Lecture 6: In Depth Passive Testing using Network Traces

Passive Testing Techniques for Communication Protocols

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Outline

Passive Testing using Network Traces

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Passive Testing using Network Traces

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- Properties that search (match) the same packets under the same constraints and conditions, but having a different semantical meaning are possible
  - For instance, the same property as shown before can be expressed as: "for all VSNP requests, a *corresponding* response should follow, and the reply number must be odd for an even request ID or even for an odd request ID"'

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- Properties that search (match) the same packets under the same constraints and conditions, but having a different semantical meaning are possible
  - For instance, the same property as shown before can be expressed as: "for all VSNP requests, a *corresponding* response should follow, and the reply number must be odd for an even request ID or even for an odd request ID"'
  - The chronological order of the packet **prototypes** (the characterization of a specific network packet) is preserved in any case

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When a property is evaluated over a set of network packets and the property concludes about that set of packets, the conclusion provided is known as a **verdict**

- Verdict sets are different from in On-line and Off-line approaches!

Passive Testing using Network Traces (Monitoring)

On-line VS. Off-line approaches

Verdicts for Passive Testing using Network Traces

For the purpose of demonstrating the possible verdicts and their differences between on-line and off-line approaches

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- Assume the VSNP trace:

ID:2	**ID:3**	**ID:4**	**ID:2**	**ID:4**	**ID:21**	**ID:21**
N:	N:	N:	N: 77	N: 89	N:	N: 101

Verdicts for Passive Testing using Network Traces

For the purpose of demonstrating the possible verdicts and their differences between on-line and off-line approaches

- Assume the VSNP trace:

ID:2	**ID:3**	**ID:4**	**ID:2**	**ID:4**	**ID:21**	**ID:21**
N:	N:	N:	N: 77	N: 89	N:	N: 101

- Assume the property:
  'for all VSNP requests, a *corresponding* response should follow, and the reply number must be odd for an even request ID or even for an odd request ID"'

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

Actions:

The Off-line Monitoring Verdicts

Read packets

ID:2

N:

Off-line Tester Storing queue / Memory

Actions:

Read REQ with ID = 2

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:2

N:

Actions:

Store packet in the requests to be replied queue

The Off-line Monitoring Verdicts

Read packets

ID:3

N:

Off-line Tester Storing queue / Memory

ID:2

N:

Actions:

Read REQ with ID = 3

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:2	**ID:3**
N:	N:

Actions:

Store packet in the requests to be replied queue

The Off-line Monitoring Verdicts

Read packets

ID:4

N:

Off-line Tester Storing queue / Memory

ID:2 **ID:3**

N: N:

Actions:

Read REQ with ID = 4

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:

Store packet in the requests to be replied queue

The Off-line Monitoring Verdicts

Read packets

ID:2

N: 77

Off-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:

Read RES with ID = 2

The Off-line Monitoring Verdicts

Read packets

ID:2

N: 77

Off-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:

Check to which stored packet it *corresponds*

The Off-line Monitoring Verdicts

Read packets

ID:2

N: 77

Off-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:

Verify the property

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:
Report PASS (+)

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:3	**ID:4**
N:	N:

Actions:
Remove corresponding stored packet from the stored requests queue

The Off-line Monitoring Verdicts

Read packets

ID:4

N: 89

Off-line Tester Storing queue / Memory

ID:3	**ID:4**
N:	N:

Actions:

Read RES with ID = 4

The Off-line Monitoring Verdicts

Read packets

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Read packets

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ID:3	**ID:4**
N:	N:

Actions:
Report PASS (+)

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:3

N:

Actions:

Remove corresponding stored packet from the stored requests queue

The Off-line Monitoring Verdicts

Read packets

ID:21

N:

Off-line Tester Storing queue / Memory

ID:3

N:

Actions:

Read REQ with ID = 21

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:

Store packet in the requests to be replied queue

The Off-line Monitoring Verdicts

Read packets

ID:21

N: **101**

Off-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:

Read RES with ID = 21

The Off-line Monitoring Verdicts

Read packets

ID:21

N: **101**

Off-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:

Check to which stored packet it *corresponds*

The Off-line Monitoring Verdicts

Read packets

ID:21

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Off-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:

Verify the property

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:
Report FAIL (-)

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:3

N:

Actions:

Remove corresponding stored packet from the stored requests queue

The Off-line Monitoring Verdicts

Read packets

EOT

(end of trace)

Off-line Tester Storing queue / Memory

ID:3

N:

Actions:

Read EOT

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

ID:3

N:

Actions:

For each packet left on memory report **?** (Attention! грильяж is on the line!)

The Off-line Monitoring Verdicts

Read packets

Off-line Tester Storing queue / Memory

Actions:
Report INCONCLUSIVE (?)! (What if the trace was cut before the packet arrived?)

The Off-line Monitoring Verdicts (cont.)

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1. Find a partially matching packet (for our previous example it translates to find a matching REQ/RES ID)
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1. Find a partially matching packet (for our previous example it translates to find a matching REQ/RES ID)
2. Verify the property (for our previous example it translates to verifying the odd/even even/odd property)

- If the verification is performed in a single stage (for our previous example to check for a matching packet and the matching packet shouls hold the even/odd odd/even property), non-matched packets will output an inconclusive verdict

Off-line Monitoring Resource Consumption

[1] At least the necessary stored elements

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  - The total number of checks can be split with a parallel algorithm

[1] At least the necessary stored elements

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

Actions:

The On-line Monitoring Verdicts

Incoming (live) packets

ID:2

N:

On-line Tester Storing queue / Memory

Actions:

Read REQ with ID = 2

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:2

N:

Actions:

Store packet in the requests to be replied queue

The On-line Monitoring Verdicts

Incoming (live) packets

ID:3

N:

On-line Tester Storing queue / Memory

ID:2

N:

Actions:

Read REQ with ID = 3

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:2	**ID:3**
N:	N:

Actions:

Store packet in the requests to be replied queue

The On-line Monitoring Verdicts

Incoming (live) packets

ID:4

N:

On-line Tester Storing queue / Memory

ID:2 **ID:3**

N: N:

Actions:

Read REQ with ID = 4

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:
Store packet in the requests to be replied queue

The On-line Monitoring Verdicts

Incoming (live) packets

ID:2

N: 77

On-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:

Read RES with ID = 2

The On-line Monitoring Verdicts

Incoming (live) packets

ID:2

N: 77

On-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:

Check to which stored packet it *corresponds*

The On-line Monitoring Verdicts

Incoming (live) packets

ID:2

N: 77

On-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:

Verify the property

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:2	**ID:3**	**ID:4**
N:	N:	N:

Actions:
Report PASS (+)

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3	**ID:4**
N:	N:

Actions:
Remove corresponding stored packet from the stored requests queue

The On-line Monitoring Verdicts

Incoming (live) packets

ID:4

N: 89

On-line Tester Storing queue / Memory

ID:3	**ID:4**
N:	N:

Actions:

Read RES with ID = 4

The On-line Monitoring Verdicts

Incoming (live) packets

ID:4

N: 89

On-line Tester Storing queue / Memory

ID:3	**ID:4**
N:	N:

Actions:

Check to which stored packet it *corresponds*

The On-line Monitoring Verdicts

Incoming (live) packets

ID:4

N: 89

On-line Tester Storing queue / Memory

ID:3	**ID:4**
N:	N:

Actions:

Verify the property

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3	**ID:4**
N:	N:

Actions:
Report PASS (+)

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3

N:

Actions:

Remove corresponding stored packet from the stored requests queue

The On-line Monitoring Verdicts

Incoming (live) packets

ID:21

N:

On-line Tester Storing queue / Memory

ID:3

N:

Actions:

Read REQ with ID = 21

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:

Store packet in the requests to be replied queue

The On-line Monitoring Verdicts

Incoming (live) packets

ID:21

N: **101**

On-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:

Read RES with ID = 21

The On-line Monitoring Verdicts

Incoming (live) packets

ID:21

N: **101**

On-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:

Check to which stored packet it *corresponds*

The On-line Monitoring Verdicts

Incoming (live) packets

ID:21

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On-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:

Verify the property

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3	**ID:21**
N:	N:

Actions:
Report FAIL (-)

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3

N:

Actions:

Remove corresponding stored packet from the stored requests queue

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3

N:

Actions:

What's next?

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3

N:

Actions:

Wait. . . wait until another packet comes (live capture)

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3

N:

Actions:

Until when do we wait? What do we do with this left-alone packet (grilyazh question)

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

ID:3

N:

Actions:

Until a determined **timeout**

The On-line Monitoring Verdicts

Incoming (live) packets

On-line Tester Storing queue / Memory

Actions:
after the determined timeout, report TIME_FAIL (!)

The On-line Monitoring Verdicts (cont.)

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Timeouts

- Timeouts can be treated as a global timeout or per prototype (for better control when to "discard" a packet)

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- Timeout function runs in parallel. Verifies all the packets in all the queues and deletes the those packets that the time in the queue is bigger than the associated timeout

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- A great idea! However, concurrent access to stored packet queues can make implementations error prone (good luck in your laboratory (:)

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- A great idea! However, concurrent access to stored packet queues can make implementations error prone (good luck in your laboratory (:)
- Just kidding, I will provide you with a library :) (good luck to me making your laboratory):)

Two stage verification

Two stage verification

1-stage verification

TWO STAGE VERIFICATION

1-stage verification

```
if REQ
(
   REQ->VSNP->Num = NULL
)
then RES>REQ
(
   RES->TCP->srcP = 1010 &
   RES->VSNP->Num % 2 = 0 &
   RES->IP->srcIP = REQ->IP->dstIP &
   REQ->VSNP->ID = RES->VSNP->ID &
   REQ->VSNP->ID %2 != 0
)
```

TWO STAGE VERIFICATION

1-stage verification

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if REQ
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Two stage verification

1-stage verification

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)
```

2-stage verification

```
if
(
   if REQ
   (
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   )
   then RES>REQ
   (
      RES->TCP->srcP = 1010 &
      RES->IP->srcIP = REQ->IP->dstIP &
      REQ->VSNP->ID = RES->VSNP->ID
   )
)
then VAL
(
   RES->VSNP->Num % 2 = 0 &
   REQ->VSNP->ID %2 != 0
)
```

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Specific Requirements:

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Specific Requirements:

- On-line needs to have better performance so that its processing can be "keep-up" with the generated data

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- In Essence, when to verify properties over the collected traces (of course not saved to a file if it is on-line)
- On-line is supposed to provide information ASAP. To provide information in 10ms is better than 3h.
- Off-line is targeted to check conformance of the implementations over long periods of time

Specific Requirements:

- On-line needs to have better performance so that its processing can be "keep-up" with the generated data
- Off-line needs to guarantee better fault (or property violation) coverage

Distributed Passive Testing Techniques
(using Network Traces)

Distributed Network Monitoring

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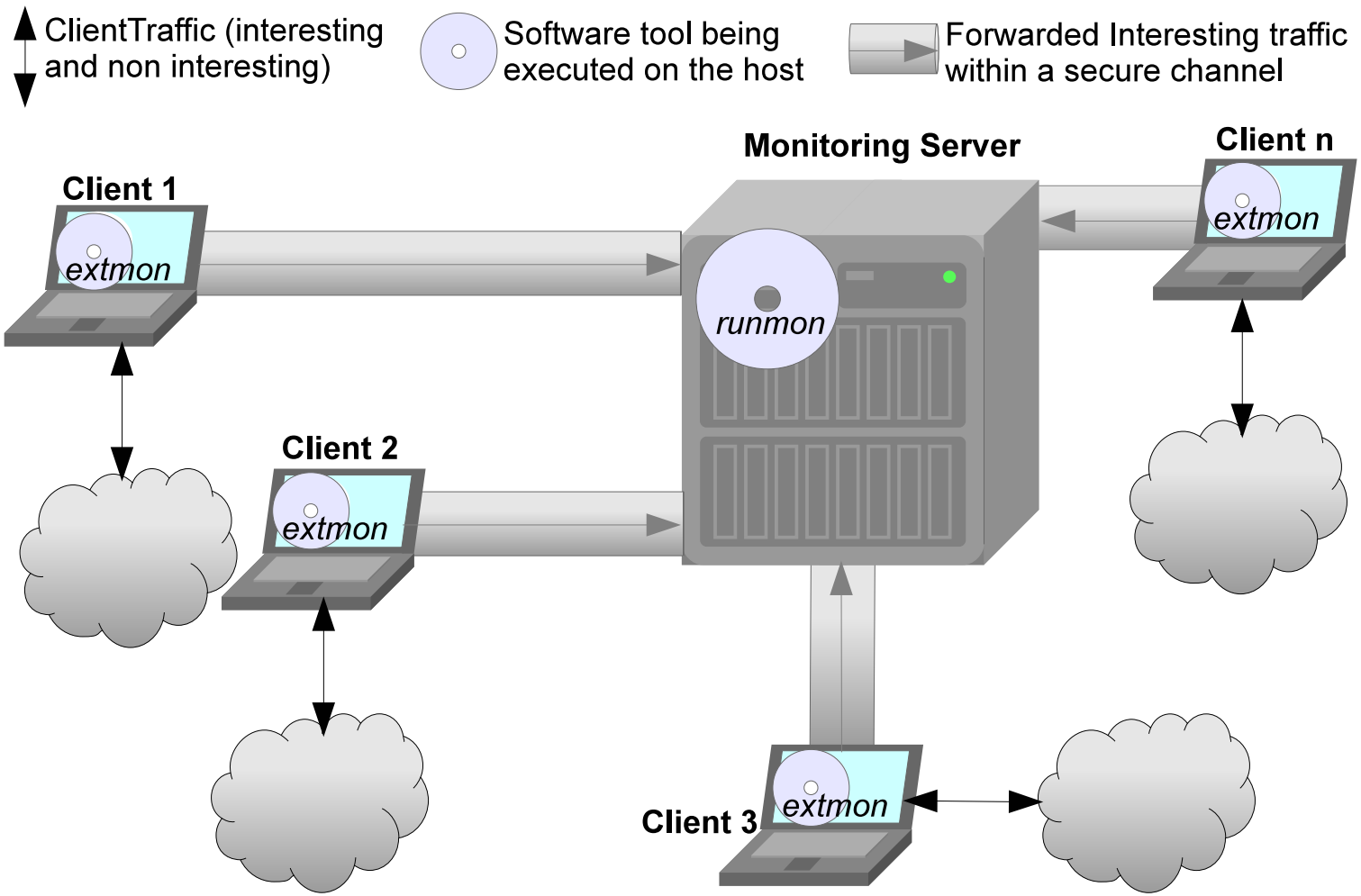
Architecture

- Under the assumption that all traces from all P.O.s are necessary to evaluate the property, a tester that collects all those traces is necessary, therefore a centralized tester
- All P.O.s (or clients) should send the filtered traffic to the centralized tester (yes, this is the tool which I should upload to a repo)

Distributed Network Monitoring (cont.)

Architecture



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Time synchronization

- It represents one of the most difficult issues to overcome since there is no way to guarantee the chronological arrangement of packets in different P.O.s
- Distributed properties can be guaranteed under the assumption that all hosts are synchronized with an external time server, usign for intance the Network Time Protocol (NTP)

Fundamentals of Packet Analysis Programming

LIBPCAP – THE HOLY LIBRARY TRACE CAPTURE

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- It provides some information about the captured packet (time of capture, size, etc.), and the packet as a block of bytes (unsigned chars)
- It does NOT provide all the passive testing using network traces concepts, prototypes, storing queues, etc.

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```
sip_packet*
   getSIPFromStream(unsigned char stream, int siz)
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- It can be computationally expensive, nonetheless, good algorithms are being studied to perform the property checking. This is an interesting are of research you might be interested
- Many languages exist to describe the properties to check, however, all have shortcomings. Studying a language that can describe such systems can be highly appreciated (specially if it is formal / has an equivalent automata model)

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Спасибо за внимание!