framework for code transformations

Tobiáš Smolka

FI MUNI

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Background

What we had?

- A lot of ideas how to secure smart card applications
- List of possibly vulnerable constructions and their semantically equivalent more secure alternatives

What we needed?

- An easy way how to use the results of research in real projects
- A way to perform automatic code transformations

Solution should be

- simple enough to be easily used and extended
- robust enough to handle all kinds of transformations

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Outline

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Proposed solution

We decided to develop

1. general framework for misc code transformations
   - no restriction on target language or type of transformation
   - powered by Ant
2. sample bundle of transformations
   - focused on improving resiliency of JavaCard code against power analysis
   - powered by ANTLR and StringTemplate engine

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Framework properties

Most important requirements:

- Easy integration into development
- Extensibility and variability

Instead of inventing the wheel we used well-known build tool Ant

- Transformations are executed from general build scripts via custom task

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Example

Executing transformation

```
<transform classname="IfSwitchTransformation">
  <classpath location="${run.classpath}" />
  <fileset dir="../sample_project" >
    <include name="**/*.java" />
    <modified/>
  </fileset>
  <mapper type="glob" from="*" to="*.transformed" />
  <param name="generateComments" value="true" />
</transform>
```

Snippet from build script, that executes specified transformation on concrete files.

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Framework properties

We got (thanks to Ant's developers):

- Powerful scripting environment for executing transformations
  - Properties, conditions, many other useful tasks
- Ant's concepts for customizing execution of transformations
  - Resource Collections (Fileset, Filelist, Dirset) for specifying what to transform
  - File selectors (filename, contains, size, modified, ...) for fine-grained file selection
  - Mappers for specifying how to map file names
  - Classpath parameters for specifying where to find transformations

Transformations can be fully adapted to concrete environment or project.

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Properties of transformations

- Transformations are general dynamically loaded Java classes
- Developer is not restricted at all
  - only simple interface: setFiles(), setParams(), execute(), ...
- Target language independent (Java, JavaCard, .NET, Java bytecode, ...)

Our build-in transformations

- Target language is JavaCard
- Focused on improving resiliency against power analysis
- Replacement of vulnerable constructions with semantically equivalent alternatives

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Build-in transformation: Shadow variables

- General protection mechanism against error induction
- Each variable has own shadow copy, which maintains inversion of the value
- Value is checked against shadow variable on each read access
- Shadow variable is updated on each modification

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Example: Shadow variables

```
short i=1,j=2;
if (i==j) i+=j;
```

```
1   /* help array, that holds shadow variables */
2  private short fault_resistant_short[] = new short[2];
3  ...
4  /* first argument is value, second variable ID */
5  short i=__set_short(1,0),j=__set_short(2,1);
6  if (__get_short(i,0)==__get_short(j,1))
7    i=__set_short(
8      __get_short(i, 0)
9        +
10     __get_short(j,1),
11   0);
```

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Build-in transformation: If-switch

- Some cards leak information about argument in IF statement
- Can be determined whether THEN or ELSE branch will be executed
  - An additional jump is performed before ELSE execution
  - Time is noticeable longer, power trace is different

Proposed protection mechanism

- All IF-THEN-ELSE constructions are replaced with equivalent SWITCH constructions
- SWITCH constructions are randomized and power trace doesn't leak the information

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- SWITCH constructions are randomized and power trace doesn't leak the information

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Example: If-switch

```
if (i==1) j=10;
else j=20;
```

```
1  // result of original expression
2  boolean expr_res1 = (i==1);
3  // negation of the result
4  boolean expr_res_neg1 = !(i==1);
5
6  switch (__getRandomBit()){ // 0 or 1
7    case -1:
8      /* any code, that will not be
9       left out by compiler */ break;
10   case 0:
11     if (expr_res1) { j=10; }
12     else { j=20; }
13     break;
14   case 1:
15     if (expr_res_neg1) { j=20; }
16     else { j=10; }
17     break;
18 }
```

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Implementation details

- Transformations have to be robust, but easy to maintain
- We use external tools (ANTLR, StringTemplate)
- Parsers and lexers are generated from nice-looking grammar files
- Grammar development environment ANTLRWorks
- Actual code replacement is performed via templates
  - Logic of transformation and generated code are separated
  - Code replacements are written naturally (see example)
  - Audit and modification of the templates is easy
  - Templates are loaded from classpath, user can specify own versions

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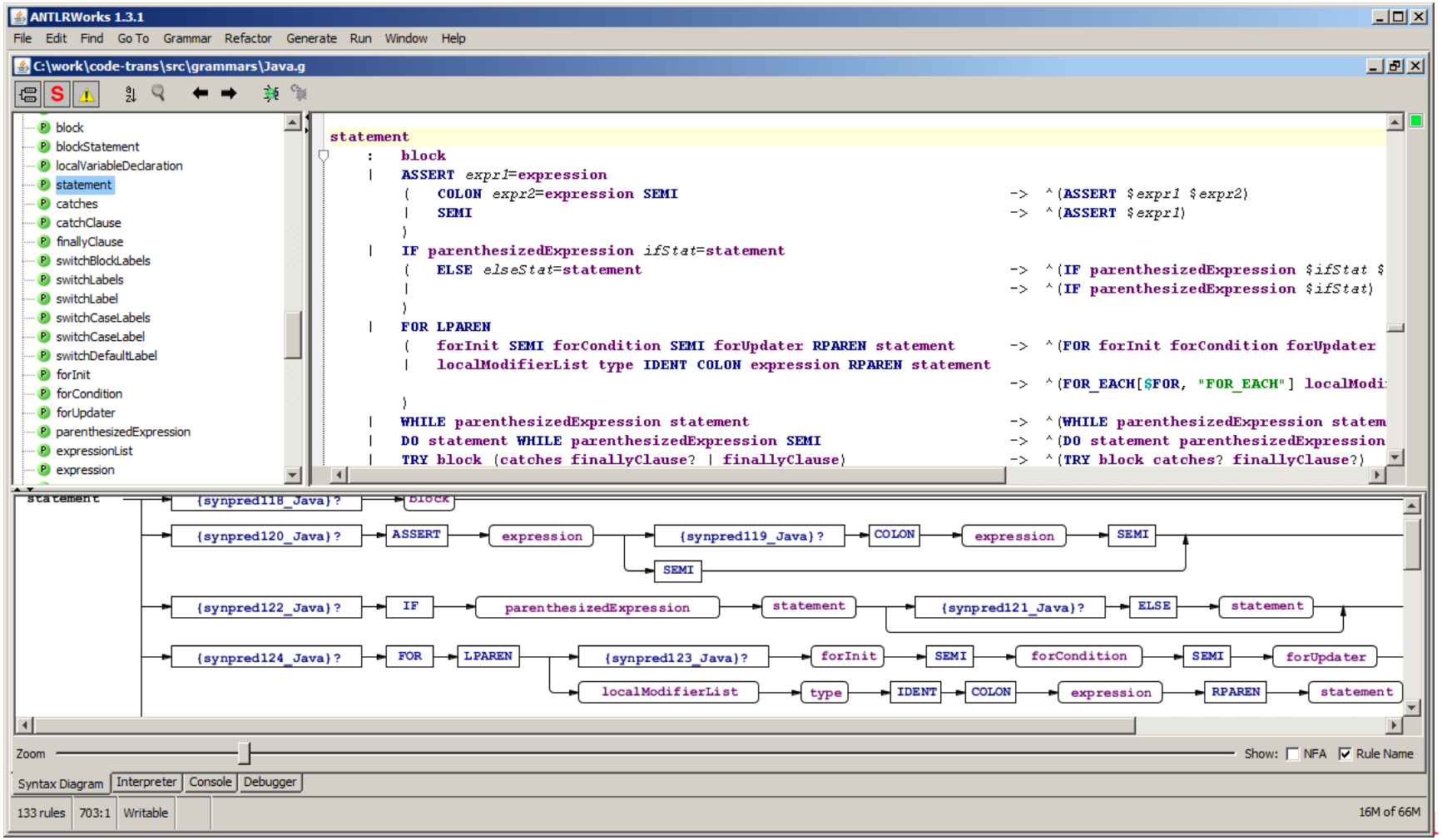
Grammar development environment ANTLRWorks



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Example: code replacement template

```
1  // result of original expression
2  boolean expr_res<ruleParams.id> = <ruleParams.expr>;
3  // negation of the result
4  boolean expr_res_neg<ruleParams.id> = !<ruleParams.expr>;
5
6  switch (__getRandomBit()){   // 0 or 1
7    case -1:
8      /* any code, that will not be
9       left out by compiler */ break;
10   case 0:
11     if (expr_res<ruleParams.id>) <ruleParams.ifTrue>
12     else <ruleParams.ifFalse>
13     break;
14   case 1:
15     if (expr_res_neg<ruleParams.id>) <ruleParams.ifFalse>
16     else <ruleParams.ifTrue>
17     break;
18 }
```

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Implementation details

Each from our build-in transformations has 3 steps:

1. Lexical analysis
   - Lexical analyzer (lexer) creates stream of vocabulary symbols (tokens)
2. Parsing
   - Parser creates abstract syntax tree (AST) from tokens
3. Tree parsing and rewriting token stream
   - Tree parser reads AST and if needed, rewrites underlying token stream
   - Another approach can be code generation, where new token stream would be created from modified AST

Modified token stream is then written back to file

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Example: IF-SWITCH tree parser

```
1  statement :
2    block
3    | ^(FOR forInit forCondition forUpdater statement)
4    | ^(WHILE parenthesizedExpression statement)
5    | ^(TRY block catches? block?)
6    | ifSwitchTransformation
7    ...
8
9  ifSwitchTransformation :
10 ^(IF parenthesizedExpression
11   ifTrue=statement
12   ifFalse=statement?){
13     performRewrite(new STAttrMap().
14       put("expr", $parenthesizedExpression.text).
15       put("ifTrue", $ifTrue.text).
16       put("ifFalse", $ifFalse.text).
17       put("rule", "IF_SWITCH")
18     );
19 };
```

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Testing

- Transformations can be pretty tricky, testing is needed
- Our Ant task can be used
- How?
  1. Prepare standard JUnit test classes with all special cases
  2. Automatically transform test classes via Ant (from build script)
  3. Check whether transformed tests pass or not

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Example: JUnit test

```
int j=0;
for (int i=0;i<10;i++){
  if (i==5) break;
  j+=i;
}
assertEquals(10, j);
```

```
1  int j=0;
2  BLOCK_1: {
3    for (int i=0;i<10;i++){
4      boolean expr_res1 = (i==5);
5      boolean expr_res_neg1 = !(i==5);
6
7      switch (__getRandomBit()){
8        case -1:
9          /* any code, that will not be
10         left out by compiler */ break;
11       case 0:
12         if (expr_res1) {
13           break BLOCK_1;
14         }
15         break;
16       case 1:
17         if (expr_res_neg1) {
18         } else {
19           break BLOCK_1;
20         }
21         break;
22     }
23     j+=i;
24   }
25 }
26 assertEquals(10, j);
```

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Summary

Code replacement framework

- Easy integration into development process (Ant)
- Can handle any transformation (general classes + dynamic loading)

Build-in transformations

- Focused on improving resiliency of JavaCard code against power analysis
- Robust, but easy to maintain (ANTLR, StringTemplate engine)

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Thank you for your attention.

Any questions or comments?

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