“Non-intrusive” Testing Techniques for Communication Protocols

12^{th} TAROT Summer School, Paris, France

Jorge López
<jorge.lopez[at]telecom-sudparis.eu>
Télécom SudParis / Université Paris-Saclay

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Outline

Acknowledgment...

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- Natalia Kushik
- Stephane Maag
- Gerardo Morales
- Nina Yevtushenko

Спасибо! ¡Gracias! Merci !

I would also like to thank all the speakers of TAROT, including students. Your presentations were fantastic and will enrich this presentation.

Motivation

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WhatsApp

Important

Testing is crucial for such systems (or applications)!

"NON-INTRUSIVE" TESTING OF COMMUNICATION SYSTEMS

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Reasons not to interfere the system?

- The data on the system are susceptible towards the execution of tests
- Certain functionality is not available if "real" data are not processed
- Even if a system can be interrupted, we might *want* to test the "real" service / application / data

Methods for Non-Intrusive Testing

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Let’s take a look at each of them… “**on y va**”

Static Code Analysis 101

STATIC ANALYSIS

```
/*Test equal distribution of random number generation algorithm*/
#include <stdio.h>
#include <stdlib.h>
#define NUM 30
#define MEM_SIZE 512*1024 //512MB
int main()
{
        short i = 0 , j;
        long acc = 0;
        char *numbers = malloc(MEM_SIZE);
        if(!numbers)
        {
                printf(``Can't allocate memory\n'');
                exit(-1);
        }
        while (1)
        {
                numbers[i] = rand() % NUM ;  //random numbers from 0 - NUM
                acc = 0;
                for (j = 0; j < i; j++)
                        acc += numbers[j];
                printf(``New average: %ld\n'',  acc/++i); //should converge to NUM/2
        }
}
```

Do you see any problems with the code?

Static Analysis (cont.)

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Hard to see, hard to detect (iteration # 32,768)

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    $(())()()((()))$ violates the property, but $((()))()$ does not (i.e., is valid)

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    For $N = 2, m = 2$, $()()()$ violates the property, and $()(())((()))$ does not
  - For a more complex grammar there is much more fun :)
- Let's look at more real-world examples…

Static Analysis for security properties

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- Works by supplying data to users which can lead to insecure actions, executing unwanted javascript, or adding a sub-site filled with publicity or others

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XSS

- Works by supplying data to users which can lead to insecure actions, executing unwanted javascript, or adding a sub-site filled with publicity or others
- Simple example: in a forum, users are allowed to insert comments. If the comment is displayed as-it-is, an attacker might successfully inject malicious code that will affect the forum users

Static Analysis for security properties II

SQLI

Static Analysis for security properties II

SQLI

- Essentially works by supplying data to the database for executing undesired actions, e.g., a user inputs a search criterion, and the database looks for the users matching this criterion:

  ```
  SELECT * from users where name='$CRIT';
  ```

  What if the criterion is:

  ```
  a'; DROP TABLE users
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STATIC ANALYSIS FOR SECURITY PROPERTIES II

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How to prevent this attack using static analysis?

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How to prevent this attack using static analysis?

- A very simple approach is to guarantee that a **sanitization** function is called before the storing or displaying the input. Many languages provide such built-in functions, e.g., PHP provides the htmlspecialchars() function

Static Analysis for security properties III

Buffer Overflow

STATIC ANALYSIS FOR SECURITY PROPERTIES III

Buffer Overflow

- The canonical example:

```
#include <string.h>
#define BUFFSIZE 100
void load (char *userdata){
   char  buff[BUFFSIZE];
   strcpy(buff, userdata);  //not good
}

int main (int argc, char **argv){
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- A string which is longer than BUFFSIZE will be written into the memory space of the function load, potentially overwriting the return address
- A string which contains code and the memory address of this code in the position of the return address will do the trick

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How to perform static analysis (SA)?

Static Analysis Principles

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Static Analysis is?

- The analysis of source code is performed by a static analyzer without executing the program under test
- The code is assumed to be compilable, thus we do not look for lexical, syntactical, or *type* errors that a compiler finds

Static Analysis Principles (cont.)

How do we analyze the source code then?

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STATIC ANALYSIS PRINCIPLES (CONT.)

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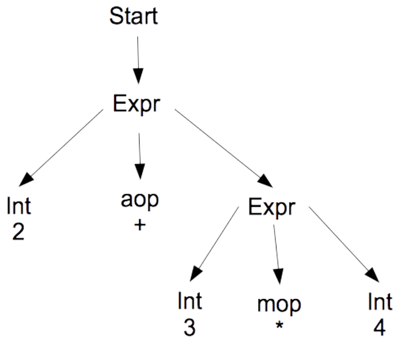
A parser…

- Can be generated automatically by a parser generator (takes a context free grammar (CFG) as an input and produces a parser)
- Takes a CFG production (a sentence / source code) and produces a "parse tree"

An AST

AST for $2 + 3 * 4$



Dataflow Analysis

Mainly cares about data flow and data dependencies

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   int y = 10;
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   if(x > 10){
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   print(z);
}
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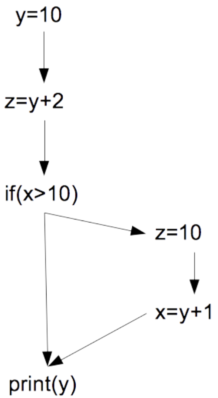
How can Dataflow analysis help us?

Dataflow Analysis — Forward Analysis

The data flow



Dataflow Analysis — Forward Analysis

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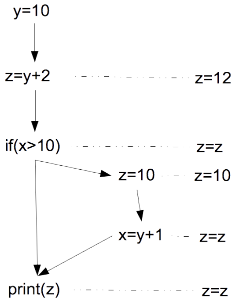

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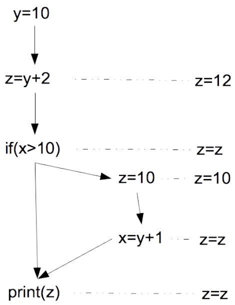

Potential values

Dataflow Analysis — Forward Analysis

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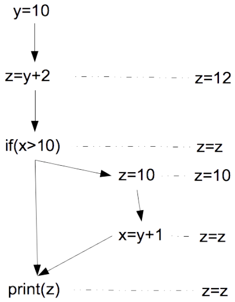

Potential values

- Negative array indices

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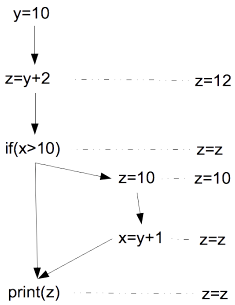
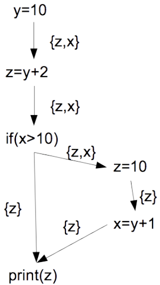


Potential values

- Negative array indices
- Closed DB connections

Dataflow Analysis — Backward Analysis

The data flow



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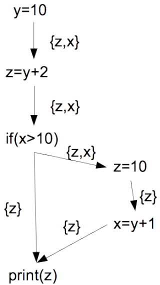

Data dependencies

Dataflow Analysis — Backward Analysis

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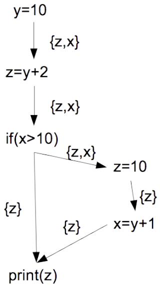

Data dependencies

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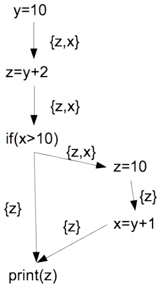

Data dependencies

- Useful for security testing
- Useful for dead code elimination

Dataflow Analysis — Control Flow Graph

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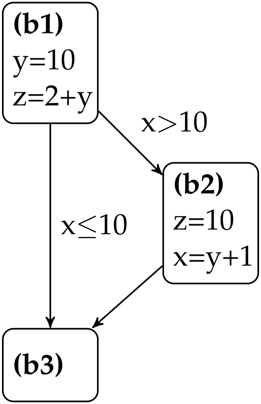
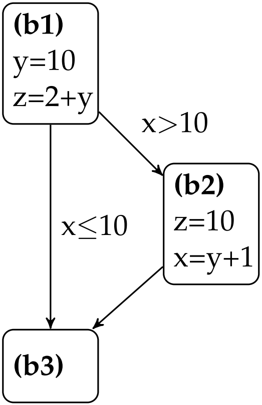
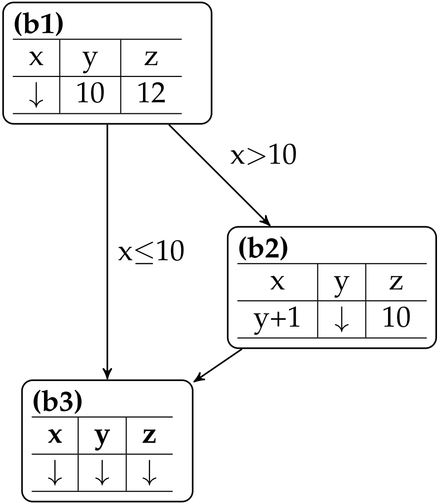
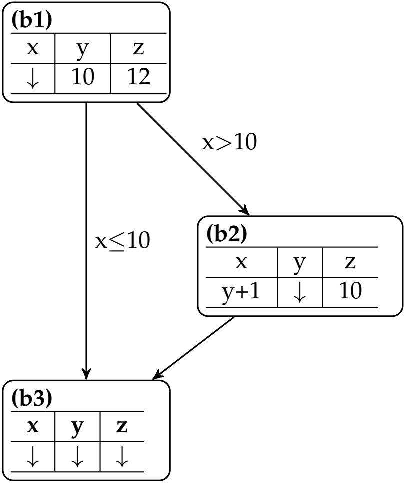


Dataflow notions



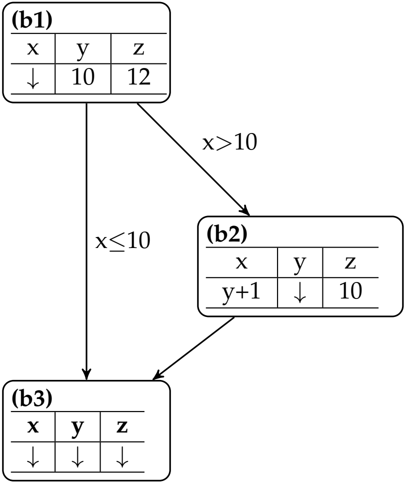


Dataflow notions (2)



Putting inputs and outputs…

Dataflow notions (2)



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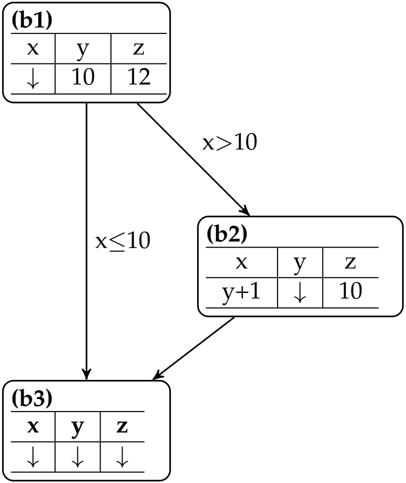
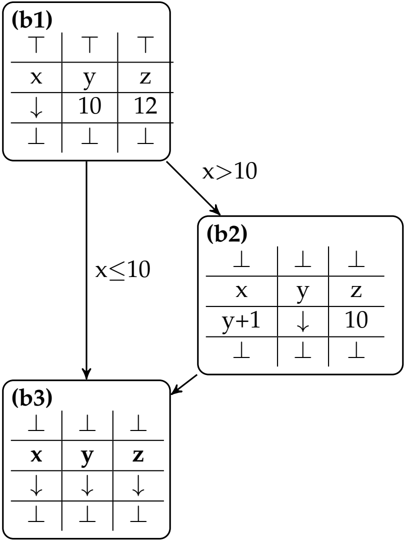


Putting inputs and outputs...

- Assume ⊥ = not enough information
- Assume ⊤ = "too much" information (all possible values)

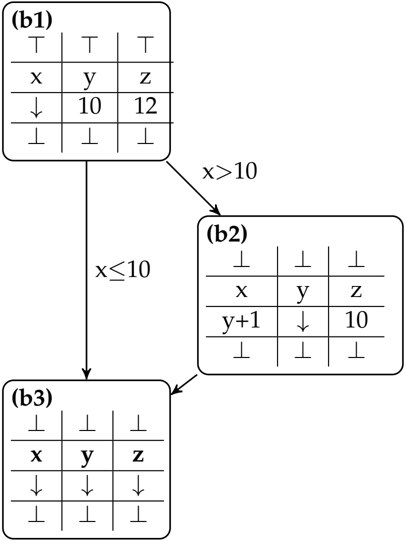
Dataflow notions (2)



Putting inputs and outputs...

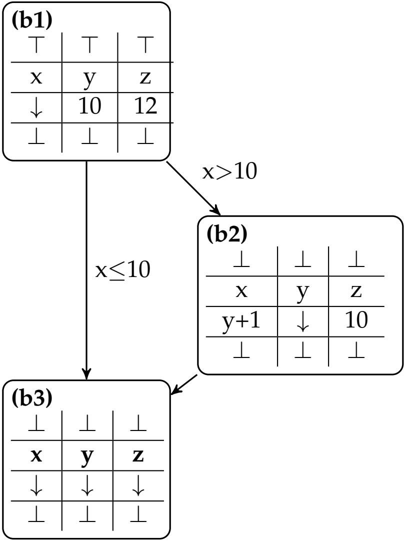
- Assume $\bot$ = not enough information
- Assume $\top$ = "too much" information (all possible values)

Dataflow Notions — The propagation game



Propagation…

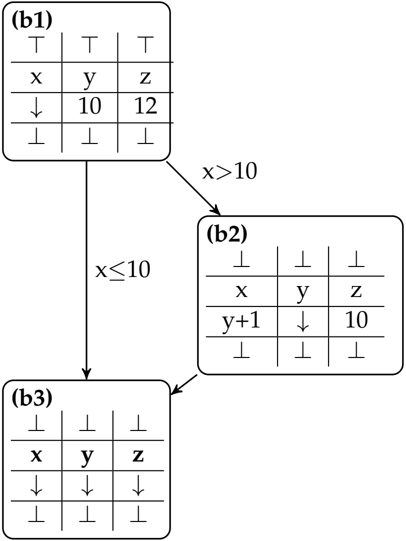
Dataflow Notions — The propagation game



Propagation…

- Propagate from inputs to outputs

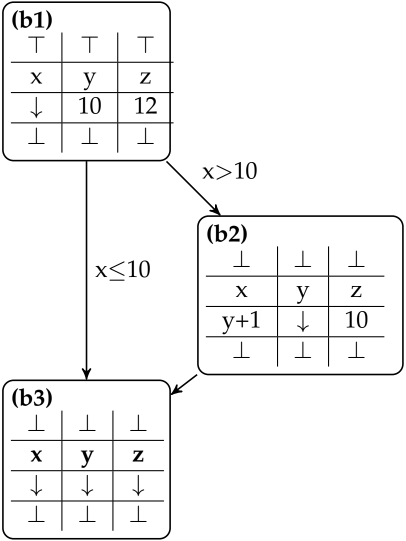
Dataflow Notions — The propagation game



Propagation…

- Propagate from inputs to outputs
- From one block to another

Dataflow Notions — The propagation game



Propagation…

- Propagate from inputs to outputs
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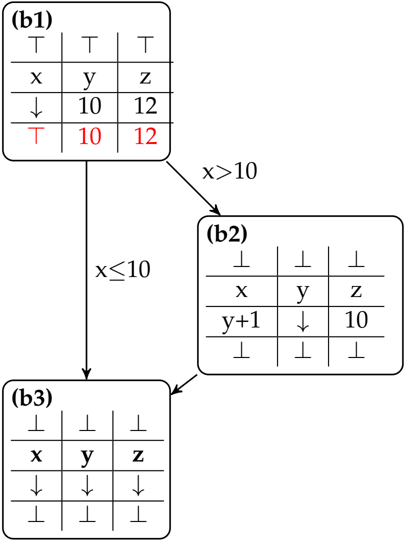
- *Join* the inputs

Dataflow Notions — The propagation game

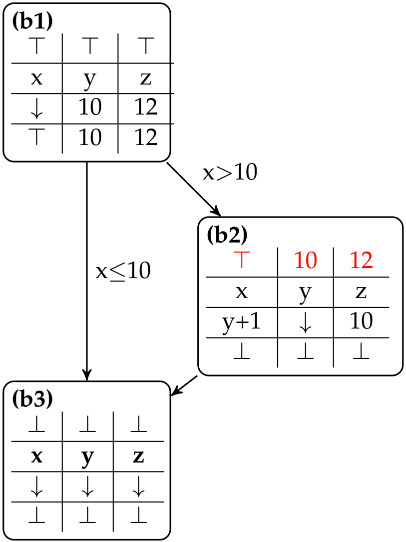


Propagation…

- Propagate from inputs to outputs
- From one block to another
- *Join* the inputs

(b1)

DATAFLOW NOTIONS — THE PROPAGATION GAME



Propagation…

- Propagate from inputs to outputs
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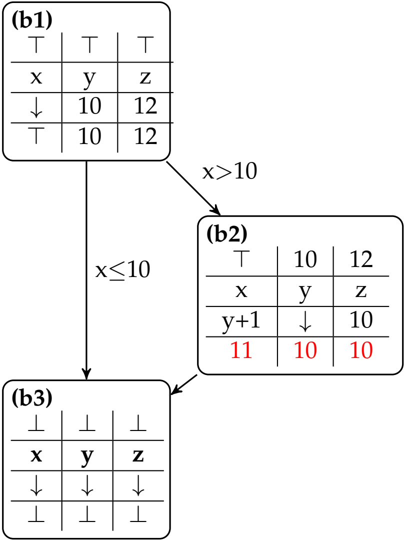
- *Join* the inputs

(b2)

Dataflow Notions — The propagation game



Propagation…

- Propagate from inputs to outputs
- From one block to another
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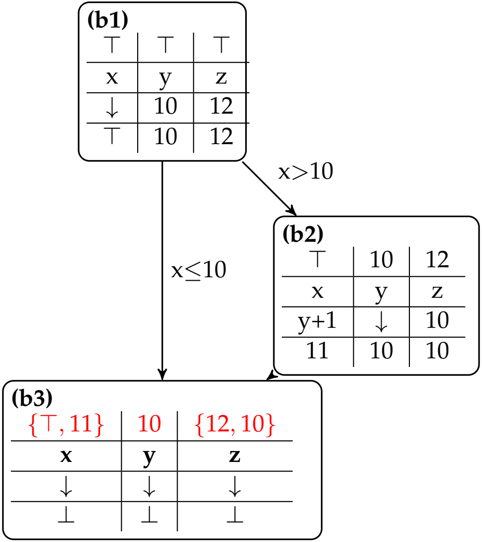
(b2)

DATAFLOW NOTIONS — THE PROPAGATION GAME



Propagation…

- Propagate from inputs to outputs
- From one block to another
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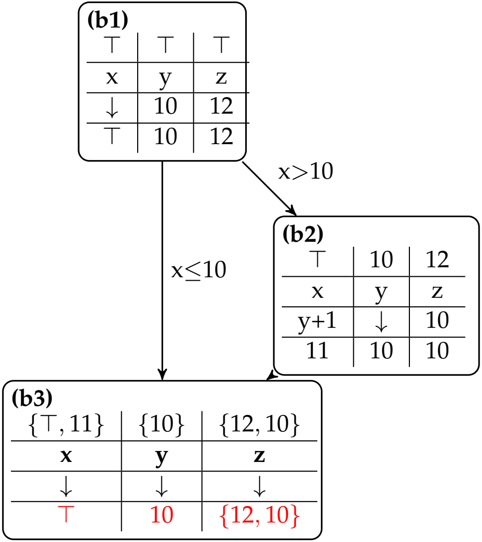
(b3)

Dataflow Notions — The propagation game



Propagation. . .

- Propagate from inputs to outputs
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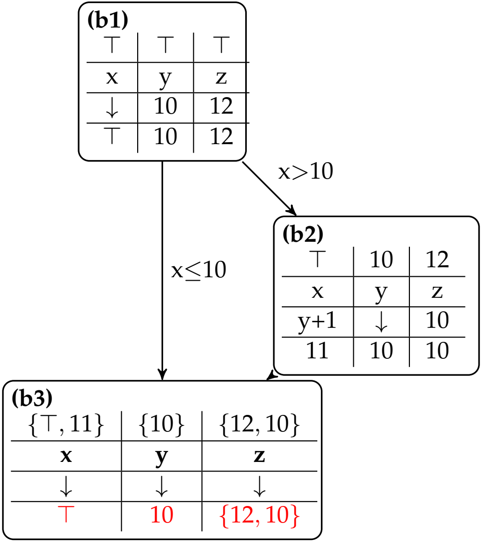
(b3)

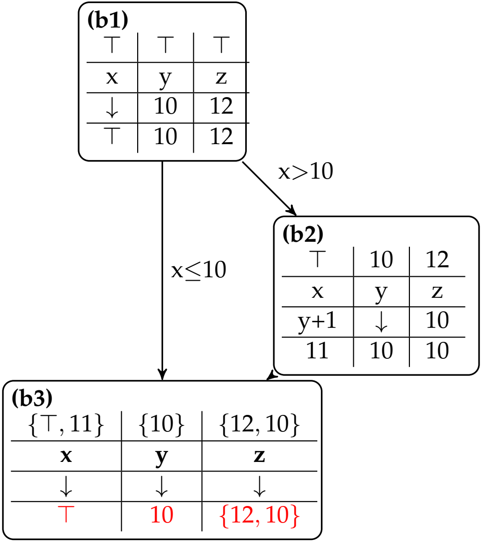
DATAFLOW NOTIONS — THE PROPAGATION GAME



Value Analysis

Yup... that's what we did

Dataflow Notions — The propagation game



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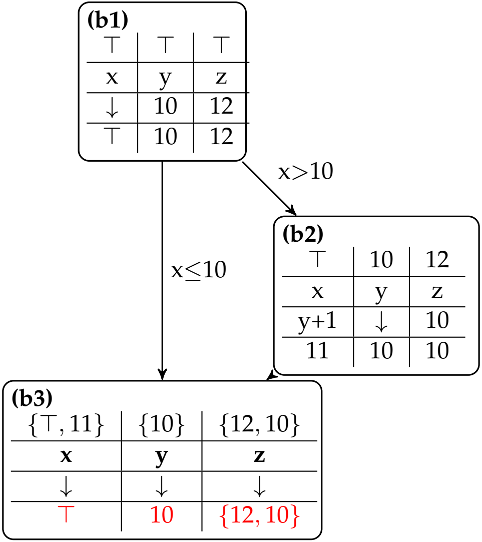
- y=10 is truth for all execution paths
  Optimizations: constant propagation (less calculations), removal of y (smaller stack consumption)

Dataflow Notions — The propagation game



Value Analysis

Yup... that's what we did

- y=10 is truth for all execution paths
  Optimizations: constant propagation (less calculations), removal of y (smaller stack consumption)
- $z \in \{10, 12\}$
  Optimizations: smaller data type of z; perhaps this might be further used to verify that all functions return values between $[11 - 20]$?

Dataflow Analysis Basics

Lattice $\mathcal{L}$ (The analysis domain)

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- $\forall x, y \in \mathcal{L}, \exists x \vee y(\text{sup})$ & $\exists x \wedge y(\text{inf})$
- If $\forall \mathcal{S} \subseteq \mathcal{L}, \exists \vee \mathcal{S}(\textit{greatest element } \top)$ & $\wedge \mathcal{S}(\textit{least element } \bot)$ $\mathcal{L}$ is a complete lattice
  - $x_0 \leq x_1 \leq x_2 \ldots \implies \exists n : x_n = x_{n+1} = x_{n+2} = \ldots$
    Ensures ascending chain condition (no infinite progress)

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- Output $out_b = f_b(in_n)$ is calculated with a transfer function
- in_b = denotes inputs of b, $in_b = \vee\{out_m | m \in pred(b)\}$ (usually $\vee = \cup$)

Dataflow Analysis Basics (cont.)

Requirements

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- The *join* operation $\vee$ must not lose information: $\vee(x, y) \supseteq x$ and $\vee(x, y) \supseteq y$

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Necessary conditions for termination!

- Previous requirements + ascending chain condition

DATAFLOW ANALYSIS BASICS (CONT.)

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Necessary conditions for termination!

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We won't see proofs

- However, this is certainly proven and easy to find…

Data Analysis Basics — Calculation Algorithm

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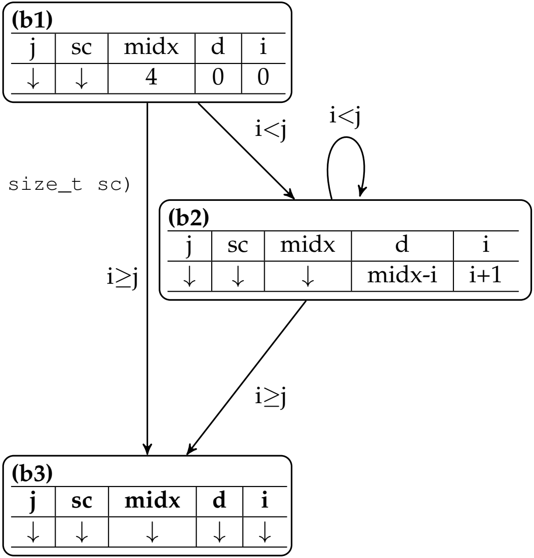
Maximal Fixed Point algorithm

for all $b \in B$ **do**
    $out_b \leftarrow f_b(\perp)$
end for
$in_{b0} \leftarrow \mathcal{I}$ //$\mathcal{I}$=initialization ($\top . \perp, \emptyset$ are usual)
$out_{b0} \leftarrow f_{n0}(I)$
worklist$\leftarrow B \setminus \{b0\}$
while worklist $\neq \emptyset$ **do**
    $b \leftarrow$ pop(worklist)
    $in_b \leftarrow \vee\{out_m | m \in pred(b)\}$
    $out_b \leftarrow f_b(in_b)$
    if out_b changed **then**
        worklist $\leftarrow$ worklist $\cup$ b
    end if
end while

Dataflow Analysis — Sign Analysis Example

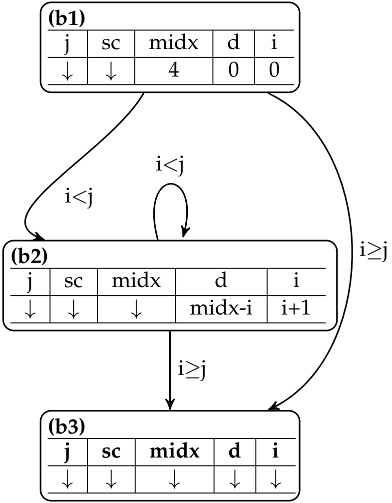
```
void bk (int j, char c[], size_t sc)
{
   size_t midx = 4;
   int d = 0,i =0;
   while(i< j)
   {
       d = midx - i;
      c[d] = i;
      i++;
   }
}
```



Dataflow Analysis — Sign Analysis Example (2)

Lattice $\mathcal{L}$ is defined over the set of all subsets of $\{-, 0, +\}$ and $\subseteq$

- $\vee = \cup$
  $\top \in \{+, -\}$
  $\bot =$ no information yet
- Operations over $\mathcal{L}$
  - Addition($\bigoplus$) and multiplication ($\bigotimes$) of lattice values:
    $\{-\} \bigoplus \{+\} =$
    $\{-, 0, +\} \wedge \{0\} \bigoplus \{+\} =$
    $\{+\} \wedge \{-\} \bigoplus \{-\} \wedge \ldots$
- $f_b \in F$ use operations + sign of constants



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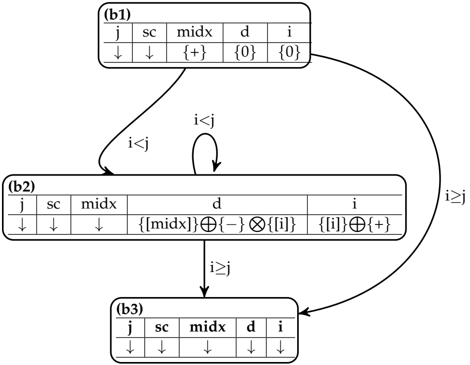

Dataflow Analysis — Sign Analysis Example (3)

for all $b \in B$ **do**
  $out_b \leftarrow f_b(\perp)$
end for
$in_{b0} \leftarrow \mathcal{I}$ //$\mathcal{I}$=initialization
($\top.\perp, \emptyset$ are usual)
$out_{b0} \leftarrow f_{n0}(I)$
worklist$\leftarrow B \setminus \{b0\}$
while worklist $\neq \emptyset$ **do**
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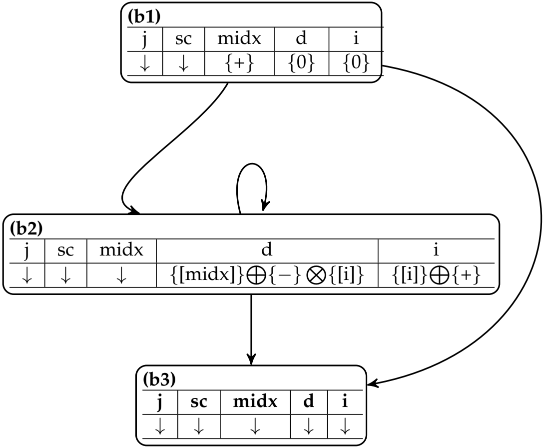
$in_b \leftarrow \vee\{out_m | m \in pred(b)\}$
  $out_b \leftarrow f_b(in_b)$
  if out_b changed **then**
    worklist $\leftarrow$ worklist
$\cup$ b
  end if
end while



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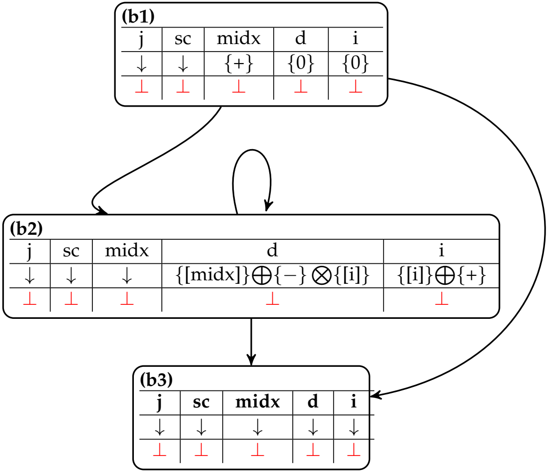

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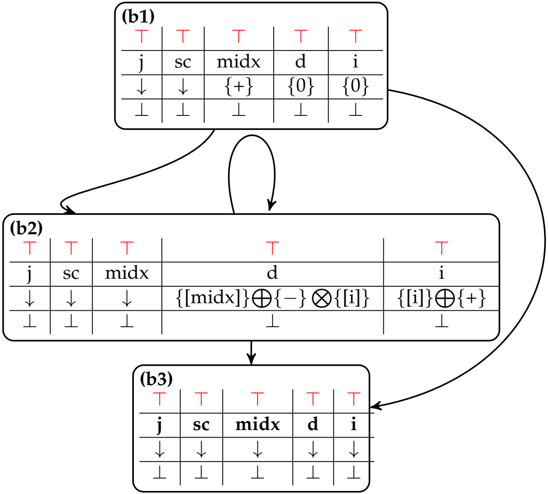

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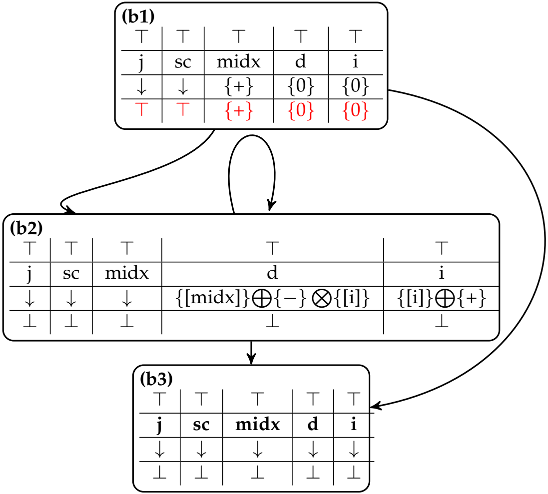

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$in_b \leftarrow \vee\{out_m | m \in pred(b)\}$
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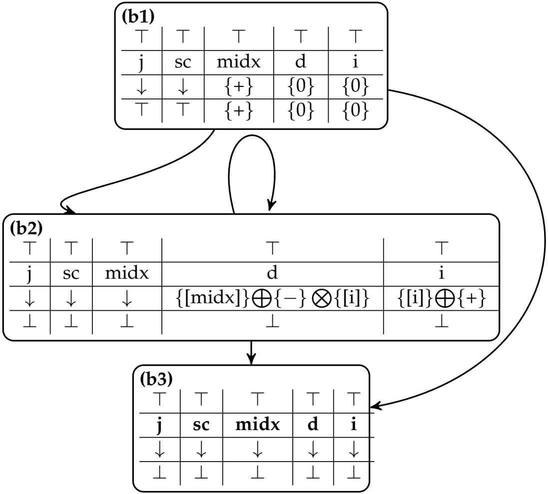
  if out_b changed **then**
    worklist $\leftarrow$ worklist
$\cup$ b
  end if
end while



DATAFLOW ANALYSIS — SIGN ANALYSIS EXAMPLE (3)

for all $b \in B$ **do**
  $out_b \leftarrow f_b(\bot)$
end for
$in_{b0} \leftarrow \mathcal{I}$ //$\mathcal{I}$=initialization
($\top.\bot, \emptyset$ are usual)
$out_{b0} \leftarrow f_{n0}(I)$
worklist$\leftarrow \{b2, b3\}$
while {b2,b3} $\neq \emptyset$ **do**
  $b \leftarrow$ pop(worklist)

$in_b \leftarrow \vee\{out_m | m \in pred(b)\}$
  $out_b \leftarrow f_b(in_b)$
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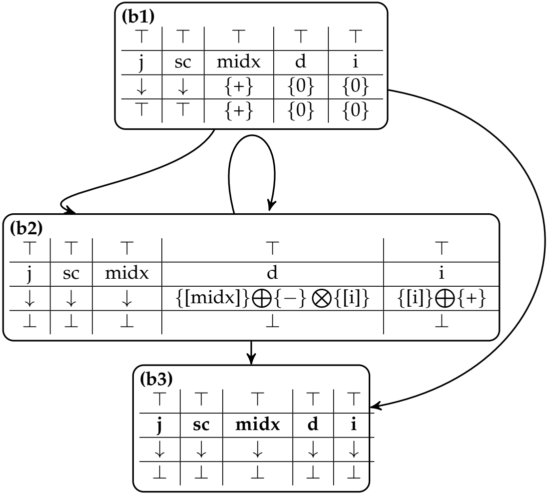

Dataflow Analysis — Sign Analysis Example (3)

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($\top.\bot, \emptyset$ are usual)
$out_{b0} \leftarrow f_{n0}(I)$
worklist$\leftarrow$ $\{b2, b3\}$
while {b2,b3} $\neq \emptyset$ **do**
  $b \leftarrow$ pop({b2,b3}
)//b=b2

$in_b \leftarrow \vee\{out_m | m \in pred(b)\}$
  $out_b \leftarrow f_b(in_b)$
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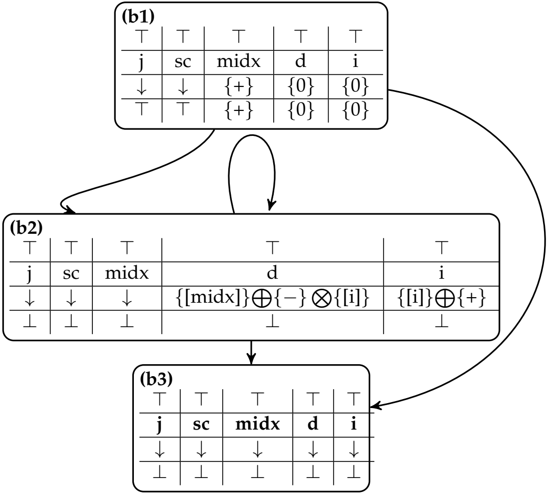

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$out_{b0} \leftarrow f_{n0}(I)$
worklist$\leftarrow \{b2, b3\}$
while {b2,b3} $\neq \emptyset$ **do**
  $b \leftarrow$ pop({b3})

$in_{b2} \leftarrow \vee\{out_m | m \in pred(b2)\}$
  $out_b \leftarrow f_b(in_b)$
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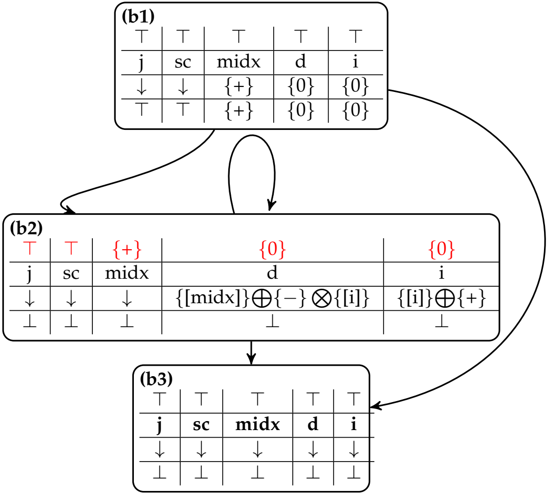

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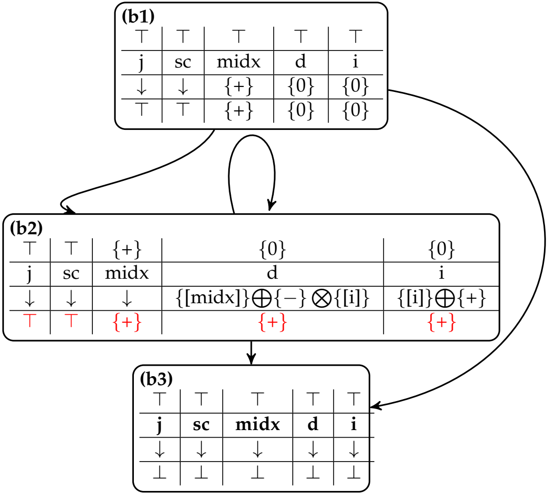

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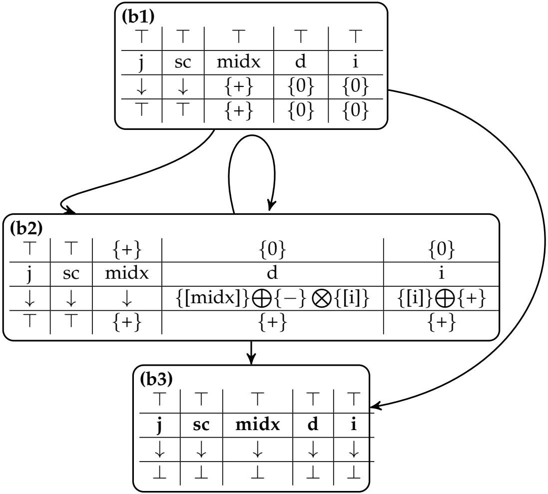

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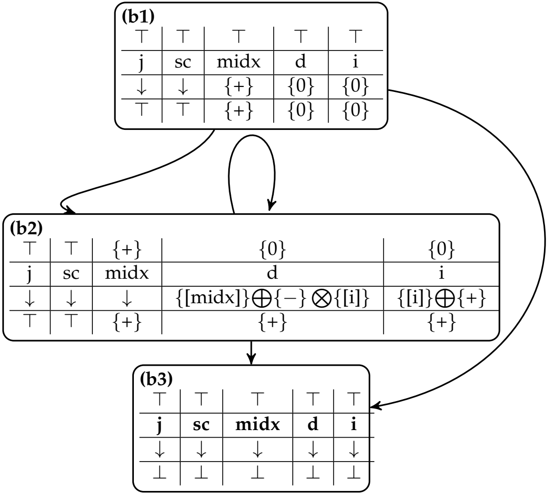
    $b \leftarrow$ pop({b3})

$in_{b2} \leftarrow \vee\{out_m | m \in pred(b2)\}$
    $out_{b2} \leftarrow f_{b2}(in_{b2})$
    if out_{b2} changed **then**
        {b3} ← {b3} ∪ {b2}
    end if
end while



DATAFLOW ANALYSIS — SIGN ANALYSIS EXAMPLE (3)

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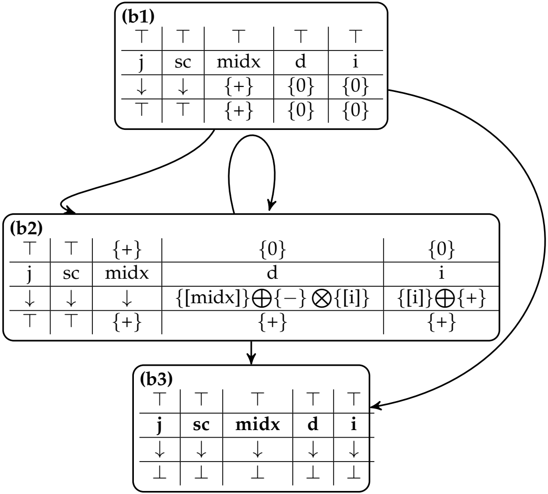

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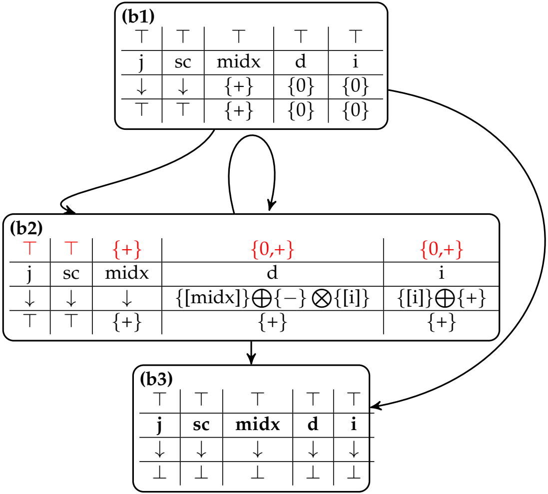

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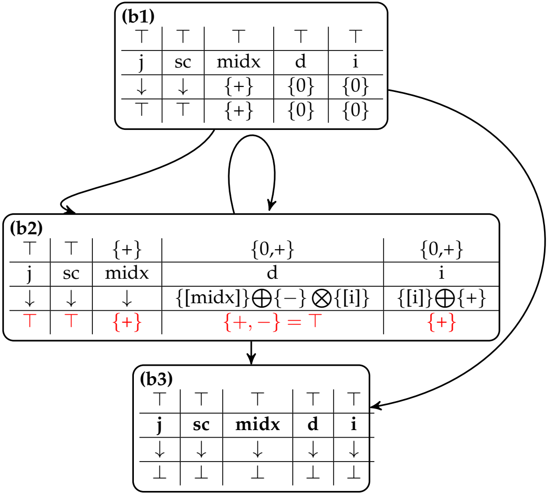

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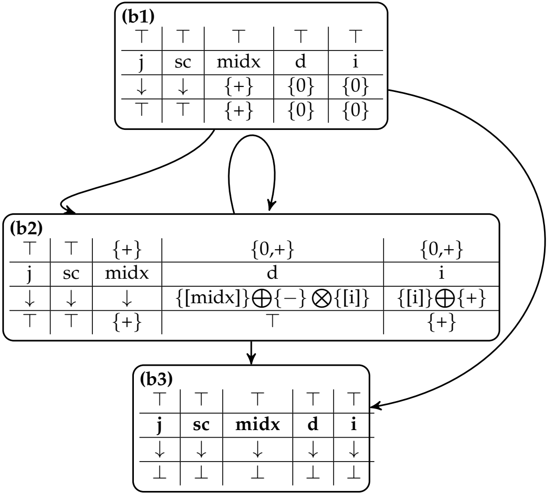

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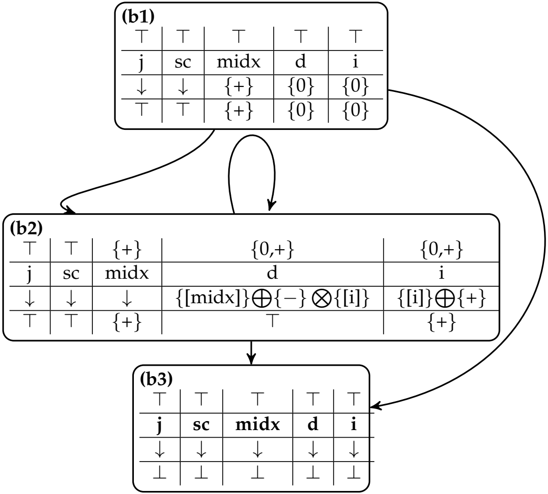

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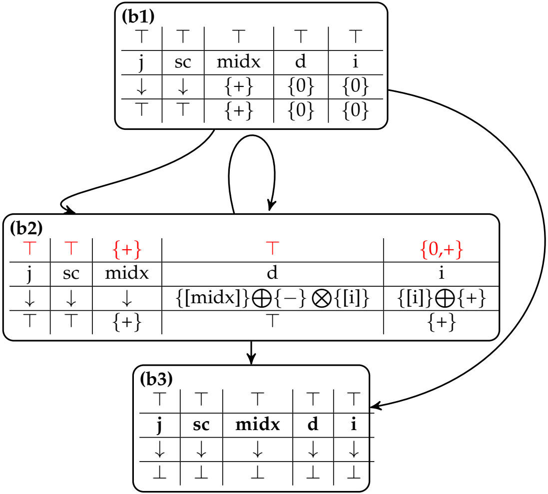

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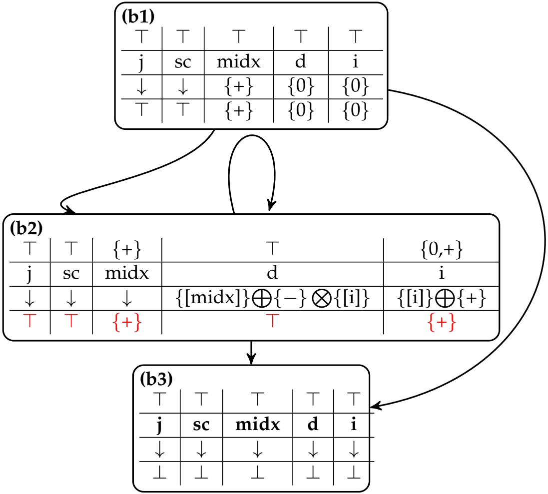

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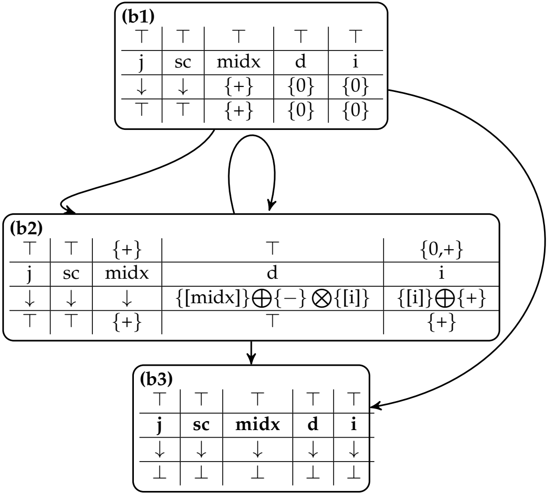

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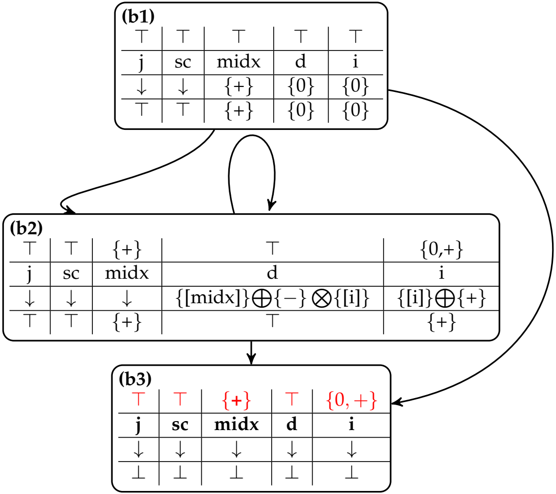

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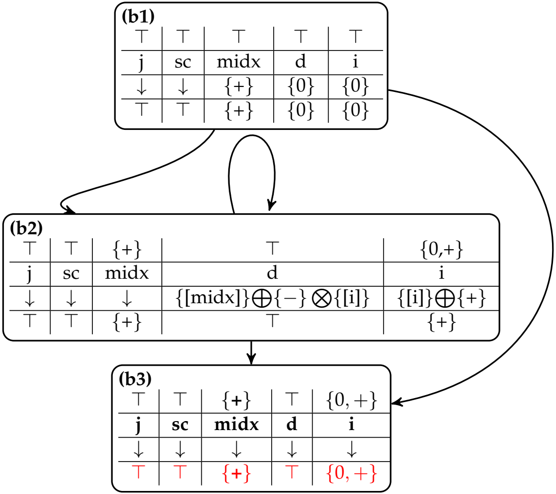

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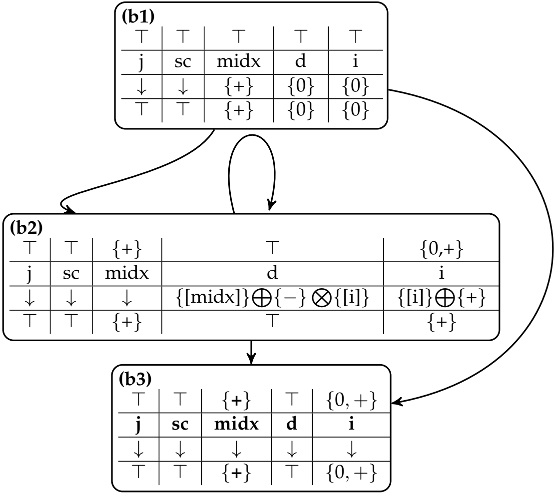

(b1)

⊤	⊤	⊤	⊤	⊤
j	sc	midx	d	i
↓	↓	{+}	{0}	{0}
⊤	⊤	{+}	{0}	{0}

(b2)

⊤	⊤	{+}	⊤	{0,+}
j	sc	midx	d	i
↓	↓	↓	{[midx]}⨁{−}⨂{[i]}	{[i]}⨁{+}
⊤	⊤	{+}	⊤	{+}

(b3)

⊤	⊤	{+}	⊤	{0, +}
j	**sc**	**midx**	**d**	**i**
↓	↓	↓	↓	↓
⊤	⊤	{+}	⊤	{0, +}

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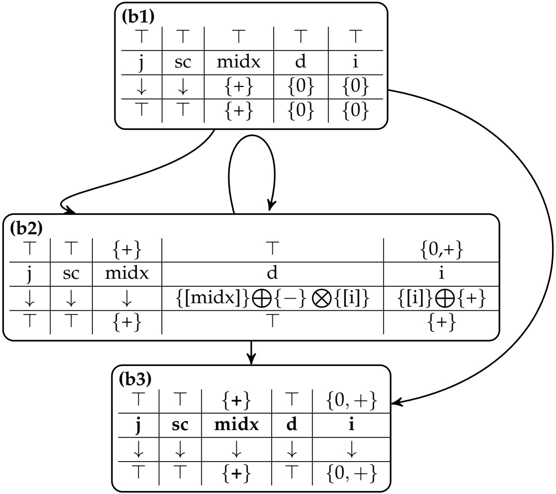

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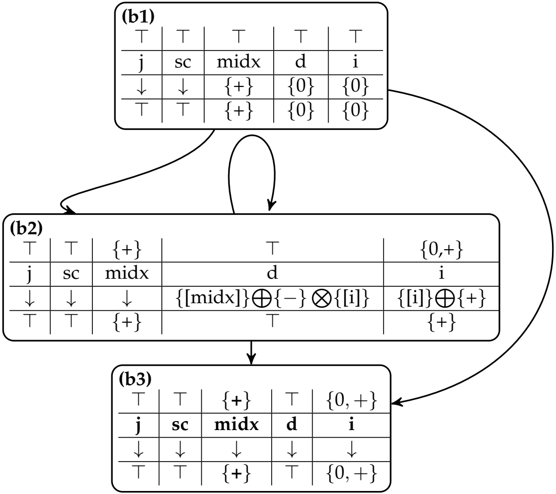

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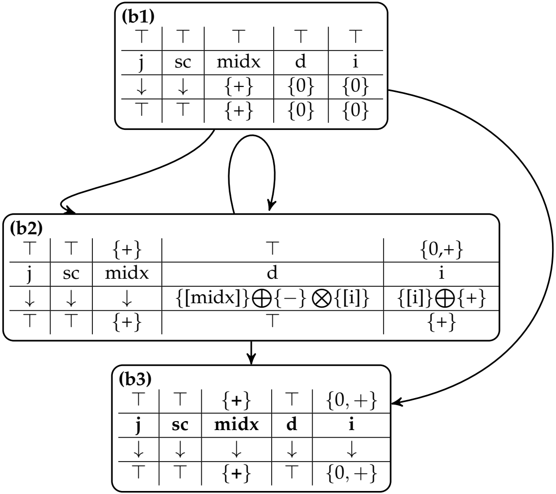

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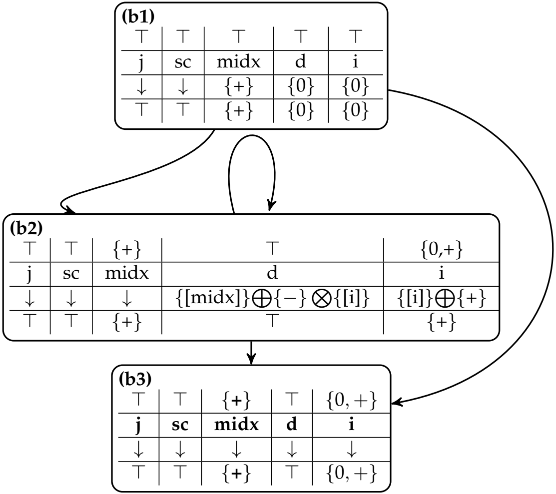

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Possible values:

j	sc	midx	d	i
$\top$	$\top$	$\{+\}$	$\top$	$\{0, +\}$

(specially in b2)

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```
void bk (int j, char c[], size_t sc)
{
    size_t midx = 4;
    int d = 0,i =0;
    while(i< j)
    {
        d = midx - i;
        c[d] = i;
        i++;
    }
}
```

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- There exist other formal approaches, e.g., abstract interpretation

Passive Testing using Network Traces

Architecture(example)

An image, 10^3 words…

ARCHITECTURE(EXAMPLE)

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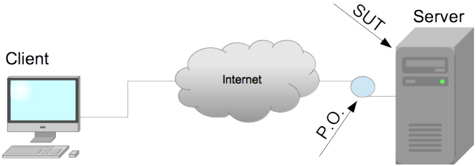

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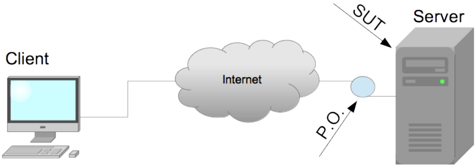

- Direction: From server to client

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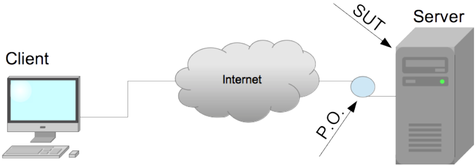

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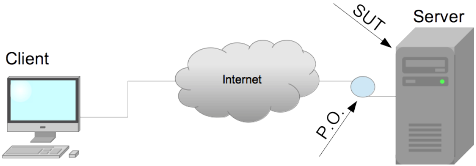

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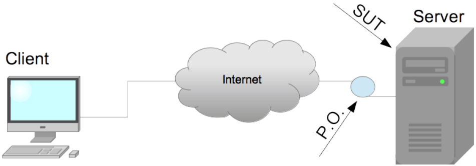

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How do we test this?

Deep Packet Inspection (DPI) 101

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What to do, once certain value is found?

- Report the finding (usually the search targets for prohibited elements)

Deep Packet Inspection (DPI) 102

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- Mostly in firewalls, Intrusion Detection Systems (IDS), and Intrusion Prevention Systems (IPS)

Deep Packet Inspection (DPI) 102

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How to describe which values to search?

- There exist various approaches (Cisco, Snort, etc.), nonetheless, they tend to have common points…

Describing values in DPI

Based on “rules”

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DESCRIBING VALUES IN DPI

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(All the previous rules were written using the syntax of snort)

Stateless and Stateful DPI concepts

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Stateful DPI

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- For example, the FTP data channel get associated to the FTP control channel

Beyond DPI

What if we want more?.. What is more?

Beyond DPI

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  - Every client request has an integer ID
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Passive Testing using Network Traces

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Consider the VSNP protocol and its even/odd, odd/even property

PASSIVE TESTING USING NETWORK TRACES 101

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Consider the VSNP protocol and its even/odd, odd/even property

- Let's take a look at a potential network trace to list some properties

UNDERSTANDING CORRELATED NETWORK INTERACTIONS

Consider the following trace

Understanding correlated network interactions

Consider the following 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

Understanding correlated network interactions

Consider the following 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

Questions

Understanding correlated network interactions

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Questions

- How can two requests / responses be together?

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- What do we do with a non-replied request?

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ID:2	**ID:3**	**ID:4**	**ID:2**	**ID:4**	**ID:21**	**ID:21**
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Questions

- How can two requests / responses be together?
  - As packets go through, the P.O. allows to observe n sequential client(s) requests before a response arrives to the P.O.
- What do we do with a non-replied request?
  - It depends if the analysis is performed on-line or off-line

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

Actions:

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

ID:2

N:

Tester Storing queue / Memory

Actions:

Read REQ with ID = 2

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

ID:2

N:

Actions:

Store packet in the requests to be replied queue

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:3

N:

Tester Storing queue / Memory

ID:2

N:

Actions:

Read REQ with ID = 3

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

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

Actions:

Store packet in the requests to be replied queue

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:4
N:

Tester Storing queue / Memory

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

Actions:
Read REQ with ID = 4

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

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 vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:2
N: 77

Tester Storing queue / Memory

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

Actions:

Read RES with ID = 2

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:2
N: 77

Tester Storing queue / Memory

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

Actions:
Check to which stored packet it *corresponds*

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:2
N: 77

Tester Storing queue / Memory

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

Actions:
Verify the property

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

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

Actions:

Report PASS (+)

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

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

Actions:
Remove corresponding stored packet from the stored requests queue

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

ID:4
N: 89

Tester Storing queue / Memory

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

Actions:
Read RES with ID = 4

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

ID:4
N: 89

Tester Storing queue / Memory

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

Actions:
Check to which stored packet it *corresponds*

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:4
N: 89

Tester Storing queue / Memory

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

Actions:
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THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

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

Actions:
Report PASS (+)

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

ID:3

N:

Actions:

Remove corresponding stored packet from the stored requests queue

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:21

N:

Tester Storing queue / Memory

ID:3

N:

Actions:

Read REQ with ID = 21

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

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

Actions:

Store packet in the requests to be replied queue

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:21
N: **101**

Tester Storing queue / Memory

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

Actions:
Read RES with ID = 21

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:21
N: **101**

Tester Storing queue / Memory

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

Actions:
Check to which stored packet it *corresponds*

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

ID:21
N: **101**

Tester Storing queue / Memory

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

Actions:
Verify the property

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

ID:3	ID:21
N:	N:

Actions:

Report FAIL (-)

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

ID:3

N:

Actions:

Remove corresponding stored packet from the stored requests queue

The On-line vs. Off-line Monitoring Verdicts

Incoming (or read) packets

Tester Storing queue / Memory

ID:3

N:

Actions:

What's next?

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

ID:3

N:

Actions:

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

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

ID:3

N:

Actions:

Until when do we wait? What do we do with this left-alone packet

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

ID:3

N:

Actions:

Until a determined **timeout**

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

Actions:
After the determined timeout, report TIME_FAIL (!) and remove packets whose time stored > timeout

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

ID:3

N:

Actions:

Now assume it was off-line

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

EOT

(end of trace)

Tester Storing queue / Memory

ID:3

N:

Actions:

Read EOT

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

ID:3

N:

Actions:

For each packet left on memory report **?**

THE ON-LINE VS. OFF-LINE MONITORING VERDICTS

Incoming (or read) packets

Tester Storing queue / Memory

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

Correlated network interactions (cont.)

Some conclusions / questions

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CORRELATED NETWORK INTERACTIONS (CONT.)

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- Given the network interactions, each packet can represent a connection in any state (bad, very bad…)

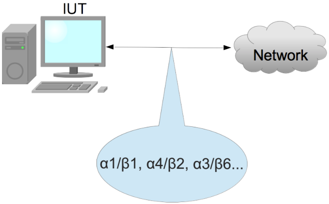
Correlated network interactions (cont.)

Some conclusions / questions

- Given the nature of properties, matching packets cannot be expressed by a regular language
  - How do we express the properties?
- Given the network interactions, each packet can represent a connection in any state (bad, very bad...)
  - How to avoid resource consumption?

Understanding correlated network interactions (cont. 2)

Interaction



Invariants or properties

UNDERSTANDING CORRELATED NETWORK INTERACTIONS (CONT. 2)

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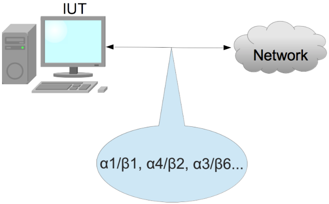

Invariants or properties

- *Test purposes* hold over all the observed network traces

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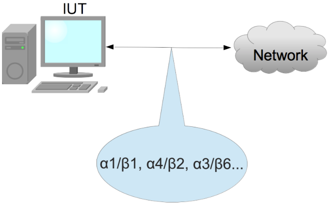

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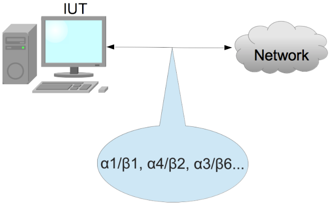

Invariants or properties

- *Test purposes* hold over all the observed network traces
- E.g., $\beta 6$ is not allowed to occur before the occurrence of $\alpha 4$
- There have been proposed **many** languages to express invariants

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  - Examples: XML-based, or others...
  - Concepts behind the languages are more important...

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  - That is, to describe a template of each packet
    Example: a packet that uses TCP in the port 1010 and the first value is an ID, etc.
- A property must be able to create relationships between the different network packets
  - That is, to describe how packet A relates to packet B (request port is equal to response port, etc.)

Passive Testing with Network Traces
Concepts (cont.)

How can we proceed to characterize packets and relationships between them?

Passive Testing with Network Traces Concepts (cont.)

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Passive Testing with Network Traces Concepts (cont.)

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PASSIVE TESTING WITH NETWORK TRACES
CONCEPTS (CONT.)

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Concepts (cont.)

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- The SYN flag of the TCP header of the *i*-th the packet
- Hierarchical as you can see…

Passive Testing with Network Traces Concepts (cont. cont.)

Granular data access is needed

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Granular data access can be achieved with hierarchical key-value structure of the packet

- A mapping function between the raw data bytes and the structure is needed

PASSIVE TESTING WITH NETWORK TRACES CONCEPTS (CONT. CONT. CONT.)

P packet

```
...

(TCP Header)
eb5d01bbd3e75a55cfa6
e7c0801810001cd50000

...
```

PASSIVE TESTING WITH NETWORK TRACES CONCEPTS (CONT. CONT. CONT.)

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...

```
(TCP Header)
eb5d01bbd3e75a55cfa6
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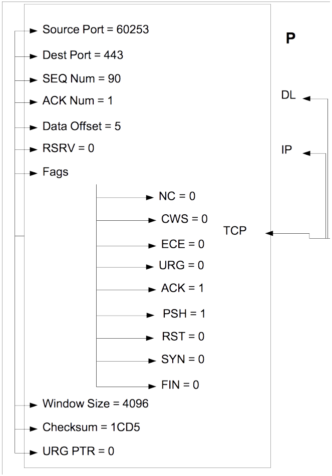

Passive Testing with Network Traces
Concepts (cont. cont. cont.)

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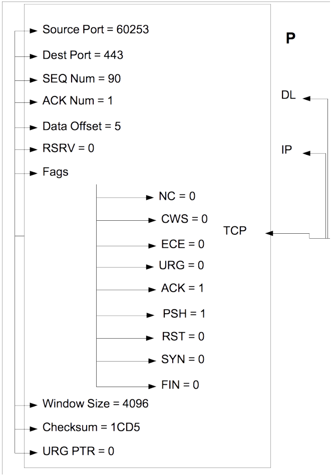
Accessing the ACK flag of the TCP header



Passive Testing with Network Traces
Concepts (cont. cont. cont.)

P packet

...

```
(TCP Header)
eb5d01bbd3e75a55cfa6
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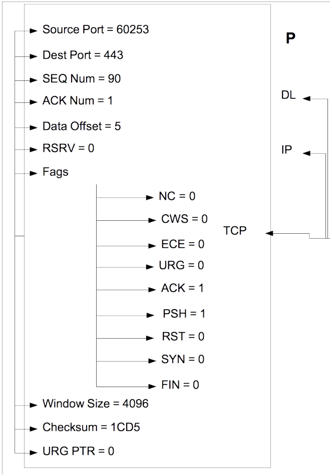
```

...

Accessing the ACK flag of the TCP header

- Given packet P, the value is 1 for

`P->TCP->flags->ACK`



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- For each response with an even number a "corresponding" request with an odd ID should have been received

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Without a “formal” language

- For each response with an even number a “corresponding” request with an odd ID should have been received
- Example:

```
if RES
(
   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
) then REQ<RES
(
   REQ->VSNP->Num = NULL
)
```

WHY IS THIS NOT COMMERCIAL / WIDESPREAD?

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Resource intensive!!! The industry lost interest…

Why is this not commercial / widespread?

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What if I could identify a subset of properties to check at the current execution point?..

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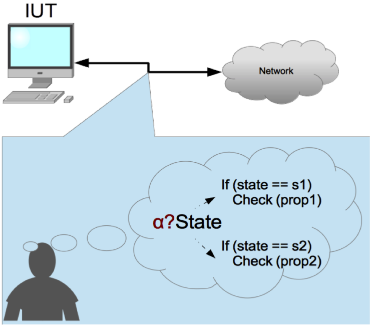
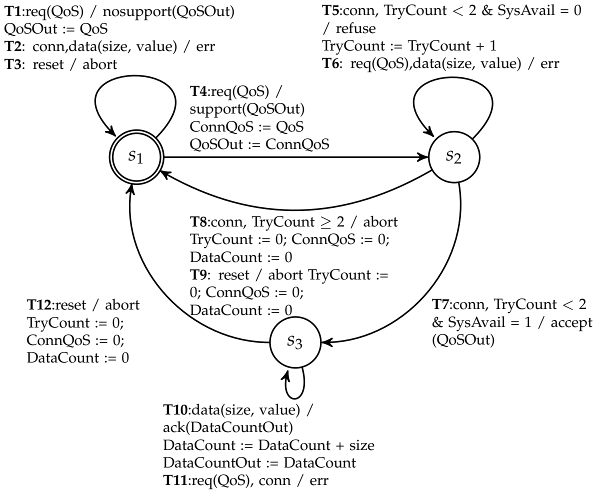
How?

An idea: model the protocol as an FSM to identify its states?



The Simple Connection Protocol (SCP)



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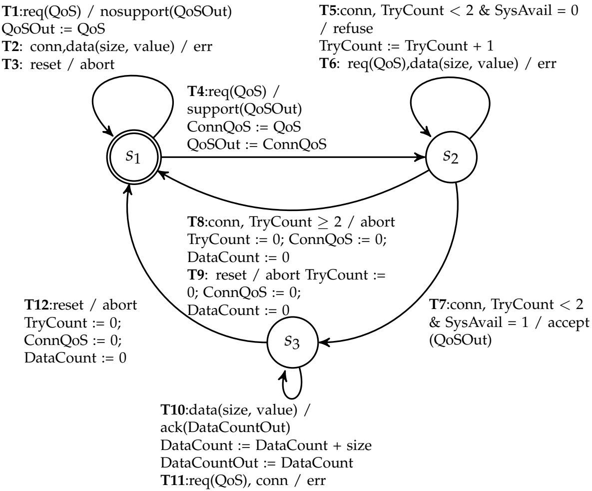
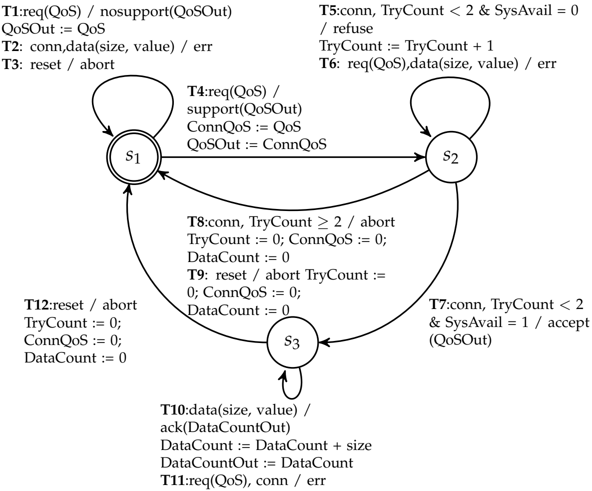


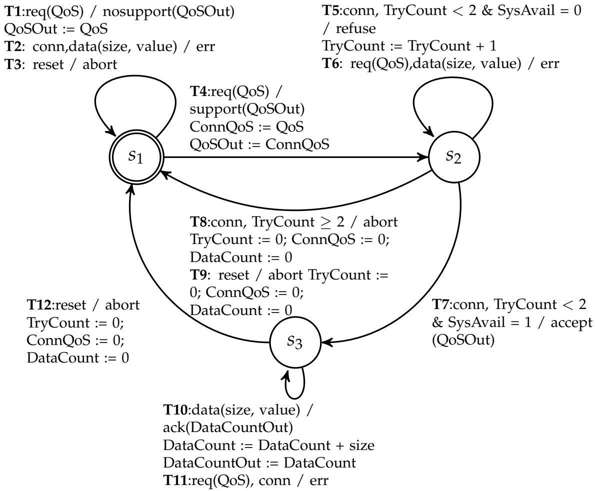
Used to transmit data from one entity (called the upper layer) to the other (called the lower layer)

The Simple Connection Protocol (SCP)



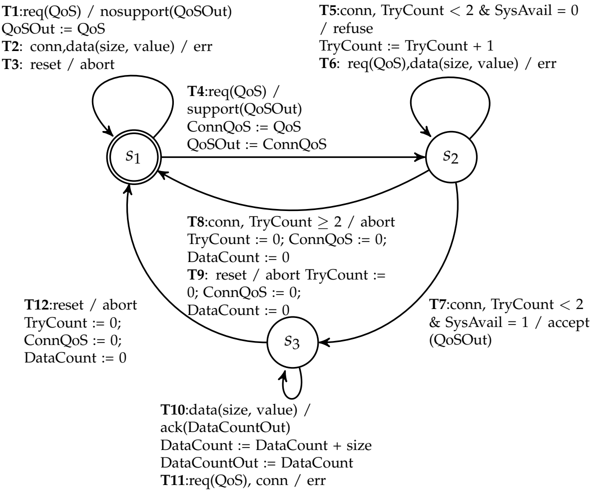
It starts with a QoS negotiation phase, the sending entity proposes the level, the receiving decides

THE SIMPLE CONNECTION PROTOCOL (SCP)



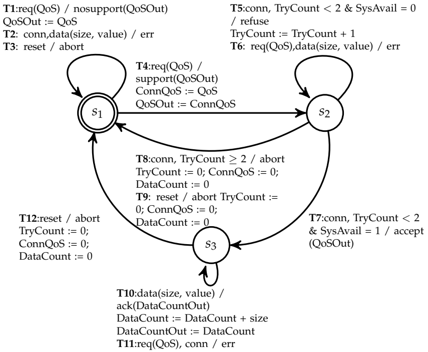
Then, the transmitting entity attempts connecting to the receiving one (up to 3 times)

The Simple Connection Protocol (SCP)



After a successful connection, the transmitting entity sends data, the receiving entity acknowledges

CHECKING SCP PROPERTIES...



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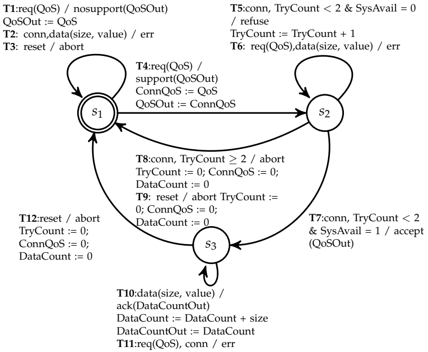
Checking SCP properties...



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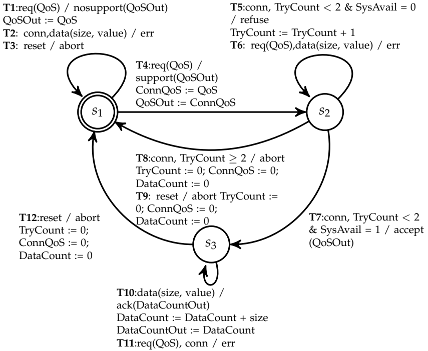

Assume we want to check that:

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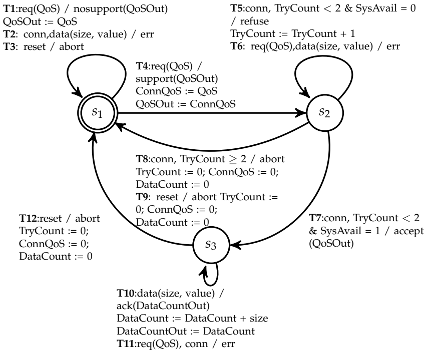
  Why to check for data packets when the connection has not been even established?

CHECKING SCP PROPERTIES...



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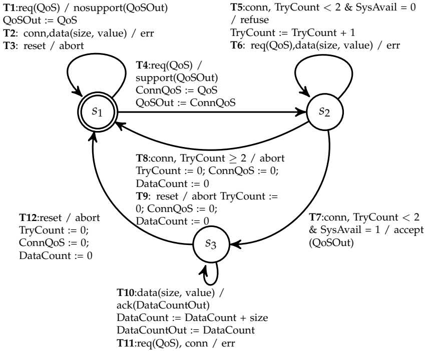

Assume we want to check that:

- An acknowledgment is always sent after transmitting data
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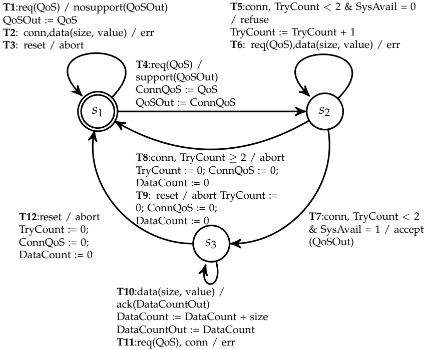
  Why to check for connection requests/replies if no QoS level has been agreed on?

CHECKING SCP PROPERTIES...



Assume we want to check that:

- An acknowledgment is always sent after transmitting data
- After a successful connection a reset is sent
- Only **relevant** properties to the current execution state!

Finite State Machine (FSM)

Do you remember?..

An FSM is a 5-tuple
$M = \langle S, I, O, h_s, S' \rangle$

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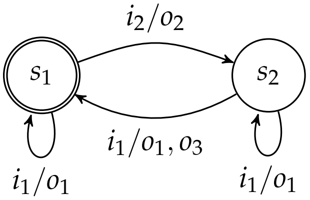

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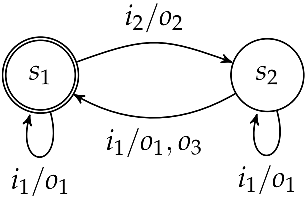

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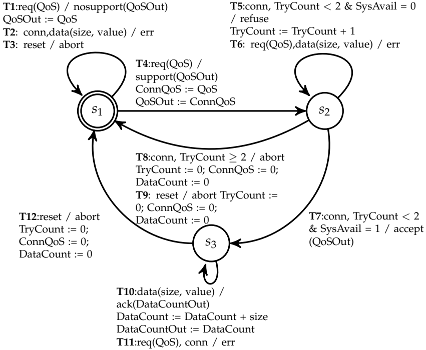

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i and o can have parameters
Context variables are updated when a transition is executed
Predicates allow to execute the transition if it is true

Properties of an FSM $M = \langle S, I, O, h_s, S' \rangle$

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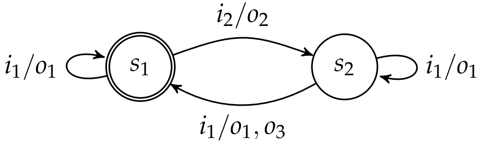
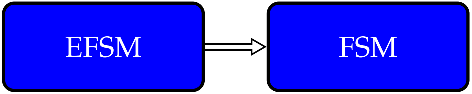
This is a partial, nondeterministic and nonobservable FSM



From an EFSM to an FSM



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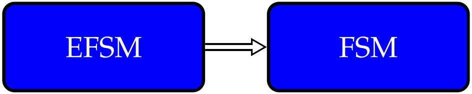

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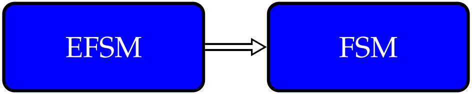

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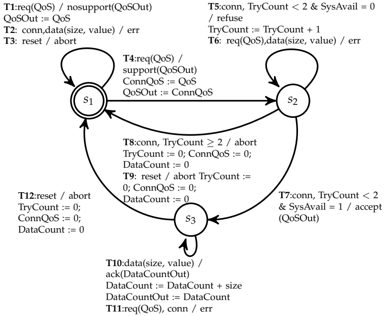
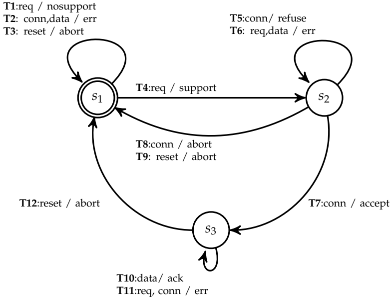


FSM



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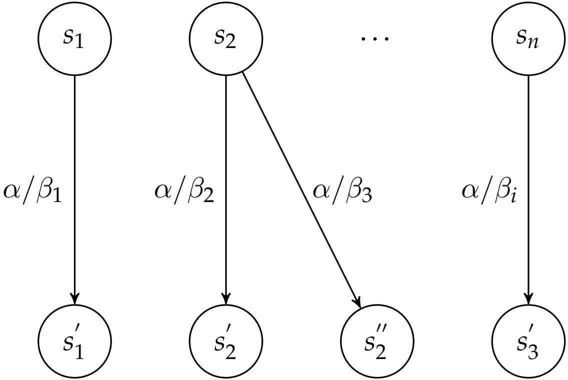

If $\beta_i = \beta_j \implies s_i^{'} = s_j^{'}$ (For observable FSMs)

Deriving ALL (non-redundant) HS of length l

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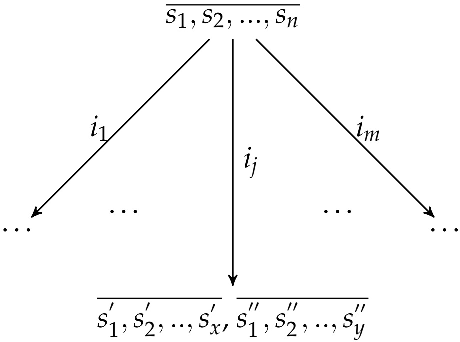
- Derive a **Truncated Successor Tree (TST)** $\exists o \in ((s_1, i_j, o, s_1^{'}) \in h_s \& (s_2, i_j, o, s_2^{'}) \in h_s \& (s_3, i_j, o, s_3^{'}) \in h_s \ldots)$



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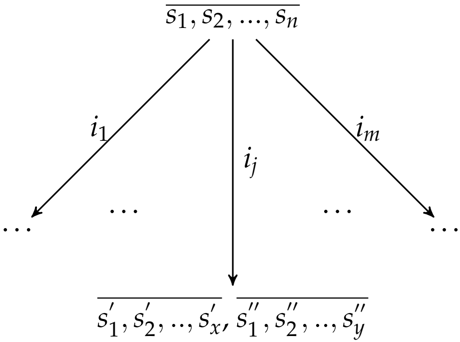
- **Truncating rules**
  - **Rule 1** The node P has only singletons



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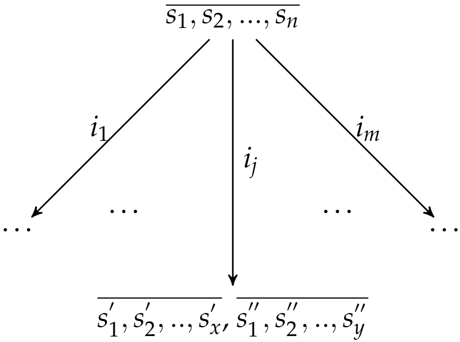

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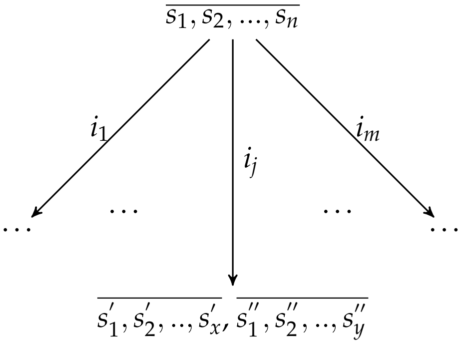

α is a homing sequence iff it labels the path truncated by **Rule 1**

Applying state identification to SCP

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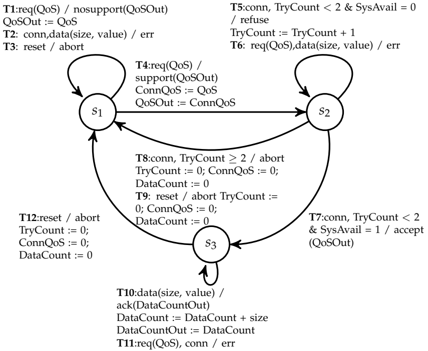
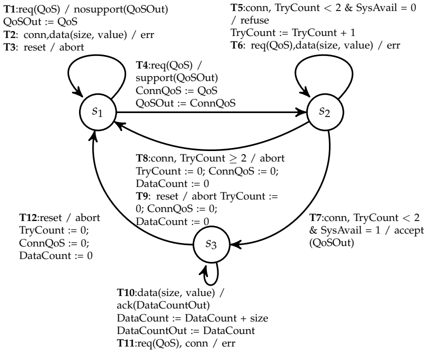


The resulting set of HSs of length $l = 2$

$\{(req.reset), (req.conn), (req.data), (reset), (data.rec), (data.conn),$
$data.reset), (conn.req), (conn.data), (conn.reset)\}$

APPLYING STATE IDENTIFICATION TO SCP

Let's assume $\alpha = (req.conn)$



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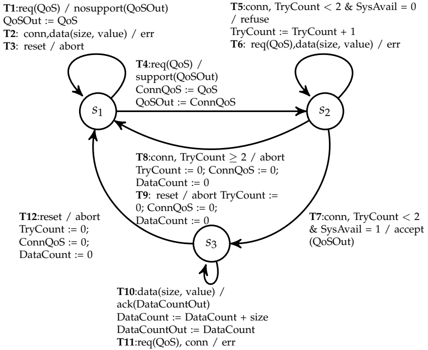

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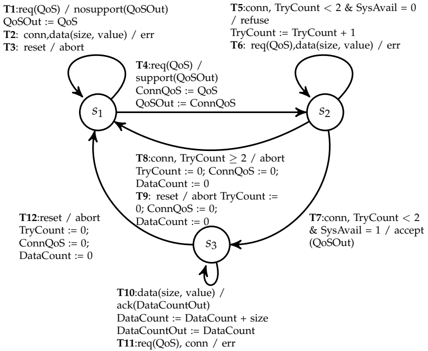

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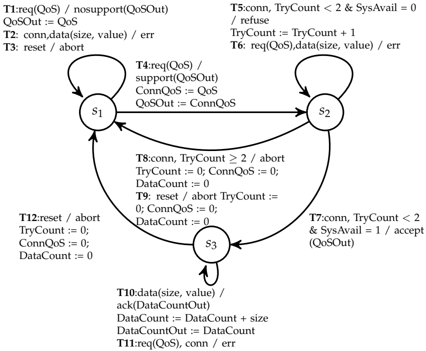
- Else current state is s_3 check for $data/ack$ + $reset/abort$ (small heuristic)



State Identification for Network Trace Analysis — Final Remarks

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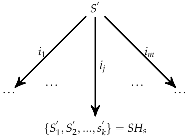

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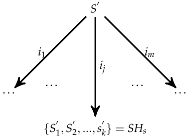

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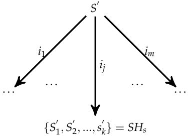

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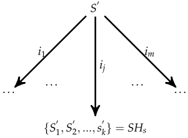

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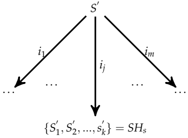

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What sequences to choose?

- Sequences that are frequent to observe!
- Sequences that follow the protocol flow, e.g., not $(conn.req)$
- Can be chosen by experimental evaluation

PASSIVE TESTING USING NETWORK TRACES – FINAL REMARKS

Passive Testing using Network Traces – Final Remarks

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- Very useful when: no access to the code is possible, real data analysis is desirable, the system cannot be influenced by test cases
- It can be computationally expensive, but techniques to reduce the complexity are being actively studied
- The approach was presented with network traces, but it can be applied to passive testing of other software/hardware (embedded) systems

Future work / Conclusions

Research Opportunities / Future Work

Static Code Analysis

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- Reducing the complexity when analyzing

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Static Code Analysis

- Reducing the complexity when analyzing
  - New methods / Heuristics

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Passive Testing using Network Traces

- Reducing the complexity when checking properties[2] (!)

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  - Through simplifying the checking algorithms

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- Considering:
  Synchronizing distributed traces…
  Encrypted protocol testing…

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  - Through simplifying the checking algorithms
  - Through minimizing the number checks :)
- Considering:
  Synchronizing distributed traces…
  Encrypted protocol testing…
- Developing efficient tools…

End

Thank you for your attention!

Q&A / SOME CLARIFICATIONS

Ariadna Barinova from ITMO asked about the applicability of static code analysis to scripting languages

In the example, we saw how static analysis can be used for sign analysis and detected a negative array index. For scripting languages this is not important as array indexes can be anything they are not the offset of a memory address. However, sign analysis can reveal errors in the code, e.g., a function that should guarantee a positive return value does not, etc. Furthermore, many other analyses can be useful, like the live variables analysis to detect potential waste of resources, etc. I hope the explanation was clear during the presentation, or at least it is now :)

Q&A / Some clarifications (2)

Natalia Kushik from Télécom SudParis pointed out the fact that the extended finite state machine under experiment to obtain a homing sequence had an initial state

In fact, as she correctly pointed out, if the initial state is known, there is no need for the entire experiment. My intention was to show a communication protocol description; this protocol description has an initial state in fact. However, it is theoretically incorrect depict an initial state when performing the state identification experiment. These slides were corrected and updated taking this into consideration.

Thank you, Natalia :)