

SDN Automation with NSO

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Abstract

Your summary.

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1 Basic Concepts

This chapter covers the following topics:

- What is an APIs
- What is it an Web Service Architecture

1.1 Web Services Architecture

For communicating with and configuring networks, software developers commonly use application programming interfaces (APIs).

APIs are mechanisms used to communicate with applications and other software.

They are also used to communicate with various components of a network through software. A developer can use APIs to configure or monitor specific components of a network. Although there are multiple different types of APIs, this chapter focuses on two of the most common APIs:

- Northbound APIs
- Southbound APIs.

1.1.1 Introduction

A web service is a part of a message that communicates from one system to another, where the message can be in XML or JSON format, and is characterised by these two features:

- Multi-platform: client and server do not have to have the same configuration to communicate. The web service makes this possible.
- Distributed: in general, a web service is not available to a single client, but is accessed by different clients over the Internet.

The architecture of a web service is designed taking into account the different tasks that the service is expected to perform, such as Service Provider, Service Registry and Service Requester. In addition, a web service is expected to flow through the network with the help of protocols following the SOA architecture and the endpoint URL called WSDL (Web Services Description Language).

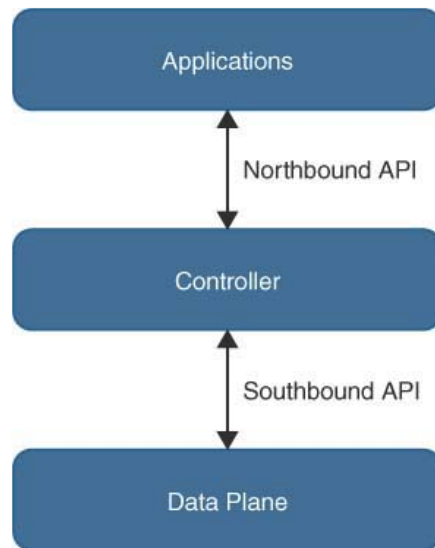


Figure 1: APIs-Introduction

1.1.2 Basic Architecture

The fundamental architecture incorporates the following:

- Publish: In this operation, a service description must be published so that a service requester can find the service.
- Find: In this operation, the service requestor directly retrieves the service description.

It is involved in two different lifecycle phases:

- At the design time to retrieve the service's interface description for program development.
- At the runtime to retrieve the service's binding and the location description for invocation.
- Bind: In this operation, the service requestor calls or initiates an interaction with the service at runtime only using the binding details available in the service description to locate, contact, and call the service.

There are three roles of web service architecture:

- Service Provider: It is the platform that hosts the services. It creates web service and makes it available to client applications who want to use it.
- Service Requestor: It is the application that is looking for and invoking or initiating an interaction with a service. Here, the browser plays the requester role, driven by a consumer or a program without a user interface.

In short, the client application that needs to contact a web service is Service Requestor. The client application can be a .Net application, a Java application, or any other language-based application that looks for some sort of functionality.

- Service Registry: Service requestors find the service and obtain binding information for services during development. It is the application that provides access to the UDDI. The UDDI enables the client application to locate the web service.

1.1.3 Web Service Description Language

It is a metalanguage for describing web services in a comprehensive way.

WSDL uses both abstract and concrete descriptions to define web services. While abstract descriptions refer to the functionality of the service, concrete descriptions communicate specific data, such as the transmission protocol.

The WSDL file has a hierarchical structure. Therefore, the information is nested.

WSDL makes use of six main elements of XML:

- Types: data types.
- Message: description of the data to be transferred.
- Interface: abstract operations describing the communication between server and client (still called portType in an earlier version of the standard).
- Binding: information about the transport protocol used.
- Endpoint: information about the communication interface, usually in the form of a URI.
- Service: access points of the web service.

If the file includes all these elements, the client gets all the information needed to access the web service. The fact that all systems get the same language via the WSDL file is what makes web services cross-platform.

1.1.4 Web Service Architecture Stack

A web service protocol stack typically contains four protocols:

1. Transport Protocol
 2. Messaging Protocol
 3. Description Protocol
 4. Discovery Protocol
- **(Service) Transport Protocol:** The network layer, also known as the foundation of the web service stack, is responsible for transporting a message between the network applications. HTTP is the network protocol available for internet web services. It also provides other network protocols such as SMTP, FTP, and BEEP (Block Extensible Exchange Protocol).

- **(XML) Messaging Protocol:** This protocol is responsible for encoding the messages in a common XML format so that they are understood at either end of a network connection. SOAP is the XML messaging protocol because it supports all the three operations: publish, find, and bind operation.
- **(Service) Description Protocol:** This protocol is used for describing the public interface to a specific web service. WSDL is the standard used for the XML-based service description.
- **(Service) Discovery Protocol:** This protocol is a centralized service in a common registry so that network Web services can publish their location as well as the description, and it becomes easy to find those services that are available on the network.

1.2 Python Basics

Data types are the categorization of data items. It represents the kind of value that tells what operations can be performed on a particular data.

Data Types	Examples	Explanation	Mutable/Immutable?
Strings	"Hello!", "23.34"	Text - anything between " "	Immutable
Integers	5364	Whole numbers	Immutable
Floats	3.1415	Decimal Numbers	Immutable
Booleans	True, False	Truth values that represent Yes/No	Immutable

1.2.1 Strings:

```
print("This is an string!")
a = "hello world"
```

1.2.2 Integers:

```
a=3
print(a)
a>4
False
type(a)
<type 'int'>
```

1.2.3 Floats:

```
pi=3.141516
pi>3
```

```

True
type(pi)
<type 'float'>
## Change data type
int(pi)
3

```

1.2.4 Booleans:

```

a = True
type(a)
<type 'bool'>

```

1.2.5 Python Data Structures

Data structures are basically are *structures* which can hold some *data* together and are fundamental constructs around which you build your programs. Each data structure provides a particular way of organizing data depending the use case.

There are four built-in data structures in Python - *list*, *tuple*, *dictionary* and *set*.

Data Structures	Examples	Explanation	Mutable/Immutable?
Lists	[1,2,3,4,5]	A collection of data, sits between []	Mutable
Tuples	(1,2,3,4,5)	A collection of data, sits between ()	Immutable
Dictionaries	{"a":1, "b":2, "c":3}	A collection of data, sits between { }	Mutable
Sets	{"a", "2", "b", "5"}	A collection of data, sits between { }	Immutable

1.2.6 List

It is a data structure that holds an ordered collection of items i.e. you can store a *sequence* of items in a list. Some of the operations can be:

```

a = [1,2,3,45,6]

# Select one item from the list
a[0]=1

# Select the last item from the list
a[: -1]=6

```

```
# Select specific items from the list
a[1:2]=[2,3]

# Create a sub-list from the list
b=a[2:]
```

1.2.7 Tuples

Are used to hold together multiple objects assuming that the collection of values will not change. One major feature of tuples is that they are *immutable* like strings i.e. you cannot modify tuples.

1.2.8 Dictionary

It is like an address-book where you can find the address or contact details of a person by knowing only his/her name i.e. we associate *keys* (name) with *values* (details). Note that the key must be unique just like you cannot find out the correct information if you have two persons with the exact same name. Note that you can use only immutable objects (like strings) for the keys of a dictionary but you can use either immutable or mutable objects for the values of the dictionary.

1.2.9 Sets

Are *unordered* collections of simple objects. These are used when the existence of an object in a collection is more important than the order or how many times it occurs.

1.2.10 Python Control Flow

There are three control flow statements in Python - **if**, **for** and **while**.

If statement is used to check a condition: *if* the condition is true, we run a block of statements (called the *if-block*), *else* we process another block of statements (called the *else-block*). The *else* clause is optional.

While statement allows you to repeatedly execute a block of statements as long as a condition is true. A **while** statement is an example of what is called a *looping* statement. A **while** statement can have an optional **else** clause.

For..in statement is another looping statement which *iterates* over a sequence of objects i.e. go through each item in a sequence, that is just an ordered collection of items.

1.2.11 Python I/O

For many programs is essential to take input from the user and print some results back, to achieve this it can be use the **input()** function and **print()** function respectively.


```
name = input("enter your name")
print(name)
```

Another common type of input/output is dealing with files (The ability to create, read and write files). You can open and use files for reading or writing by creating an object of the `file` class and using its `read`, `readline` or `write` methods appropriately to read from or write to the file.

```
string = "string"
file = open('filename.ext', 'w') # w --> mode
while True:
    line = file.readline()
    if len(line) == 0:
        break
    file.write(string)
file.close()
```

The **mode** can be a read mode (`'r'`), write mode (`'w'`) or append mode (`'a'`).

When the file is opened in append mode, the handle is positioned at the end of the file. The data being written will be inserted at the end, after the existing data.

1.2.12 Python Functions

Functions are reusable pieces of programs. They allow you to give a name to a block of statements, allowing you to run that block using the specified name anywhere in your program and any number of times.

Functions are defined using the `def` keyword. After this keyword comes an *identifier* name for the function, followed by a pair of parentheses which may enclose some names of variables, and by the final colon that ends the line. Next follows the block of statements that are part of this function.

```
def function():
    print("Function working")
```

```
function() # Calling the function
```

A function can take parameters, which are values you supply to the function so that the function can *dosomething* utilising those values. These parameters are just like variables except that the values of these variables are defined when we call the function and are already assigned values when the function runs.

Parameters are specified within the pair of parentheses in the function definition, separated by commas.

```
def function_w_args(a, b):
    if a > b:
        print(a, 'maximum')
```

```

elif a == b:
    print(a, 'equal to' ,b)
else:
    print(b, 'maximum')

```

```

function_w_args(10, 7) # Calling the function with args
function_w_args(x, y) # Calling the function with args in global variables

```

Local Variables: are declared inside a function definition, they are not related in any way to other variables with the same names used outside the function.

```

x = 50
def func(x):
    print('x is', x)
    x = 2
    print('Changed local x to', x)
func(x)
print('x is still', x)

```

```

#It will print
x is 50
Changed local x to 2
x is still 50

```

Global statement: Using the global statement is possible to assign a value to a variable defined outside a function.

```

x = 50
def func():
    global x
    print('x is', x)
    x = 2
    print('Changed global x to', x)
func()
print('Value of x is', x)

```

```

# It will print
x is 50
Changed global x to 2
Value of x is 2

```

Default Arg Values: specifying default argument values for parameters appending to the parameter name in the function definition the assignment operator (=) followed by the default value, set some parameters *optional* and use default values in case the user does not want to provide values for them.

```

def say(message, times=1):
    print(message * times)
say('Hello')

```

```
say('World', 5)
```

```
# It will print
```

```
Hello
```

```
WorldWorldWorldWorldWorld
```

Return: Is used to *return* from a function i.e. break out of the function. We can optionally *return a value* from the function as well.

```
def maximum(x, y):
    if x > y:
        return x
    elif x == y:
        return 'The numbers are equal'
    else:
        return y
```

```
print(maximum(3, 2))
```

```
# It will print
```

```
3
```

1.2.13 Python Operators

Operators are special symbols in Python that carry out arithmetic or logical computation. The value that the operator operates on is called the operand.

There are seven type operators in Python - *arithmetic, comparison, logical, bitwise, assignment, identity and membership*.

Arithmetic operators are used to perform mathematical operations like addition, subtraction, multiplication, etc.

Operator Meaning		Example
+	Add two operands or unary plus	$x + y + 2$
-	Subtract right operand from the left or unary minus	$x - y - 2$
*	Multiply two operands	$x * y$
/	Divide left operand by the right one (always results into float)	x / y
%	Modulus - remainder of the division of left operand by the right	$x \% y$ (remainder of x/y)
//	Floor division - division that results into whole number adjusted to the left in the number line	$x // y$
**	Exponent - left operand raised to the power of right	$x ** y$ (x to the power y)

Comparison operators are used to compare values. It returns either **True** or **False** according to the condition.

Operator	Meaning	Example
>	Greater than - True if left operand is greater than the right	x > y
<	Less than - True if left operand is less than the right	x < y
==	Equal to - True if both operands are equal	x == y
!=	Not equal to - True if operands are not equal	x != y
>=	Greater than or equal to - True if left operand is greater than or equal to the right	x >= y
<=	Less than or equal to - True if left operand is less than or equal to the right	x <= y

Logical operators are used to perform logical operations like and, or, not.

Operator	Meaning	Example
and	True if both the operands are true	x and y
or	True if either of the operands is true	x or y
not	True if operand is false (complements the operand)	not x

Bitwise operators act on operands as if they were strings of binary digits. They operate bit by bit, hence the name.

For example, 2 is 10 in binary and 7 is 111.

In the table below: Let x = 10 (0000 1010 in binary) and y = 4 (0000 0100 in binary)

Operator	Meaning	Example
&	Bitwise AND	x & y = 0 (0000 0000)
	Bitwise OR	x y = 14 (0000 1110)
~	Bitwise NOT	~x = -11 (1111 0101)
^	Bitwise XOR	x ^ y = 14 (0000 1110)
»	Bitwise right shift	x » 2 = 2 (0000 0010)
«	Bitwise left shift	x « 2 = 40 (0010 1000)

Assignment operators are used in Python to assign values to variables.

a = 5 is a simple assignment operator that assigns the value 5 on the right to the variable a on the left.

There are various compound operators in Python like **a += 5** that adds to the

variable and later assigns the same. It is equivalent to `a = a + 5`.

Operator	Example	Equivalent to
<code>=</code>	<code>x = 5</code>	<code>x = 5</code>
<code>+=</code>	<code>x += 5</code>	<code>x = x + 5</code>
<code>-=</code>	<code>x -= 5</code>	<code>x = x - 5</code>
<code>*=</code>	<code>x *= 5</code>	<code>x = x * 5</code>
<code>/=</code>	<code>x /= 5</code>	<code>x = x / 5</code>
<code>%=</code>	<code>x %= 5</code>	<code>x = x % 5</code>
<code>//=</code>	<code>x //= 5</code>	<code>x = x // 5</code>
<code>**=</code>	<code>x **= 5</code>	<code>x = x ** 5</code>
<code>&=</code>	<code>x &= 5</code>	<code>x = x & 5</code>
<code> =</code>	<code>x = 5</code>	<code>x = x 5</code>
<code>^=</code>	<code>x ^= 5</code>	<code>x = x ^ 5</code>
<code>»=</code>	<code>x »= 5</code>	<code>x = x » 5</code>
<code>«=</code>	<code>x «= 5</code>	<code>x = x « 5</code>

Identity operators in Python are used to check if two values (or variables) are located on the same part of the memory. Two variables that are equal does not imply that they are identical.

Operator	Meaning	Example
<code>is</code>	True if the operands are identical (refer to the same object)	<code>x is True</code>
<code>is not</code>	True if the operands are not identical (do not refer to the same object)	<code>x is not True</code>

Membership operators in Python are used to test whether a value or variable is found in a sequence (string, list, tuple, set and dictionary).

In a dictionary we can only test for presence of key, not the value.

Operator	Meaning	Example
<code>in</code>	True if value/variable is found in the sequence	<code>5 in x</code>
<code>not in</code>	True if value/variable is not found in the sequence	<code>5 not in x</code>

1.3 Git Basics

1.3.0.0.1 Version control systems Version control is a system that records changes to a file or set of files over time so that you can recall specific versions later.

Version Control System (VCS) allows you to revert selected files back to a previous state, revert the entire project back to a previous state, compare changes over time, see who last modified something that might be causing a problem, who introduced an issue and when, and more. Using a VCS also generally means that if you screw things up or lose files, you can easily recover.

1.3.0.0.2 Local Version Control System Is the version-control method where users copy files into another directory (perhaps a time-stamped directory, if they're clever). This approach is very common because it is so simple, but it is also incredibly error prone. It is easy to forget which directory you're in and accidentally write to the wrong file or copy over files you don't mean to.

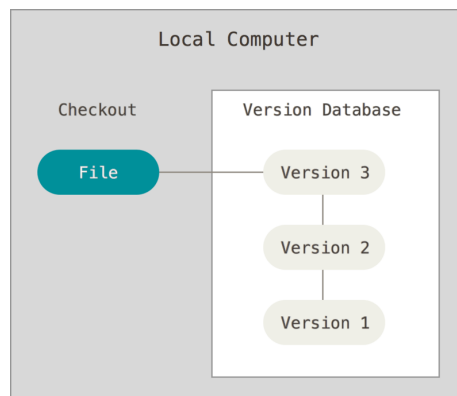


Figure 2: localVCS

1.3.0.0.3 Centralized Version Control System These systems have a single server that contains all the versioned files, and a number of clients that check out files from that central place. This setup also has some serious downsides. The most obvious is the single point of failure that the centralized server represents.

1.3.0.0.4 Distributed Version Control Systems In a DVCS, clients don't just check out the latest snapshot of the files; rather, they fully mirror the repository, including its full history. Thus, if any server dies, and these systems were collaborating via that server, any of the client repositories can be copied back up to the server to restore it. Every clone is really a full backup of all the data.

1.3.0.0.5 GIT Is an open source (git-scm.com) Distributed Version Control System, its VCS technology and utility track changes and provide tools to work with the files under "version control."

Basic Git Terminology

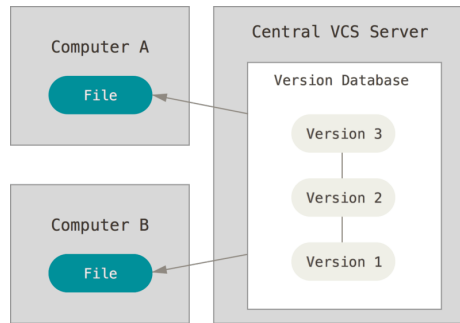


Figure 3: centralizedVCS

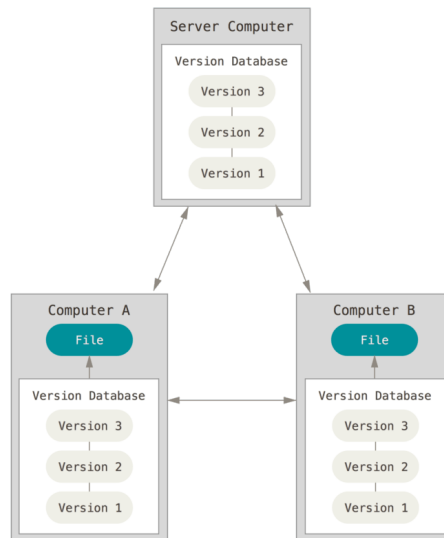


Figure 4: distributedVCS

- **Repository (Repo):** A repository is essentially what its name describes: a vault (or repository) for storing the version-controlled files and data. On your computer a Git repository will look like a regular folder or directory, with one important difference: the repository directory will have a hidden `.git/` subdirectory. This subdirectory is where Git stores the committed version controlled files and other repository data.
- **Working Directory:** This is what you see on your computer when you look in the repository directory on your computer - the visible directory and its contents - these are your version-controlled and un-versioned files and folders.
- **Versioned Files:** Files that you have asked git to track.
- **Un-Versioned Files:** Files in your working directory that you haven't asked git to track.
- **Commit:** A commit is a snapshot in time of your version controlled files. Once committed, this snapshot is (almost) indelibly locked into the repository - always available for future retrieval and comparison.
- **Branches:** Branches enable parallel work within a repository. We create new branches to split-off work done by different people, to experiment with changes we might want to back out later, or to develop new features. Git provides tools to help visualize, reconcile and merge together changes made in different branches.

When committing changes to version controlled **files**, Git stores **full copies** of all the changed files. It also stores a **tree** which contains links to all the changed files and previously-committed-unchanged-files in the current commit. Git computes a SHA1 hash of all stored files, trees and commits, and then uses the commit hashes to uniquely refer to individual commits. By computing and storing these hashes, git can detect changes to files and assure that the files retrieved from the repository are exactly as they were when committed to the repository.

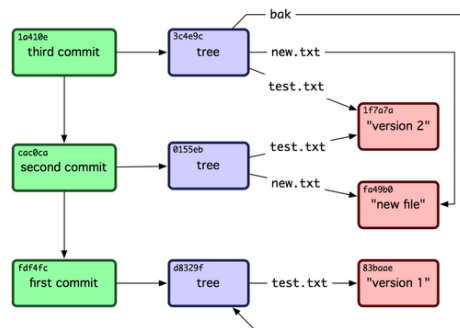


Figure 5: GitStructure

1.4 APIs and OpenAPI

API is the acronym for **Application Programming Interface**, which is a software intermediary that allows two applications to talk to each other through a documented interface.

User interfaces are designed for use by humans, APIs are designed for use by a computer or application.

Here's how an API works:

1. **A client application initiates an API call** to retrieve information (also known as a *request*). This request is processed from an application to the web server via the API's Uniform Resource Identifier (URI) and includes a request verb, headers, and sometimes, a request body.
2. **After receiving a valid request**, the API makes a call to the external program or web server.
3. **The server sends a "response"** to the API with the requested information.
4. **The API transfers the data** to the initial requesting application.

Note: Developers don't need to know how an API is implemented, they simply use the interface to communicate with other services.

There are four types of APIs:

- **Open APIs** are open source application programming interfaces you can access with the HTTP protocol. Also known as public APIs, they have defined API endpoints and request and response formats.
- **Partner APIs** are application programming interfaces exposed to or by strategic business partners. Typically, developers can access these APIs in self-service mode through a public API developer portal. Still, they will need to complete an onboarding process and get login credentials to access partner APIs.
- **Internal APIs** are application programming interfaces that remain hidden from external users. These private APIs aren't available for users outside of the company and are instead intended to improve productivity and communication across different internal development teams.
- **Composite APIs** combine multiple data or service APIs. These services allow developers to access several endpoints in a single call. Composite APIs are useful in microservices architecture where performing a single task may require information from several sources.

OpenAPI is a specification for the creation of machine-readable interface files used to describe, produce, consume, and visualize **RESTful web services**.

The advantages of **OpenAPI** are:

- It offers a standard and language-agnostic interface for describing RESTful APIs.

- It is both machine readable and interpretable by human readers.
- Both machines and human consumers of the OpenAPI can understand the capabilities of the service that's being developed, even without access to the latter's source code, network traffic, or any additional documentation.

The benefits of **OpenAPI** are:

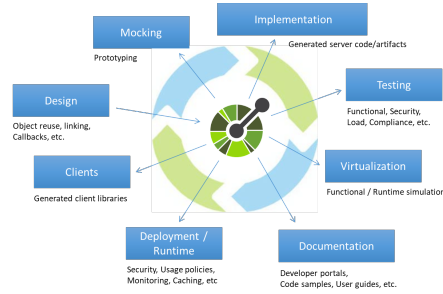


Figure 6: openapistucture

1.5 YANG, YAML, JSON (Add XML)

YANG is a data modeling language used to model configuration, state data, and administrative actions of network devices manipulated by the NETCONF protocol. The latest version of YANG is 1.1, and the full specification of the language is documented in RFC 7950.

YANG Capabilities

- Human readable, easy to learn representation
- Hierarchical configuration data models
- Reusable types and groupings (structured types)
- Extensibility through augmentation mechanisms
- Supports the definition of operations (RPCs)
- Formal constraints for configuration validation
- Data modularity through modules and submodules
- Versioning rules and development support

YANG Modules and Submodules

A module contains three types of statements: module-header statements, revision statements, and definition statements. The module header statements describe the module and give information about the module itself, the revision statements give information about the history of the module, and the definition statements are the body of the module where the data model is defined.

The labels yang-version, namespace, organization, etc are known as “statements” in YANG terminology.

- **yang-version** - Identifies the YANG language specification that the module will conform to. We'll ensure our module conforms to YANG 1.1 which is defined in RFC 7950.
- **namespace** - This is an XML namespace that must be unique for the module. It can be use a URL, URN, URI or any other unique identifier here. The namespace specified here must match the namespace on any XML objects which conform to our YANG model.
- **prefix** - A short and unique string to identify our module. This prefix may be used in other YANG modules to import definitions contained in this one.
- **organization** - A string identifying the entity responsible for the module.
- **contact** - Contact details for the entity responsible for the module.
- **description** - A description of the module.
- **revision** - Used for version control. Each edit to a YANG module will add a new revision statement detailing the changes in sub-statements.

The **include** statement allows a module or submodule to reference material in submodules, and the **import** statement allows references to material defined in other modules.

YANG defines four types of nodes for data modeling:

Leaf node contains simple data like an integer or a string. It has exactly one value of a particular type, and no child nodes.

```
leaf host-name {
    type string;
    description "Hostname for this system";
}
```

Leaf-list node is a sequence of leaf nodes with exactly one value of a particular type per leaf.

```
leaf-list domain-search {
    type string;
    description "List of domain names to search";
}
```

Container node is used to group related nodes in a subtree. It has only child nodes and no value and may contain any number of child nodes of any type (including leafs, lists, containers, and leaf-lists).

```
container system {
    container login {
        leaf message {
            type string;
            description
                "Message given at start of login session";
        }
    }
}
```

```

    }
}

```

List node defines a sequence of list entries. Each entry is like a structure or a record instance, and is uniquely identified by the values of its key leafs. A list can define multiple keys and may contain any number of child nodes of any type (including leafs, lists, containers etc.).

```

list user {
    key "name";
    leaf name {
        type string;
    }
    leaf full-name {
        type string;
    }
    leaf class {
        type string;
    }
}

```

YANG can model state data, as well as configuration data, based on the **config** statement. When a node is tagged with **config false**, its sub hierarchy is flagged as state data, to be reported using NETCONF's **get** operation, not the **get-config** operation. Parent containers, lists, and key leafs are reported also, giving the context for the state data.

In the next example, two leafs are defined for each interface, a configured speed and an observed speed. The observed speed is not configuration, so it can be returned with NETCONF **get** operations, but not with **get-config** operations. The observed speed is not configuration data, and cannot be manipulated using **edit-config**.

```

list interface {
    key "name";
    config true;

    leaf name {
        type string;
    }
    leaf speed {
        type enumeration {
            enum 10m;
            enum 100m;
            enum auto;
        }
    }
    leaf observed-speed {

```

```

        type uint32;
        config false;
    }
}

```

YANG has a set of built-in types, similar to those of many programming languages, but with some differences due to special requirements from the management domain. The following table summarizes the built-in types:

Name	Type	Description
binary	Text	Any binary data
bits	Text/Number	A set of bits or flags
boolean	Text	“true” or “false”
decimal64	Number	64-bit fixed point real number
empty	Empty	A leaf that does not have any value
enumeration	Text/Number	Enumerated strings with associated numeric values
identityref	Text	A reference to an abstract identity
instance-identifier	Text	References a data tree node
int8	Number	8-bit signed integer
int16	Number	16-bit signed integer
int32	Number	32-bit signed integer
int64	Number	64-bit signed integer
leafref	Text/Number	A reference to a leaf instance
string	Text	Human readable string
uint8	Number	8-bit unsigned integer
uint16	Number	16-bit unsigned integer
uint32	Number	32-bit unsigned integer
uint64	Number	64-bit unsigned integer
union	Text/Number	Choice of member types

YANG can define derived types from base types using the **typedef** statement. A base type can be either a built-in type or a derived type, allowing a hierarchy of derived types. A derived type can be used as the argument for the **type** statement.

```

typedef percent {
    type uint16 {
        range "0 .. 100";
    }
    description "Percentage";
}

leaf completed {
    type percent;
}

```

Groups of nodes can be assembled into the equivalent of complex types using the **grouping** statement. **grouping** defines a set of nodes that are instantiated with the **uses** statement:

```
grouping target {
  leaf address {
    type inet:ip-address;
    description "Target IP address";
  }
  leaf port {
    type inet:port-number;
    description "Target port number";
  }
}

container peer {
  container destination {
    uses target;
  }
}
```

YANG allows the data model to segregate incompatible nodes into distinct choices using the **choice** and **case** statements. The **choice** statement contains a set of **case** statements which define sets of schema nodes that cannot appear together. Each **case** may contain multiple nodes, but each node may appear in only one **case** under a **choice**.

When the nodes from one case are created, all nodes from all other cases are implicitly deleted. The device handles the enforcement of the constraint, preventing incompatibilities from existing in the configuration.

The choice and case nodes appear only in the schema tree, not in the data tree or XML encoding. The additional levels of hierarchy are not needed beyond the conceptual schema.

```
container food {
  choice snack {
    mandatory true;
    case sports-arena {
      leaf pretzel {
        type empty;
      }
      leaf beer {
        type empty;
      }
    }
    case late-night {
```

```

        leaf chocolate {
            type enumeration {
                enum dark;
                enum milk;
                enum first-available;
            }
        }
    }
}

```

YANG allows a module to insert additional nodes into data models, including both the current module (and its submodules) or an external module. The **augment** statement defines the location in the data model hierarchy where new nodes are inserted, and the **when** statement defines the conditions when the new nodes are valid.

```

augment /system/login/user {
    when "class != 'wheel'";
    leaf uid {
        type uint16 {
            range "1000 .. 30000";
        }
    }
}

```

YANG allows the definition of NETCONF RPCs. The method names, input parameters and output parameters are modeled using YANG data definition statements.

```

rpc activate-software-image {
    input {
        leaf image-name {
            type string;
        }
    }
    output {
        leaf status {
            type string;
        }
    }
}

```

YANG allows the definition of notifications suitable for NETCONF. YANG data definition statements are used to model the content of the notification.

```

notification link-failure {
    description "A link failure has been detected";
    leaf if-name {

```

```

        type leafref {
            path "/interfaces/interface/name";
        }
    }
    leaf if-admin-status {
        type ifAdminStatus;
    }
}

```

JSON is a text-based data exchange format derived from JavaScript that is used in web services and other connected applications and is often used as a common format to serialize and deserialize data in applications that communicate with each other over the Internet.

JSON defines only two data structures: objects and arrays. An object is a set of name-value pairs, and an array is a list of values. JSON defines seven value types: string, number, object, array, true, false, and null.

The following example shows JSON data for a sample object that contains name-value pairs. The value for the name "phoneNumbers" is an array whose elements are two objects.

```

{
    "firstName": "Duke",
    "lastName": "Java",
    "age": 18,
    "streetAddress": "100 Internet Dr",
    "city": "JavaTown",
    "state": "JA",
    "postalCode": "12345",
    "phoneNumbers": [
        { "Mobile": "111-111-1111" },
        { "Home": "222-222-2222" }
    ]
}

```

JSON has the following syntax.

- Objects are enclosed in braces (`{}`), their name-value pairs are separated by a comma (`,`), and the name and value in a pair are separated by a colon (`:`). Names in an object are strings, whereas values may be of any of the seven value types, including another object or an array.
- Arrays are enclosed in brackets (`[]`), and their values are separated by a comma (`,`). Each value in an array may be of a different type, including another array or an object.
- When objects and arrays contain other objects or arrays, the data has a tree-like structure.

YAML is an indentation-based markup language which aims to be both easy

to read and easy to write.

SCALAR TYPES

Our root object (which continues for the entire document) will be a map, which is equivalent to a dictionary, hash or object in other languages.

```
key: value
another_key: Another value goes here.
a_number_value: 100
scientific_notation: 1e+12
```

The number 1 will be interpreted as a number, not a boolean. if you want it to be interpreted as a boolean, use true

```
boolean: true
null_value: null
key with spaces: value
```

Notice that strings don't need to be quoted. However, they can be.

```
however: 'A string, enclosed in quotes.'
'Keys can be quoted too.': "Useful if you want to put a ':' in your key."
single quotes: 'have ''one'' escape pattern'
double quotes: "have many: \", \0, \t, \u263A, \x0d\x0a == \r\n, and more."
```

UTF-8/16/32 characters need to be encoded

```
Superscript two: \u00B2
```

Multiple-line strings can be written either as a 'literal block' (using |), or a 'folded block' (using >).

literal_block: | This entire block of text will be the value of the 'literal_block' key, with line breaks being preserved.

```
literal_block: |
    This entire block of text will be the value of the 'literal_block' key,
    with line breaks being preserved.
```

The literal continues until de-dented, and the leading indentation is stripped.

Any lines that are 'more-indented' keep the rest of their indentation - these lines will be indented by 4 spaces.

```
folded_style: >
    This entire block of text will be the value of 'folded_style', but this
    time, all newlines will be replaced with a single space.
```

Blank lines, like above, are converted to a newline character.

```
'More-indented' lines keep their newlines, too -
  this text will appear over two lines.
```

COLLECTION TYPES

Nesting uses indentation. 2 space indent is preferred (but not required).

```
a_nested_map:
  key: value
  another_key: Another Value
  another_nested_map:
    hello: hello
```

Maps don't have to have string keys.

```
0.25: a float key
```

Keys can also be complex, like multi-line objects We use ? followed by a space to indicate the start of a complex key.

```
? |
  This is a key
  that has multiple lines
: and this is its value
```

YAML also allows mapping between sequences with the complex key syntax Some language parsers might complain An example:

```
? - Manchester United
  - Real Madrid
: [2001-01-01, 2002-02-02]
```

Sequences (equivalent to lists or arrays) look like this (note that the '-' counts as indentation):

```
a_sequence:
  - Item 1
  - Item 2
  - 0.5 # sequences can contain disparate types.
  - Item 4
  - key: value
    another_key: another_value
  -
    - This is a sequence
    - inside another sequence
  - - - Nested sequence indicators
    - can be collapsed
```

Since YAML is a superset of JSON, you can also write JSON-style maps and sequences:

```
json_map: {"key": "value"}
json_seq: [3, 2, 1, "takeoff"]
and quotes are optional: {key: [3, 2, 1, takeoff]}
```

EXTRA YAML FEATURES

YAML also has a handy feature called ‘anchors’, which let you easily duplicate content across your document. Both of these keys will have the same value:

```
anchored_content: &anchor_name This string will appear as the value of two keys.
other_anchor: *anchor_name
```

anchors can be used to duplicate/inherit properties

```
base: &base
  name: Everyone has same name
```

The regexp « is called Merge Key Language-Independent Type. It is used to indicate that all the keys of one or more specified maps should be inserted into the current map.

```
foo:
  <<: *base
  age: 10
```

```
bar:
  <<: *base
  age: 20
```

foo and bar would also have name: Everyone has same name

YAML also has tags, which you can use to explicitly declare types.

```
explicit_string: !!str 0.5
```

Some parsers implement language specific tags, like this one for Python’s complex number type.

```
python_complex_number: !!python/complex 1+2j
```

We can also use yaml complex keys with language specific tags

```
? !!python/tuple [5, 7]
: Fifty Seven
```

Would be {(5, 7): ‘Fifty Seven’} in Python

EXTRA YAML TYPES

Strings and numbers aren’t the only scalars that YAML can understand. ISO-formatted date and datetime literals are also parsed.

```
datetime: 2001-12-15T02:59:43.1Z
datetime_with_spaces: 2001-12-14 21:59:43.10 -5
date: 2002-12-14
```

The `!!binary` tag indicates that a string is actually a base64-encoded representation of a binary blob.

```
gif_file: !!binary |
  R0lGODlhDAAMAIQAAP//9/X17unp5WZmZgAAA0fn515eXvPz7Y6QjuDg4J+fn5
  OTk6enp56enmlpaWNjY6Qjo4SEhP/++f/++f/++f/++f/++f/++f/++f/++f/+
  +f/++f/++f/++f/++f/++SH+Dk1hZGUgd2l0aCBHSU1QACwAAAAADAAMAAFLC
  AgjoEwnuNAFOhpEMTRiggcz4BNJHrv/zCFcLiwMWYNG84BwwEeECcggoBADs=
```

YAML also has a set type, which looks like this:

```
set:
  ? item1
  ? item2
  ? item3
or: {item1, item2, item3}
```

Sets are just maps with null values; the above is equivalent to:

```
set2:
  item1: null
  item2: null
  item3: null
```

OpenAPI basic structure in YAML syntax

All keyword names are **case-sensitive**.

Every API definition must include the version of the OpenAPI Specification that this definition is based on:

```
openapi: 3.0.0
```

The OpenAPI version defines the overall structure of an API definition – what you can document and how you document it. OpenAPI 3.0 uses semantic versioning with a three-part version number. The available versions are 3.0.0, 3.0.1, 3.0.2, and 3.0.3; they are functionally the same.

The `info` section contains API information: `title`, `description` (optional), `version`:

```
info:  title: Sample API
description: Optional multiline or single-line description in [CommonMark] http://commonmark
version: 0.1.9
```

title is your API name. **description** is extended information about your API. It can be multiline and supports the CommonMark dialect of Markdown for rich text representation. **version** is an arbitrary string that specifies the version of your API (do not confuse it with file revision or the `openapi` version). You can use semantic versioning like *major.minor.patch*, or an arbitrary string like *1.0-beta* or *2017-07-25*. **info** also supports other keywords for contact information, license, terms of service, and other details.

The **servers** section specifies the API server and base URL. You can define one or several servers, such as production and sandbox.

```
servers:
  - url: http://api.example.com/v1
    description: Optional server description, e.g. Main (production) server
  - url: http://staging-api.example.com
    description: Optional server description, e.g. Internal staging server for testing
```

All API paths are relative to the server URL. In the example above, `/users` means `http://api.example.com/v1/users` or `http://staging-api.example.com/users`, depending on the server used.

The **paths** section defines individual endpoints (paths) in your API, and the HTTP methods (operations) supported by these endpoints. For example, GET `/users` can be described as:

```
paths:
  /users:
    get:
      summary: Returns a list of users.
      description: Optional extended description in CommonMark or HTML
      '200':
        description: A JSON array of user names
        content:
          application/json:
            schema:
              type: array
              items:
                type: string
```

An operation definition includes parameters, request body (if any), possible response status codes (such as 200 OK or 404 Not Found) and response contents.

Operations can have parameters passed via URL path (`/users/{userId}`), query string (`/users?role=admin`), headers (`X-CustomHeader: Value`) or cookies (`Cookie: debug=0`). You can define the parameter data types, format, whether they are required or optional, and other details:

```
paths:
  /users/{userId}:
    get:
      summary: Returns a user by ID.
      parameters:
        - name: userId
          in: path
          required: true
          description: Parameter description in CommonMark or HTML.
          schema:
```

```

        type : integer
        format: int64
        minimum: 1
    responses:
        '200':
            description: OK

```

If an operation sends a request body, the **requestBody** keyword **MUST** be used to describe the body content and media type.

```

paths:
    /users:
        post:
            summary: Creates a user.
            requestBody:
                required: true
                content:
                    application/json:
                        schema:
                            type: object
                            properties:
                                username:
                                    type: string
            responses:
                '201':
                    description: Created

```

For each response operation, you can define possible status codes, such as 200 OK or 404 Not Found, and the response body **schema**. Schemas can be defined inline or referenced via **\$ref**. You can also provide example responses for different content types:

```

paths:
    /users/{userId}:
        get:
            summary: Returns a user by ID.
            parameters:
                - name: userId
                  in: path
                  required: true
                  description: The ID of the user to return.
                  schema:
                      type: integer
                      format: int64
                      minimum: 1
            responses:
                '200':
                    description: A user object.

```

```

content:
  application/json:
    schema:
      type: object
      properties:
        id:
          type: integer
          format: int64
          example: 4
        name:
          type: string
          example: Jessica Smith
      '400':
        description: The specified user ID is invalid (not a number).
      '404':
        description: A user with the specified ID was not found.
      default:
        description: Unexpected error

```

Note that the response HTTP status codes must be enclosed in quotes: “200”.

For input and output models the global **components/schemas** section lets you define common data structures used in your API. They can be referenced via **\$ref** whenever a **schema** is required – in parameters, request bodies, and response bodies. For example, this JSON object:

```

{
  "id": 4,
  "name": "Arthur Dent"
}

```

can be represented as:

```

components:
  schemas:
    User:
      properties:
        id:
          type: integer
        name:
          type: string
      # Both properties are required
      required:
        - id
        - name

```

and then referenced in the request body schema and response body schema as follows:

```

paths:
  /users/{userId}:
    get:
      summary: Returns a user by ID.
      parameters:
        - in: path
          name: userId
          required: true
          type: integer
      responses:
        '200':
          description: OK
          content:
            application/json:
              schema:
                $ref: '#/components/schemas/User'
  /users:
    post:
      summary: Creates a new user.
      requestBody:
        required: true
        content:
          application/json:
            schema:
              $ref: '#/components/schemas/User'
      responses:
        '201':
          description: Created

```

The **securitySchemes** and **security** keywords are used to describe the authentication methods used in your API.

```

components:
  securitySchemes:
    BasicAuth:
      type: http
      scheme: basic

```

```

security:
  - BasicAuth: []

```

Supported authentication methods are:

- HTTP authentication: Basic, Bearer, and so on.
- API key as a header or query parameter or in cookies.
- OAuth 2.
- OpenID Connect Discovery.

1.6 SOAP, gRPC, REST, Netconf, Restconf (Maybe add GraphQL)

1.6.1 SOAP (Simple Object Access Protocol)

Is an API protocol built with XML, enabling users to send and receive data through SMTP and HTTP. With SOAP APIs, it is easier to share information between apps or software components that are running in different environments or written in different languages.

The structure of a SOAP message:

A SOAP message is encoded as an XML document, consisting of an `<Envelope>` element, which contains an optional `<Header>` element, and a mandatory `<Body>` element. The `<Fault>` element, contained in `<Body>`, is used for reporting errors.

- The SOAP envelope

`<Envelope>` is the root element in every SOAP message, and contains two child elements, an optional `<Header>` element, and a mandatory `<Body>` element.

- The SOAP header

`<Header>` is an optional subelement of the SOAP envelope, and is used to pass application-related information that is to be processed by SOAP nodes along the message path.

- The SOAP body

`<Body>` is a mandatory subelement of the SOAP envelope, which contains information intended for the ultimate recipient of the message.

- The SOAP fault

`<Fault>` is a subelement of the SOAP body, which is used for reporting errors.

XML elements in `<Header>` and `<Body>` are defined by the applications that make use of them, although the SOAP specification imposes some constraints on their structure. The following diagram shows the structure of a SOAP message.

The **SOAP nodes** act as points in the flow where web service processing is configured and applied. Properties on the SOAP nodes control the processing carried out and can be configured by supplying a WSDL definition, or by manually configuring properties, or both.

The SOAPInput and SOAPReply nodes are used in a message flow which implements a web service. These SOAP nodes are used to construct a message flow that implements a web service provider. The SOAPInput node listens for incoming web service requests, and the SOAPReply sends responses back to the client.

The SOAPRequest node is used in a message flow to call a web service provider synchronously. Calling a web service synchronously means that the node sends a web service request and waits, blocking the message flow, for the associated web service response to be received before the message flow continues.

The SOAPAsyncRequest and SOAPAsyncResponse nodes are used to construct a message flow (or pair of flows) which calls a web service asynchronously. Calling a web service asynchronously means that the SOAPAsyncRequest node sends a web service request, but the request does not block the message flow by waiting for the associated web service response to be received because the web service response is received at the SOAPAsyncResponse node, which is in a separate flow. The Node Correlator identifies the logical pairing of the responses against the original requests. Multiple requests can, therefore, be handled in parallel.

The SOAPExtract node can interoperate with the SOAP domain. The SOAP nodes do not require the SOAPEnvelope node, because they can directly handle non-SOAP messages, but the SOAPEnvelope node is still required for the HTTP nodes.

1.6.2 RPC

Is a acronym for Remote Procedure Call, a old model that was much used on the past. On that model, a client-server solution is developed, where the details of transport are abstracted from the developer, been responsible only for implementing the server and client inner logic. Famous RPC models were CORBA, RMI and DCOM.

1.6.3 gRPC

Is Google's approach to a client-server application that takes principles from the original RPC. However, gRPC allows us to use more sophisticated technologies such as HTTP2 and streams. gRPC is also designed as technology-agnostic, which means that can be used and interacted with server and clients from different programming languages.

gRPC services are generated based on a proto file provided. Using the proto file, gRPC generates for a server and a stub (some languages just call it a client) the logic. The following diagram, taken from gRPC documentation, represents the client-server schematics:

Protocol buffer is gRPC's serialization mechanism, which allows send compressed messages between services, allowing to process more data with less network roundtrips between the parts.

According to Protocol Buffers documentation, Protocol Buffers messages offers the following advantages, if we compare to a traditional data schema such as XML:

- are simpler

- are 3 to 10 times smaller
- are 20 to 100 times faster
- are less ambiguous
- generate data access classes that are easier to use programmatically

gRPC applications can be written using 3 types of processing, as follows:

- **Unary RPCs:** The simplest type and more close to classical RPC, consists of a client sending one message to a server, that makes some processing and returns one message as response.
- **Server streams:** On this type, the client sends one message for the server, but receives a stream of messages from the server. The client keeps reading the messages from the server until there is no more messages to read.
- **Client streams:** This type is the opposite of the server streams one, where on this case is the client who sends a stream of messages to make a request for the server and then waits for the server to produce a single response for the series of request messages provided.

On gRPC are two styles of processing supported:

- **Synchronous processing:** A communication where the client thread is blocked when a message is sent and is been processed.
- **Asynchronous processing:** A communication with the processing been done by other threads, making the whole process been non-blocking.

1.6.4 REST

Stands for **R**epresentational **S**tate **T**ransfer. It is an **architecture style** for designing loosely coupled applications over HTTP, that is often used in the development of web services.

REST defines **6 architectural constraints** which make any web service – a true RESTful API.

Uniform interface: A resource in the system should have only one logical URI, and that should provide a way to fetch related or additional data. Any single resource should not be too large and contain each and everything in its representation. Whenever relevant, a resource should contain **links (HATEOAS) pointing to relative URIs** to fetch related information. Also, the resource representations across the system should follow specific guidelines such as naming conventions, link formats, or data format (XML or/and JSON).

Client-Server: Client application and server application **MUST** be able to evolve separately without any dependency on each other. A client should know only resource URIs.

Stateless: The server will not store anything about the latest HTTP request the client made.

Cacheable: Brings performance improvement for the client-side and better scope for scalability for a server because the load has reduced.

Layered system: REST allows you to use a layered system architecture where you deploy the APIs on server A, and store data on server B and authenticate requests in Server C.

1.6.5 Netconf

Is a network management protocol which provides mechanisms to install, manipulate, and delete the configuration of network devices.

NETCONF uses a simple RPC-based mechanism to facilitate communication between a client and a server

Its operations are realized on top of a simple Remote Procedure Call (RPC) layer. The NETCONF protocol uses an Extensible Markup Language (XML) based data encoding for the configuration data as well as the protocol messages. The protocol messages are exchanged on top of a secure transport protocol.

The NETCONF protocol can be conceptually partitioned into four layers:

- The Content layer consists of configuration data and notification data.
- The Operations layer defines a set of base protocol operations to retrieve and edit the configuration data.
- The Messages layer provides a mechanism for encoding remote procedure calls (RPCs) and notifications.
- The Secure Transport layer provides a secure and reliable transport of messages between a client and a server.

The base protocol defines the following protocol operations:

OPERATION	DESCRIPTION
	Retrieve running configuration and device state information
	Retrieve all or part of a specified configuration datastore
	Edit a configuration datastore by creating, deleting, merging or replacing content
	Copy an entire configuration datastore to another configuration datastore
	Delete a configuration datastore
	Lock an entire configuration datastore of a device
	Release a configuration datastore lock previously obtained with the operation
	Request graceful termination of a NETCONF session
	Force the termination of a NETCONF session

The NETCONF messages layer provides a simple, transport-independent framing mechanism for encoding

- RPC invocations (messages),
- RPC results (messages), and
- event notifications (messages).

1.6.6 RESTCONF

Is an HTTP-based protocol that provides a programmatic interface for accessing data defined in YANG, using the datastore concepts defined in NETCONF. Gives us a RESTful HTTP interface that we can use to query and configure devices with NETCONF configuration datastores.

RESTCONF methods are what expect from a RESTful protocol. Here's how they overlap with the NETCONF operations:

RESTCONF	NETCONF
OPTIONS	None
HEAD	,
GET	,
POST	(nc:operation="create")
POST	invoke an RPC operation
PUT	(PUT on datastore)
PUT	(nc:operation="create/replace")
PATCH	(nc:operation depends on PATCH content)
DELETE	(nc:operation="delete")

1.7 Network controller architectures

1.7.1 OpenDaylight

Is an open-source collaborative project based on the OSGi architecture that focuses on building a multi-vendor, multi-project ecosystem to encourage innovation and an open/transparent approach toward SDN.

1.7.2 The OSGi (Open Services Gateway initiative)

Is a framework provides a dynamic modular architecture which has been used in many applications such as Eclipse Equinox, Apache Felix, etc. OSGi framework architecture consists three conceptual layers. Each layer is dependent on the layer(s) beneath it. The diagram below describe the overview of each layer:

Module layer defines OSGi module concept - bundle, which is a JAR file with extra metadata. A bundle contains class files and related resources such as images, xml files.

Lifecycle layer defines how bundles are dynamically installed and managed in the OSGi framework. It provides a way for a bundle to

gain access to the underlying OSGi framework.

Service layer, is where service providers publish services to service registry, while service clients search the registry to find available services to use.

This is like a service-oriented architecture (SOA) which has been largely used in web services. Here OSGi services are local to a single VM, so it is sometimes called SOA in a VM.

OpenDayLight supports:

- Network programmability via southbound protocols
- Bunch of programmable network services
- Collection of northbound APIs
- Set of applications.

1.7.2.1 OpenDayLight Architecture As shown in Figure, the architecture mainly comprises three layers:

1. Northbound APIs and applications forming the application layer.

OpenDaylight, supports both the OSGi framework and the bidirectional REST APIs in the northbound layer. The OSGi framework is mainly used by applications that will run in the same address space as the controller, whereas the REST (Web-based) API is used by applications that can run on same machine as the controller or on a different machine. These applications typically realize a business logic and may include all the necessary algorithms.

2. Service adaptation and network functions forming the coordination and control layer.

The basic network functions included are services for topology discovery and dissemination, a forwarding manager for managing basic forwarding rules, and a switch manager for identifying networking elements in the underlying physical topology.

Service Abstraction Layer (SAL): Is the key design that enables the abstraction of services between the services consumers and producers. Acts like a large registry of services advertised by various modules and binds them to the applications that require them. Modules providing services, or producers, can register their APIs with the registry.

3. Southbound plugins and protocols forming the network device layer.

Supports multiple protocols (as separate plugins), e.g. OpenFlow 1.0, OpenFlow 1.3, BGP-LS, LISP, SNMP, etc. These modules are dynamically linked to a service abstraction layer (**SAL**), which determines how to fulfill the service requested (by applications) irrespective of the underlying protocol used between the controller and the network devices.

Note: The controller acts like middleware in the OpenDaylight ecosystem. It is the framework that glues together the applications requiring services of the network devices and the protocols that talk to the network devices for extracting services.

1.7.3 Open Network Operating System (ONOS)

Is an SDN controller open source project that uses OSGI technology to manage sub-projects. Its design has the next goals:

- Code modularity: support the introduction of new functions as a new independent unit
- Features are configurable: support dynamic loading and unloading features no matter at startup or runtime
- Protocol-independent: applications do not need to be bound to specific protocol libraries and implementations

Irrelevant to the protocol, ONOS is divided into the following parts:

- Protocol awareness module that interacts with the network
- Protocol-independent system Core, tracking and serving network status information
- Applications that consume and operate based on system information provided by Core

Each of the below layers is a layered architecture, where the network-oriented modules interact with the Core through a southbound (provider) API, and the Core interacts with the application through the northbound (consumer) API. Southbound API defines a protocol-neutral means to pass network status information to the core, and the core interacts with network devices through network-oriented modules. The Northbound API provides applications with abstractions describing network components and attributes so that they can define their required actions based on policies.

1.7.4 Open Network Automation Platform (ONAP)

Is a networking project that provides a digital environment for the orchestration and automation of complex network services. ONAP consolidates resources that help to manage the lifecycles of virtual network functions (VNFs), software defined networks (SDNs) and systems that enable programming in the cloud.

ONAP platform allows end-user organizations and their network/cloud providers to collaboratively instantiate network elements and services in a rapid and dynamic way, together with supporting a closed control loop process that supports real-time response to actionable events.

A high-level view of the ONAP architecture with its microservices-based platform components its shown in the above image:

A simplified functional description of the architecture, which highlights the role of a few key components:

- Design time environment for onboarding services and resources into ONAP and designing required services.
- External API provides northbound interoperability for the ONAP Platform and Multi-VIM/Cloud provides cloud interoperability for the ONAP workloads.
- OOM provides the ability to manage cloud-native installation and deployments to Kubernetes-managed cloud environments.
- ONAP Shared Services provides shared capabilities for ONAP modules. MUSIC allows ONAP to scale to multi-site environments to support global scale infrastructure requirements. The ONAP Optimization Framework (OOF) provides a declarative, policy-driven approach for creating and running optimization applications like Homing/Placement, and Change Management Scheduling Optimization. Logging provides centralized logging capabilities, Audit (POMBA) provides capabilities to understand orchestration actions.
- ONAP shared utilities provide utilities for the support of the ONAP components.
- Information Model and framework utilities continue to evolve to harmonize the topology, workflow, and policy models from a number of SDOs including ETSI NFV MANO, TM Forum SID, ONF Core, OASIS TOSCA, IETF, and MEF.

2 NSO Overview

Creating and configuring network services is a complex task that often requires multiple configuration changes to all devices participating in the service. Additionally changes generally need to be made concurrently across all devices with the changes being either completely successful or rolled back to the starting configuration. And configuration need to be kept in sync across the system and the network devices. NSO approaches these challenges by acting as interface between people or software that want to configure the network, and the devices in the network.

The key features of NSO that comes into play includes:

1. Multi-vendor device configuration management using the native protocols of the network devices.
2. A Configuration Database (CDB) managing synchronized configurations for all devices and services in the network domain.
3. A set of northbound interfaces including human interfaces like web UI and a CLI; programmable interfaces including RESTCONF, NETCONF, JSON-RPC; and language bindings including Java, Python and Erlang.

3 NSO System Admin

3.1 NSO Architecture

NSO has two main layers that serve different purposes but are tightly integrated with a transactional engine and database.

Device Manager manage device configurations in a transactional manner. It supports features like fine-grained configuration commands, bidirectional device configuration synchronization, device groups and templates, and compliance reporting. Following Device Manager overall features are described:

- Deploy configuration changes to multiple devices in a fail-safe way using distributed transactions.
- Validate the integrity of configurations before deploying to the network.
- Apply configuration changes to named device groups.
- Apply templates (with variables) to named device groups.
- Easily roll back changes, if needed.
- Configuration audits: Check if device configurations are in synch with the NSO database. If they are not, what is the diff?
- Synchronize the NSO database and the configurations on devices, in case they are not in synch. This can be done in either direction (import the diff to the NSO database or deploy the diff on devices).

Service Manager makes it possible for an operator to manage high-level aspects of the network that are not supported by the devices directly, or is supported in a cumbersome way. Following Service Manager challenges are described:

- Transaction-safe activation of services across different multi-vendor devices.
- What-if scenarios, (dry-run), showing the effects on the network for a service creation/change.
- Maintaining relationships between services and corresponding device configurations and vice versa.
- Modeling of services
- Short development and turn-around time for new services.
- Mapping the service model to device models.

Network Element Drivers (NEDs) are used to communicate with devices and are modeled in a data-model using the YANG data modelling language.

NSO uses a dedicated built-in storage Configuration Database (CDB) for all configuration data keeping the CDB in sync with the real network device configurations.

3.2 NSO System Operations

3.2.0.1 1. How Start (Installation) To start with, it is necessary to note that NSO requires the following for proper installation and operation:

1. Ensure that root permissions are enabled.

2. Choose the correct operating system (Linux). Currently only the Linux operating system is supported.
3. Make sure Java JDK-7.0 or higher is installed.

The installation process consists of 6 steps, which were summarised in this document. For more information please see Chapter 3, NSO System Install in NSO Installation Guide.

1. Use `-system-install` option to perform system installation. This option creates a system install of NSO, suitable for deployment.
2. Change to Super User privileges.
3. The installation program creates a shell script file in each NSO installation which sets environment variables needed to run NSO.
4. Start NSO.
5. NSO uses Cisco Smart Licensing, as described in Chapter 3, *Cisco Smart Licensing in NSO 5.2 Administration Guide*, to make it easy to deploy and manage NSO license entitlements.

3.2.0.2 2. How Monitor This section describes how to monitor NSO via Shell and CLI.

Checking the overall status of NSO can be done using the shell:

```
$ **ncs -status
```

** or in the CLI `ncs# show ncs-state`

For details on the output see `$NCS_DIR/src/yang/tailf-common-monitoring.yang` and Below follows an overview of the output:

- **daemon-status** Shows NSO daemon mode, starting, phase0, phase1, started, stopping.

NOTE: The phase0 and phase1 modes are schema upgrade modes and will appear if you have upgraded any data- models.

- **version:** The NSO version.
- **smp:** Number of threads used by the daemon.
- **ha:** The High-Availability mode of the ncs daemon will show up here: slave, master, relay-slave.
- **internal/callpoints:** All your deployed service models should have a corresponding service-point.

(The `ncs-rfs-service-hook` is an obsolete call-point, ignore this one). • **UNKNOWN** code tries to register a call-point that does not exist in a data-model. • **NOT-REGISTERED** a loaded data-model has a call-point but no code has registered.

For example:

servicepoints: id=l3vpn-servicepoint daemonId=10 daemonName=ncs-dp-6-l3vpn:L3VPN

- **internal/cdb:** Look for any locks. This might be a sign that a developer has taken a CDB lock without releasing it.
- **loaded-data-models:** Shows all namespaces and YANG modules that are loaded.
- **cli, netconf, rest, snmp, webui:** All northbound agents like CLI, REST, NETCONF, SNMP etc are listed with their IP and port.
- **patches:** Lists any installed patches.
- **upgrade-mode:** If the node is in upgrade mode, it is not possible to get any information from the system over NETCONF.

It is also important to look at the packages that are loaded. This can be done in the CLI with “**show packages**” command.

3.2.0.3 3. How Config NSO can be configured in two ways:

1. Configuration file “ncs.conf”.
2. Configuration data at run-time over northbound.

There is a large number of configuration items in ncs.conf, most of them have sane default values. The ncs.conf file is an XML file that must adhere to the **tailf-ncs- config.yang** model.

The **tailf-ncs- config.yang** is the most important YANG module that is used to control and configure NSO. Everything in that module is available through the northbound APIs. The YANG module has descriptions for everything that can be configured.

Note: The **ncs.conf** file is described by the the section called “**CONFIGURATION PARAMETERS**” in *NSO 5.2 Manual Pages*.

It is possible to edit the ncs.conf file, and then tell NSO to reload the edited file without restarting the daemon and also close and reopen all log files with: **ncs -reload**

Dynamic config can be made through the NSO northbound interfaces manipulating YANG modules its structure is stored in CDB, any change under, /devices/device will change the CDB. Most relevant settings that can be manipulated are:

Setting name	Description
aaa	AAA management, users and groups
cluster	Cluster configuration
devices	Device communication settings

Setting name	Description
java-vm	Control of the NCS Java VM
nacm	Access control
packages	Installed packages
python-vm	Control of the NCS Python VM
services	Global settings for services, (the services themselves might be augmented)
session	Global default CLI session parameters
snmp	Top-level container for SNMP related configuration and status objects
snmp-notification-receiver	Configure reception of SNMP notifications
software	Software management
ssh	Global SSH connection configuration

3.2.0.4 4. How Backup and Restore (File system) All elements of the NSO, can be **Backed Up** and **Restored** with standard file system backup procedures.

In a “system install” of NSO, the most convenient way to do backup and restore is to use the **ncs-backup** command. This backs up the database (CDB) files, state files, config files and rollback files from the installation directory.

To switch back to a previous good state or restore a backup, it’s necessary to perform the next three steps:

1. Stop NSO: # **/etc/init.d/ncs stop**
2. Restore the backup: # **ncs-backup -restore** -> Select the backup to be restored from the available list of backups; **The configuration and database with run-time statefiles are restored in /etc/ncs and /var/opt/ncs.**
3. Start NSO: # **/etc/init.d/ncs start**

3.3 NSO Package Overview

A package is basically a directory of files with a fixed file structure, or a tar archive with the same directory layout. A package consists of code, YANG modules, etc., that are needed in order to add an application or function to NSO.

Note: All user code must be part of a package to run in NSO.

At start NSO searches and copies the packages to a private directory tree in the directory defined by the **/ncs-config/state-dir** parameter in **ncs.conf**, and loads and starts all the packages found.

3.3.0.1 Loading Packages To add or update (If the package changes include modified, added, or deleted) **Packages**, can be made via the reload action

- from the NSO CLI: **packages reload**

This action makes that NSO copy all packages found in the load path to a temporary version of its private directory, and load the packages from this directory.

- When loading is successful, this temporary directory will be made permanent, otherwise the temporary directory is removed and NSO continues to use the previous version of the packages.

Note: Always update the version in the load path, and request that NSO does the reload via **packages reload** command.

It's recommended to run the command adding the **max-wait-time** and **timeout-action** parameters, to prevent fail reload operation or upgrade canceling action.

Example: **packages reload max-wait-time 30 timeout-action kill** -> to wait for up to 30 seconds, by default these parameters are 10 and fail.

Some warnings will be triggered when reload NSO Packages, if a warning has been triggered it is a strong recommendation to fix the root cause. If all of the warnings are intended, it is possible to proceed with “packages reload force” command.

For more information about warnings triggered please read Chapter 5, *Loading Packages in NSO 5.2 Administration Guide*.

3.3.0.2 Managing Packages NSO has the possibility to configure remote software repositories from which packages can be retrieved.

The **/software/repository** list allows for configuration of one or more remote repositories.

Example 3 shows how to configure the Tail-f delivery server:

```
admin@ncs(config)# software repository tail-f
Value for 'url' (<string>): https://support.tail-f.com/delivery
admin@ncs(config-repository-tail-f)# user name
admin@ncs(config-repository-tail-f)# password
(<AES encrypted string>): *****
admin@ncs(config-repository-tail-f)# commit
Commit complete.
```

The following are the **Actions** provided to list, fetch, install or deinstall packages:

- **software packages list [...]**: List local packages, categorized into *loaded*, *installed*, and *installable*.
- **software packages fetch package-from-file file**: Fetch a package by copying it from the file system, making it *installable*.

- **software packages install package package-name [...]**: Install a package, making it available for loading via the **packages reload** action, or via a system restart with package reload.
- **software packages deinstall package package-name**: Deinstall a package, i.e. remove it from the set of packages available for loading.
- **software repository name packages list [...]**: List packages available in the repository identified by name. The list can be filtered via the name-pattern option.
- **software repository name packages fetch package package-name**: Fetch a package from the repository identified by name, making it *installable*.

There is also an **upload** action that can be used via NETCONF or REST to upload a package from the local host to the NSO host, making it *installable* there.

Important Note: It is not feasible to use in the CLI or Web UI, since the actual package file contents is a parameter for the action. It is also not suitable for very large (more than a few megabytes) packages, since the processing of action parameters is not designed to deal with very large values, and there is a significant memory overhead in the processing of such values.

3.4 Troubleshooting

3.4.0.0.1 Installation Problems During installation the program gives error messages as:

```
tar: Skipping to next header
gzip: stdin: invalid compressed data--format violated
```

This happens if the installation program has been damaged, most likely because it has been downloaded in ‘**ascii**’ mode.

To resolve this problem, remove the installation directory. Download a new copy of NSO from servers. And make sure use binary transfer mode every step of the way.

3.4.0.0.2 Running Problems Sending NETCONF commands and queries with ‘netconf-console’ fails. The error message is below:

You must install the python ssh implementation paramiko in order to use ssh.

This occurs because Netconf-console command is implemented using the Python and depends on the python SSH implementation Paramiko.

To resolve this Install Paramiko (and pycrypto, if necessary) using the standard installation of the OS used.

Note: A workaround is to use ‘netconf-console-tcp’. It uses TCP instead of SSH and doesn’t require Paramiko or Pycrypto. Consider that TCP traffic is not encrypted.

3.4.0.0.3 General Troubleshooting Strategies In case of problems during starting or running, take note these troubleshooting tips:

1. Transcript all commands, responses and shell scripts used.
2. Save log files: ‘devel.log’, ‘ncs.log’, ‘audit.log’ and ‘ncserr.log’. If you are working with your own system, make sure the log files are enabled in ncs.conf.
3. Run **ncs -status**, to save status information available.
4. Run **ncs -check-callbacks**, to verify if “**Data Provider**” works for all possible data items.
5. Run **ncs -debug-dump mydump1**, to create a “**debug dump**”. It contains a lot of status information (including a full ncs -status report) and some internal state information.
6. To catch certain types of problems, especially relating to system start and configuration, the operating system’s “**system call trace**” can be invaluable. This tool is called strace/ktrace/truss depending of the OS.
 - linux: **strace -f -o mylog1.strace -s 1024 ncs ...**
 - BSD: **ktrace -ad -f mylog1.ktrace ncs** and **kdump -f mylog1.ktrace > mylog1.kdump**
 - Solaris: **truss -f -o mylog1.truss ncs ...**

3.5 Disaster Management

There are different disaster scenarios described below:

1. NSO fails to start

When NSO starts and fails to initialize, the following exit codes can occur:

- Exit codes *1* and *19* mean that an internal error has occurred. A text message should be in the logs, or if the error occurred at startup before logging had been activated, on standard error (standard output if NSO was started with -foreground -verbose).
- Exit codes *2* and *3* are only used for the ncs “control commands”, and mean that the command failed due to timeout. Code *2* is used when the initial connect to NSO didn’t succeed within 5 seconds (or the TryTime if given), while code *3* means that the NSO daemon did not complete the command within the time given by the -timeout option.
- Exit code *10* means that one of the init files in the CDB directory was faulty in some way. Further information in the log.

- Exit code *11* means that the CDB configuration was changed in an unsupported way. This will only happen when an existing database is detected, which was created with another configuration than the current in `ncs.conf`.
- Exit code *13* means that the schema change caused an upgrade, but for some reason the upgrade failed. Details are in the log. The way to recover from this situation is either to correct the problem or to re-install the old schema (`fxs`) files.
- Exit code *14* means that the schema change caused an upgrade, but for some reason the upgrade failed, corrupting the database in the process. This is rare and usually caused by a bug. To recover, either start from an empty database with the new schema, or re-install the old schema files and apply a backup.
- Exit code *15* means that `A.cdb` or `C.cdb` is corrupt in a non-recoverable way. Remove the files and re-start using a backup or init files.
- Exit code *20* means that NSO failed to bind a socket.
- Exit code *21* means that some NSO configuration file is faulty. More information in the logs.
- Exit code *22* indicates a NSO installation related problem, e.g. that the user does not have read access to some library files, or that some file is missing.

If NSO is stopped, files `A.cdb`, `C.cdb`, `O.cdb` and `S` can simply be copied, and the copy is then a full backup of CDB.

2. NSO failure after startup

- Out of memory: If NSO is unable to allocate memory, it will exit by calling `abort(3)`. This will generate an exit code as for reception of the `SIGABRT` signal - e.g. if NSO is started from a shell script, it will see 134 as exit code (128 + the signal number).
- Out of file descriptors for `accept(2)`: If NSO fails to accept a TCP connection due to lack of file descriptors, it will log this and then exit with code 25. To avoid this problem, make sure that the process and system-wide file descriptor limits are set high enough, and if needed configure session limits in `ncs.conf`.

3. Transaction commit failure

When NSO considers the configuration to be in a inconsistent state, operations will continue. It is still possible to use `NETCONF`, the CLI and all other northbound management agents.

The MAAPI API has two interface functions which can be used to set and retrieve the consistency status. This API can thus be used to manually

reset the consistency state. Apart from this, the only way to reset the state to a consistent state is by reloading the entire configuration.

4 NSO Developers

4.1 Architecture

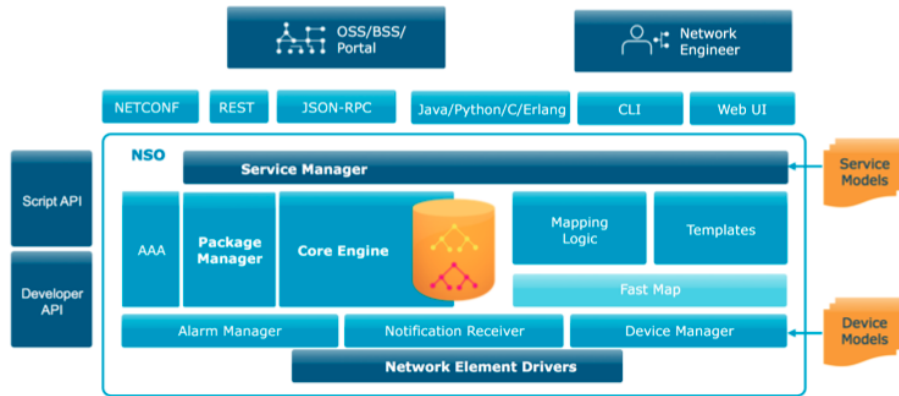


Figure 7: NSO-DEV-Architecture

Next two main layers are described:

Device Manager: Supports functions like device templates, device groups, configuration changes, configuration view and audit. The Device Manager does all this in a generic way and sits north of the Network Element Drivers.

4.1.1 NED (Network Element Driver)

Is the adaptation layer between the XML representation of the network configuration (YANG data-model for the supported device) contained inside NSO and the wire protocol between NSO and managed devices. NEDs are separate packages. Every individual NED packages is for a specific device OS.

SNPM: Devices can be managed automatically, by supplying NSO with the MIBs for the device, with some additional declarative annotations.

CLI: Devices can be managed by writing YANG models describing the data in the CLI, and a relatively thin layer of Java code to handle the communication to the devices. **The key point though, is that the Cisco CLI NED Java programmer doesn't have to understand and parse the structure of the CLI, this is entirely done by the NSO CLI engine.**

Generic: Devices can be managed by writing a required Java program to translate operations on the NSO XML tree into configuration operations towards the device. (this may be more complicated), usually devices that have other proprietary CLIs, devices that can only be configured over other protocols such as REST, Corba, XML-RPC, SOAP, other proprietary XML solutions.

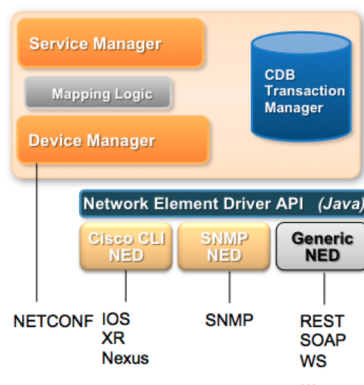


Figure 8: cisco-ned-architecture

Service Manager: Configure devices using service-aware applications, each service type is a package that is defined exactly according to the specific requirements. It can be modified and re-loaded into a running system, giving flexibility in the service portfolio.

The main parts of a service package is a YANG Service Model and a mapping definition towards the desired configurations. **The Service Manager supports the full life-cycle for a service.**

4.2 Python VM

The Python VM does not run on a hypervisor and does not contain a guest operating system. It is a tool that allows programs written in the Python programming language to run on a variety of CPUs.

Similar to Java, Python translates its programs into an intermediate format called bytecode, storing it in a file ready for execution. When the program is executed, the Python VM converts the bytecode into machine code for fast execution.

NSO is able to start one or more Python VMs where Python code in user-supplied packages can be executed.

By default, a Python VM will be started for each Python package that has a python class name defined in its package-meta-data.xml file. In this Python VM

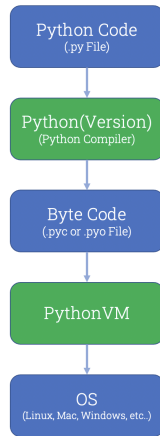


Figure 9: Python VM

the environment variable `PYTHONPATH` will point to the python directory of the package.

The `tailf-ncs-python-vm.yang` defines the *python-vm* container which, along with `ncs.conf`, is the entry point for controlling the NSO Python VM functionality:

```

+---rw python-vm
|   +---rw logging
|   |...
|   |# More data
|   |...
|   +---rw status
|   |   +---ro start* [node-id]
|   |   |...
|   |   |# More data
|   |   |...
|   |   +---ro current* [node-id]
|   |
|   +---x stop
|   |   |..
|   |   |# More data
|   |   |..
|   +---x start
|   |   |..
|   |   |# More data
|   |   |..

```

- The *status/start* and *status/current* contains operational data.
- The *status/start* command will show information about what Python

classes, as declared in the package-meta-data.xml file, that where started and whether the outcome was successful or not.

- The *status/current* command will show which Python classes that are currently running in a separate thread.
- The *start* and *stop* actions makes it possible to start and stop a particular Python VM.

4.2.0.1 Structure of the User provided code The package-meta-data.xml file must contain a *component* of type *application* with a *python-class-name* specified, where the component name (Service Name in the example) is a human readable name of this application component.

```
<component>
<name>Service Name</name> <application>
<python-class-name>Name.service.Service</python-class-name> </application>
</component>
```

The *python-class-name* should specify the Python class that implements the application entry point.

Note: the application entry point MUST to be specified using Python's dot-notation and should be fully qualified (given the fact that *PYTHONPATH* is pointing to the package python directory).

4.2.0.2 Python package directory structure Note that directly above the main directory is another directory named as the package (Name) that contains the user code.

```
packages/
+-- {{Name}}/
    +-- package-meta-data.xml
    +-- python/
        +-- {{Name}}/
            +-- __init__.py
            +-- service.py
            +-- _namespaces/
                +-- __init__.py
                +-- {{Name}}_ns.py
        +-- src
            +-- Makefile
            +-- yang/
                +-- {{Name}}.yang
```

- The **service.py** is located according to the description above. There is also a **init.py** (which is empty) there to make the {{Name}} directory considered a *module* from Python's perspective.
- The ****_namespaces/{{Name}}_ns.py**** file. It is generated from the **{{Name}}.yang** model using the **ncsc -emit-python** command and

contains constants representing the namespace and the various components of the YANG model, which the User code can import and make use of.

- The **service.py** file should include a class definition named *Service* which acts as the component's entry point.
- A Python class specified in the **package-meta-data.xml** file will be started in a Python thread which we call a *component thread*.
- The Python class should inherit ***ncs.application.Application*** and should implement the methods ***setup()*** and ***teardown()***.

Example of component class skeleton:

```
import ncs

class Service(ncs.application.Application):
    def setup(self):
        # The application class sets up logging for us. It is accessible
        # through 'self.log' and is a ncs.log.Log instance.
        self.log.info('Service RUNNING')

        # Service callbacks require a registration for a 'service point',
        # as specified in the corresponding data model.
        self.register_service('{{Name}}-servicepoint', ServiceCallbacks)

        # If we registered any callback(s) above, the Application class
        # took care of creating a daemon (related to the service/action point).

        # When this setup method is finished, all registrations are
        # considered done and the application is 'started'.
    def teardown(self):
        # When the application is finished (which would happen if NCS went
        # down, packages were reloaded or some error occurred) this teardown
        # method will be called.
        self.log.info('Service FINISHED')
```

- The *Service* class will be instantiated by NSO when started or whenever packages are reloaded.
- Custom initialization such as registering service- and action callbacks should be done in the *setup()* method.
- If any cleanup is needed when NSO finishes or when packages are reloaded it should be placed in the *teardown()* method.
- The existing log functions are named after the standard Python log levels, thus in the example above the *self.log* object contains the functions *debug, info, warning, error, critical*.

4.3 The Service Algorithm - FastMap

As a Service Developer you need to express the mapping from a YANG service model to the corresponding device YANG model. This is a declarative mapping in the sense that no sequencing is defined.

Observe that irrespective of the underlying device type and corresponding native device interface, the mapping is towards a YANG device model, not the native CLI for example. This means that as you write the service mapping, you do not have to worry about the syntax of different devices' CLI commands or in which order these commands are sent to the devices. This is all taken care of by the NSO device manager.

NSO reduces this problem to a single data-mapping definition for the “create” scenario. At run-time NSO will render the minimum change for any possible change like all the ones mentioned below. This is managed by the FASTMAP algorithm.

FASTMAP covers the complete service life-cycle: creating, changing and deleting the service. The solution requires a minimum amount of code for mapping from a service model to a device model.

FASTMAP is based on generating changes from an initial create. When the service instance is created the reverse of the resulting device configuration is stored together with the service instance. If an NSO user later changes the service instance, NSO first applies (in a transaction) the reverse diff of the service, effectively undoing the previous results of the service creation code. Then it runs the logic to create the service again, and finally executes a diff to current configuration. This diff is then sent to the devices.



Figure 10: Python VM

4.4 Troubleshooting

4.4.0.1 History log In order to find out whether a scheduled task has run successfully or not, the easiest way is to view the history log of the scheduler. It will display the last five runs of the scheduled task.

```
admin# show scheduler task sync history | notab history 2017-11-01T02:00:00.55003+00:00
```

```
duration "0.15 sec"
succeeded true
history 2017-12-01T02:00:00.549939+00:00
duration "0.09 sec"
```

```

succeeded true
history 2017-01-01T02:00:00.550128+00:00
duration "0.01 sec"
succeeded false
info      "Resource device ce0 doesn't exist"

```

4.4.0.2 XPath log Detailed information from the XPath evaluator can be enabled and made available in the xpath log. Add the following snippet to ncs.conf.

```

<xpathTraceLog>
  <enabled>true</enabled>
  <filename>./xpath.trace</filename>
</xpathTraceLog>

```

4.4.0.3 Devel Log Error information is written to the development log. The development log is meant to be used as support while developing the application. It is enabled in ncs.conf:

```

<developer-log>
  <enabled>true</enabled>
  <file>
    <name>./logs/devel.log</name>
    <enabled>true</enabled>
  </file>
</developer-log>
<developer-log-level>trace</developer-log-level>

```

4.4.0.4 Suspending the Scheduler While investigating a failure with a scheduled task or performing maintenance on the system, like upgrading, it might be useful to suspend the scheduler temporarily.

```
admin# scheduler suspend
```

When ready the scheduler can be resumed.

```
admin# scheduler resume
```

4.5 Subscriptions

The CDB subscription mechanism allows an external program to be notified when some part of the configuration changes. When receiving a notification it is also possible to iterate through the changes written to CDB. Subscriptions are always towards the running data-store (it is not possible to subscribe to changes to the startup data-store). Subscriptions towards operational data (see the section called “Operational Data in CDB”) kept in CDB are also possible, but the mechanism is slightly different.

The first thing to do is to inform CDB which paths we want to subscribe to. Registering a path returns a subscription point identifier. This is done by acquiring an subscriber instance by calling `CdbSubscription Cdb.newSubscription()` method. For the subscriber (or `CdbSubscription` instance) the paths are registered with the `dbSubscription.subscribe()` that that returns the actual subscription point identifier. A subscriber can have multiple subscription points, and there can be many different subscribers. Every point is defined through a path - similar to the paths we use for read operations, with the exception that instead of fully instantiated paths to list instances we can selectively use tagpaths.

When a client is done defining subscriptions it should inform NSO that it is ready to receive notifications by calling `CdbSubscription.subscribeDone()`, after which the subscription socket is ready to be polled.

We can subscribe either to specific leaves, or entire subtrees. Explaining this by example we get:

/ncs:devices/global-settings/trace: Subscription to a leaf. Only changes to this leaf will generate a notification.

/ncs:devices: Subscription to the subtree rooted at `/ncs:devices`. Any changes to this subtree will generate a notification. This includes additions or removals of device instances, as well as changes to already existing device instances.

/ncs:devices/device{“ex0”}/address: Subscription to a specific element in a list. A notification will be generated when the device “ex0” changes its ip address.

/ncs:devices/device/address: Subscription to a leaf in a list. A notification will be generated leaf address is changed in *any* device instance.

When adding a subscription point the client must also provide a priority, which is an integer (a smaller number means higher priority). When data in CDB is changed, this change is part of a transaction. A transaction can be initiated by a **commit** operation from the CLI or a **edit-config** operation in NETCONF resulting in the running database being modified. As the last part of the transaction CDB will generate notifications in lock-step priority order. First all subscribers at the lowest numbered priority are handled, once they all have replied and synchronized by calling `CdbSubscription.sync()` the next set - at the next priority level - is handled by CDB. Not until all subscription points have been acknowledged is the transaction complete. This implies that if the initiator of the transaction was for example a **commit** command in the CLI, the command will hang until notifications have been acknowledged.

Note that even though the notifications are delivered within the transaction it is not possible for a subscriber to reject the changes (since this would break the two-phase commit protocol used by the NSO backplane towards all data-providers).

As a subscriber has read its subscription notifications using `CdbSub-`

`scription.read()` it can iterate through the changes that caused the particular subscription notification using the `CdbSubscription.diffIterate()` method. It is also possible to start a new read-session to the `CdbDB-Type.CDB_PRE_COMMIT_RUNNING` database to read the running database as it was before the pending transaction.

To view registered subscribers use the **`ncs -status`** command.

4.6 NSO Python API

NCS Python high level module.

The high-level APIs provided by this module are an abstraction on top of the low-level APIs. This makes them easier to use, improves code readability and development rate for common use cases, such as service and action callbacks.

As an example, the `maagic` module greatly simplifies the way of accessing data. First it helps in navigating the data model, using standard Python object dot notation, giving very clear and readable code. The context handlers remove the need to close sockets, user sessions and transactions. Finally, by removing the need to know the data types of the leafs, allows you to focus on the program logic.

This top module imports the following modules:

- `application` – module for implementing packages and services
- `cdb` – placeholder for low-level `_ncs.cdb` items
- `dp` – data provider, actions
- `error` – placeholder for low-level `_ncs.error` items
- `events` – placeholder for low-level `_ncs.events` items
- `ha` – placeholder for low-level `_ncs.ha` items
- `log` – logging utilities
- `maagic` – data access module
- `maapi` – MAAPI interface
- `template` – module for working with templates
- `service_log` – module for doing service logging
- `upgrade` – module for writing upgrade components

4.6.1 Sub-modules

- `ncs.application`: Module for building NCS applications.
- `ncs.cdb`: CDB high level module.
- `ncs.childlist`: Internally used classes and functions.
- `ncs.dp`: Callback module for connecting data providers to ConfD/NCS.
- `ncs.error`
- `ncs.events`
- `ncs.experimental`: Experimental stuff ...
- `ncs.fsm`: Internally used classes and functions ...
- `ncs.ha`

- `ncs.keypath`: Internally used classes and functions.
- `ncs.log`: This module provides some logging utilities.
- `ncs.maagic`: Confd/NCS data access module ...
- `ncs.maapi`: MAAPI high level module ...
- `ncs.ns`
- `ncs.pool`: Resource Pool
- `ncs.service_log`: This module provides service logging
- `ncs.template`: This module implements classes to simplify template processing.
- `ncs.tm`: Internally used classes and functions.
- `ncs.upgrade`: Module for NSO upgrade components.
- `ncs.util`: Utility module, low level abstractions

4.7 Service Packages

A package is basically a directory of files with a fixed file structure. A package consists of code, YANG modules, custom Web UI widgets etc., that are needed in order to add an application or function to NSO. Packages is a controlled way to manage loading and versions of custom applications.

A package is a directory where the package name is the same as the directory name.

At the toplevel of this directory a file called `package-meta-data.xml` must exist.

The structure of that file is defined by the YANG model `$NCS_DIR/src/ncs/yang/tailf-ncs-packages.yang`.

A package may also be a tar archive with the same directory layout. The tar archive can be either uncompressed with suffix `.tar`, or gzip-compressed with suffix `.tar.gz` or `.tgz`.

Packages are composed of components. The following types of components are defined: NED, Application, and Callback.

The file layout of a package is:

```
<package-name>/package-meta-data.xml
    load-dir/
    shared-jar/
    private-jar/
    webui/
    templates/
    src/
    doc/
    netsim/
```

Local-dir is the directory where all `.fxs` (compiled YANG files) and `.ccl` (compiled CLI spec files) are located.

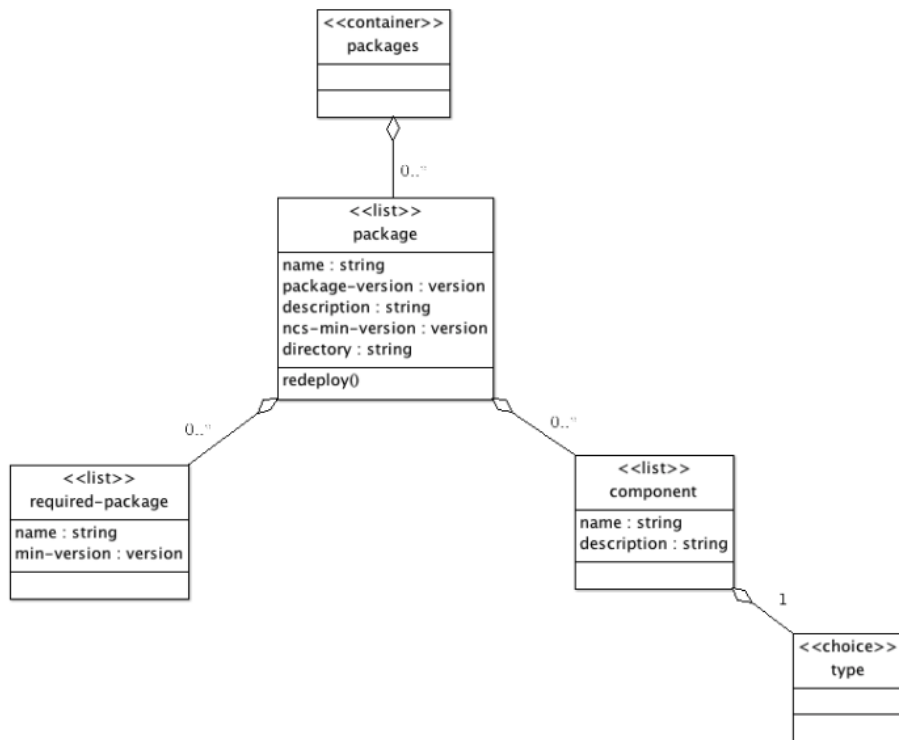


Figure 11: Package-Model

Shared-jar is the directory where all jars are located and are reach using the `LOAD_SHARED_JARS` request for each deployed NSO package (the classes and resources in these jars are globally accessible for all deployed NSO packages).

Private-jar is the directory where all jars are located and are reach using the `LOAD_PACKAGE` request for each deployed NSO package (these classes and resources will be private to respective NSO package. In addition, classes that are referenced in a component tag in respective NSO package `package-meta-data.xml` file will be instantiated).

Note: By putting code for a specific service in a private jar, NSO can dynamically upgrade the service without affecting any other service.

The optional `webui` directory contains webui customization files.

The `package-meta-data.xml` file defines the name of the package as well as one *component*. Let's go through the different parts of the meta data file:

- `name` - the name of the package. All packages in the system must have unique names.
- `package-version` - The version of the package. This is for administrative purposes only, NSO cannot simultaneously handle two versions of the same package.
- `ncs-min-version` - which is the oldest known NSO version where this package works.
- `required-package` - a list of names of other packages that are required for this package to work.
- `component` - Each package defines zero or more components.

Each component in a package has a name. The names of all the components must be unique within the package.

The YANG model for packages contain:

The mandatory choice that defines a component must be one of ***ned***, ***callback***, ***application*** or ***upgrade***.

NED Component

A Network Element Driver component is used southbound of NSO to communicate with managed devices. The easiest NED to understand is the `NETCONF` NED which is built in into NSO.

There are 4 different types of NEDs:

- ***netconf*** - used for `NETCONF` enabled devices such as Juniper routers, ConfD powered devices or any device that speaks proper `NETCONF` and also has YANG models. Plenty of packages in the NSO example collection have `NETCONF` NED

```

.....
list component {
    key name;
    leaf name {
        type string;
    }
    ...
    choice type {
        mandatory true;
        case ned {
            ...
        }
        case callback {
            ...
        }
        case application {
            ...
        }
        case upgrade {
            ...
        }
        .....
    }
    .....

```

Figure 12: Component-structure

components, for example `$NCS_DIR/examples.ncs/getting-started/developing-with-ncs/0-router-network/packages/router`.

- *snmp* - used for SNMP devices. The example `$NCS_DIR/examples.ncs/snmp-ned/basic` has a

package which has an SNMP NED component. • *cli* - used for CLI devices. The package `$NCS_DIR/packages/neds/`

`cisco-ios` is an example of a package that has a CLI NED component. • *generic* - used for generic NED devices. The example `$NCS_DIR/`

`examples.ncs/generic-ned/xmlrpc-device` has a package called `xml-rpc` which defines a NED component of type *generic*

Note: A CLI NED and a generic NED component must also come with additional user written Java code, whereas a NETCONF NED and an SNMP NED have no Java code.

Callback Component

The *callback* type of component is used for a wide range of callback type Java applications, where one of the most important are the Service Callbacks.

A package that has a *callback* component usually has some YANG code and then also some Java code that relates to that YANG code. By convention the YANG and the Java code resides in a `src` directory in the component. When the source of the package is built, any resulting `fxs` files (compiled YANG files) must reside in the *load-dir* of the package and any resulting Java compilation results must reside in the *shared-jar* and *private-jar* directories.

Application Component

Used to cover Java applications that do not fit into the *callback* type. Typically this is functionality that should be running in separate threads and work autonomously.

The example `$NCS_DIR/examples.ncs/getting-started/developing-with-ncs/1-cdb` contains three components that are of type *application*. These components must also contain a *java-class-name* element. For application components, that Java class must implement the *ApplicationComponent* Java interface.

Upgrade Component

Used to migrate data for packages where the yang model has changed and the automatic cdb upgrade is not sufficient. The upgrade component consists of a java class with a main method that is expected to run one time only.

4.8 Service Application Development

This section describes how to develop a service application.

A service application maps input parameters to create, modify, and delete a service instance into the resulting commands to devices in the network.

The input parameters are given from a northbound interface to NSO or a network engineer using any of the NSO User Interfaces such as the NSO CLI.

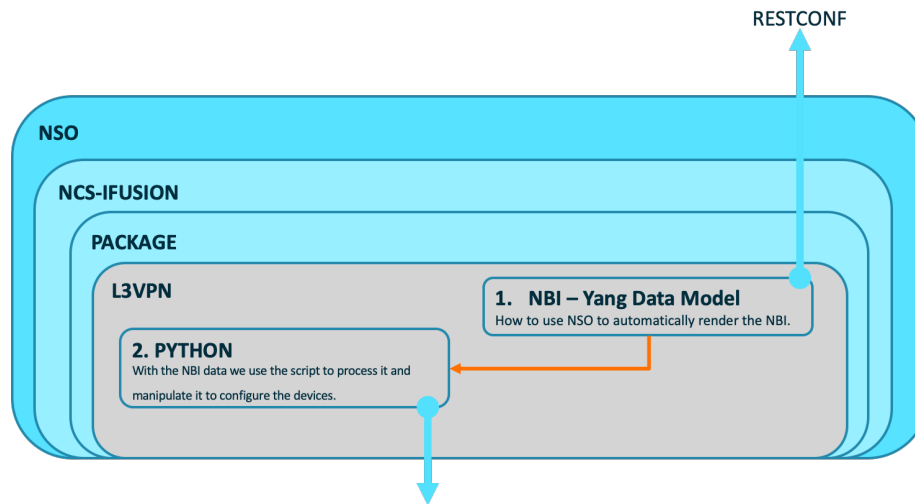


Figure 13: Cisco-NSO-Logical-Architecture

Who writes the NBI and SBI models?

- Developing the service model is part of developing the service application and is covered later in this chapter.
- Every device NED comes with a corresponding device YANG model. This model has been designed by the NED developer to capture the configuration data that is supported by the device. This means that a service application has two primary.

4.9 Python examples of executing common tasks using the NSO Maagic API

4.9.1 Example of how to create a session into NSO.

A sessions allows for reading data from NSO and executing Actions. It does not create a transaction into NSO.

```
def create_session():
    with ncs.maapi.Maapi() as m:
        with ncs.maapi.Session(m, 'admin', 'python', groups=['ncsadmin']):
            root = ncs.maagic.get_root(m)
```

4.9.2 Example of how to create a transaction into NSO.

It create the transaction with the `ncs.maapi.single_write_trans` against the `ncs` module, and commit the transaction with the `apply()` method inside the transaction object we created above.

```
def create_transaction():
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        t.apply()
```

4.9.3 Example of how to understand and navigate a devices config in the python API.

This example will show by printing the directory of different levels of the config.

```
def navigate_config(device_name):
    with ncs.maapi.Maapi() as m:
        with ncs.maapi.Session(m, 'admin', 'python', groups=['ncsadmin']):
            root = ncs.maagic.get_root(m)
            device_config = root.devices.device[device_name].config
            print(dir(device_config))
            print(dir(device_config.ip))
            print(dir(device_config.ip.dhcp))
            print(dir(device_config.ip.dhcp.snooping))
```

4.9.4 Function to change the hostname of a provided device.

This is to give an example of making config changes in NSO It can be made doing this by:

1. create a transaction
2. create a device pointer by passing the device name into the NSO list of devices. The list (`root.devices.device`) acts much like a Python List, it has key value pairs with key being the device name and value being the object for that device.
3. Set the value of the device's config hostname by assigning the device objects `config.hostname` attribute to the new value.
4. Finish by applying the transaction created.

```
def change_config_hostname(device_name):
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        device = root.devices.device[device_name]
        device.config.hostname = "new_host_name"
        t.apply()
```


4.9.5 Example of how to delete data (config or NSO) via python.

uses python **del** operator **Note:** If you **del** a pointer to a NCS object this will only delete the pointer!

```
def delete_data(device_name):
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        del root.devices.device[device_name].config.hostname
        t.apply()
```

4.9.6 Example of how to add a new item into a list resource.

In the IOS YANG model there are many instances of Lists. For example, adding a new VLAN would be adding a new item to a list. This can be made invoking the `.create()` method of the ncs list objects

```
def create_list_item():
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        root.devices.device.config.interface.vlan.create("200")
        t.apply()
```

4.9.7 This function takes a device hostname as an input and adds that device into NSO.

Then does an nslookup on the hostname This function uses 3 separate transactions do to sequencing and default admin-state in NSO of locked. First Transaction: Adds the device and IP to add the device into the cDB Second Transaction: adds the port and creates the device-type/ NED info and unlocks the device. Third Transaction: Gets ssh keys, syncs-from and southbound-locks the device.

```
def add_device(device_name):
    ip_addr = socket.getaddrinfo(device_name,0,0,0,0)
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        root.devices.device.create(device_name)
        root.devices.device[device_name].address = ip_addr[0][4][0]
        t.apply()
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t2:
        root = ncs.maagic.get_root(t2)
        root.devices.device[device_name].port = 22
        root.devices.device[device_name].device_type.cli.create()
        root.devices.device[device_name].device_type.cli.ned_id = "ios-id:cisco-ios"
        root.devices.device[device_name].device_type.cli.protocol = "ssh"
        root.devices.device[device_name].authgroup = "branblac"
        root.devices.device[device_name].state.admin_state = "unlocked"
        t2.apply()
```

```

with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t3:
    root = ncs.maagic.get_root(t3)
    root.devices.device[device_name].ssh.fetch_host_keys()
    root.devices.device[device_name].sync_from()
    root.devices.device[device_name].state.admin_state = "southbound-locked"
    t3.apply()

```

4.9.8 Example of how to loop over devices in NSO and execute actions or changes per each device.

Within this example we will iterate over devices and print the device name and the HW platform. Then per device print what extended ACL are present on the device. Notice how the configuration for the device is navigated via a python object In this case config -> ip -> access-list -> extended -> ext_named_acl If you think about it, this object structure is very similiar to the IOS syntax and navigation It can be made doing this by:

1. Creating a transaction
2. Using a for loop over the the root.devices.device list
3. Printing the info, print info per box

In this example, we should have used a session! but if we desire changes we per box we would want a transaction. In this case, even if we changed config info, nothing would be done! Since we never apply/commit the transaction changes.

```

def iterate_devices():
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        for box in root.devices.device:
            print(box.name,": ", box.platform.model)
            for acl in root.devices.device[box.name].config.ip.access_list.extended.ext_named_acl:
                print(acl.name)

```

4.9.9 Use a MAAPI session via maagic api to get the results of a passed show command.

Uses the devices name in NSO as an input parameter and the commnd ie: CDP Neighbors, ip int br. prints the raw text results of the command. It can be made doing this by:

1. Creating a NSO session
2. Create a pointer to our device
3. Create an input object but calling the device.live_status.ios_stats__exec.show.get_input() emthod
4. Pass the command function input into the input objects args variable
5. Invoke the command by passign the input object into the device.live_status.ios_stats__exec.show() method

6. set the output variable to the result attribute of our invoked command object above
7. Print the output.

```
def show_commands(command, device_name):
    with ncs.maapi.Maapi() as m:
        with ncs.maapi.Session(m, 'admin', 'python'):
            root = ncs.maagic.get_root(m)
            device = root.devices.device[device_name]
            input1 = device.live_status.ios_stats__exec.show.get_input()
            input1.args = [command]
            output = device.live_status.ios_stats__exec.show(input1).result
            print(output)
```

Same as above but for clearing

```
def clear_commands(command, device_name):
    with ncs.maapi.Maapi() as m:
        with ncs.maapi.Session(m, 'admin', 'python'):
            root = ncs.maagic.get_root(m)
            device = root.devices.device[device_name]
            input1 = device.live_status.ios_stats__exec.clear.get_input()
            input1.args = [command]
            output = device.live_status.ios_stats__exec.clear(input1).result
            print(output)
```

4.9.10 Example that shows one scenario where you will use a leaflist YANG type.

This example iterates over the devices in a provided group the passes the string value from the list into `root.devices.device[]` to get the ip address of the device.

```
def using_leaflists_data(device_group):
    with ncs.maapi.single_write_trans('ncsadmin', 'python', groups=['ncsadmin'], db=ncs.RUNNING) as t:
        root = ncs.maagic.get_root(trans)
        group = root.devices.device_group[device_group].device_name
        for box in group:
            print type(box)
            print(root.devices.device[box].address)
```

4.9.11 Single search to see if a provided IP address is present inside any of a devices extended ACLs.

```
def check_in_string(ip):
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        for box in root.devices.device:
            for acl in root.devices.device[box.name].config.ip.access_list.extended_ext_name:
```

```

        for rule in root.devices.device[box.name].config.ip.access_list.extended.extended:
            if ip in rule.rule:
                print(ip + "Is in acl " + str(acl))

```

4.9.12 Function example that shows values that are of data type boolean.

These can be set to be True or False. Also showing object assignment for fun.

```

def work_with_boolean(device_name):
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        dot_one_q_config = root.devices.device[device_name].config.interface.GigabitEthernet1
        dot_one_q_config.vlan_id = 10
        dot_one_q_config.native = True

```

4.9.13 Example function to show how to check if a certain interface is on a device.

We do this by using by if in operators and the maagic API dictionary methods.

```

def check_if_interface_exists(device_name, interface_type, interface_number):
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        device = root.devices.device[device_name]
        print type(device.interface[interface_type])
        if interface_number in device.interface[interface_type]:
            print("Interface is on the device!")
        else:
            print("Interface is not on the device!")

```

4.9.14 Prints each interface number on the device of the given type

```

def print_interfaces(device_name, interface_type):
    with ncs.maapi.single_write_trans('admin', 'python', groups=['ncsadmin']) as t:
        root = ncs.maagic.get_root(t)
        device = root.devices.device[device_name]
        for interface in device.interface[interface_type]:
            print interface.name

```

4.10 Writing a Python background worker for Cisco NSO

In the YANG model servicepoints are used to attach a create callback to a particular subtree in the YANG model. In addition to create servicepoint it also have actionpoints which allows attach python code to YANG actions. Both servicepoint and actionpoint attach to the YANG model and lets code be executed upon external stimuli, either the request to run an action or the change of configuration.

The purpose of the background worker, as an example, will be to increment a counter at a periodic interval. It's simple and not useful on its own but around setting up a worker and so, this will serve as a simple example.

1. Start making a new package of python service skeleton.

```
ncs-make-package --service-skeleton python
```

2. Edit or replace the YANG model to the following. A simple leaf called counter, that is config false (i.e. operational state data).

```
module bgworker {

    namespace "http://example.com/bgworker";
    prefix bgworker;

    container bgworker {
        leaf counter {
            config false;
            type uint32;
            default 0;
        }
    }
}
```

Note: Set the default value to 0 which means the counter will be 0 each time NCS starts up. Unlike configuration data, state data in NCS is not persisted per default which is why our leaf will go back to a value of 0 each time NCS starts. We could add `tailf:persistent "true"` to the leaf to make it persisted in CDB.

And move the YANG source file that should be stored in:

```
PACKAGE-NAME/src/yang
```

3. Make package, the normal example skeleton code produced by `ncs-make-package` shows the use of the `setup()` and `teardown()` methods to hook into the start and stop of the Application.

The comment indicates that this is a component thread and runs as a thread in the Python VM.

```
# -----
# COMPONENT THREAD THAT WILL BE STARTED BY NCS.
# -----
class Main(ncs.application.Application):
    def setup(self):
        ...
```

The modified Python code, to deploy a background worker MUST start another thread from `setup()` method:

```

import threading
import time
import ncs
from ncs.application import Service

class BgWorker(threading.Thread):
    def run(self):
        while True:
            print("Hello from background worker")
            time.sleep(1)

class Main(ncs.application.Application):
    def setup(self):
        self.log.info('Main RUNNING')
        self.bgw = BgWorker()
        self.bgw.start()

    def teardown(self):
        self.log.info('Main FINISHED')
        self.bgw.stop()

```

Note: ServiceCallbacks class with its `cb_create()` was deleted since it doesn't need anymore and instead a new thread definition called `BgWorker` was created which is instantiated and started from the `setup()` method of the Application.

4. loading the package by running `request packages reload`

```
admin@ncs> request packages reload force
```

```

>>> System upgrade is starting.
>>> Sessions in configure mode must exit to operational mode.
>>> No configuration changes can be performed until upgrade has completed.
>>> System upgrade has completed successfully.
reload-result {
    package bgworker
    result true
}
[ok] [2019-07-01 13:43:04]
admin@ncs>

```

Running `tail -f ncs-python-vm.log` will show the printed messages made by the **background worker**

```

<INFO> 1-Jul-2019::13:43:04.534 nuc ncs[11832]: Started PyVM: <<"bgworker">> , Port=#Port<0
<INFO> 1-Jul-2019::13:43:04.535 nuc ncs[11832]: bgworker :: Starting /home/kll/ncs-4.7.4.2/s
<INFO> 1-Jul-2019::13:43:04.595 nuc ncs[11832]: bgworker :: Hello from background worker
<INFO> 1-Jul-2019::13:43:05.597 nuc ncs[11832]: bgworker :: Hello from background worker

```

```
<INFO> 1-Jul-2019::13:43:06.598 nuc ncs[11832]: bgworker :: Hello from background worker
<INFO> 1-Jul-2019::13:43:07.599 nuc ncs[11832]: bgworker :: Hello from background worker
<INFO> 1-Jul-2019::13:43:08.599 nuc ncs[11832]: bgworker :: Hello from background worker
```

4.11 Creating an NSO Service Application

1. Create a service package:

```
cd ncs-run/packages
ncs-make-package --service-skeleton python <package-name>
ncs-make-package --service-skeleton python iFusion-slice
```

The yang file can be compiled inside the NSO using pyang. Some error can appear, so the sentences ‘yang-version’ and ‘reference’ in imported files should be removed from Yang.

- ietf-network-slice@2021-07-20.yang:2: error: bad value “1.1” (should be version)
- ietf-network-slice@2021-07-20.yang:9: error: unexpected keyword “reference”
- ietf-network-slice@2021-07-20.yang:14: error: unexpected keyword “reference”
- ietf-network-slice@2021-07-20.yang:19: error: unexpected keyword “reference”

```
chmod 777 ietf-network-slice@2021-07-20.yang
```

2. Edit the skeleton YANG service model in the generated package. Move the YANG source file that should be stored in:

```
PACKAGE-NAME/src/yang
```

The two “*uses*” lines ncs:service-data and ncs:servicepoint “attribute” tells NSO that this is a service.

Two additional models should be added in the main yang file:

```
import tailf-common {
    prefix tailf;
}

import tailf-ncs {
    prefix ncs;
}
```

Once those models were imported, the service points can be added:

```
list vpn-node { key "vpn-node-id ne-id";
    uses ncs:service-data;
    ncs:servicepoint l3vpn-ntw-vpn-node-servicepoint;
}
```

3. Now build the service model.

```
cd <package-name>/src make
```

If additional models are required, the following lines must be change in the 'Makefile':

```
## Uncomment and patch the line below if you have a dependency to a NED
## or to other YANG files
YANGPATH += ../../<package-name>/src/yang
YANGPATH += ../../<package-name>/src/yang/import
```

A nice property of NSO is that already at this point you can load the service model into NSO and try if it works well in the CLI etc. Nothing will happen to the devices since the mapping is not defined yet. This is normally the way to iterate a model; load it into NSO, test the CLI towards the network engineers, make changes, reload it into NSO etc.

4. Try the service model in the NSO CLI. In order to have NSO to load the new package including the service model, do:

```
admin@ncs#
packages reload
```

5. Create the XML templates and move it to the template folder of the package:

```
python cd <package-name>/template
```

6. Make sure the service-point name in the YANG service model has a corresponding service-point in the XML file or in the main python file.

```
from ncs.application import Service
from ncs.dp import Action
```

```
class Main(ncs.application.Application):
    def setup(self):
        # The application class sets up logging for us. It is accessible
        # through 'self.log' and is a ncs.log.Log instance.
        self.log.info('Main RUNNING')

        # Service callbacks require a registration for a 'service point',
        # as specified in the corresponding data model.
        #
        self.register_service('l3vpn-ntw-site-network-access-servicepoint',
                              L3VPNSiteNetworkAccess)
        self.register_service('l3vpn-ntw-vpn-node-servicepoint', L3VPN_VPNNode)
```