Lecture 4: Static Analysis – Notions, Techniques and Formal Methods

Passive Testing Techniques for Communication Protocols

Dr. Jorge López, PhD.
jorgelopezcoronado[at]gmail.com

National Research Tomsk State University

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OUTLINE

HOMEWORK & LAB INFORMATION

Remove ambiguity from:

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Lab Information

- Given the hosts endianess no guarantee the correct transmission of data from the hosts to network functions to transform data from the hosts representation to network and vice-versa are necessary. Use the functions:
  - `ntohs // network to host short (2 bytes)`
  - `htons // host to network short (2 bytes)`
  - `ntohl // network to host long (4 bytes)`
  - `htonl // host to network short (4 bytes)`

An AST as a data structure

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- Is a **Parse Tree**

AN AST AS A DATA STRUCTURE

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- A directed graph $T =< V, A >$, where V is a set of vertices (nodes), A is a set of ordered arcs formed by a pairs $(v_1, v_2) \in V \times V$, in which each two vertices are connected by a unique simple path (tree-like structure)

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- Each non-terminal is a data structure with *pointers* to other terminal and non-terminals data structures according to the non-terminal production rules of the [abstract] grammar

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As a data structure

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- Terminal symbols **might** be represented as primitive data types

AN AST AS A DATA STRUCTURE (CONT.)

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(Hacked) Grammar

- $mop = /|*$
- $aop = +|-$
- $int = [0-9]^+$,
  $opar = ($,$cpar =)$

1. $Start \mapsto Expr$
2. $Expr \mapsto Expr\ aop\ Term$
3. $Expr \mapsto Term$
4. $Term \mapsto Term\ mop\ Num$
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Data structure

```
typedef enum optypetag
{
   VALUE,
   MUL,
   DIV,
   PLUS,
   MIN
} optype;

typedef struct exprtag
{
   optype type; // type of operation

   int value; // for VALUE
   struct exprtag *left;
   struct exprtag *right;
} expr;
```

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An AST as a data structure (cont. 2)

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- Operations to delete AST nodes are important

What will be the root of the AST data structure for the general case?

- The data structure associated to the CFG start symbol!

Let's see how we use the AST then…

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  - An AST has different data structures for different non-terminal symbols of the grammar, the tree transversal algorithm needs to be aware of those types and perform the transversing accordingly

Let's take a look of each case for the grammar $P \mapsto P\ P|(P)|()$

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        struct partag *L;
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}P;
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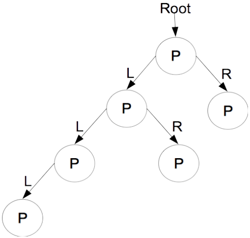

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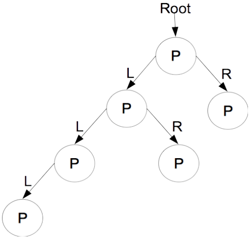

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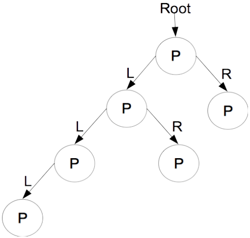

Data structure design 2, AST of ((())()))

```
typedef enum ttag{
        PLIST,
        PAR
}astType;
typedef struct listtag{
        list L; //initial
}plist;
typedef struct partag{
        struct partag *in;
        list L; //null in case of in
}P;
```

VISITING THE AST (CONT.)

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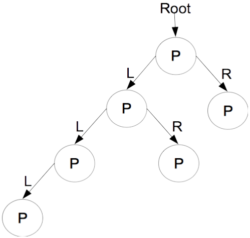

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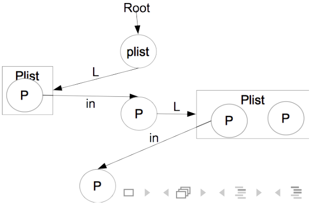

VISITING THE AST (CONT. 2)

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Single recursive visitor

```
void visitAST(void *astNode, astType t){
   if(t == PLIST){
      ... //list instructions
      foreach p = (list*)astNode
         visitAST(p, PAR);
   }
   else if(t == PAR){
      ... // P instructions
      if(p->in != NULL)
         visitAST(p->in, PAR);
      else
         visitAST(p->L, PLIST);
   }
   ...
}
```

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         visitAST(p->in, PAR);
      else
         visitAST(p->L, PLIST);
   }
   ...
}
```

Multiple *recursive* visitors

```
void visitAST(list *astRoot){
   visitASTList(astRoot);
}
void visitASTList(list L){
   ... //list instructions
   foreach p = (list*)astNode
      visitASTPars(p);
}

void visitASTPars(P p){
   ... // P instructions
   if(p->in != NULL)
      visitASTPar(p->in);
   else
      visitASTList(p->L);
}
...
```

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From a simple AST visiting function you can build your very first static program analyzer

Static Program Analysis 101

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  - Imagine the possibilities for a more complex grammar
- Let's look at more real-world examples...

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- Essentially works by supplying other users data which can lead to insecure actions, for example visiting a link or executing some code (javascript), or even adding a sub-site filled with publicity or others

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XSS

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- An easy example is to allow a user in a forum to insert a comment and then display it. If the comment contains HTML and it is displayed as-is, the attacker would successfully execute the attack on users seeing that page

Static Analysis for security properties II

SQLI

Static Analysis for security properties II

SQLI

- Essentially works by supplying data to the database that the database will execute, for example, the user inputs a search criteria, and the database looks for the users matching that search criteria:

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

  What if entered criteria is:

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How to protect using static analysis?

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

STATIC ANALYSIS FOR SECURITY PROPERTIES III

Buffer Overflow

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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){
   load(argv[1]);
   ...
}
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Static Analysis for security properties III

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- A string which is lager than BUFFSIZE will write inside 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

Static Analysis for security properties IV

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STATIC ANALYSIS FOR SECURITY PROPERTIES IV

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- Some rely on guaranteeing calling some specific functions (sometimes replaced safe functions)
- Others propose a mathematical approach of calculating the bound automatically
- Any new approach for such a problem will be welcomed!

Static Analysis 101 – Final Remarks

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- Static Analysis programs can be complex and can try guarantee <<**generic**>> properties, However, new analysis even of single properties can be important and incorporated to known solutions
- Providing false-positives is an issue, however, in some cases accepted
- Sound approaches have been proposed, they are based on formal methods, let's get a quick overview of them. . .

Formal Methods Overview

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   int y = 10;
   int z = 2 + y;

   if(x > 10){
      z=10;
      x = y + 1;
   }
   print(z);
}
```

Data Flow Analysis

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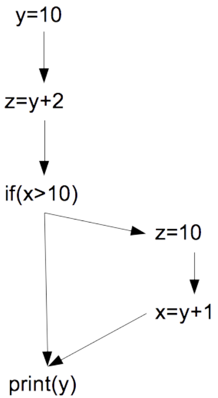
What does the flow analysis can help us analyze?

Data Flow Analysis (cont.)

The data flow



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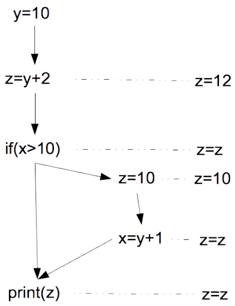

DATA FLOW ANALYSIS (CONT.)

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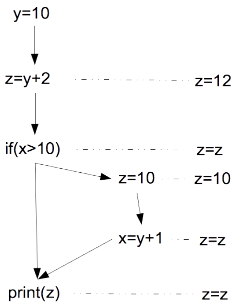

Potential values

Data Flow Analysis (cont.)

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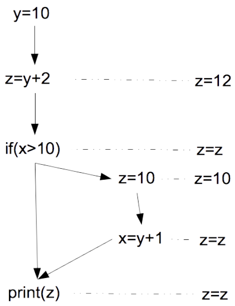
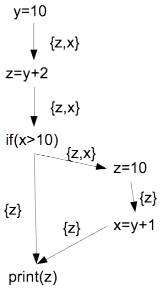


Potential values

- Ranges can be useful, e.g., negatives for array indexing

Data Flow Analysis (cont. 2)

The data flow



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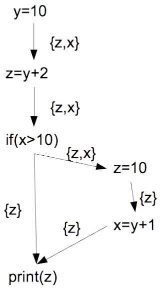
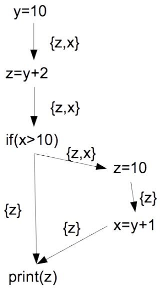


Data dependencies

Data Flow Analysis (cont. 2)

The data flow



Data dependencies

- Useful for security testing, for example, or to check useless code

Data Flow Analysis – Final Remarks

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- It can be used for many things, including statement reachability
- Popular use for test generation, based on the data flow, get such inputs that will build a test case that will execute ALL statements
- Many others. . . For the moment, let's try to get our hands on to get a better understanding :)

Lex & Bison $\mapsto$ AST Demo