Reverse and Simulate your Enemy Botnet C&C

Mapping a P2P Botnet with Netzob

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Abstract

Have you ever been staring at binary or hexadecimal data flows extracted from an USB channel ? Don't you remember yourself searching for some patterns and other similarities in this fuc***g mess of zeros and ones grabbed from a binary configuration file ?

Did you know you were not a alone and that others including Rob Savoye **[Sav09]** and Drew Fisher **[Fis10]** have already described the main difficulties of the RE[1] operations. Both of them have called for the creation of a tool which would help the expert in its process. For about these last 2 years, we've been working to respond to this call to create this kind of tool. Hence, this article will describe a new semi-automated RE process based on Netzob[2]. This tool simplifies the manipulation of binary flows, finds relations, deduce data formats, infer grammatical definition and other few little things ;)

Introduction

There are many reasons why an I.T. Advance User would engage himself in a RE operations. For example, some wants to understand how their favorite game store their player's profile while others wants to use their USB device on an originally unsupported OS. In addition to these common usages, security

[1] "RE" is a common acronym for Reverse Engineering.

[2] See project website: http://www.netzob.org

auditors (and evaluators) often use RE process in their work. **This article will discusses usage of RE by security auditors and evaluators**.

In recent years, the field of security analysis systems or software was extended with new approaches and new tools based on the fuzzing. Compared to more traditional techniques (static and dynamic analyzes binary, potentially combined with the analysis of the source code) that require specialized skills, resources and time, these new tools offer many advantages : relative simplicity of implementation, semi-automated approach, rapid acquisition of results, etc... . However, experience shows that to be truly effective, an effective fuzzing analysis requires a good knowledge of the target, and in particular of the communication protocol. This fact limits the effectiveness and completeness of results obtained in the analysis of products implementing proprietary protocols or undocumented.

On the other hand, in the analysis of security products such as firewall or network intrusion detection (NIDS), an evaluator often needs to generate realistic traffic in order to assess the relevance and reliability of the tested product (that is, its ability to limit false positives and false negatives). This operation is complex because it requires the complete characterization and control over the generated traffic. Hence, an evaluator can't generate traffic if he doesn't have access to the specification of the protocol.

This is to meet the many needs of reverse engineering protocols that Netzob was developed. This tool is a framework to infer protocols. It supports the expert in his reverse engineering work by offering a set of semi-automated features to reduce the analysis time and ultimately improve its understanding of the targeted protocol. We organize the remainder of the article as follows. After presenting terminology and our assumptions in Section 2, we detail Netzob's design and functionnalities in Section 3. We discuss it and provide a real pratical example of its usages in Section 4 and conclude in Section 5.

Terminology and design assumptions

Few days of bibliography on the RE field illustrated the huge differences between the academic world and the “applied” world. The first one regroups multiple work and papers while in the applied world, experts are specialized ninjas computing CRCs and other format trans-coding with their eyes.

On the academic field, most of the researchers consider A. Beddoe as the initiator of the automated RE with its tool named PI[3] published in [Bed04]. Following years brought multiple papers including those of W. Cui and al. [Cal.06d][Cui07] and of C. Leita [LMD05]. Each of them include new algorithms and next-gen complicated approaches, but none of them effectively brought to the applied world a useable tool. This resulted to an important dis-synchronization between the researchers and the security experts we'll try to

[3]See the “Protocol Informatics” Project : *http://www.4tphi.net/~awalters/PI/PI.html*

tackle with this article.

Definition of a Communication Protocol

A communication protocol can be defined as the set of rules allowing one or more entities (or actors) to communicate. Applied to the field of computer networking, protocols have been the subject of many standardization activities, particularly from the OSI model, which establishes, among other things, the principle of protocol layers. However, few studies have attempted to give a formal and generic definition of a protocol. We refer here to the definition provided by Gerard Holzmann in his reference book "*Design and Validation of Computer Protocols*" [Hol91]. According to the author, a protocol specification consists of five distinct parts:

1. The **service** provided by the protocol.
2. The **assumptions** about the environment in which the protocol is executed.
3. The **vocabulary** of messages used to implement the protocol.
4. The **encoding (format)** of each message in the vocabulary.
5. The **procedure rules** guarding the consistency of messages exchanges.

In our work, we seek to infer the three last elements of the specification since there are mandatory to configure the fuzzing process and to generate valid traffic. Subsequently, we consider protocol inference requires to learn both:

1. The set of messages and their format, also called **vocabulary of a protocol**.
2. All the rules of procedure that we name **grammar of a protocol**.

These two parts of a protocol are detailed in the followings.

Definition of the Vocabulary of a Protocol

Within Netzob, the vocabulary consists of a set of symbols. **A symbol represents an abstraction of similar messages**. We consider the similarity property refers to messages having the same role from a protocol perspective. For example, the set of *TCP SYN* messages can be abstracted to the same symbol. An *ICMP ECHO REQUEST* or an *SMTP EHLO* command are other kinds of symbols.

A symbol structure follows a format that specifies a sequence of expected fields (e.g. TCP segments contains expected fields as sequence number and checksum). Fields have either a fixed or variable size. A field can similarly be composed of sub-elements (such as a payload field). Therefore, by considering the concept of protocol layer as a kind of particular field, it is possible to retrieve the protocol stack (e.g. TCP encapsulated in IP, itself encapsulated in Ethernet) each layer having its own vocabulary and grammar. The identification of the different fields allows to define the symbol format.

In our model, a field has different attributes: some of them concern every fields, others are specific to the field type and only relevant for a visualization

purpose. **The domain defines the authorized values of a field, under a disjunctive normal form**[4]. An element of the domain can be:

- A static value (e.g. a magic number in a protocol header).
- A value that depends on another field, or set of fields, within the same symbol. We call this notion intra-symbol dependency (e.g. a CRC code).
- A value depending on another field, or set of fields, that are part of a previous symbol transmitted during the same session. We call this notion inter-symbol dependency (e.g. an acknowledgment number).
- A value depending on the environment. We call this notion environmental dependency (for example, a timestamp).
- A random value (e.g. the initial value of the TCP sequence number field).

Besides, fields have some interpretation attributes, notably for visualization and data seeking purposes. We associate a field content with a unit size (the size of atomic elements that compose the field, such as bit, half-byte, word, etc.), an endianness, a sign and a representation (i.e. decimal, octal, hexadecimal, ASCII, DER, etc.). Optionally, a semantic may be associated to a field (such as an IP address, an URL, etc.). As an example, the Illustration 1 depicts different format and visualization attributes of Botnet SDBot C&C messages.

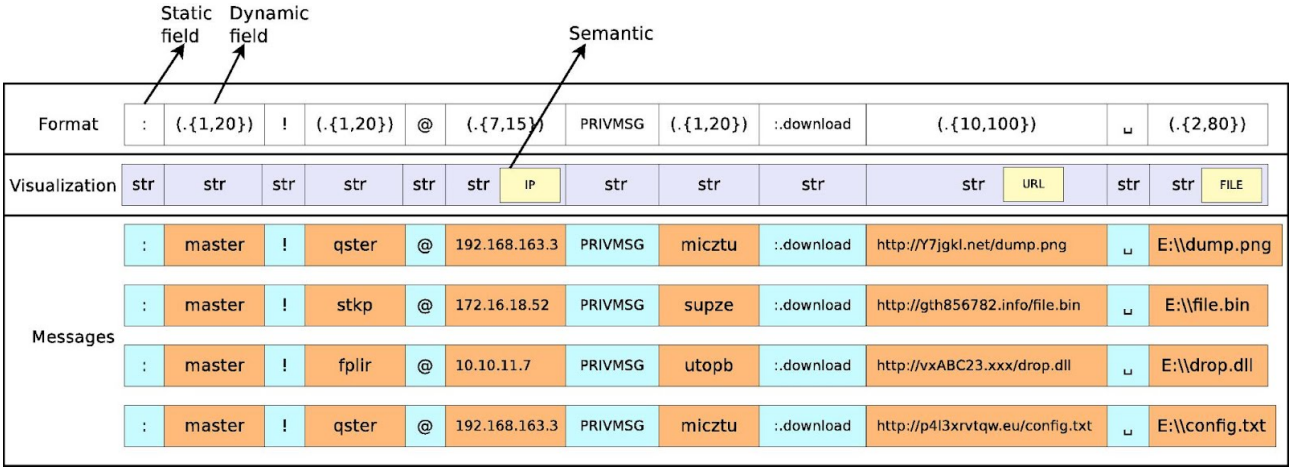


Illustration 1: Format of SDBot C&C messages. The first line depicts the symbol format. The second line corresponds to the visualization attributes. These attributes are optionally overloaded by semantic characteristics.

Definition of the Grammar of a Protocol

The grammar represents the ordered sets of messages exchanged in a valid communication. Applied to the ICMP protocol, its grammar include a rule which state that an *ICMP ECHO REPLY TYPE 8* always follow an *ICMP ECHO REQUEST TYPE 8*. Another example of a grammar is the set of rules which describe the ordered symbols sent between two actors of a TCP session. **These rules can be represented using an automata which define the states**

[4]A Disjunctive Normal Form (DNF) is a logical formula built with OR of AND : ((a AND b) OR (c AND d)).

and the sent and received symbols on each transitions (see example on Illustration 2).

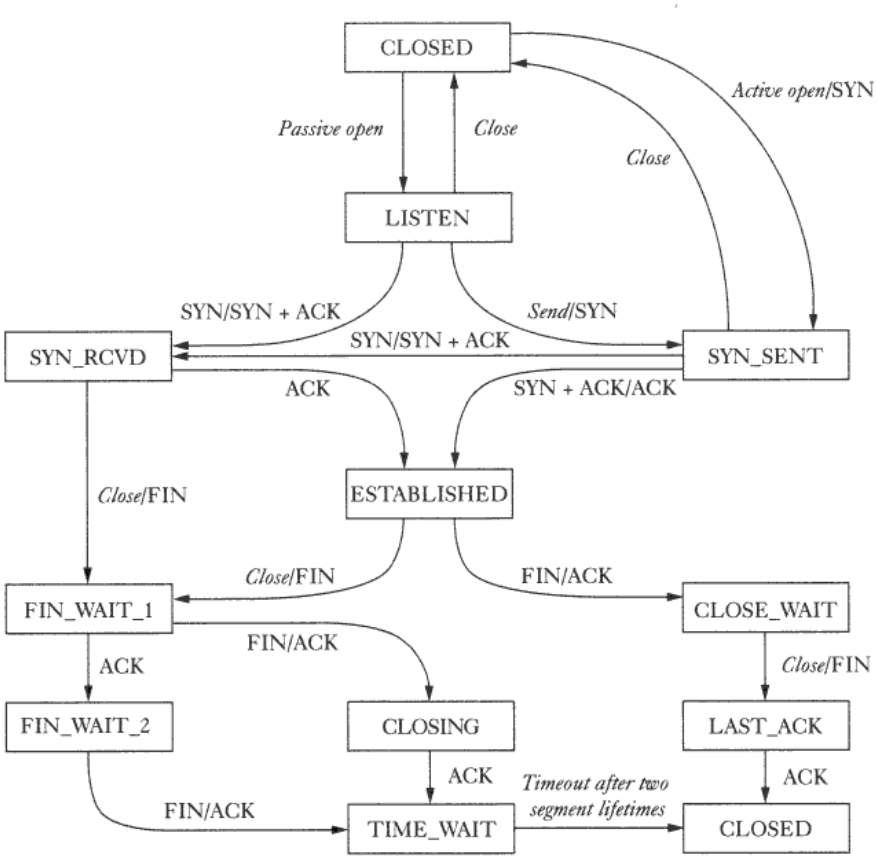


Illustration 2: TCP State Transition Automata (http://www.ssfnet.org/Exchange/tcp/tcpTutorialNotes.html)

Within Netzob, the grammar is defined with our own mathematical model named Stochastic Mealy Machine with Determinist Transitions (an SMMDT). This extension of traditional Mealy Machines allows to have multiple output symbols on the same transition and to represent multiple answers to the same command. In addition to this feature, our model also include the reaction time for each couple of request and reply symbols. The interested reader can contact us[5] for any questions regarding the model, we've some nice equations available ;)

Few Assumptions

Our objective is to infer the vocabulary and the grammar of a communication protocol in order to audit (using fuzzing approaches) and to evaluate (using traffic simulator). These operations do not require previous knowledge on the protocol but still the followings assumptions are made :

[5]You can contact authors on *contact@netzob.org*.

1. The inferring process requires initial input data. Hence the expert must obtain examples of multiple communication channels hosting the targeted protocols. It can be any data flow from an USB channel (e.g. external devices) to network flows (e.g. Botnets' C&C) through inter-process calls (e.g. API Hooking) or file protocols (e.g. configuration files, …).
2. The input data should include the largest diversity of included environmental values (IP addresses, pseudos and other user data, hostnames, date and time, …).
3. The expert must have access to an implementation which uses the targeted protocol. It must be possible to automate its execution and to reinitialize it to its initial state. We recommend snapshot mechanism included in VMWare or VirtualBox for this.
4. Naturally, the targeted protocol should not include encrypted or compressed content. If some exists, the expert can use included entropy measures to identify some of them and use solutions like API Hooking to get the clear data.

Inferring Vocabulary and Grammar with Netzob

In this Section, we describe the learning process implemented in Netzob to semi-automatically infer the vocabulary and the grammar of a protocol. This process, illustrated in picture 3, is performed in three main steps:

6. Clustering messages and partitioning these messages in fields.
7. Characterizing message fields and abstracting similar messages in symbols.
8. Inferring the transition graph of the protocol.

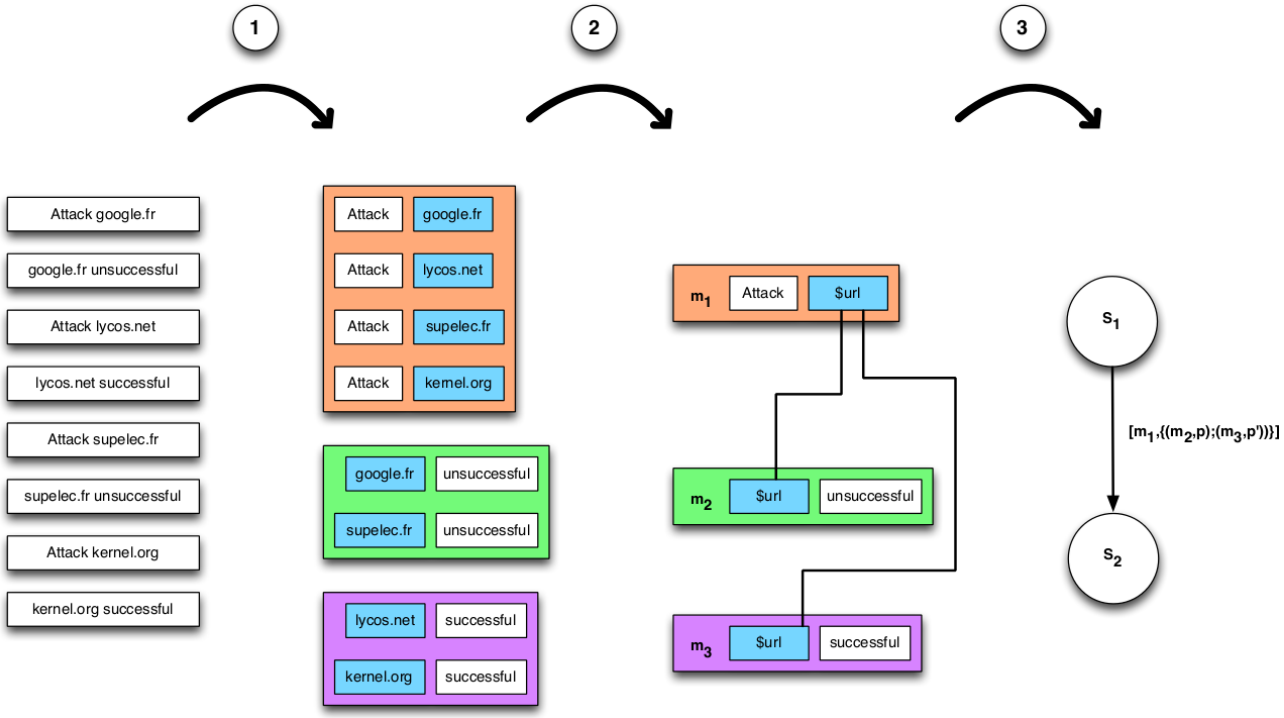


Illustration 3: Steps of protocol inference in Netzob

Step 1: clustering Messages and Partitioning in Fields

To discover the format of a symbol, Netzob supports different partitioning approaches. In this article we describe the most accurate one, that leverages sequence alignment processes. This technique permits to align invariants in a set of messages. The Needleman-Wunsh algorithm [NW70] performs this task optimally. Needleman-Wunsh is particularly effective on protocols where dynamic fields have variable lengths (as shown on picture 4).

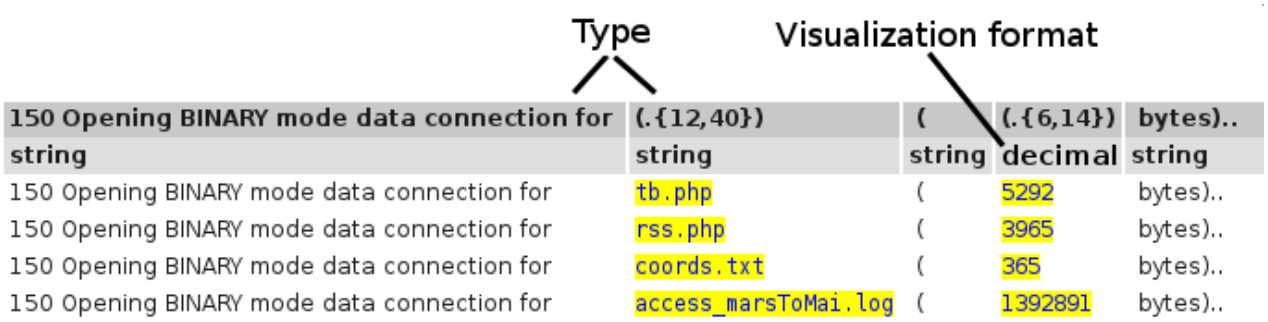


Illustration 4: Example of sequence alignment on FTP messages

When partitioning and clustering processes are done, we obtain a relevant first approximation of the overall message formats. The next step consists in determining the characteristics of the fields.

If the size of those fields is fixed, as in TCP and IP headers, it is preferable to apply a basic partitioning, also provided by Netzob. Such partitioning works by aligning each message by the left, and then separating successive fixed columns from successive dynamic columns.

To regroup aligned messages by similarity, the Needleman-Wunsh algorithm is used in conjunction with a clustering algorithm. The applied algorithm is UPGMA [Smi58].

Step 2 : characterization of Fields

The field type identification partially derives from the partitioning inference step. For fields containing only invariants, the type merely corresponds to the invariant value. For other fields, the type is automatically materialized, in first approximation, with a regular expression, as shown on figure 3. This form allows to easily validate the data conformity with a specific type. Moreover, Netzob offers the possibility to visualize the definition domain of a field. This helps to manually refine the type associated with a field.

Some intra-symbol dependencies are automatically identified. The size field, present in many protocol formats, is an example of intra-symbol dependency. A search algorithm has been designed to look for potential size fields and their associated payloads. By extension, this technique permits to discover encapsulated protocol payloads.

Environmental dependencies are also identified by looking for specific values retrieved during message capture. Such specific values consist of characteristics of the underlying hardware, operating system and network configuration. During the dependency analysis, these characteristics are searched in various encoding.

Step 3: inferring the Transition Graph of the Protocol

The third step of the learning process discovers and extracts the transition graph from a targeted protocol. This step is achieved by a set of active experiments that stimulate a real client or server implementation using successive sequences of input symbols and analyze its responses.

Each experiment includes a sequence of selected symbols according to an adapted version of Angluin's L* algorithm [Ang87] that originally applies to DFA[6] machines. This choice is justified by its effectiveness to infer a deterministic transition graph in polynomial time. Its use on a protocol's grammar requires:

- The knowledge of input symbols of the model (also called the vocabulary).

[6]DFA stands for "Deterministic Finite Automaton" also known as "Deterministic Finite State Machine".

- That clients or servers fail in some obvious way, for instance by crashing, if the submitted sequence of symbol is not valid.
- The capability of reseting clients/servers to their initial states between experiment.
- That we can temporary ensure the protocol's grammar to be deterministic.

The inferring process implies a Learner who initially only knows the input symbols extracted from the previous step. It tries to discover $\mathbf{L}(\mathrm{M})$ that represents the language generated by the model M by submitting queries to a Teacher and to an Oracle.

Among the possible queries, the original algorithm considers the following:

- **Membership queries**, which consist in asking the Teacher whether a sequence of symbols is valid. The Teacher replies yes or no.
- **Equivalence queries**, which consist in asking if the language of an hypothesized model is equal to the language of the inferring model. If not, the Oracle supplies a counterexample.

This algorithm progressively builds a hypothesized model based on results brought by submitted membership queries. Once the learned model is considered stable by the algorithm, an equivalence query is made. If the query is successful, the model is considered equal to the inferred model, otherwise more membership queries are submitted according to the returned counterexample.

Finally, we consider that environmental variations may impact output symbols. Therefore, we confine the client/server in a restrictive environment to limit its indeterminism on output symbols. For example, we use network whitelist-based filtering to limit Internet accessibility to only identified necessary websites.

Netzob Implementation

This chapter presents the implementation-specific aspects of Netzob, which is **distributed under the GPLv3 license**. At the time of writing (September 2012), the source code comprises about 33.000 lines of code, mostly in Python some specific parts being implemented in C for performance purposes. All algorithms described in this article have been reimplemented.

The source code is publicly available[7] on a git repository and packages for Debian, Gentoo, ArchLinux and Windows are provided. Currently, Netzob works on both x86 and x64 architectures and includes the following modules (as shown on picture):

[7]See: http://www.netzob.org

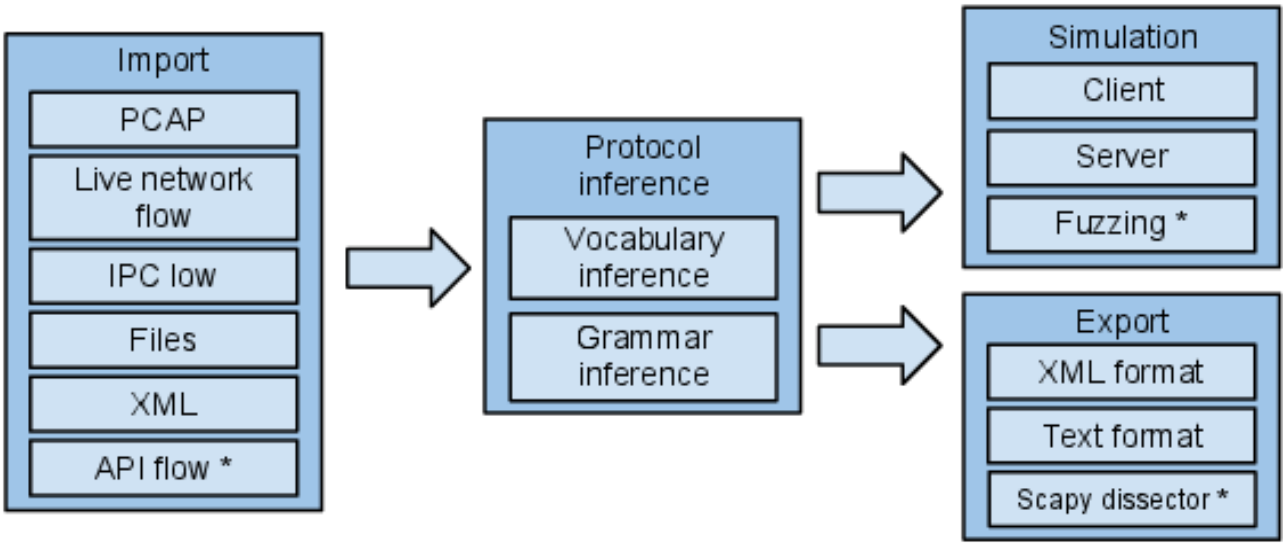


Illustration 5: Architecture of Netzob

- **Import module**: Data import is available in two ways: either by leveraging the channel-specific captors, or by using the XML interface format. As communication protocols are omnipresent, it is fundamental to have the possibility to capture data in a maximum number of contexts. Therefore, Netzob provides native captors and easily allow the implementation of new ones. Current work focuses on data flow analysis, that would permit to acquire clear messages before they get encrypted. Besides, Netzob supports many input formats, such as network flows, PCAP files, structured files and Inter-process communication (pipes, socket and shared memory).
- **Protocol inference modules**: The vocabulary and grammar inference methods constitute the core of Netzob.
- **Simulation module**: One of our main goal is to generate realistic network traffic from undocumented protocols. Therefore, we have implemented a dedicated module that, given vocabulary and grammar models previously inferred, can simulate a communication protocol between multiple bots and masters. Besides their use of the same model, each actors is independent from the others and is organized around three main stages. The first stage is a dedicated library that reads and writes from the network channel. It also parses the flow in messages according to previous protocols layers. The second stage uses the vocabulary to abstract received messages into symbols and vice-versa to specialize emitted symbols into messages. A memory buffer is also available to manage dependency relations. The last stage implements the grammar model and computes which symbols must be emitted or received according to the current state and time.
- **Export module**: This module permits to export an inferred model of a protocol in formats that are understandable by third party software or by a human. Current work focuses on export format compatible with main

traffic dissectors (Wireshark and Scapy) and fuzzers (Peach and Sulley).

Practical example

In this section, we'll describe a typical use case of Netzob : "Modeling and afterward simulating a Botnet". After a very-short description of the scenario, we'll explain step-by-step how you can infer a ZeroAccess P2P protocol and afterward simulate it. The examples shown below are adapted for pedagogical purpose.

The Scenario

You're a security evaluator and your boss has assigned you a new target. If we forget CC[8] evaluations and consider more "constrained time" security evaluations (like French's CSPN[9] for example), you only have few days to verify it does its work.

Your target is an IDS/IPS or an Yet-Another-Hyper-Smart-Highly-Effective Applicative Firewall and you want to verify if it detects botnets and other malwares. Meaning you need to create a botnet in your lab using some samples you've collected (on your spare time ?) and produce you're 100 infected hosts network and you're 5 networks of botnet supervision[10].

But you don't have time for this, and want a solution to generate realistic traffic which will allow you to evaluate your target. It's where comes Netzob. With this tool, you'll be able to reverse the communication protocol of a targeted botnet and afterward to simulate it. **OK, we'll show you.**

Reverse engineering ZeroAccess P2P protocol

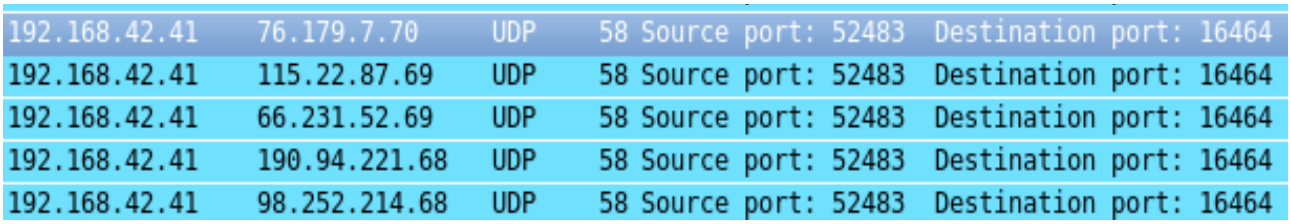
First step is to capture some data from a real life botnet's communication. To do this, you need your sample of the malware, your favorite sandbox system and Wireshark.

Figure 6 show a set of UDP packets sent from your sandbox ("192.168.42.41") to the port 16464 of various distant IP ("76.179.7.70", "115.22.87.69", …). This is the bootstrap procedure of our sample.

[8]CC stands for "Common Criteria", an international standard (ISO/CEI 15408) defining a security evaluation process.

[9]CSPN stands for "Certification de Sécurité de Premier Niveau" can roughly be translated in "First level security certification level".

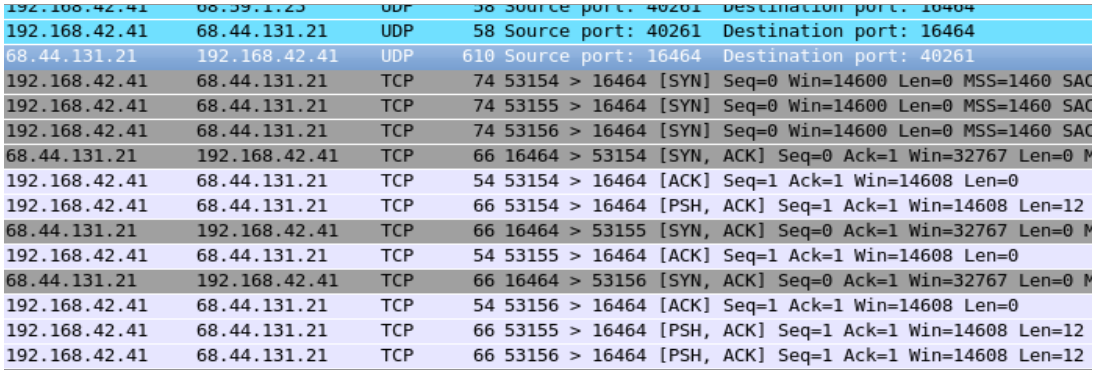
[10]Makes me remember this famous XKCD sktech: http://xkcd.com/350



192.168.42.41	76.179.7.70	UDP	58 Source port: 52483 Destination port: 16464
192.168.42.41	115.22.87.69	UDP	58 Source port: 52483 Destination port: 16464
192.168.42.41	66.231.52.69	UDP	58 Source port: 52483 Destination port: 16464
192.168.42.41	190.94.221.68	UDP	58 Source port: 52483 Destination port: 16464
192.168.42.41	98.252.214.68	UDP	58 Source port: 52483 Destination port: 16464

Illustration 6: Initial communications captured with Wireshark

All these packets have the same length (58 bytes) and seems rather static. When a peer responds, it sends back a larger UDP packet which triggers the creation of a TCP session between our sample and the remote peer, as shown on figure 7.



192.168.42.41	68.44.131.21	UDP	58 Source port: 40261 Destination port: 16464
68.44.131.21	192.168.42.41	UDP	610 Source port: 16464 Destination port: 40261
192.168.42.41	68.44.131.21	TCP	74 53154 > 16464 [SYN] Seq=0 Win=14600 Len=0 MSS=1460 SAC
192.168.42.41	68.44.131.21	TCP	74 53155 > 16464 [SYN] Seq=0 Win=14600 Len=0 MSS=1460 SAC
192.168.42.41	68.44.131.21	TCP	74 53156 > 16464 [SYN] Seq=0 Win=14600 Len=0 MSS=1460 SAC
68.44.131.21	192.168.42.41	TCP	66 16464 > 53154 [SYN, ACK] Seq=0 Ack=1 Win=32767 Len=0 M
192.168.42.41	68.44.131.21	TCP	54 53154 > 16464 [ACK] Seq=1 Ack=1 Win=14608 Len=0
192.168.42.41	68.44.131.21	TCP	66 53154 > 16464 [PSH, ACK] Seq=1 Ack=1 Win=14608 Len=12
68.44.131.21	192.168.42.41	TCP	66 16464 > 53155 [SYN, ACK] Seq=0 Ack=1 Win=32767 Len=0 M
192.168.42.41	68.44.131.21	TCP	54 53155 > 16464 [ACK] Seq=1 Ack=1 Win=14608 Len=0
68.44.131.21	192.168.42.41	TCP	66 16464 > 53156 [SYN, ACK] Seq=0 Ack=1 Win=32767 Len=0 M
192.168.42.41	68.44.131.21	TCP	54 53156 > 16464 [ACK] Seq=1 Ack=1 Win=14608 Len=0
192.168.42.41	68.44.131.21	TCP	66 53155 > 16464 [PSH, ACK] Seq=1 Ack=1 Win=14608 Len=12
192.168.42.41	68.44.131.21	TCP	66 53156 > 16464 [PSH, ACK] Seq=1 Ack=1 Win=14608 Len=12

Illustration 7: A peer answers which triggers the creation of a TCP session.

Since we're interested in the P2P protocol, we extract the UDP packets with source or destination port : 16464. The obtained PCAPS can then be analyzed in Netzob.

Downloading and Installing Netzob

Since Netzob is still in "beta" version, we recommend the use of the latest available version you can get from the official git repository:

$ git clone https://dev.netzob.org/git/netzob.git/

Netzob follows typical python installation process which includes the use of "setup.py" file:

$ python setup.py build

$ python setup.py develop

Once ready, we can start Netzob:

$ ./netzob

Configuring the Project

We create a new project named "RE_ZeroAccess", and import in it the captured PCAPS of UDP packets, with a dedicated importer (see figure 8). The objective of our work will be to understand those messages.

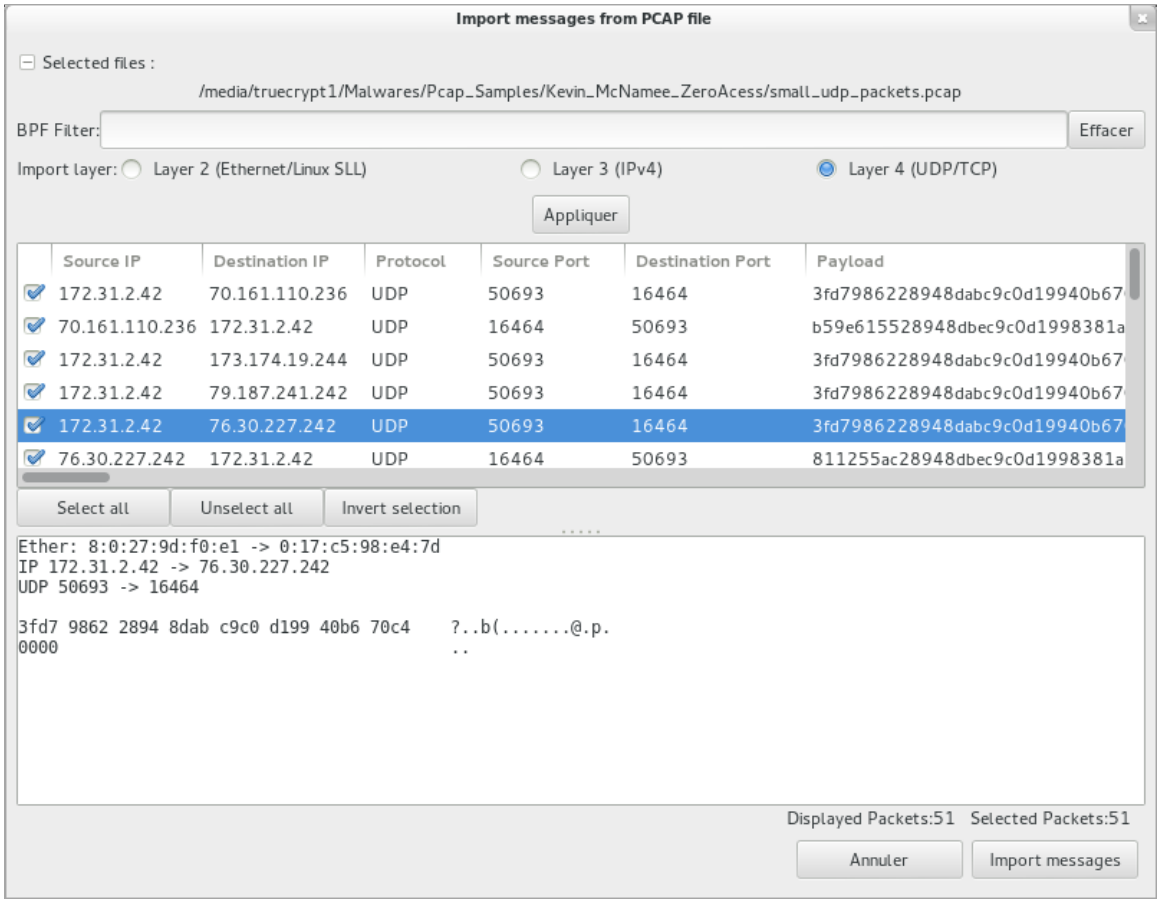


Illustration 8: Import of PCAP in Netzob

Reversing the vocabulary

The first step consists in "playing" with the features of Netzob : partitioning (sequence alignment, basic alignment, etc.), encoding and visualization attributes (hex, octal, string, etc.), search of known pattern, splitting and concatenation of fields, etc. We used these features (see figure 9) until we get a first outline of the message format.

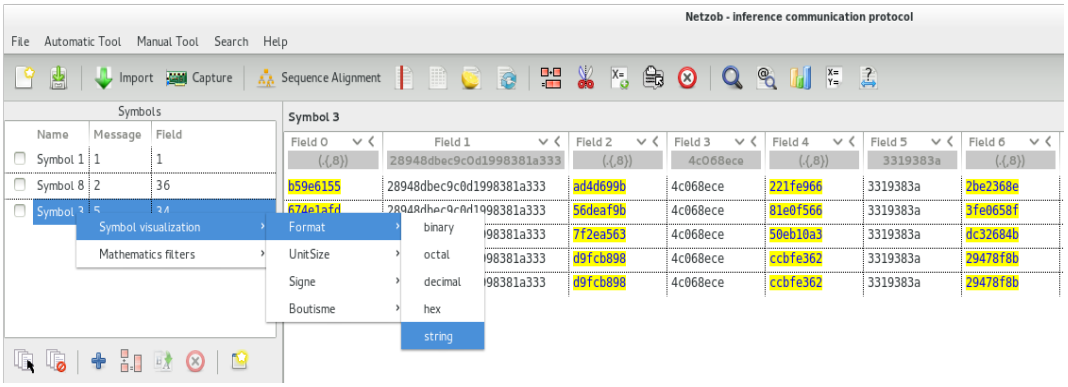


Illustration 9: Main panel of the vocabulary inference in Netzob

The first analysis shows some static and dynamic fields of fixed length. This looks a good beginning. However, the field content appears quite awkward. An analysis of the byte distribution (see figure 10) shows a probable encrypted or obfuscated content.

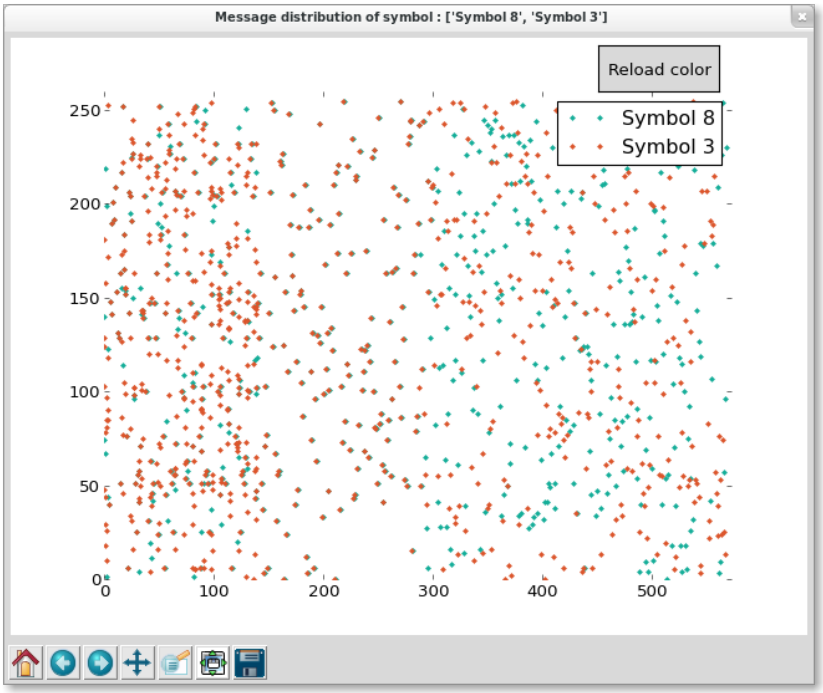


Illustration 10: Byte distribution of probably encrypted messages

Decryption of raw payloads

A previous analysis (by Kevin McNamee [KMN12]) provides the decryption algorithm. Netzob allows us to create a "Mathematical Filter" which applies on a message to transform its payload.

Hence, we provide the source code of the mathematical filter which is a specific xor decryption routines. The initial key ("ftp2") is bit shifted every 4 bytes and used to xor the content of every exchanged data. Figure 11 shows the source

code of this specific Mathematical Filter.

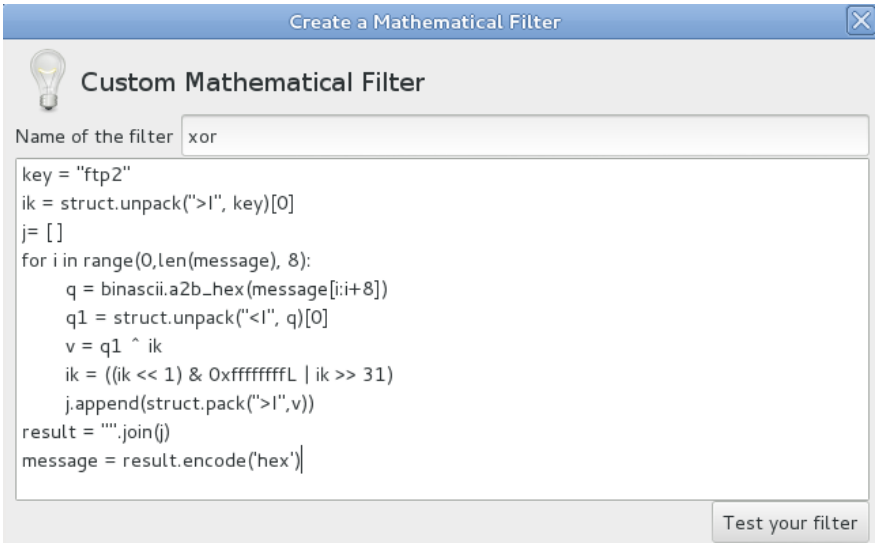


Illustration 11: Add a xor-decryption filter

Partitioning of messages in fields

Then, we apply an alignment process on the clear messages using the Sequence Alignment functionality (see figure 12). Our objective is to identify common messages, to regroup them in dedicated symbols, and to obtain a field partitioning of each identified symbol.

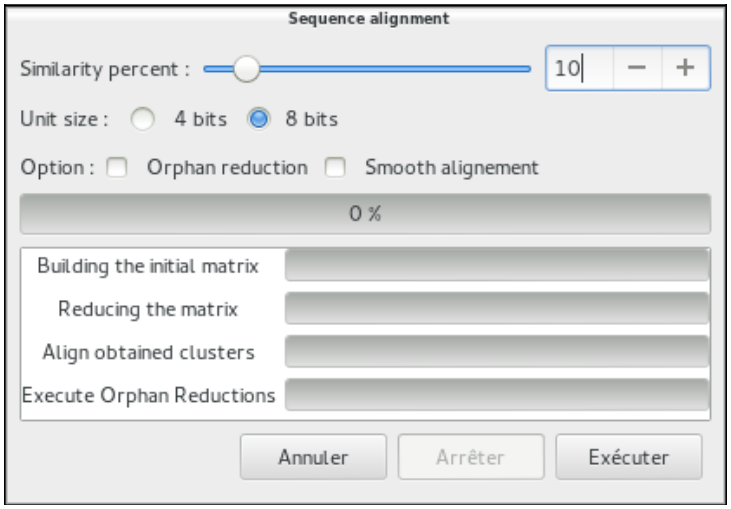


Illustration 12: Sequence alignment parameter

Once done, the alignment reveals only one symbol with all the messages splitted in 47 fields. Such an amount of fields for a single type of symbol is "unlikely". It means we must continue the alignment process on this particular symbol and try to split it in different symbols. So we incrementally increase the "similarity threshold". Around 70% of similarity, we obtain an interesting result: two different symbols: the first one contains small messages with three fields while the second one is made of 33 "small" fields alternatively dynamic and static values and a huge static field at the end. We will not

consider this huge static field in this article, and will rather concentrate on the first part.

When visualizing the messages as string, we can identify that the second field corresponds to a botnet command. The first command is "getL", as shown on figure 13, and correspond to the first packet sent by the malware. It appears that its message format is identical for each sample of the malware. We used two samples of the malware to produce the partitioning shown on the figure 13.

Field 1 (.{,8}) hex	Command getL string	Field 3 00000000 hex	Field 4 (.{,8}) hex
04eca70d	getL	00000000	f7d337d3
d039c13e	getL	00000000	e66a669a

Illustration 13: Message format of the first command : "getL"

Identification of environmental data

The second command is "retL", and corresponds to the answer of a "getL" request message. As we are studying a P2P protocol that retrieves IP addresses of other peers, we then try to look for those IP in the payloads of the "retL" message response. To do that, we leverage the search for environmental dependencies functionality. We simply look for IP addresses used during the networking communication of our malware sample.

After some searches, we are able to find many of these IP addresses in a structured format :

[IP1] xxxx [IP2] xxxx [IP3] xxxx …

The IP addresses appears in reverse order due to endianness.

Identification of relations

We then launch another functionality of Netzob, which tries to find basic relations between field of a symbol. As a result, Netzob finds that the fourth field corresponds to the number of IP addresses found:

The resulting message format is therefore:

yyyy [command] 000..000 [NbIP] [IP1] xxxx [IP2] xxxx [IP3] xxxxx ...

The message format and associated message of the "retL" command, as it appears in Netzob, in shown on figure 14:

Field 1 (.{,8}) hex	Command retL string	Field 2 00000000000000 hex	NbIPs (.{2}) decimal	IP1 (.{,8}) ipv4	Field N1 00000000 hex	IP2 (.{,8}) ipv4	N 00
4ab333be	retL	00000000000000	8	255.255.255.255	00000000	255.255.179.85	000
ca2162b3	retL	00000000000000	5	255.255.255.255	00000000	255.255.179.85	000
3b3470b2	retL	00000000000000	3	255.255.255.255	00000000	255.255.254.255	000
80dfd4fa	retL	00000000000000	7	253.117.24.188	00000000	2.127.122.109	000
e656d8c1	retL	00000000000000	16	248.192.81.71	00000000	4.197.83.78	000
ef85d01f	retL	00000000000000	16	252.181.182.173	00000000	1.100.56.84	000
3315ee87	retL	00000000000000	16	252.46.78.139	00000000	251.245.19.187	000
5138c196	retL	00000000000000	16	254.254.254.169	00000000	254.254.254.117	000

Illustration 14: Message format of the second command : "retL"

Modeling relations in Netzob

The message format, and especially the expected content of each field, can also be represented as a tree, as shown on figure 15. This interface provided by Netzob allows to specify relations between fields. For example, we have seen that the fourth field corresponds to the number of IP addresses in the payload. We can integrate this relation in Netzob through the tree interface. Other kind of relation could also be represented (size field, CRC, sequence number, etc.).

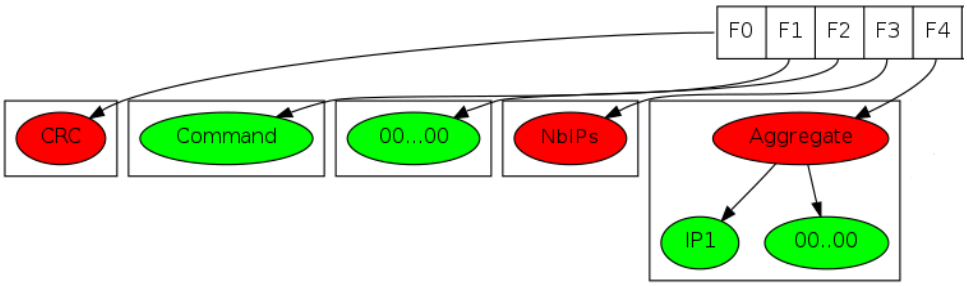


Illustration 15: Fields content representation

Another important relation we have previously discovered is that IP addresses which appears in the payload are used to launch TCP connection. In Netzob, this relation is modeled by associating the content of an IP field with the metadata of a future network communication (the destination IP in our example and the layer 4 protocol). This relation will be leveraged during traffic simulation, as described below.

Reversing the grammar

As explained in the first part of the article, Netzob allows to reverse and to model complex grammars. In our case and in order to make it simple, we've only considered the two previous symbols (“getL” and “retL”). A complete inferring process of the vocabulary would have highlighted other symbols including “getF”, “retF”, “srv”, ….

Reversing the grammar is based on an active grammatical inferring process conducted by an adaptation of the Angluin L* algorithm which includes the stimulation of the malware. Between each stimulation (a.k.a experiments), the malware is reseted to its initial state. This is achieved using the snapshot solution provided by your favorite sandbox.

To be effective, this module needs to be highly customizable allowing to adapt itself to the high diversity of cases. Netzob allows to :

- Infer the grammar of a network server or a network client.
- Infer communication channels over TCP and UDP.

The expert provides the “script” which resets the malware to it is initial state. A simple reset script which stop, clean and restart a sandbox based on virtualbox looks like :

```
#!/bin/sh
vboxName="TargetWindowsXP"
vboxId="ab922c7e-1c88-404a-a9fa-87fd9d4ff59e"
snapshotId="NetzobReady"
# First we stop the current instance of the virtualbox
vboxmanage controlvm $vboxName poweroff
# Restore to the snapsot
vboxmanage snapshot $vboxName restorecurrent
# restart the vm
vboxmanage startvm $vboxName --type headless
```

During the inferring process, emitted messages are generated following the definition provided by the reversed vocabulary.

In our case, the grammar is computed in few minutes since we only used two symbols “getL” and “retL”. Inferring larger grammar can takes hours.

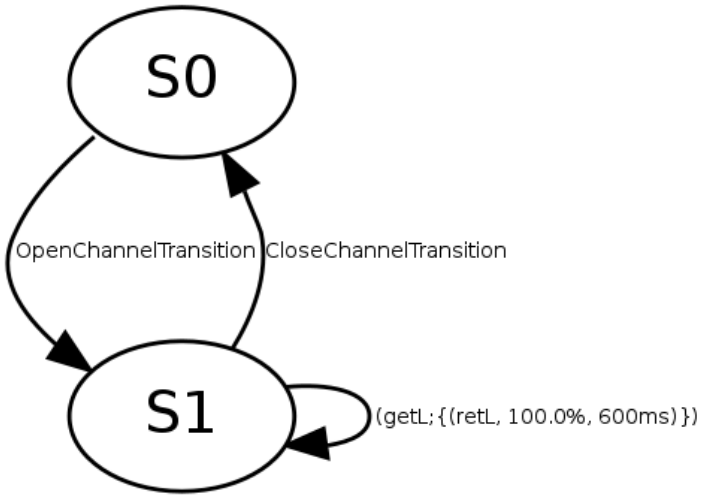


Illustration 16: Example of the automatically inferred grammar for "getL"/"retL" exchange.

Simulating traffic

The previous steps has presented how Netzob can be used to understand/ reverse an unspecified protocol. Once we modeled the vocabulary and the grammar of a protocol, we can easily generate valid traffic using the dedicated perspective in the tool.

Let's say we want to simulate a client which follows the inferred protocol to communicate with a target. In few seconds, we can test its specifications by creating a Netwok Actor. For example, figure 17 shows the parameters required to create a ZeroAccess Bot which will connect on (udp:// 115.22.87.69:16464) and initiates a communication described by the inferred grammar and vocabulary.

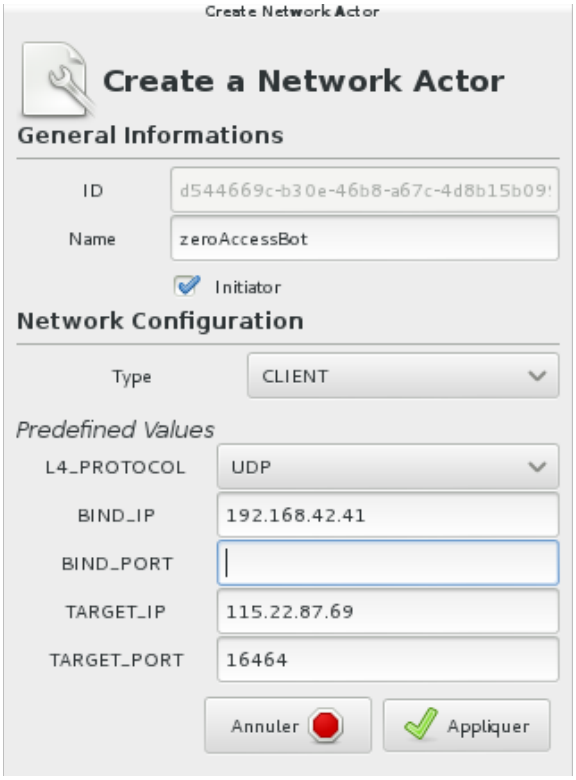


Illustration 17: Creation of a ZeroAccess Bot Simulator

Once started, the created actor "navigates" in the grammar and executes the transitions given the current state. If the initiated transitions is valid (meaning the sent and received messages are valid) it changes of states. It exists three main types of transitions :

1. "**OpenChannelTransition**" : opens the communication channel following the specified protocol. Its parameters (ip_source, port_source, ip_destination, port_destination) are extracted from the memory.
2. "**CloseChannelTransition**" : closes the current communication channel.
3. "**SemiStochasticTransition**" : Receives, parses (save obtained field values in memory) and answer using the associated message. A typical example is the transition which waits for "getL" message and answers with the "retL" message.

A very simple bot simulator which uses the grammar described in Figure initiates a communication to a first peer and after the simple "getL"/"retL" exchanges closes the communication. 500 ms after, it re-opens the connect with one of the peer he retrieved from the obtain list. This way, the simulator can be used to map the botnet and to generate valid network traffic.

Conclusion

In this article, we introduced Netzob, an open source tool dedicated to the reverse engineering and simulation of communication protocols. Besides

its original goal of inferring undocumented protocols, Netzob is also used in operational contexts in a french security lab. The tool has been successfully applied for the reimplementation of undocumented protocols and vulnerability analysis of proprietary protocols. The project also receives regular external contributions.

As future work, different directions are followed. We are currently addressing advanced fuzzing as an extension of the traffic simulator module. We also aim at generating NIDS rules, that would leverage model checking approach for protocol recognition. This would allow a more efficient detection of botnets than most current approaches, that are based on pattern matching. Netzob will also be extended to support the generation of protocol parsers, allowing the manipulation of inferred protocols in third-party-products. Finally, this community project will continue to support up-to-date academic researches while being available in operational context.

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