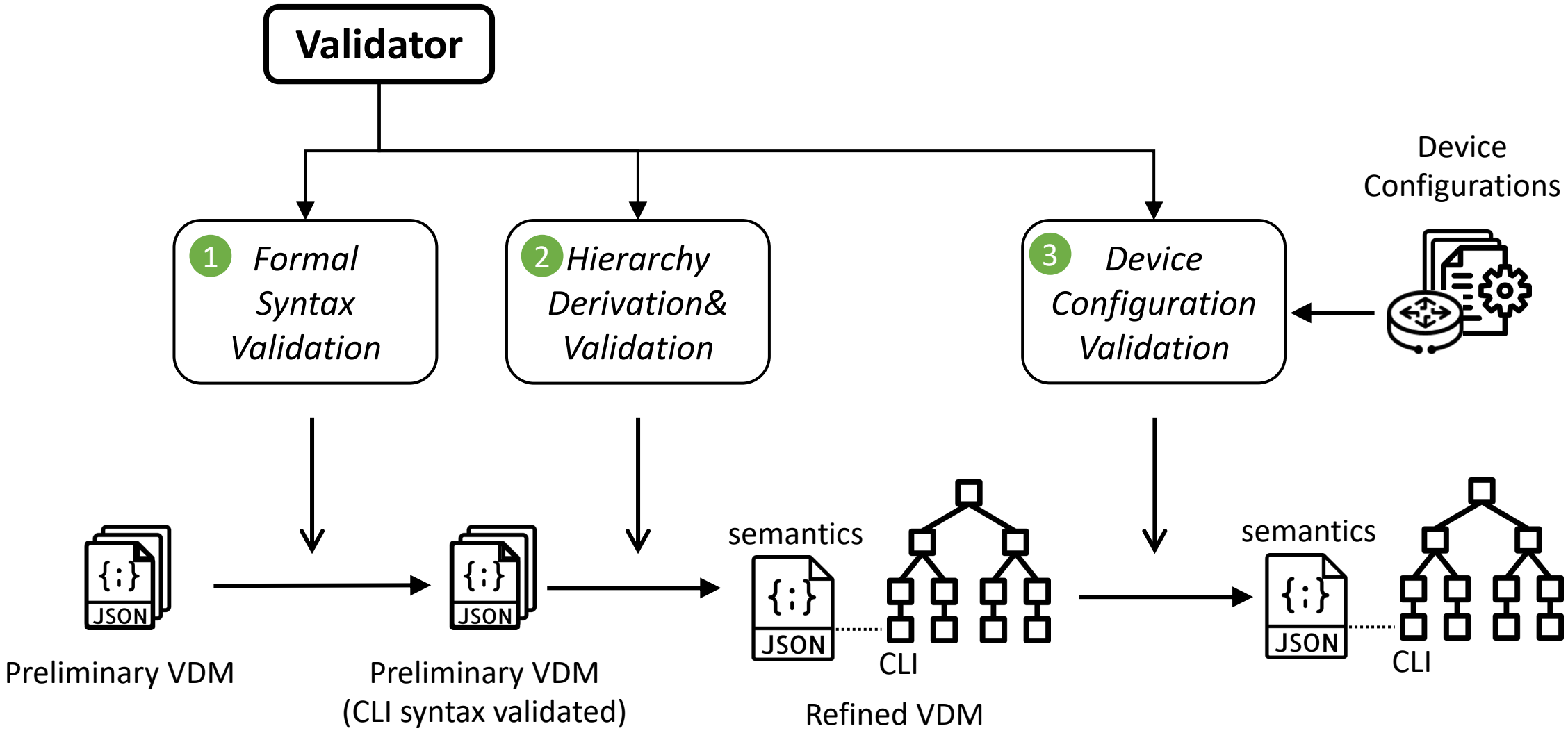
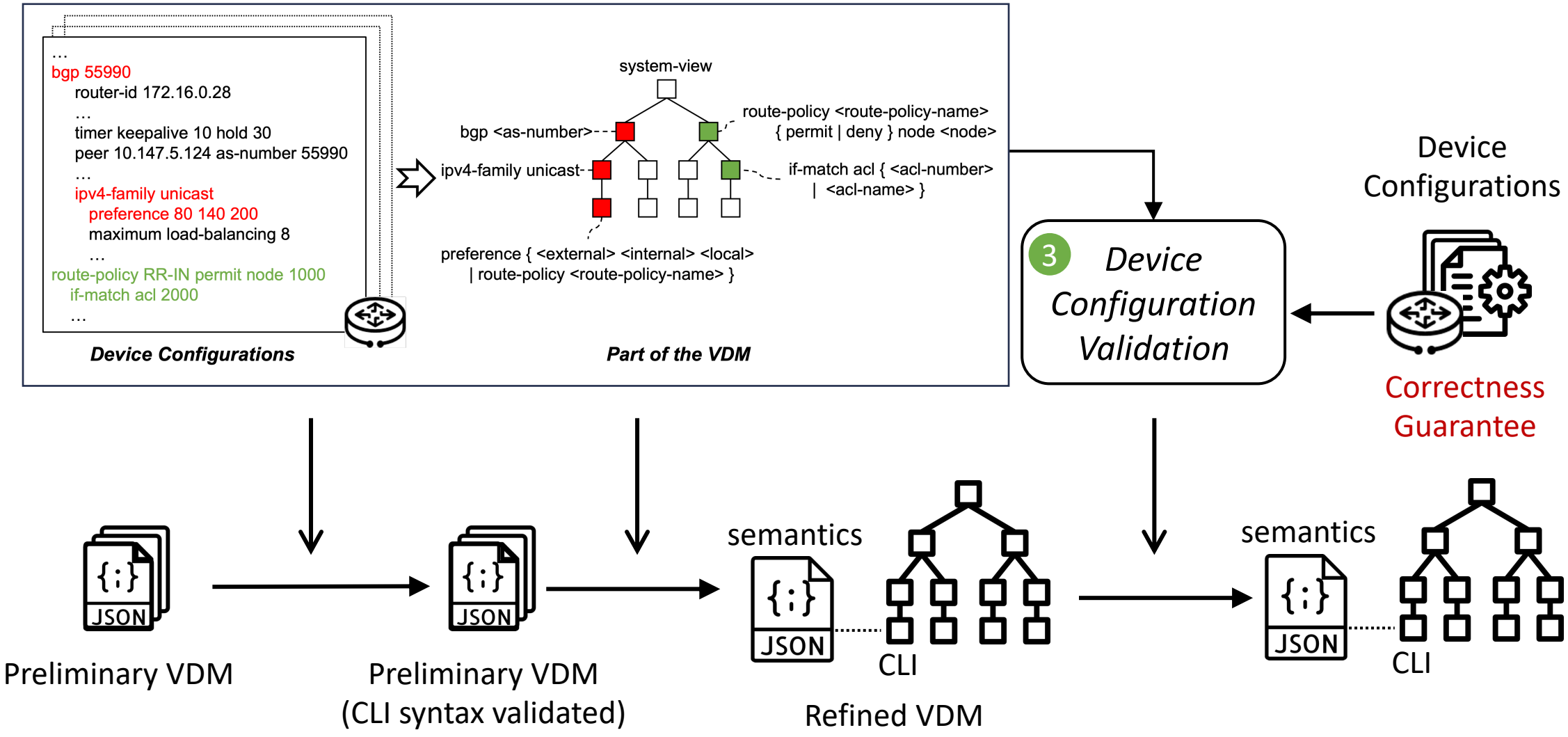
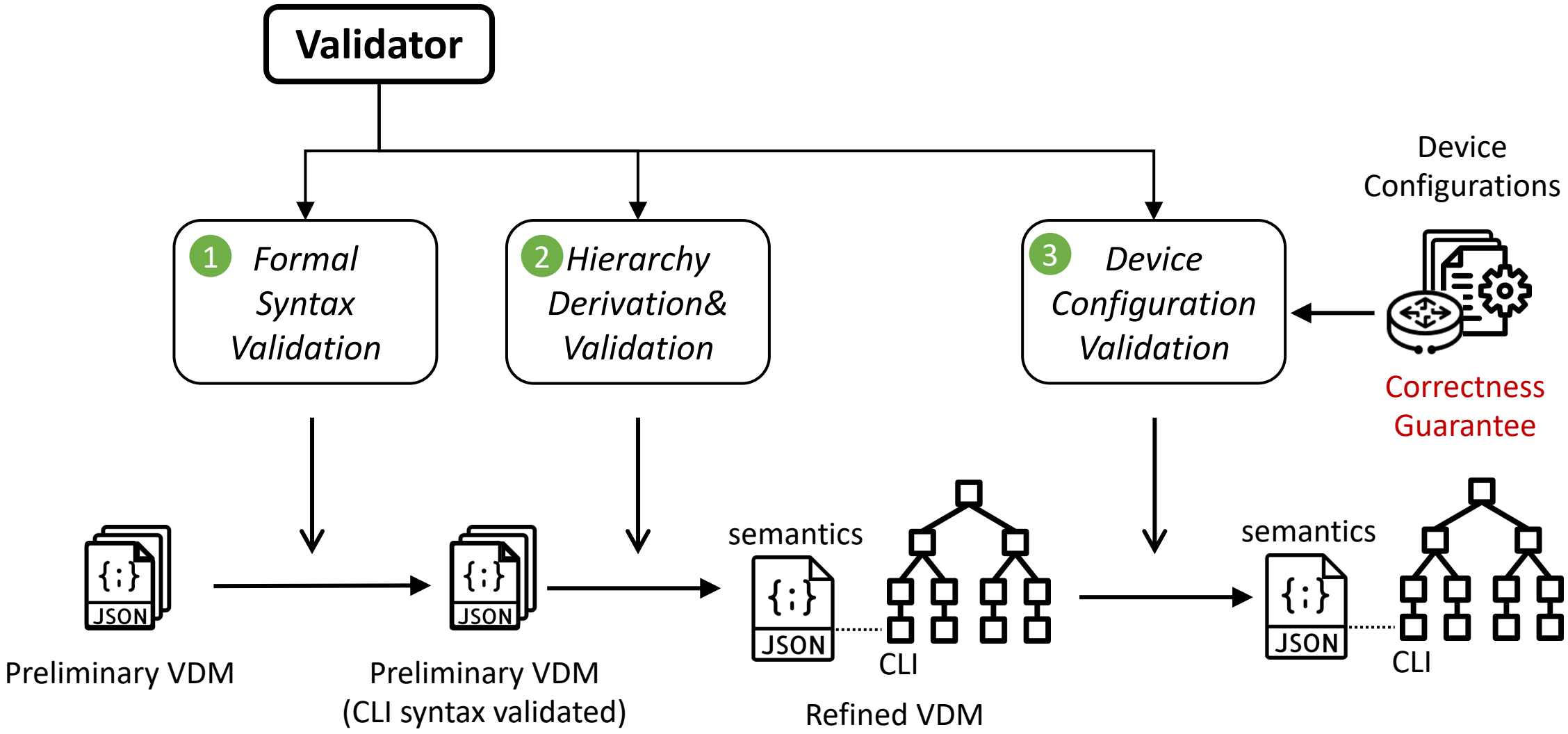


NAssim Validator: Design



NAssim Validator: Design



VDM Construction Phase: Parser + Validator

Vendor/Model/ReleaseYear	-	Huawei/NE40E/2021	Cisco/Nexus5500/2011	Nokia/7750SR/2021	H3C/S3600/2009
Main Statistics	#CLI Commands	12874	278	14046	759
	#Views	607	27	3832	28
	#CLI-View Pairs	36274	366	22734	851
Adaption Cost	`parsing()` LOC	45	52	57	41
	`get_cli_parser()` LOC	8	6	10	8
Syntax Validation	#Invalid CLI Commands	13	19	139	13
Model Hierarchy Derivation & Validation	#Example Snippets	15466	523	/	1147
	Construction Time (second)	785.58	14.29	94.56*	34.3
	#Ambiguous Views	47	8	/	4
Device Configuration Validation	#Config Files	197	/	416	/
	Matching Ratio	100%	/	100%	/

Table 3: Evaluation of the VDM Construction Phase. *Nokia manuals do not provide examples, but they explicitly specify model hierarchy in the manuals. Thus, we extract the hierarchy using `Parser_<nokia>` by implementing extra functions

VDM Construction Phase: Parser + Validator

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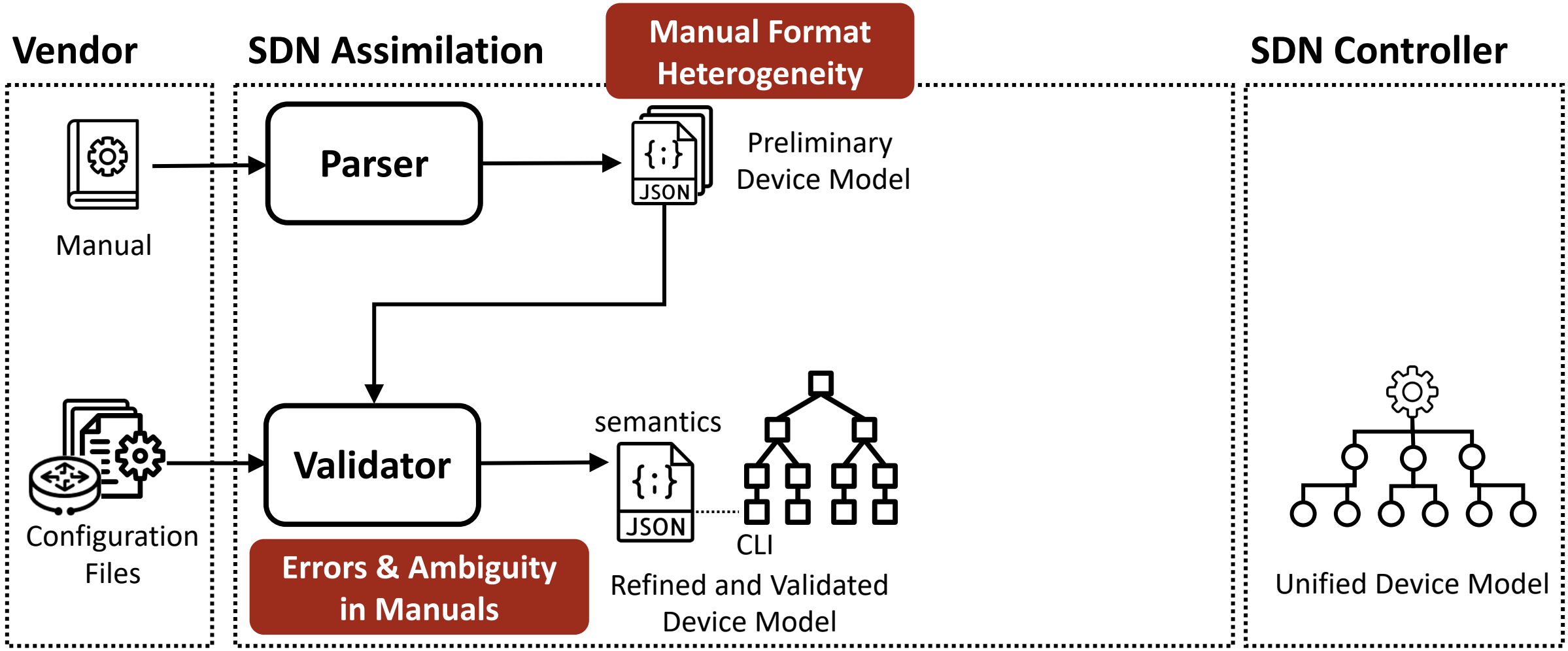
Refer to our repo for more details: https://github.com/AmyWorkspace/nassim

SDN Network Assimilation(NAssim) in a Nutshell



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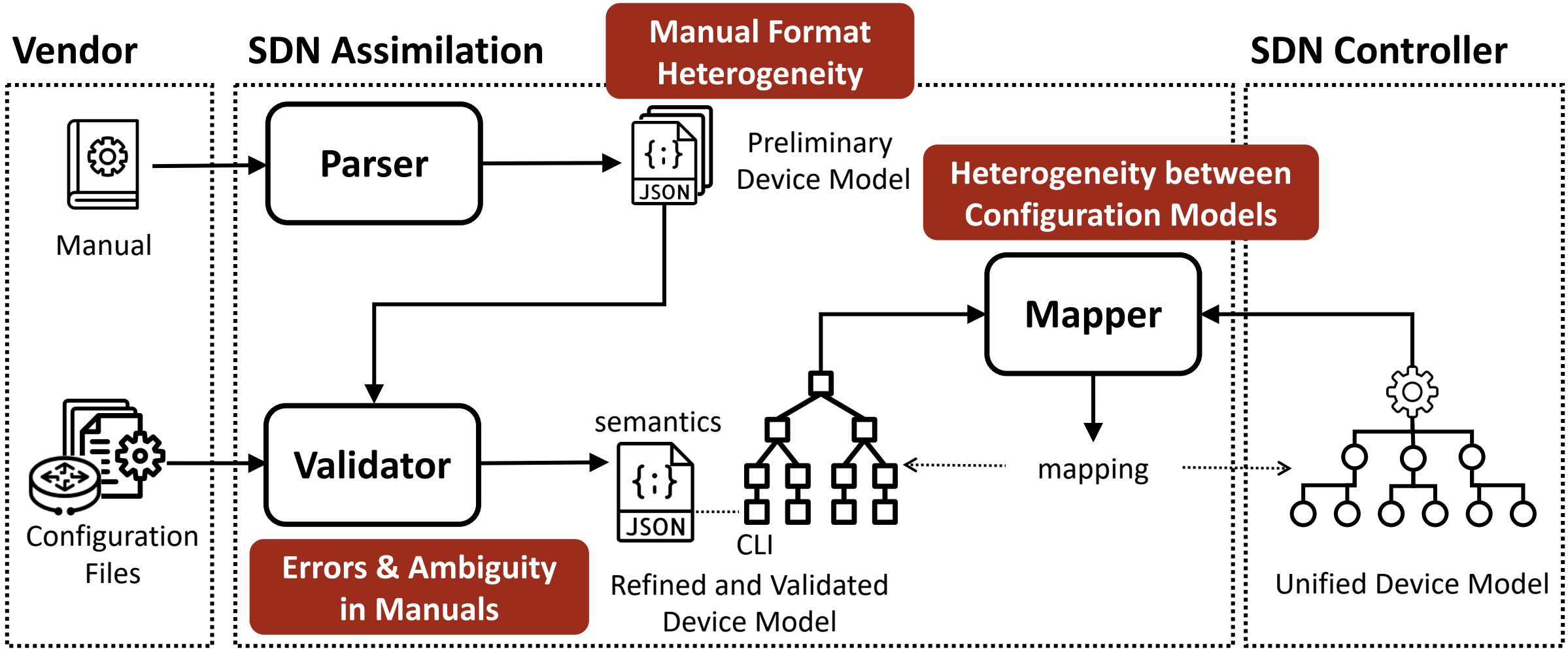
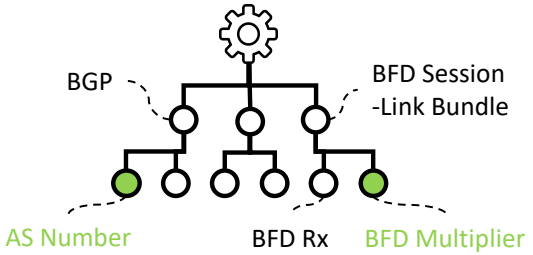


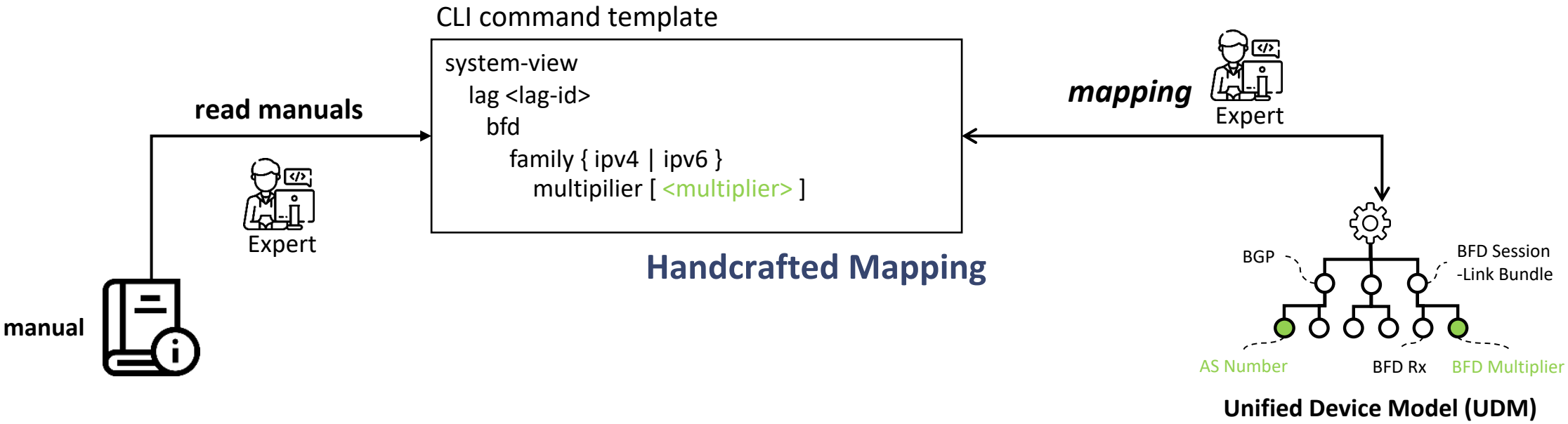
NAssim Mapper: Key Insights

manual

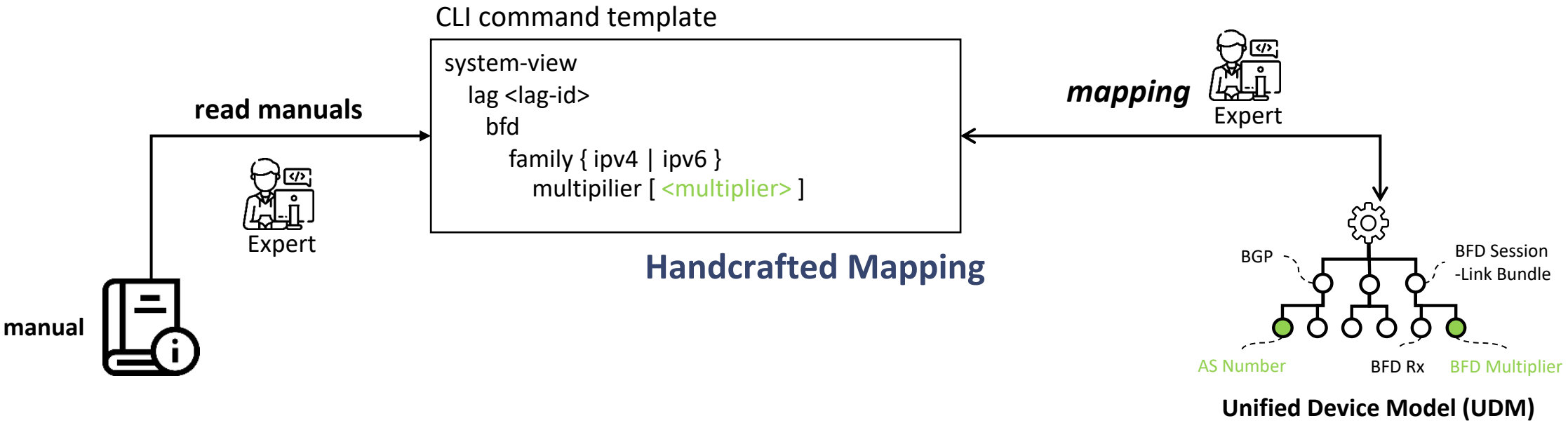


Unified Device Model (UDM)

NAssim Mapper: Key Insights

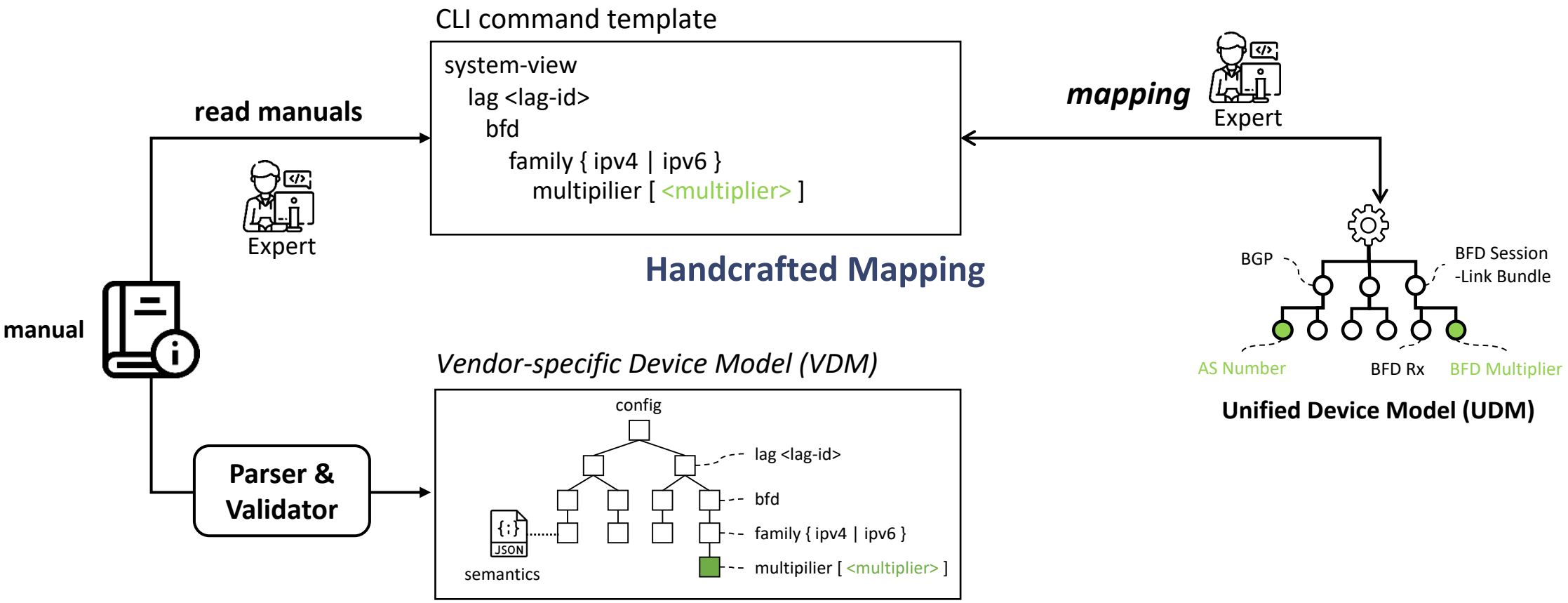


NAssim Mapper: Key Insights



The key of SNA is to pair semantically similar configuration items.

NAssim Mapper: Key Insights



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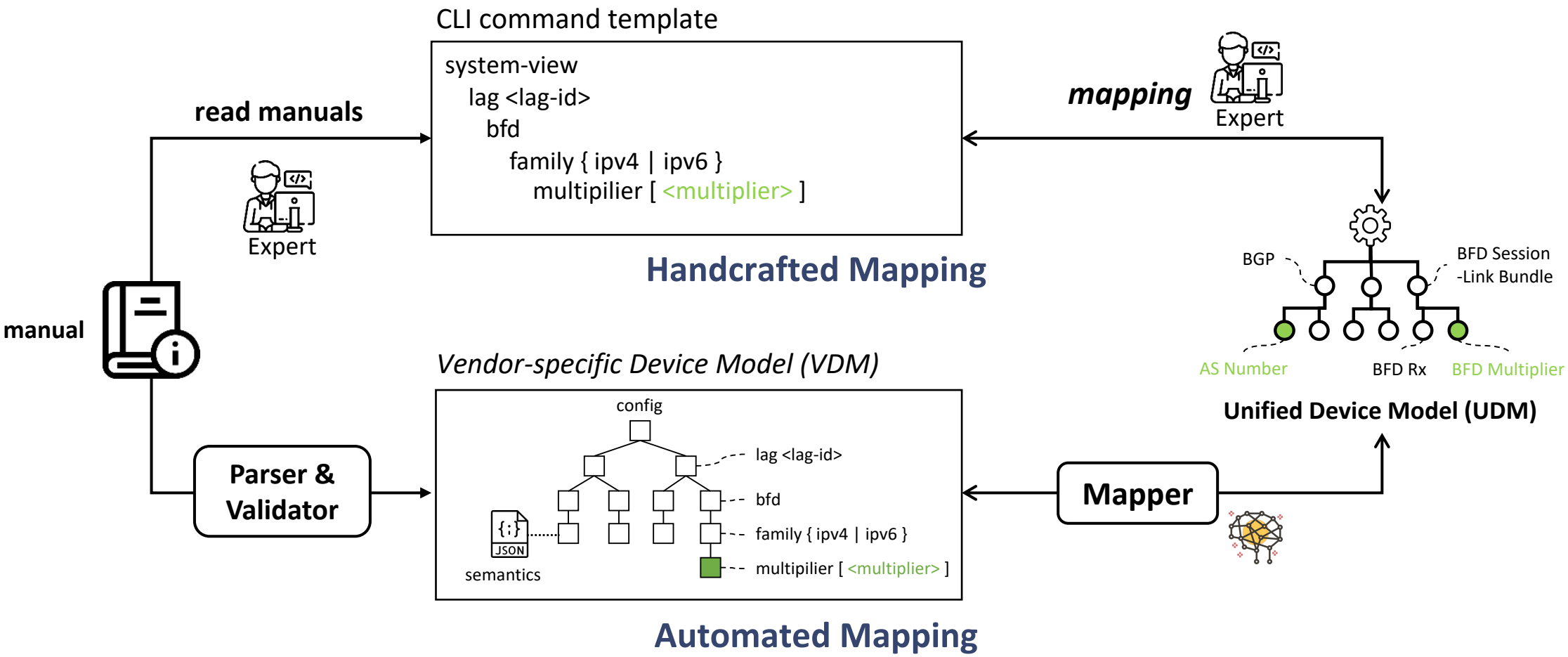

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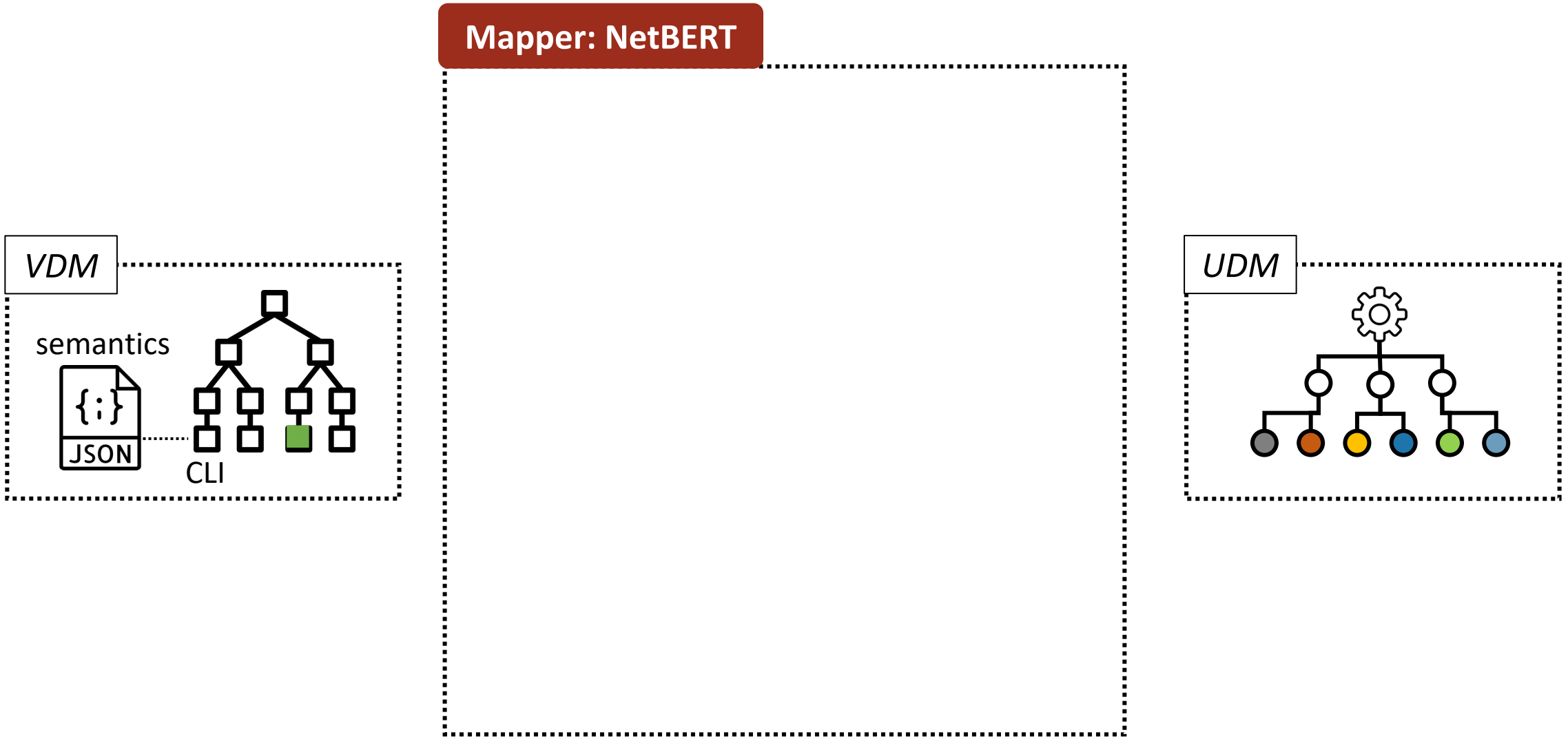
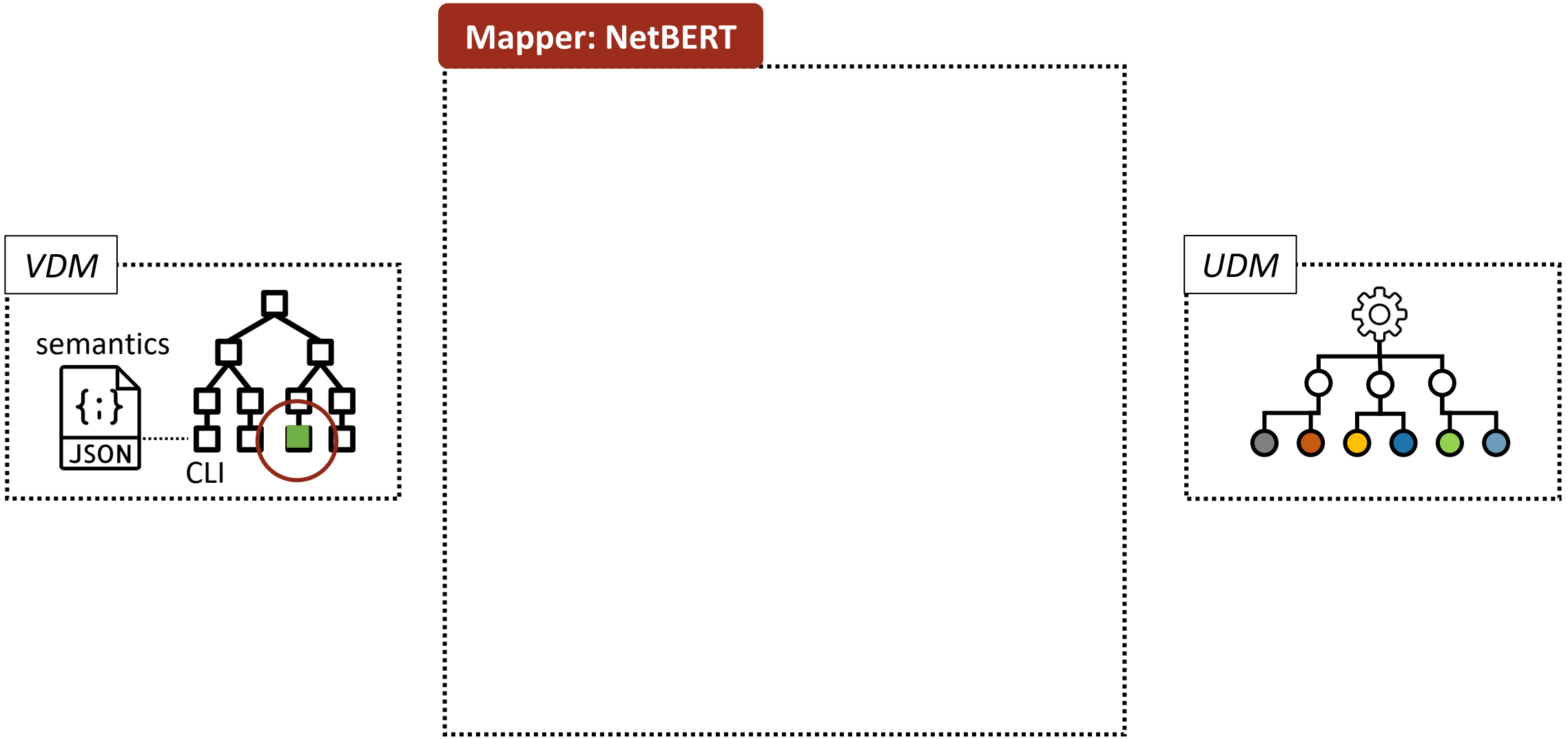
HUAWEI

NAssim Mapper: NetBERT



NAssim Mapper: NetBERT



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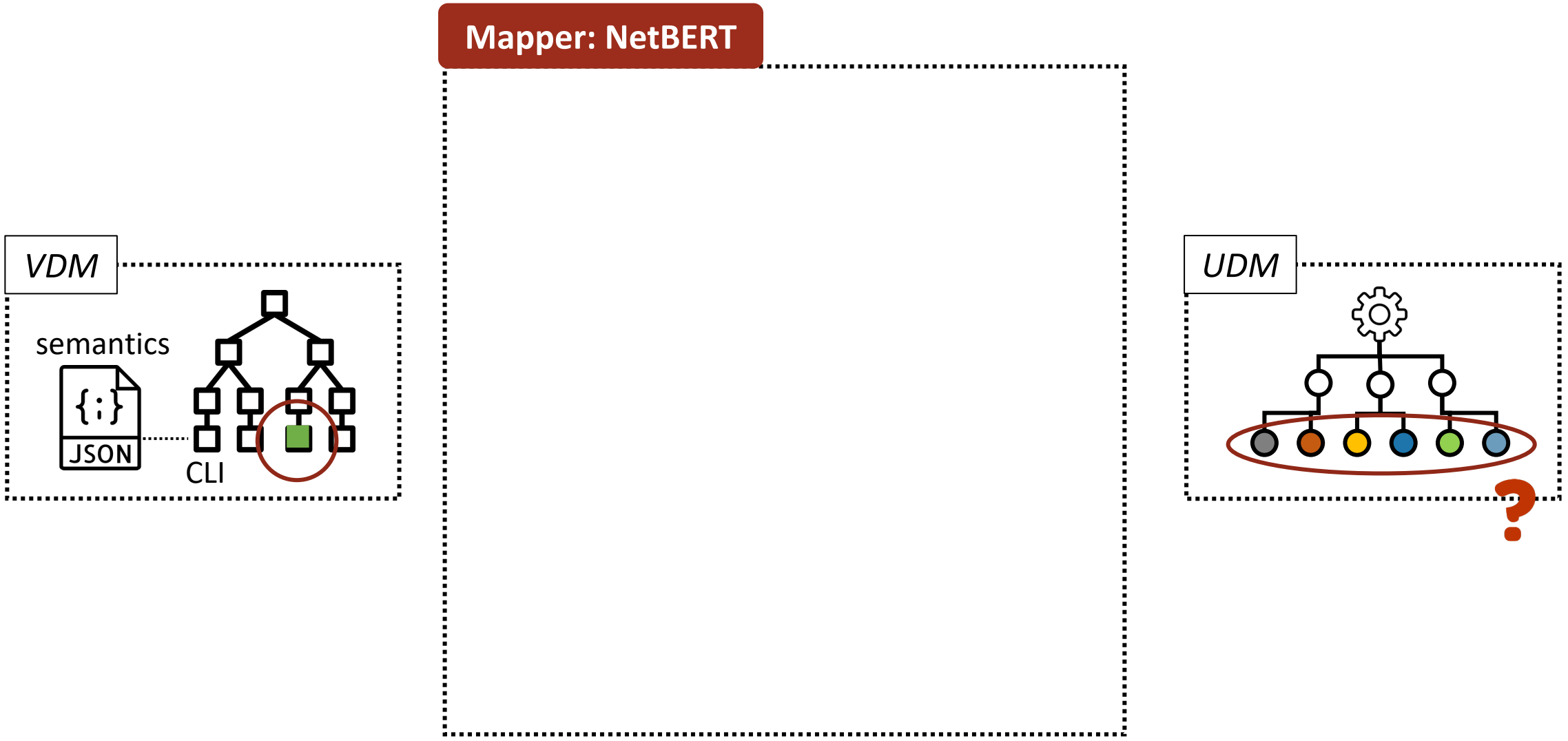

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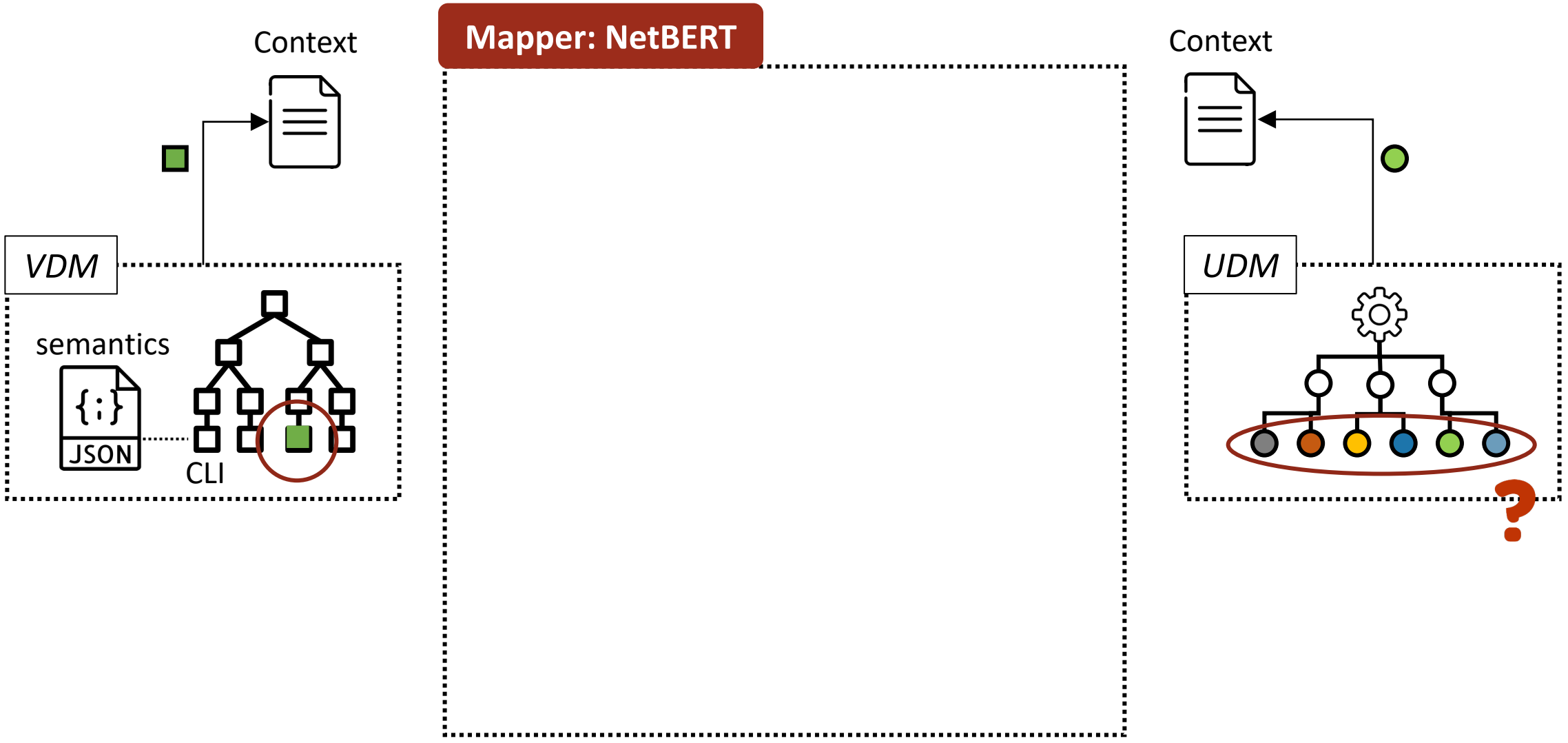
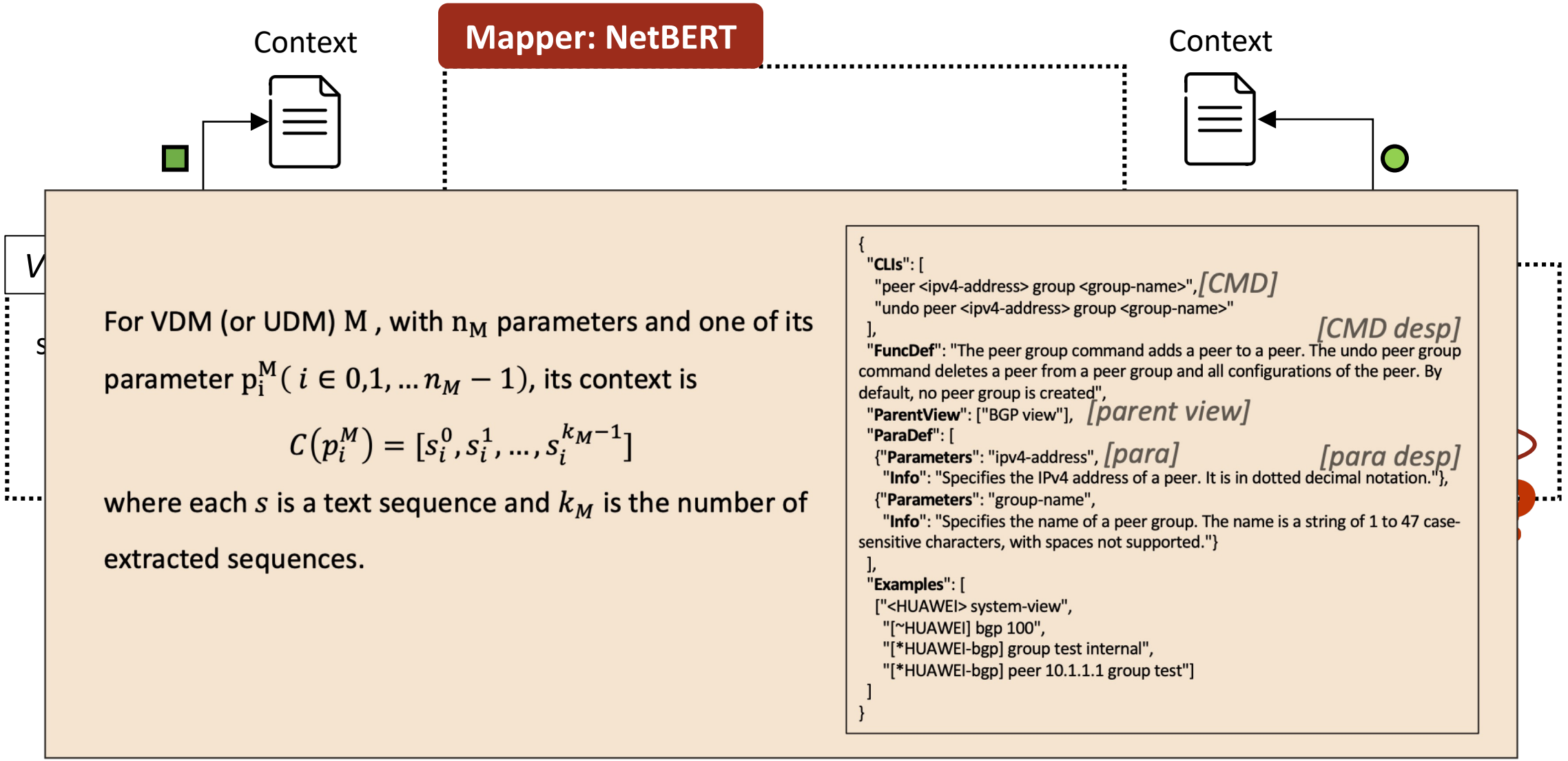


NAssim Mapper: NetBERT



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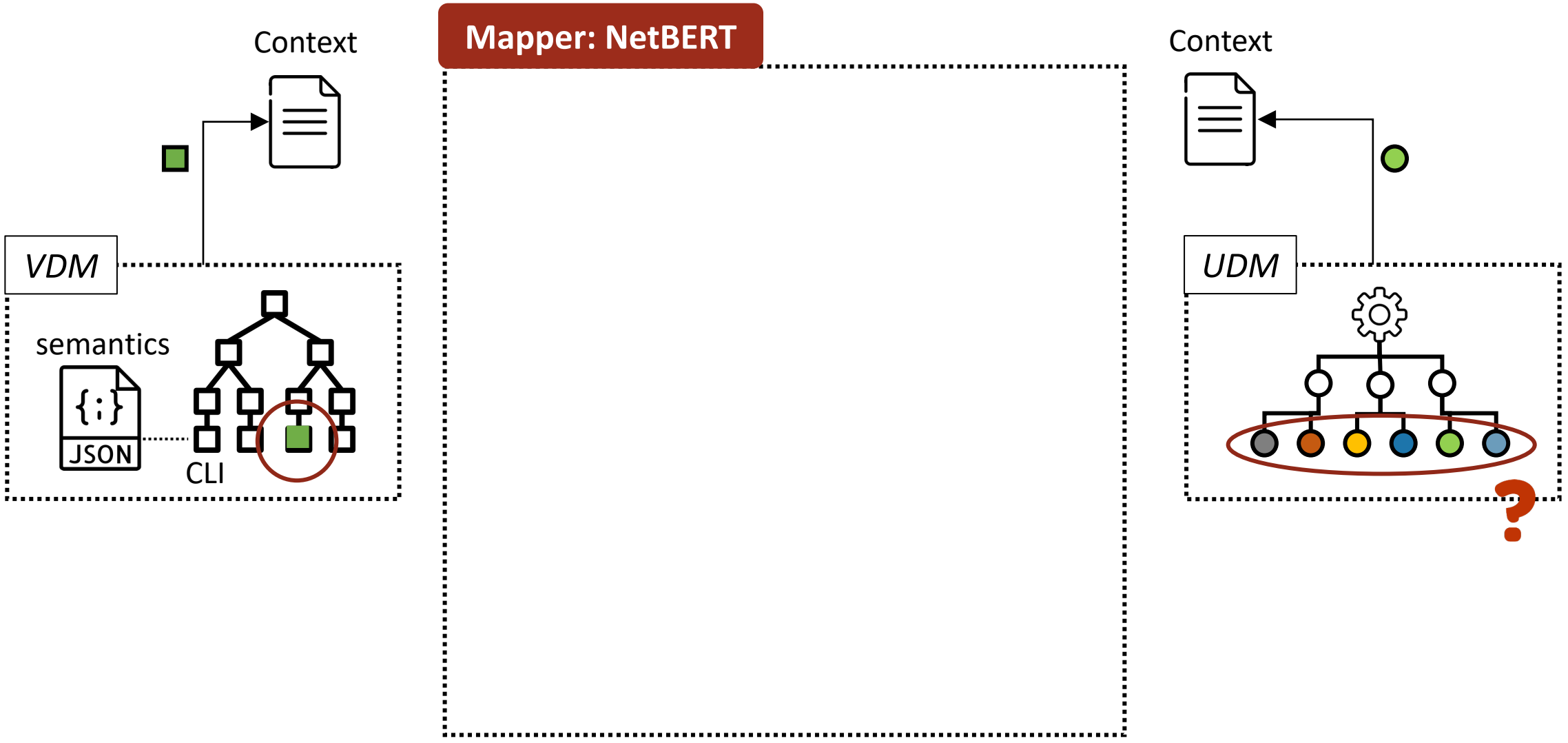
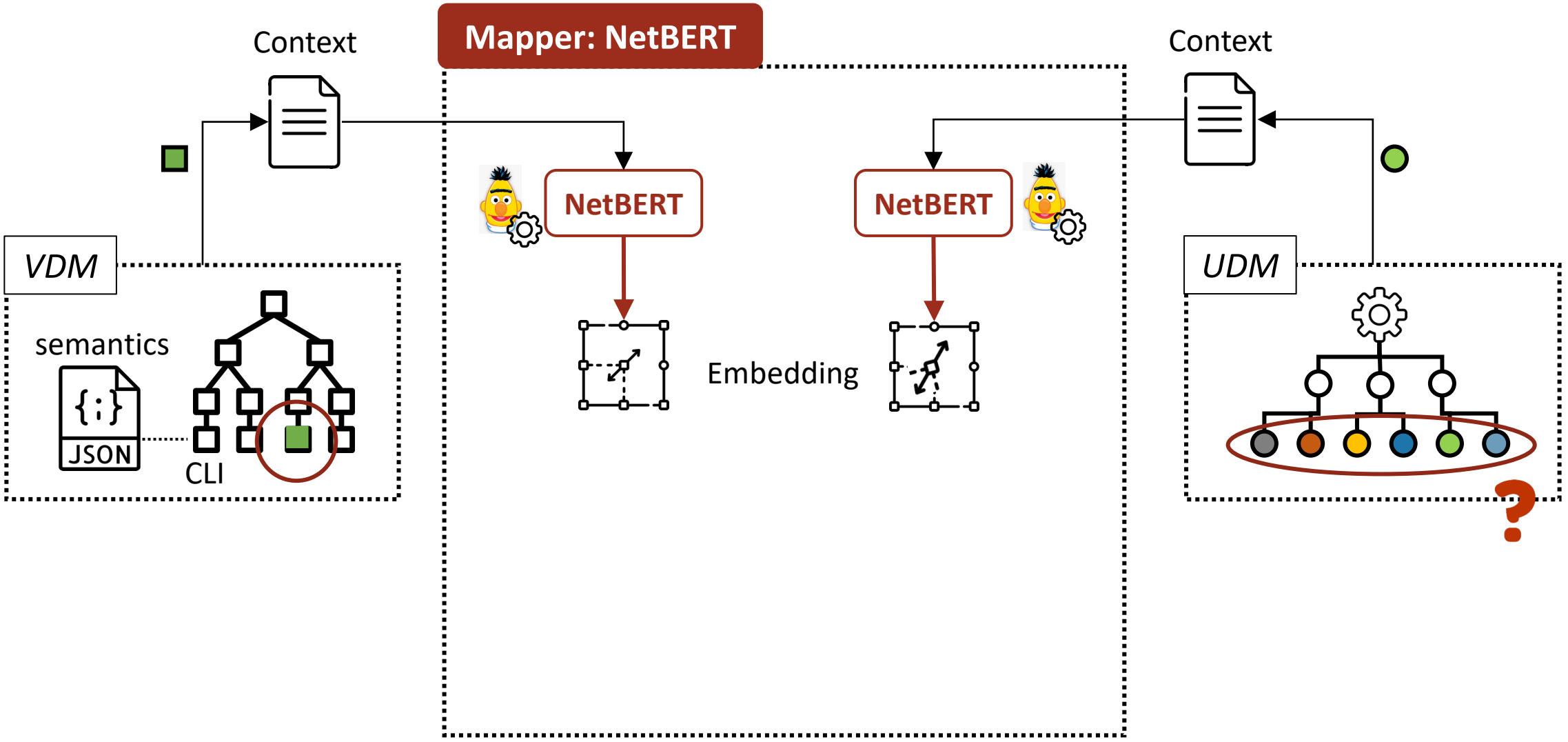


NAssim Mapper: NetBERT



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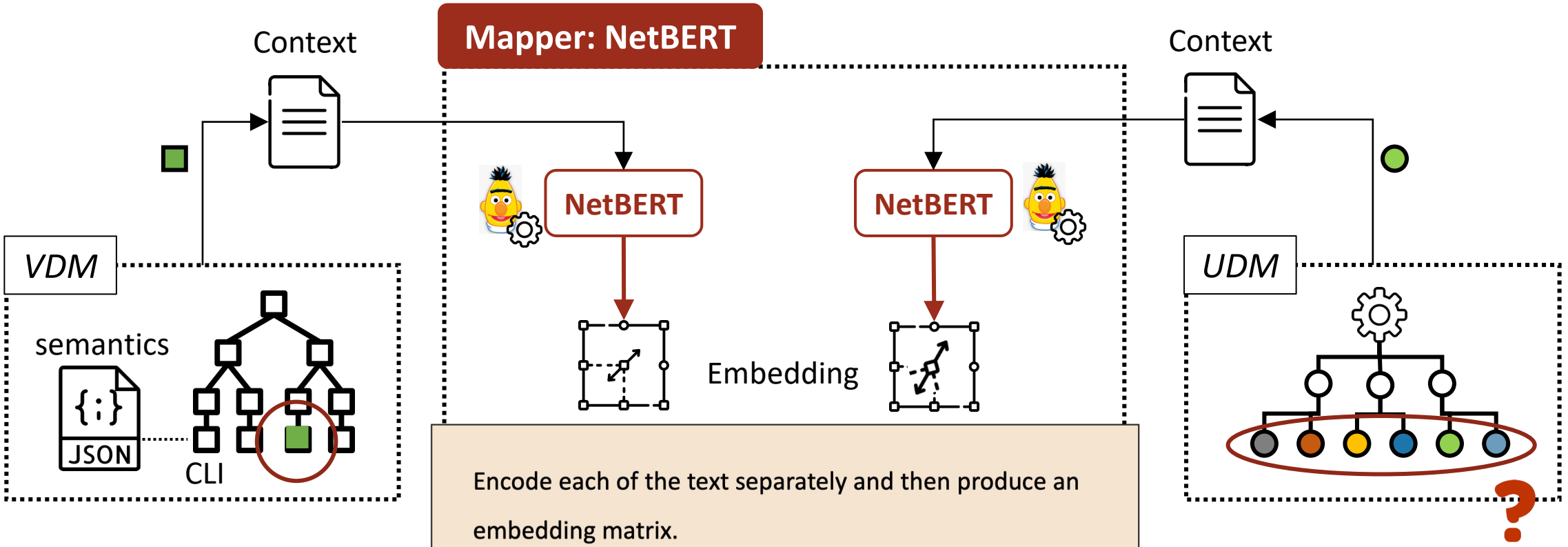
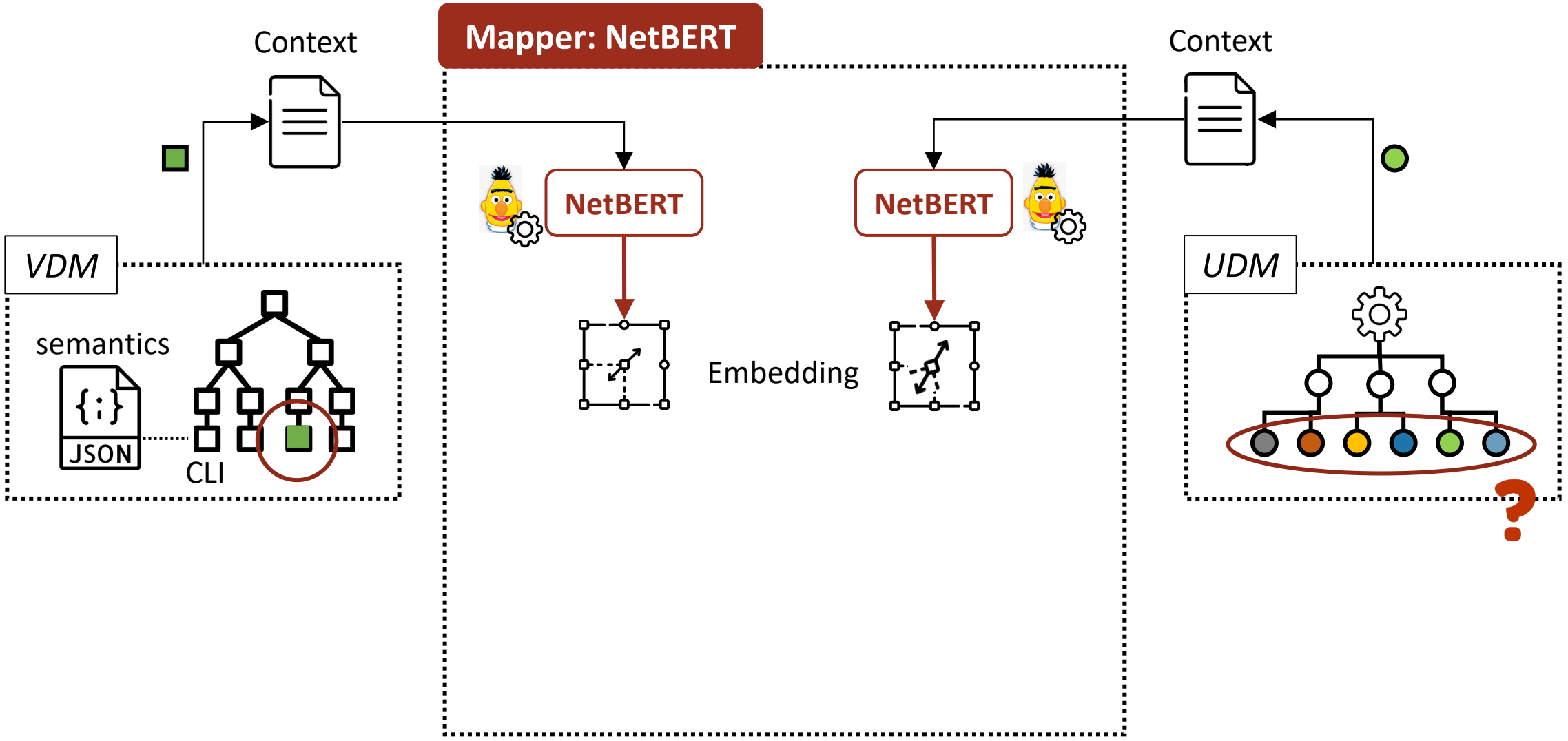


Encode each of the text separately and then produce an embedding matrix.

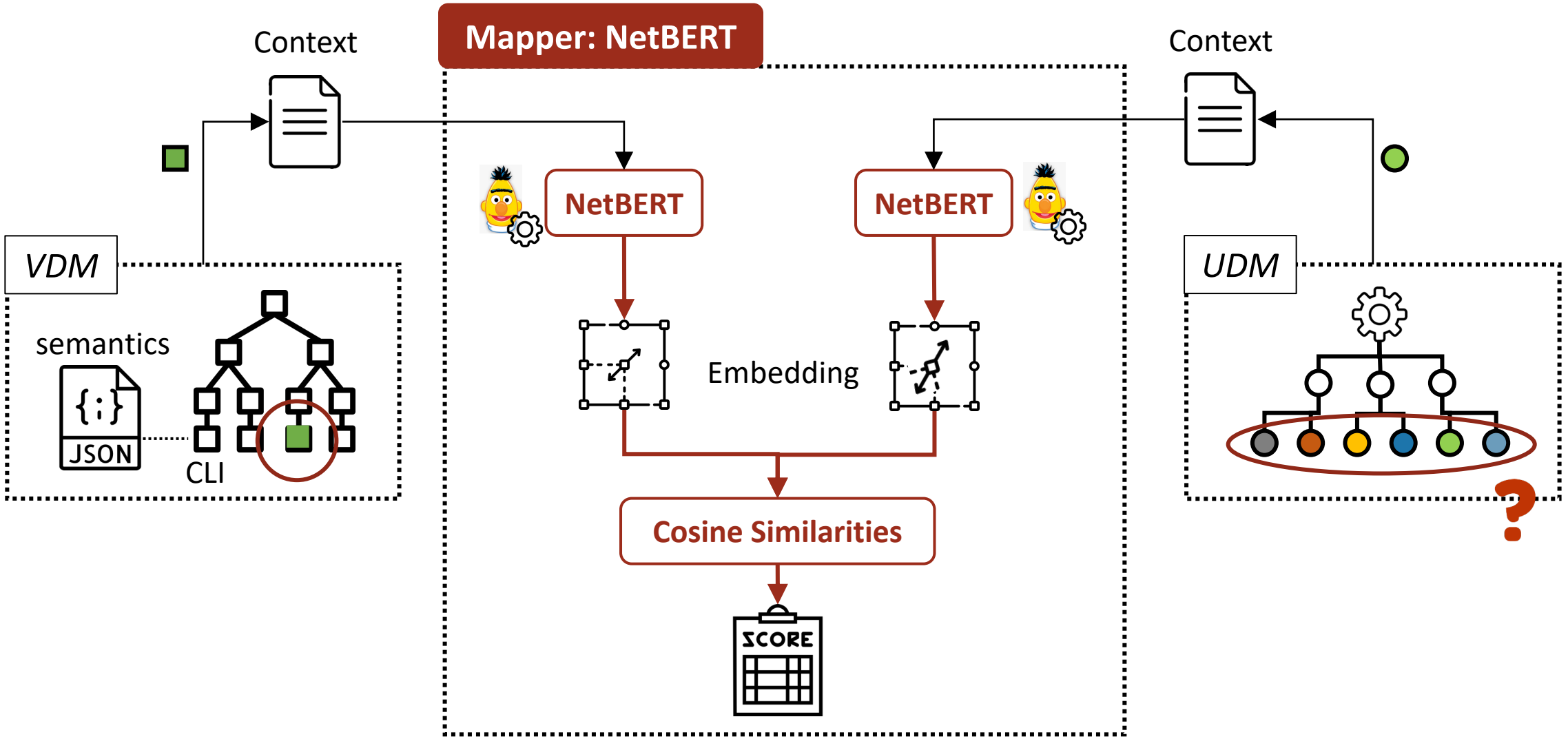
Assume the output dimension of the encoder $e(\cdot)$ is m, the context embedding of $\mathrm{p}_\mathrm{i}^\mathrm{M}$ is:

$$E_i^M = e(C(p_i^M)) = e([s_i^0, s_i^1, \ldots, s_i^{k_M-1}]) \in R^{k_M \times m}$$

NAssim Mapper: NetBERT



NAssim Mapper: NetBERT



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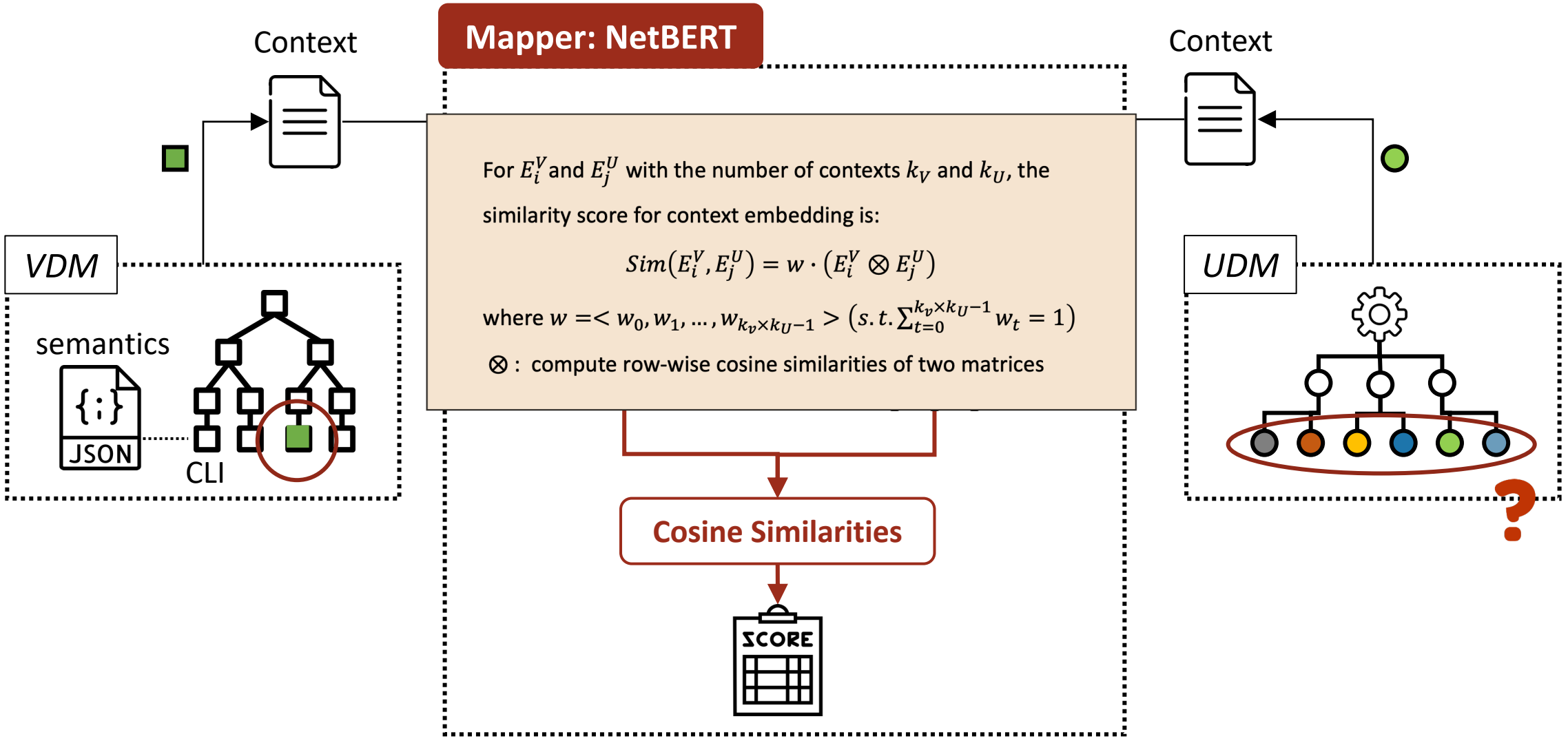

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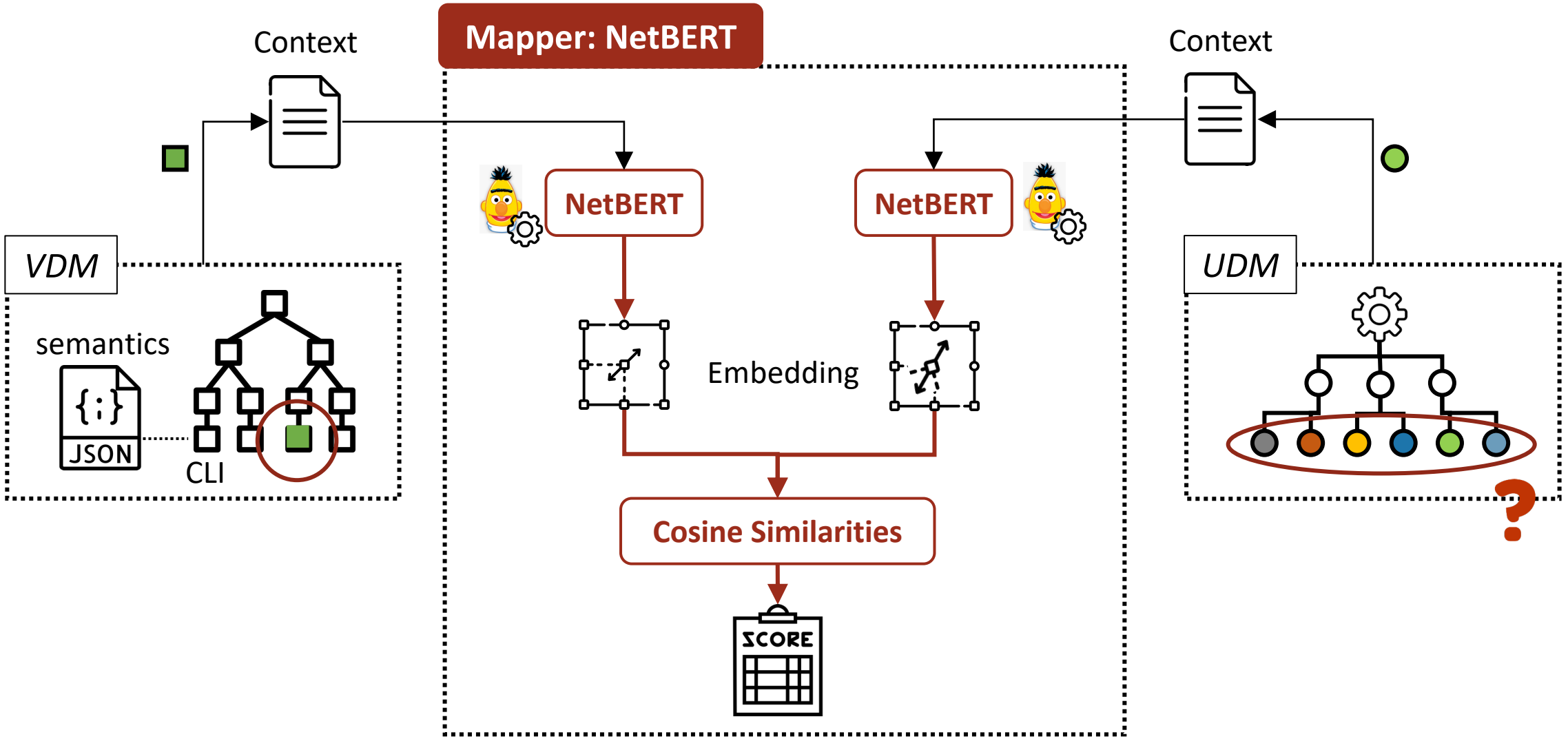

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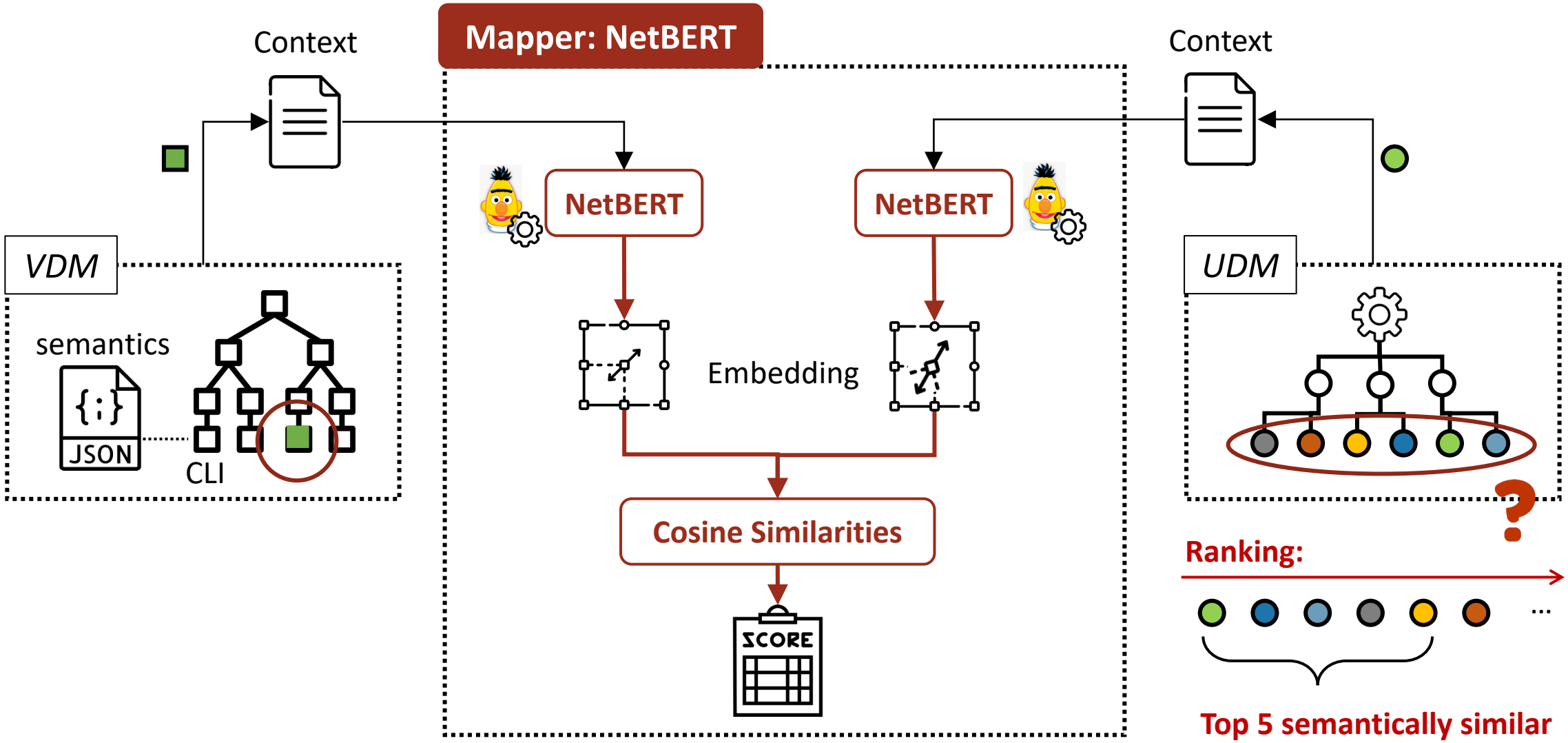
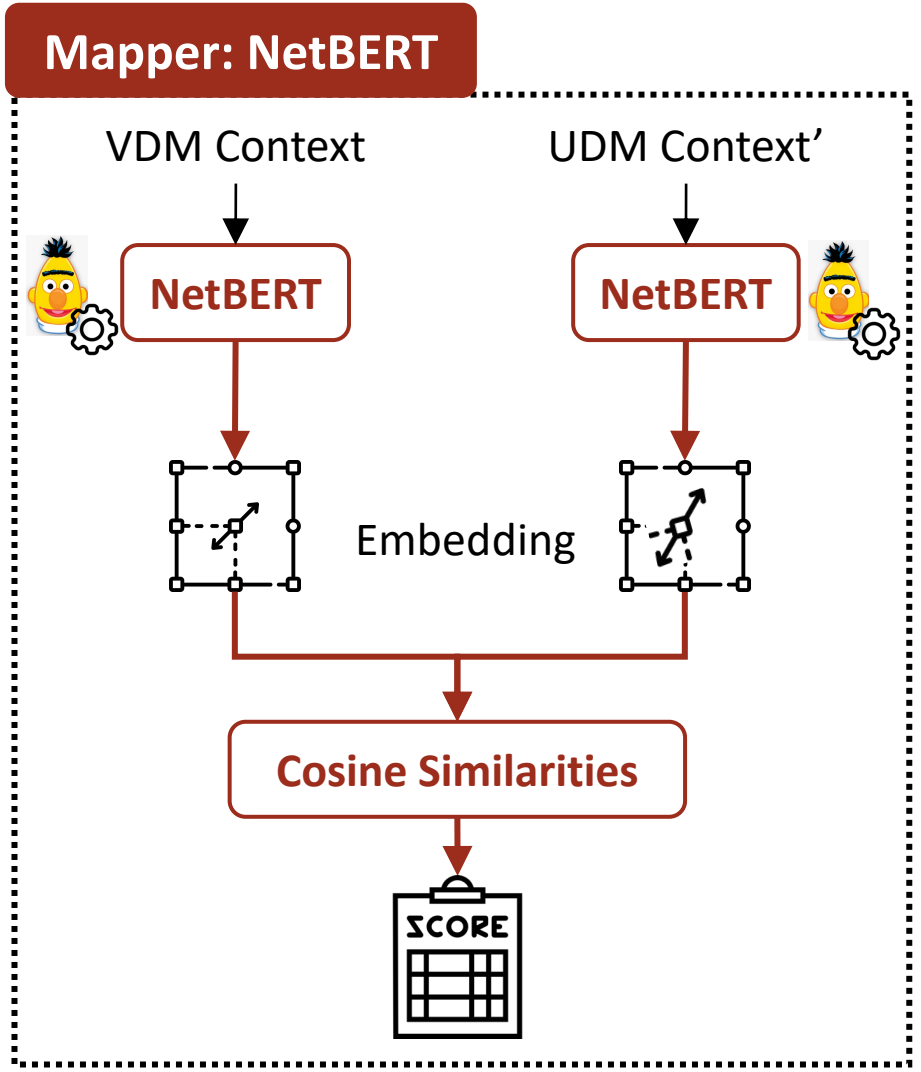
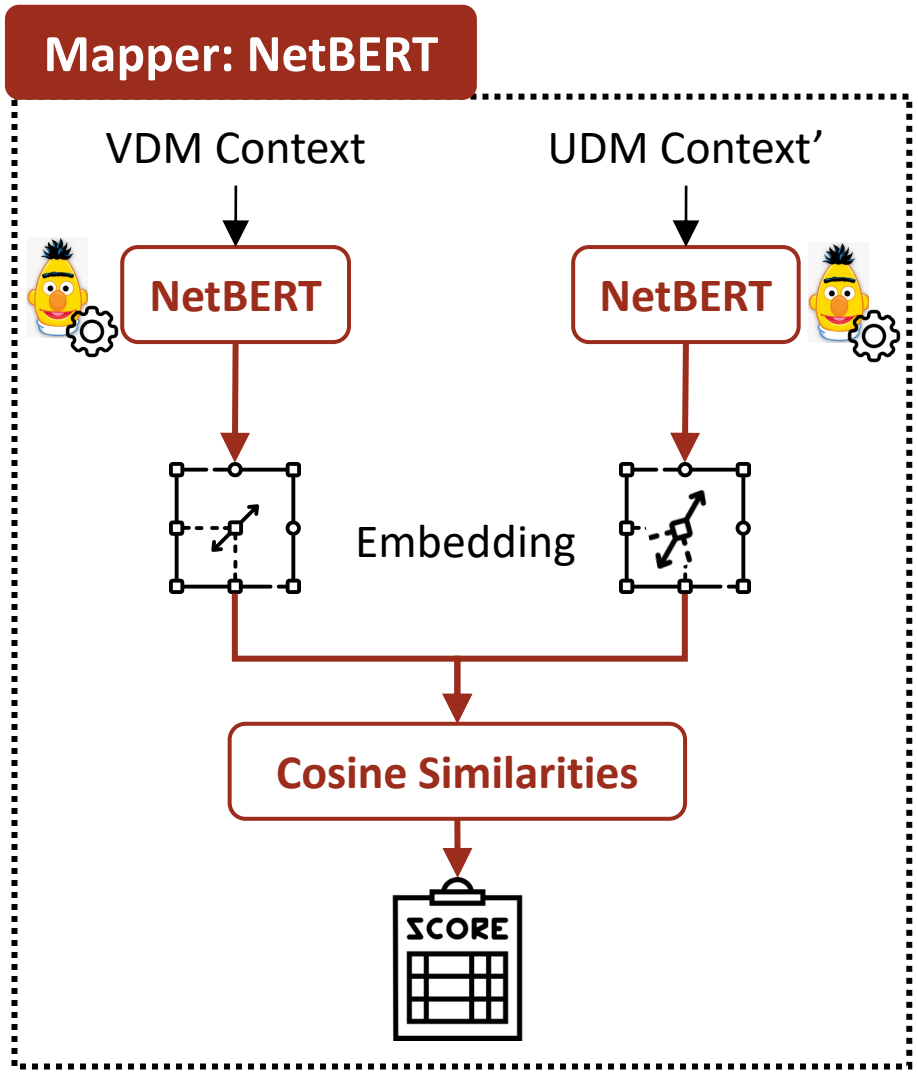


NAssim Mapper: NetBERT Training



NAssim Mapper: NetBERT Training

Pre-trained model*

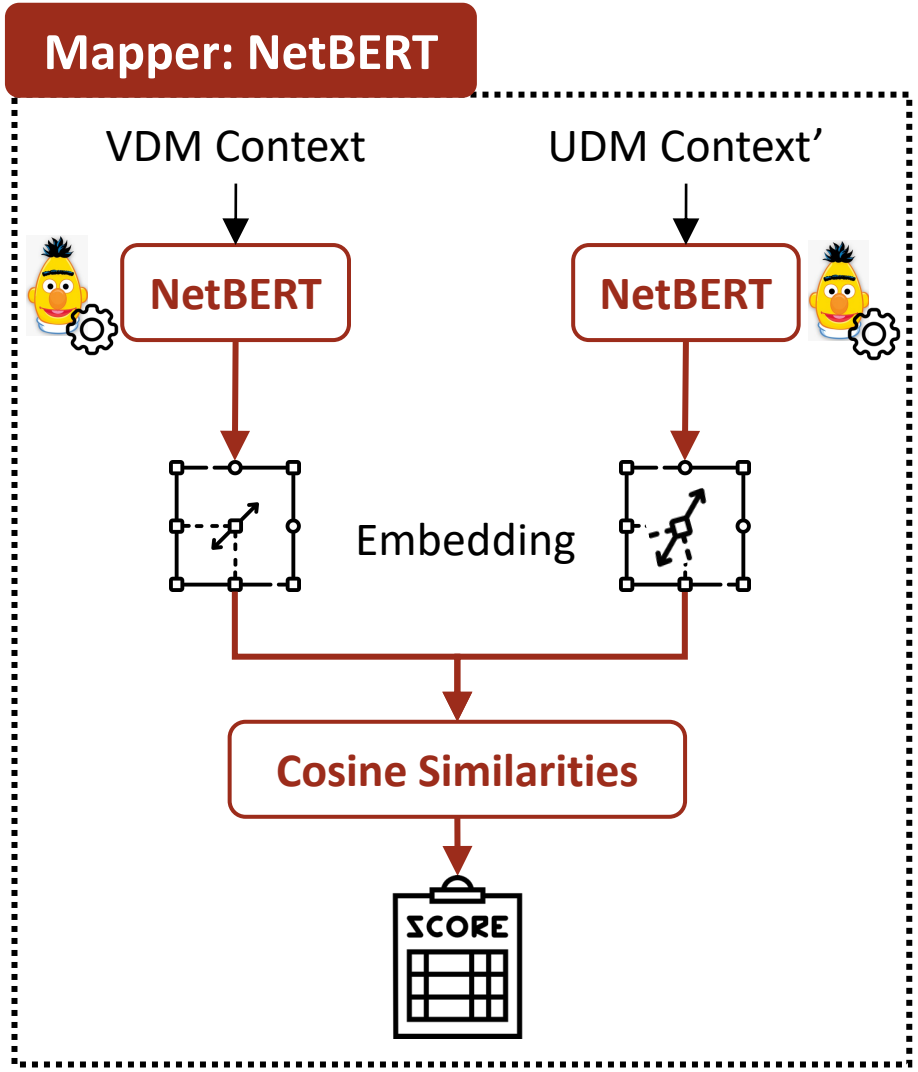


**Reimers, Nils, et al. "Sentence-BERT: Sentence Embeddings using Siamese BERT-Networks." EMNLP, 2019.*

NAssim Mapper: NetBERT Training

Pre-trained model*

Net-Config Domain Data



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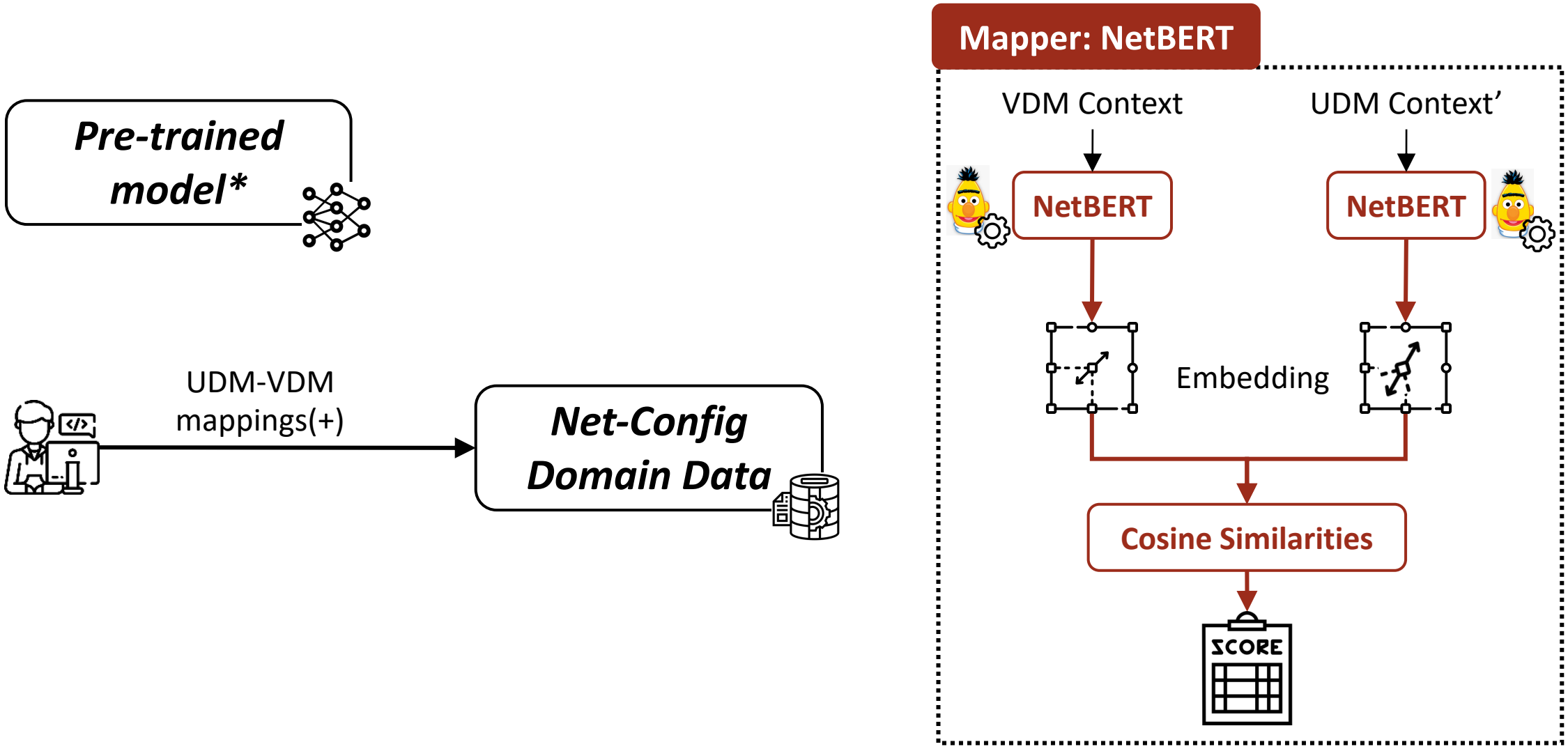

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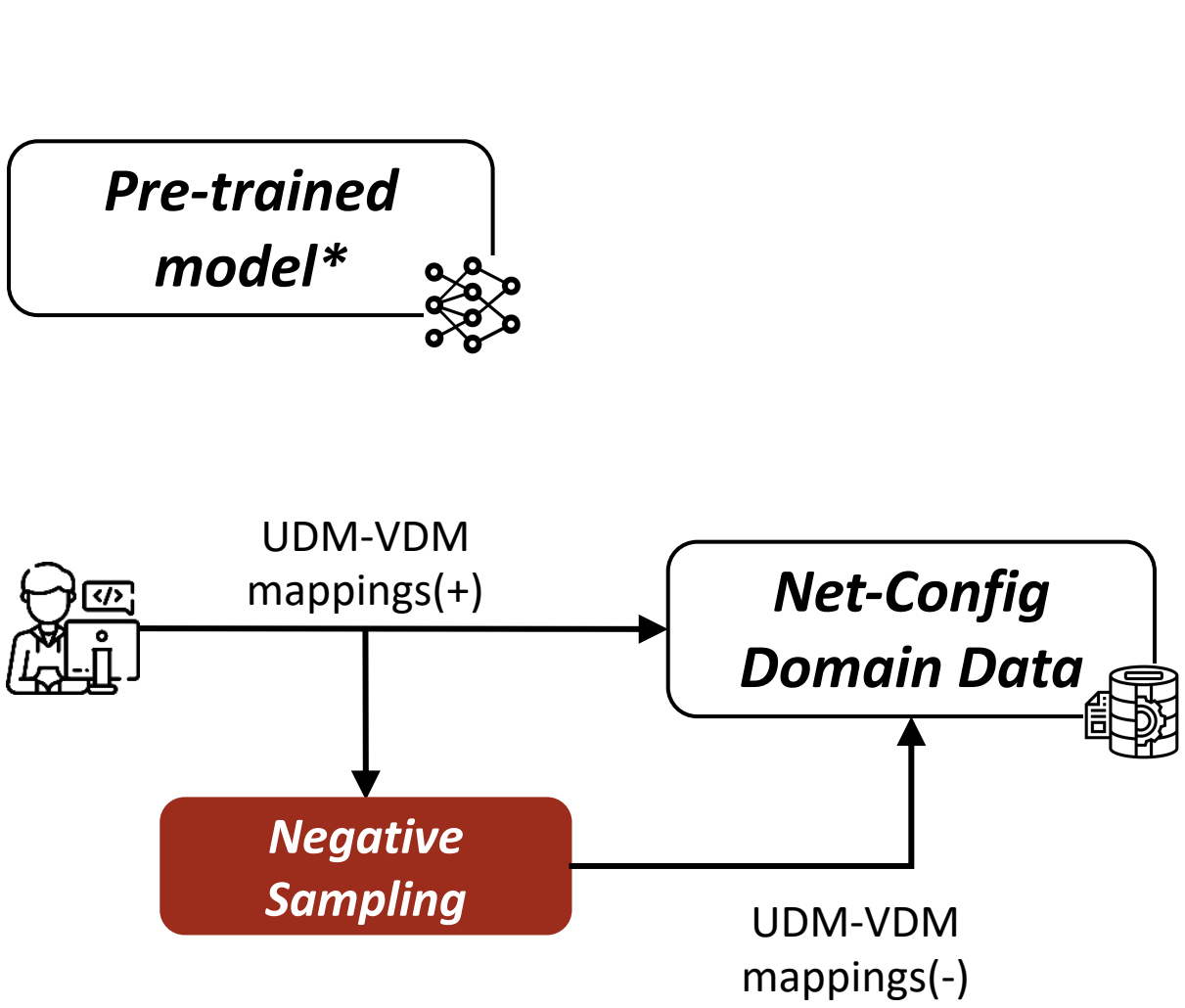

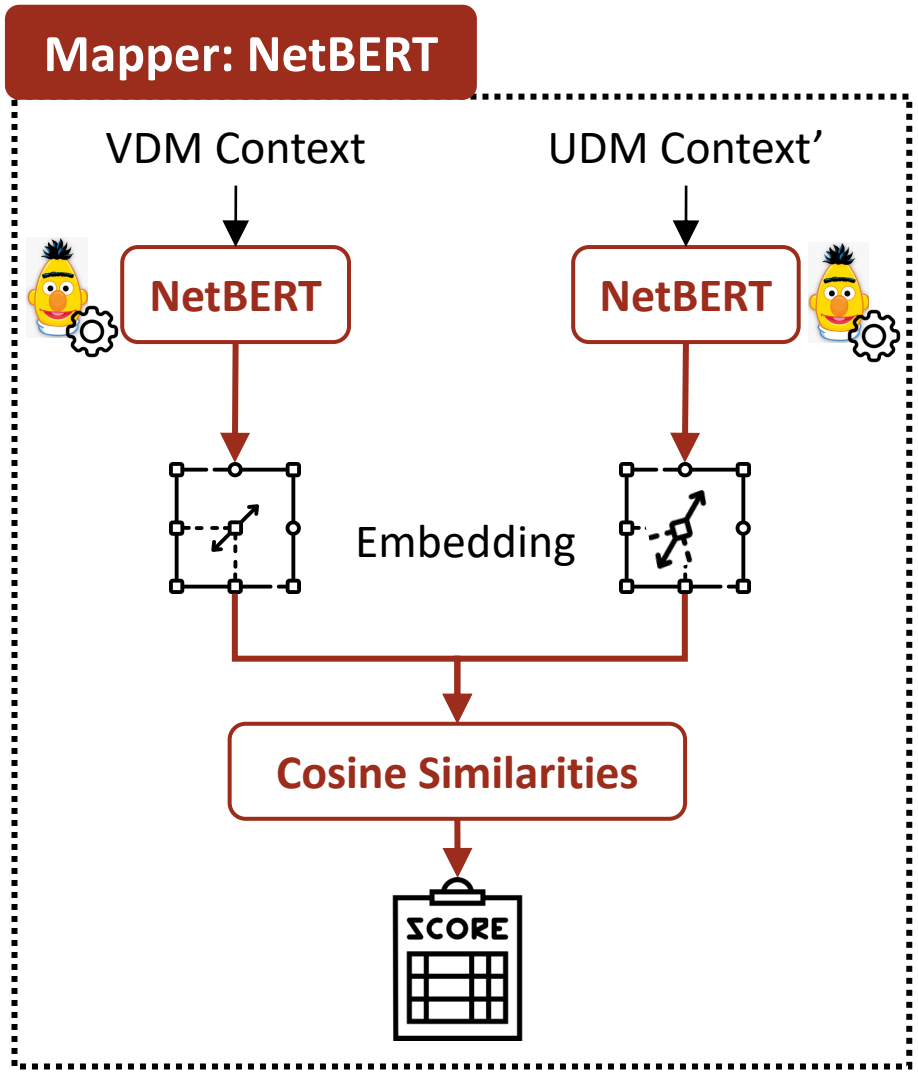

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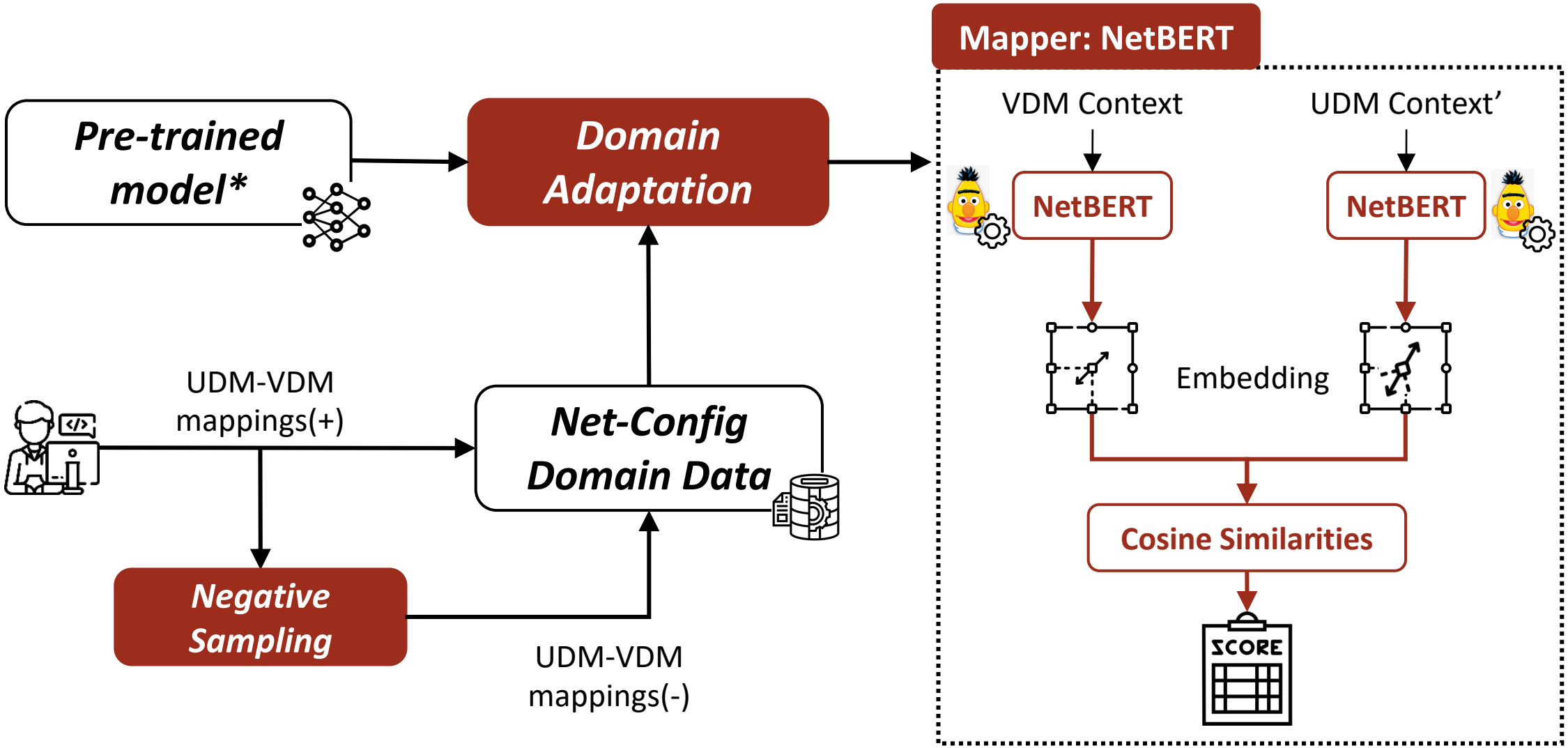

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VDM-UDM Mapping Phase: Mapper

Mapping Setting	Models	k in recall@top k (%)											
		1	2	3	4	5	6	7	8	9	10	20	30
Huawei-UDM	IR	41	52	61	66	69	74	76	78	79	80	90	93
	SimCSE	40	53	59	63	66	67	68	69	70	72	77	81
	SBERT	53	66	72	76	79	80	81	82	84	85	89	92
	IR+SimCSE	43	61	68	74	75	77	79	80	81	82	89	92
	IR+SBERT	56	69	75	79	81	83	85	86	87	88	91	94
	NetBERT	57	69	74	78	80	84	85	86	86	87	91	94
	IR+NetBERT	**58**	**71**	**78**	**81**	**83**	**85**	**86**	**87**	**88**	**89**	**93**	**95**
Nokia-UDM	IR	24	31	41	45	48	56	57	59	59	60	66	70
	SimCSE	20	27	31	33	37	38	39	39	39	42	45	48
	SBERT	34	35	38	44	49	49	49	52	52	52	58	53
	IR+SimCSE	24	31	35	40	42	43	46	48	48	48	57	61
	IR+SBERT	34	40	42	49	52	52	54	55	55	58	62	72
	NetBERT	34	40	43	50	53	**58**	**66**	67	67	**70**	71	73
	IR+NetBERT	**35**	**41**	**47**	**51**	**55**	57	65	**67**	**68**	68	**71**	**73**

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Nokia-UDM	IR	24	31	41	45	48	56	57	59	59	60	66	70
	SimCSE	20	27	31	33	37	38	39	39	39	42	45	48
	SBERT	34	35	38	44	49	49	49	52	52	52	58	53
	IR+SimCSE	24	31	35	40	42	43	46	48	48	48	57	61
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Recall@top-k denotes the percentage of test cases where the correct matching parameters are in top k recommendation by Mapper.

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Nokia-UDM	IR	24	31	41	45	48	56	57	59	59	60	66	70
	SimCSE	20	27	31	33	37	38	39	39	39	42	45	48
	SBERT	34	35	38	44	49	49	49	52	52	52	58	53
	IR+SimCSE	24	31	35	40	42	43	46	48	48	48	57	61
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Nokia-UDM	IR	24	31	41	45	48	56	57	59	59	60	66	70
	SimCSE	20	27	31	33	37	38	39	39	39	42	45	48
	SBERT	34	35	38	44	49	49	49	52	52	52	58	53
	IR+SimCSE	24	31	35	40	42	43	46	48	48	48	57	61
	IR+SBERT	34	40	42	49	52	52	54	55	55	58	62	72
	NetBERT	34	40	43	50	53	**58**	**66**	67	67	**70**	71	73
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9.1x

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Key Takeways

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- We release a validated and expert-curated dataset of parsed manual corpus for future research. (https://github.com/AmyWorkspace/nassim)

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Huangxun Chen, Yukai Miao, Li Chen, Haifeng Sun, Hong Xu, Libin Liu, Gong Zhang, Wei Wang

Thank you!
Q&A

https://amyworkspace.github.io/hxchen/
https://github.com/AmyWorkspace/nassim