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Automatic Detection of Web Application Security Flaws

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Outline

- Ouverture: the need for web application security
- Three simple variations over the problem
- The main theme: lack of input validation
- Crescendo: a problem of automs and grammars
- Concerto for a flow of variables
- A contrappunto of grammars
- Conclusion & Future Works

The need for web application security

- Web applications and web services touted as the "next paradigm" in computing
- Web applications opened (literally) a can of worms
  - HTTP is a vulnerable, stateless protocol unsuitable for persistent state applications
  - A web server is by its own nature a public repository, with access control thrown in as an afterthought
  - A web app offers access to "crown jewel" data, over an unauthenticated and stateless protocol, to the world
- @stake estimates that 70% of the web apps they reviewed showed relevant security defects
  - Relevant cost in rebuilding and redesigning
- A web application is so exposed that any bug may have an immediate reflex against customers

White box vs. Black box

- How to check for security vulnerabilities ?
  - Black box approach: inject all possibly fault-inducing inputs in the web app and look for hints that something strange has happened
    - Lots of simple app vuln scanners, also commercial ones (WebInspect, AppScan, ScanDo, SensePost tools...)
    - You don’t know what the scanners DON’T check for
    - You don't know how well they check for the things they do
    - Technically speaking: *no reliable metric for test coverage*
  - White box approach (code review)
    - Basically, NO TOOLS do this (it's not simple)
    - Conceptually, much more complete and thorough
- I know what you are thinking: “static code analysis is ANTTDNW !”
- Let us consider three (simple!) examples...
  - In PHP, since it is the most widely understood language

Variation nr. 1: Directory Transversal

- PhpMyAdmin: a PHP tool for MySQL web admin
- Up to version 2.5.x, in file:

  db_details_importdocsql.php

- ```
  if (isset($do) && $do == 'import') {
   if (substr($docpath, strlen($docpath)-2, 1)!='/')
     { $docpath = $docpath . '/'; }
   if (is_dir($docpath)) {
        ...
        $handle = opendir($docpath);
        while ($file = @readdir($handle))
              {....showDir, Import, etc...}
  ```

- What happens if I call:

  http://localhost/mysql/db_details_importdocsql.php?submit_show=true&do=import&docpath=../../../

- A simple Directory Transversal Vulnerability
  ```

Variation nr. 2: SQL Injection

- Squirrel Mail (www.squirrelmail.org) is a webmail application developed in PHP
- Squirrel uses MySQL for storing the address book
- In version 1.15.2.1 in page **squirrelmail/squirrelmail/functions/abook_database.php**
- **$query = sprintf("SELECT * FROM %s WHERE owner='%s' AND nickname='%s'", $this->table, $this->owner, $alias);**
  $res = $this->dbh->query($query);
- What if **$alias** contains **' UNION ALL SELECT * FROM address WHERE '1'='1** ?

Variation nr. 2: SQL Injection (cont')

- `SELECT * FROM address WHERE owner='me' AND nickname='' UNION ALL SELECT * FROM address WHERE '1'='1'`
- So, unless an user has an empty nickname, the second SELECT will return all the DB tuples
- Using SQL aliasing statement AS allows to bypass visualization problems
- Problem: no check performed on **`$alias`**
- Resolution (ver. 1.15.2.2): use **`quoteString`**, from the PEAR MDB library, to escape the single quote
- So the fix was “easy”, but evidently getting it right is not always possible

Variation nr. 3: Cross-Site Scripting

- Another example from SquirrelMail, file **event_delete.php**
- ```
  $day=$_GET['day'];
  $month=$_GET['month'];
  $year=$_GET['year'];
  echo"<a href=\"day.php?year=$year&"
  echo"month=$month&day=$day\">";
  ```
- We are implicitly trusting that parameters “day”, “month” and “year” actually contain the date...
- What if the page was called like this ?
  event_delete.php?year=><script>myCode();</script>
- HTML now contains:
  <a href="day.php?year=><script>myCode();</script>
- **is_numeric($_GET['month'])** would have been enough to avoid this...
  ```

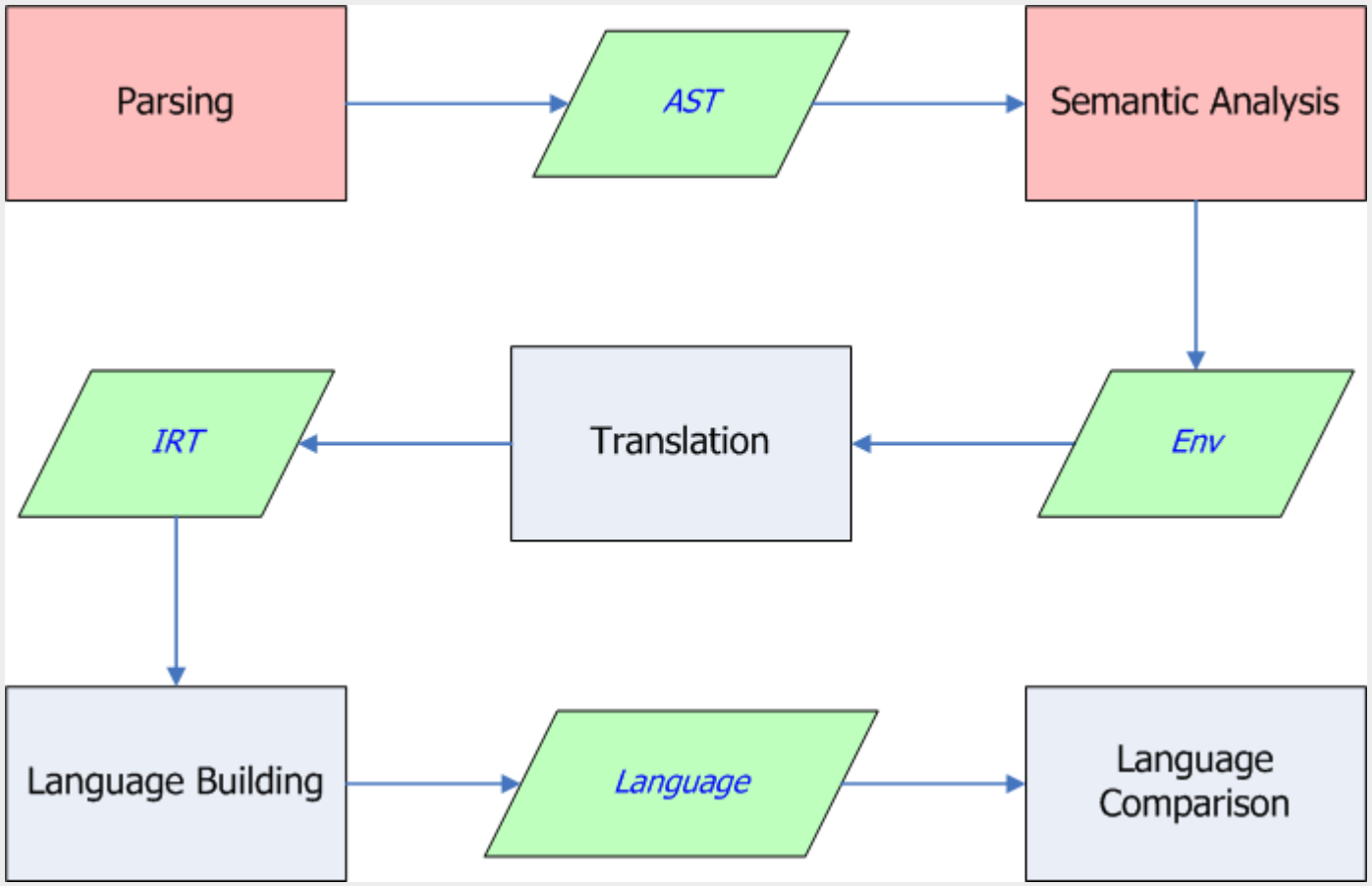
A common theme: lack of input validation

- Our simple examples show how most web application vulnerabilities come from *lack of user input validation*
- What do you do if you need to code review, say, 1000 files written by way-too-smart-people who do not comment their code
- What we want is an *assisted code evaluation tool* that enables us to focus on *poorly controlled input*, suggesting where we need to strenghten input filtering
- What we purposefully avoid to address, for now:
  - Poor authentication mechanisms
  - Session handling and the like
  - Timing vulnerabilities (TOCTOU and the like)

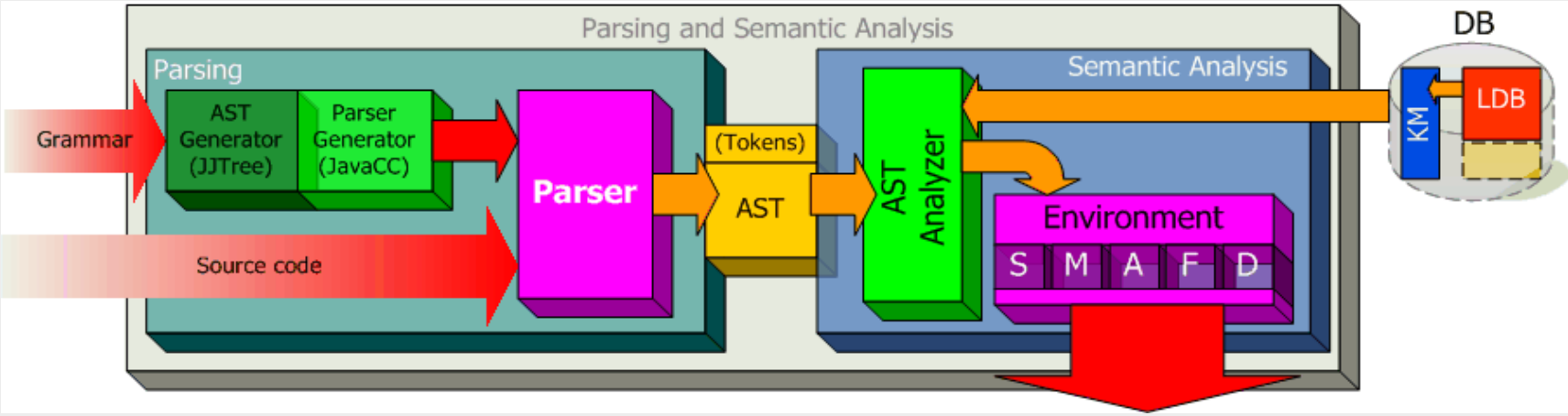
Signatures: functions, languages, grammars

- Our model of vulnerabilities:
  - We have a set of *unsafe functions* (e.g. execution of database statements, display of dynamic data to the user client)
  - We can identify the structure of safe operands for those function as *regular expressions*
  - We can build a ruleset expressing these *assertions*
- Language, here and in the following, means a *formal language* generated by a *grammar*
- What we need therefore is an engine which can
  - Parse web application code
  - Reconstruct the *language* of each variable at each point during the execution flow through static analysis
  - Checkpoints (blacklist/whitelists/stripping/substitutions...) translate to language modifications
  - Compare this language to the regular expressions provided in the ruleset

It's not *that* simple, you know...



From code to an abstract representation



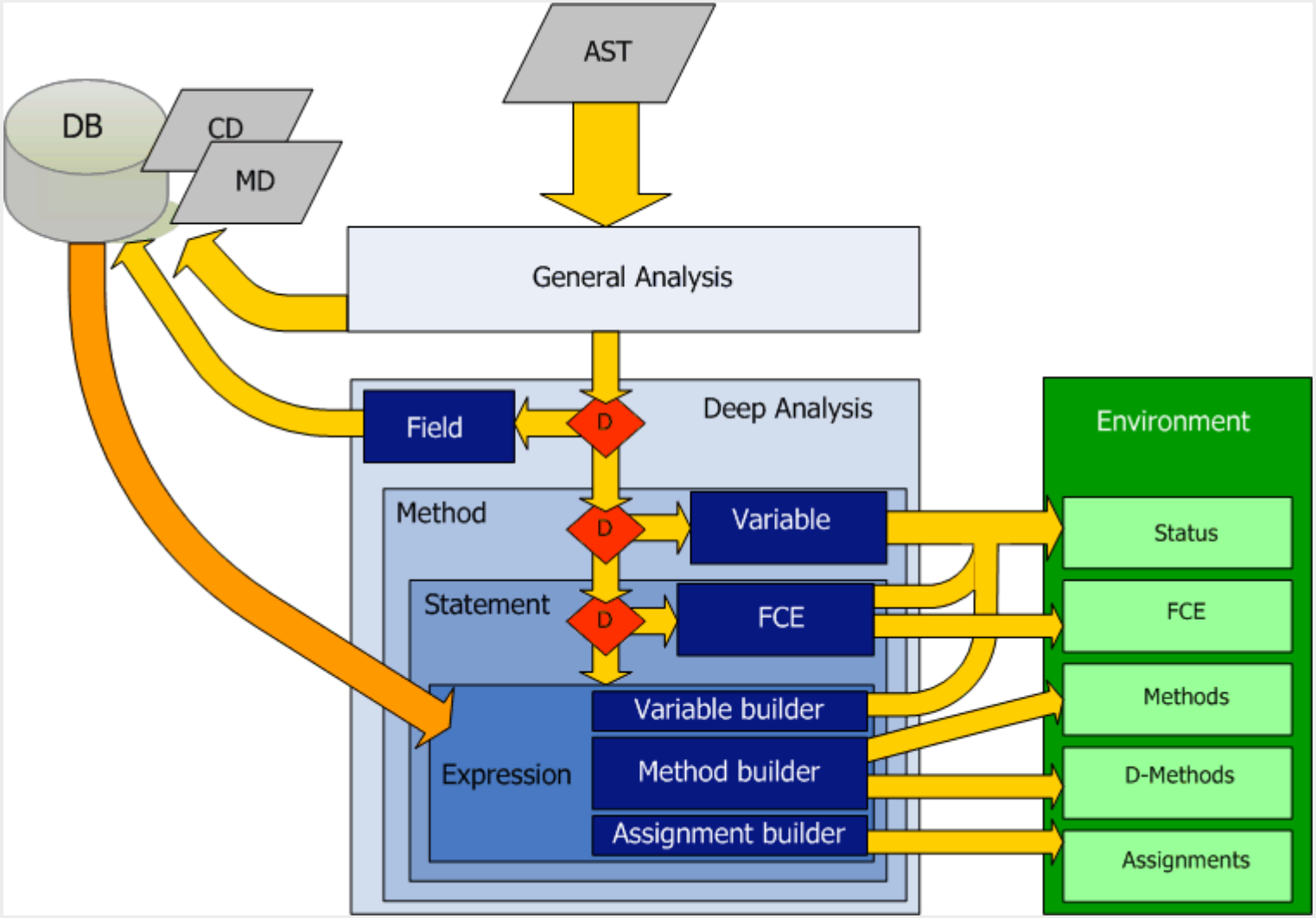
- The first two phases of translation are highly language-dependent and resemble closely the parsing – semantic analysis of a classical compiler
- The output is what we call an "environment", loosely similar to the symbol table in a compiler
- Parsing is simple, let us examine the semantic analysis phase more closely...

Example of AST translation

```
public class MYClass {
  String content;
  public MYClass(){
    content="myContent";
  }
}
```

```
CompilationUnit [null]
 Class [MYClass]
  Field [null]
   Type [null]
    Name [String]
   VariableDeclaratorId [content]
  ConstructorDeclaration [null]
   ConstructorDeclarator [MYClass]
   Statement [null]
    StatementExpression [null]
     PrimaryExpressionPrefix [null]
      Name [content]
     AssignmentOperator [=]
     PrimaryExpressionPrefix [null]
      Literal ["myContent"]
```

A two-pass analysis of the code



Intermediate representation tree

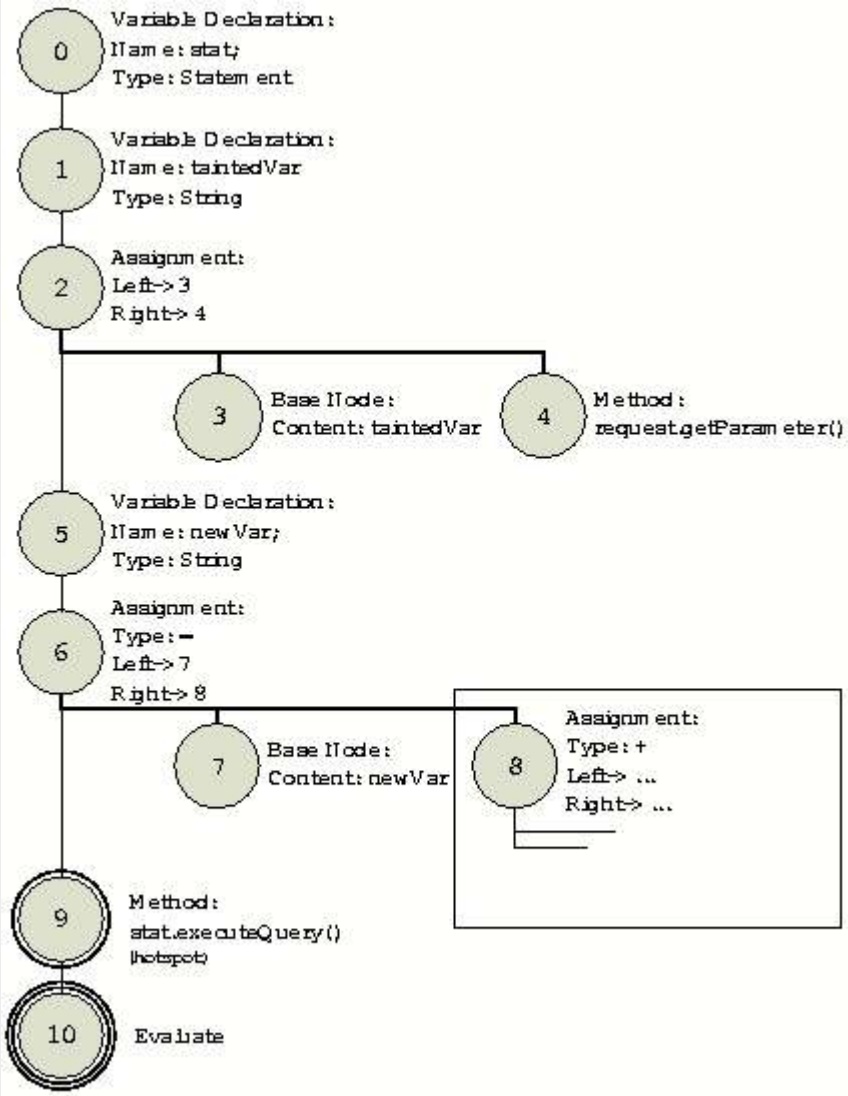
- The AST and the Environment are then used in order to build an IRT
  - Integrates the knowledge on variables into the tree
  - Allows to generate the AST simply and then separate the analysis, reducing complexity of each module
  - The IRT is a (mostly) language-independant construct
- Node types in an IRT:
  - Base node: atomic information (var, value, etc.)
  - Variable declaration node
  - Assignment/operation node (2 children + next)
  - Method node (a method we couldn't expand)
  - FCE node: flow control element (1 child + next)
  - Evaluation node: this node marks the need for language evaluation (occurrence of a an unsafe method)
- Most nodes have just a next: it is almost a chain

Building the IRT

- AST+Environment -> IRT
  - Construction begins from a doGet or doPost
  - Bottom-up construction, beginning with the last rows of the D-method table (restricted to the method scope)
  - Starting from an occurrence of a potentially *unsafe* method a pool of "suspect variables" is built, starting with the parameters of the unsafe methods and recursively adding in variables that interact with these
  - Method calls and instructions that do *not* operate on suspect variables are safely discarded; the same happens for FCEs
  - Method calls are flattened with variable actualization and global name translation
  - An FCE generates a branch in the IRT
  - Above a variable declaration, said variable does not exist: removed from the pool

IRT example (simplified!)

```
[...]
Statement stat;
[...]
String taintedVar =
request.getParameter("name");
String newVar;
newVar="SELECT * FROM table
WHERE name='"+taintedVar+"'";
stat.executeQuery(newVar);
[...]
```

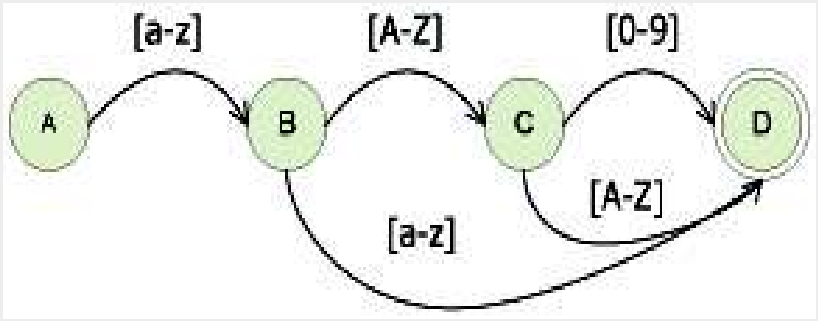


Generating languages from the IRT

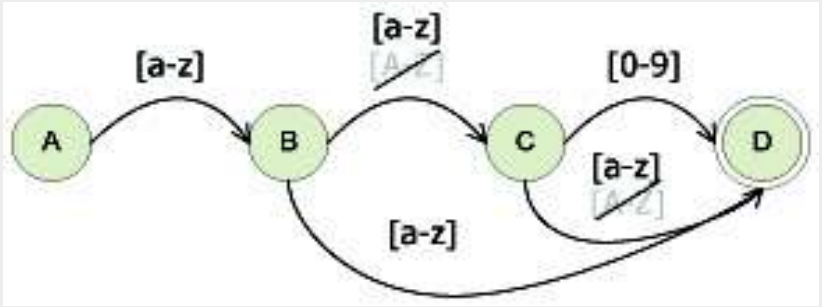
- For each suspect variable
  - Initialize a regexp as .* and generate a corresponding finite state autom
  - Each operation on a variable corresponds to an operation on the FSA (there is a *theorem* proving correctness...)
- There are, of course, approximations due to FCEs
  - An FCE corresponds to a IRT branch: we generate a language for each branch, and do a union (OR)
  - If an FCE creates a loop, we approximate it as either "never" or "infinity"
  - FCEs used for creating filters: e.g. **`if (var1.matches("[a-zA-Z0-9]*")){...}`** the clause itself tells me that inside the {} L(var1')=[a-zA-Z0-9]*

Simple example of language transformations

Input: [a-z][[a-z]|[A-Z][[A-Z]|[0-9]]]
Examples: aa, ab, yh, gTT, hYJ, oT6



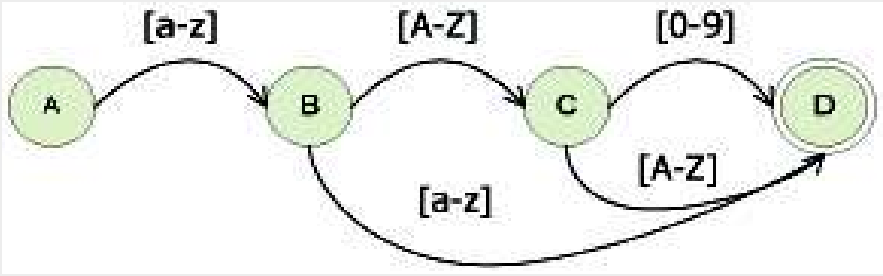
To Lowercase (a simple transformation)



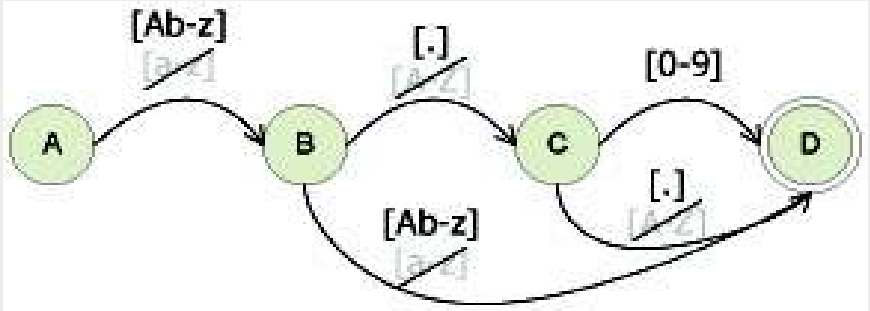
Output:[a-z][[a-z]|[a-z][[a-z]|[0-9]]]
(can be simplified, and also the FSA)

Simple example of language transformations

Input: [a-z][[a-z]|[A-Z][[A-Z]|[0-9]]]

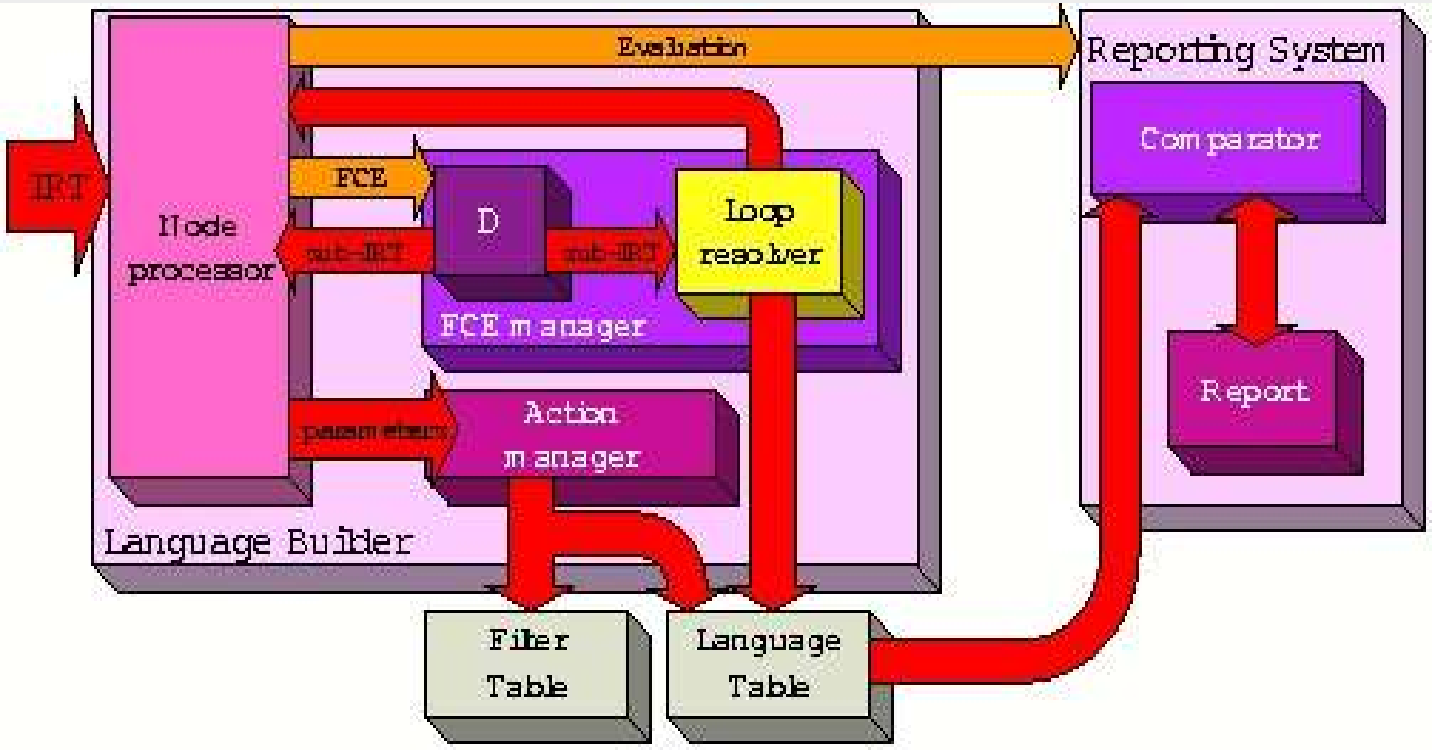


replace('a','A') and replace('Z', char), where char cannot be statically determined



The second transformation makes the edeg go in '.' because of indetermination

Language Builder diagram



Approximations, limitations, and errors

- We want errors to be predictable
  - We prefer false positives to false negatives: approximate languages by "rounding up" (-> false positives)
  - We will then implement a testing procedure to "validate" positives and reduce the number of false positives
- Approximations and limitations
  - "Lost in translation":
    - Dynamic arrays (cannot reconstruct access)
  - During language generation:
    - replace() with a parameter character: approx.
    - substring(int) or substring(int,int) cannot be properly represented unless "int" is hardcoded, we must approximate them by excess
    - We have seen approx for loops; just go figure recursion...
- How many times did you use recursion in a webapp?

Finding and verifying the vulnerabilities

- Finding vulnerabilities means "comparing the languages" between the safe language defined in the ruleset and the actual language
- An algorithm verifies that:
  [NOT(L(db) INT L(act)] == ø
- If != ø, we can immediately obtain a counterexample, i.e. a candidate "exploit string"
- Clearly, this candidate does not "exploit" anything, but we can use it to *verify* that this is not a false positive
- Stay tuned for the next step: "automatically exploiting" the critter

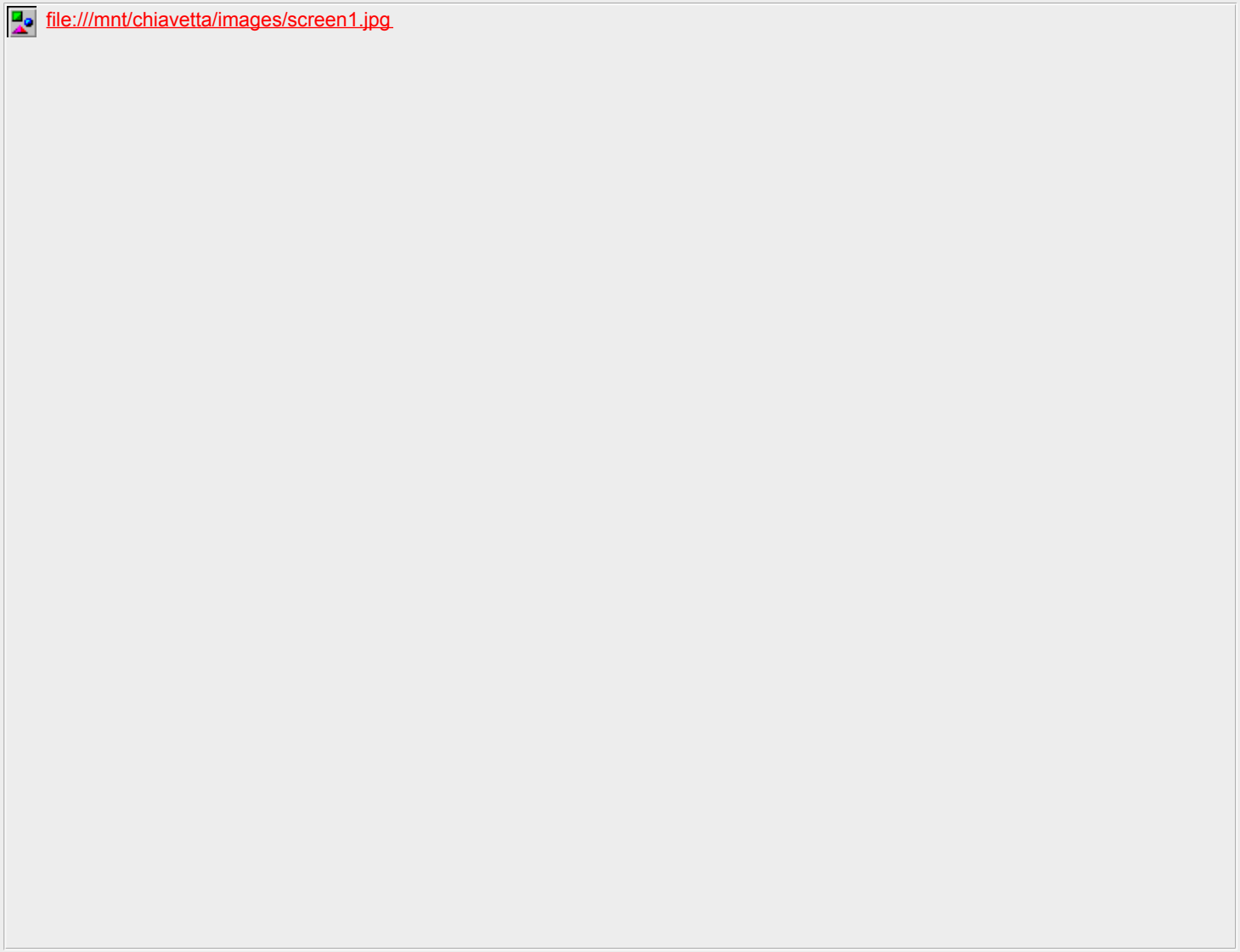
Performance of the tool

- ... we really don't know, but surely right now it's slower than it could be due to implementation issues
- Remember: this is done statically at development time and surely it is lighter and faster than your average compiler
- But really, I'm not here to sell this to anybody (oh, well...)

Our prototype tool

- Implements the whole architecture as seen
- Tested only on small-scale projects
- The interface is usable and nice, but surely not ready for prime time (see below...)
- As of now, we implement only the JSP language-dependent module, PHP is the next addition
- Various lesser limitations, to be resolved in the near future
  - E.g. currently, we handle “String”, not Stringbuffer or char[] variables, but just because we're too lazy...
- We prepared a small demo on a toy application for BH, but being Java it's WORRN: “Write Once, Runs Reliably Nowhere” ...
- As soon as it's reliable, we'll put the demo on BH website for you to play with

The tool interface (backup for the demo)



Conclusions & Future Work

- Web applications are poorly programmed, highly vulnerable, and highly exposed
- Black-box analysis of web apps is relatively easy but limited; white-box analysis of source code is promising but difficult
- Input validation problems are the most common vulnerability in web apps
- We have created a tool which implements a language-theoretic approach for static source code analysis, capable of assessing web applications security against a set of rules
- Our tool is still under heavy development for refining many simplifications

Thank you!

Any question?

We would greatly appreciate your feedback !

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