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# Experiments with String Analysis

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# String Analysis

- **Compute values a string expression can take at a given program point**
- **Potential uses**
  - Security vulnerability detection
  - Input sanitisation and validation
  - Query generation
  - Data format generation (XML, JSON, HTML etc.)
  - Dynamic code generation
  - Dynamic class loading

# Analysis Performance

- **Trade-offs between precision and scalability**
- **RegEx generation**
  - More precise, less scalable
- **Constant propagation**
  - More scalable, less precise
- **Practical perspective**
  - Do we need to compute regular expressions for every client analysis?
  - Would a less precise but more scalable technique suffice for some?

# Evaluation

- **Investigate performance trade-offs of different string analysis techniques**
- **Investigate precision of a client analysis**
- **String analysers**
  - Java String Analyser
  - Oracle Labs String Analyser

# Java String Analyser (JSA)

- **Christensen, Møller and Schwartzbach**

  *Precise Analysis of String Expressions, SAS 2003*

- **Goal**

  Compute over-approximation of values a string expression may take at runtime

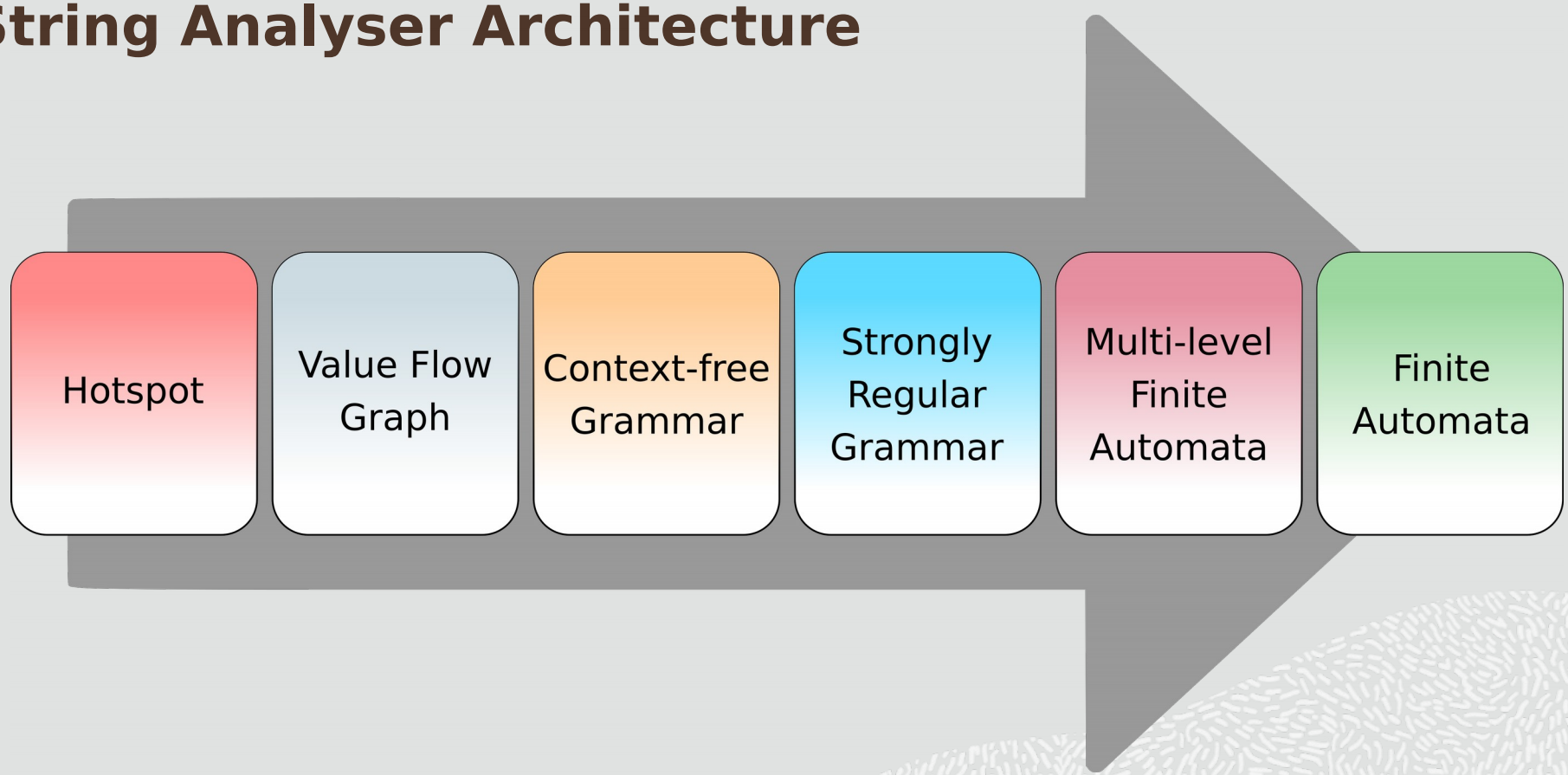
- **Target**

  Relevant string expressions (hotspots)

- **Outputs**

  Finite State Automata

# Java String Analyser Architecture



# Value Flow Graph

- **Edges**

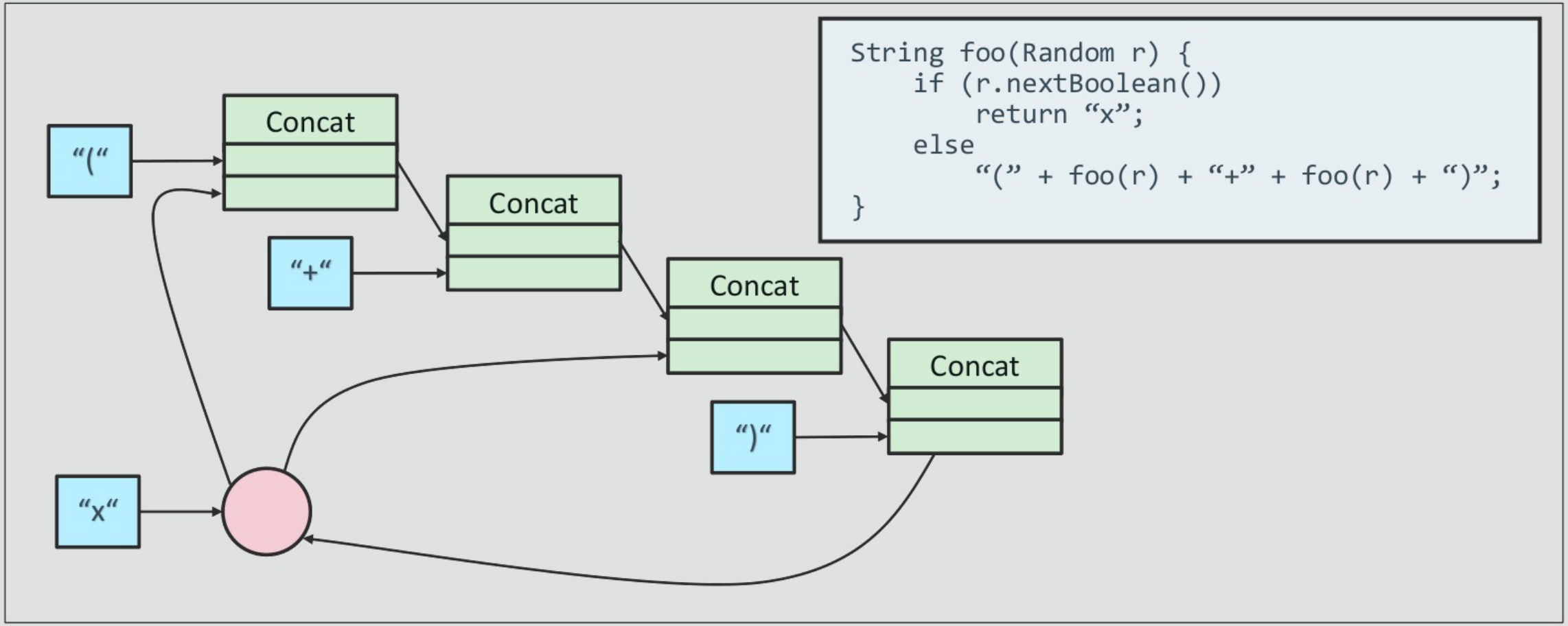
  directed def-use edges representing possible data flows

- **Nodes**

  variables or expressions

  - **Init** – string value from a constant
  - **Join** – assignment or other join location
  - **Concat** – string concatenation
  - ***UnaryOp*** – unary string operation
  - ***BinaryOp*** – binary string operation

# Value Flow Graph Example



# Value Flow Graph to Regular Expressions

- **Value Flow Graph to Context-free Grammar**

  Transform VFG to Context Free Grammar using transformation rules

- **Context-free Grammar to Finite Automata**

  Approximate CFG with a regular grammar containing original language

  Convert strongly regular grammar to Multi-level Finite Automata (MLFA, a hierarchical directed acyclic graph of NFA)

  Extract minimal FA for each hotspot from MLFA

# Oracle Labs String Analyser (OLSA)

- **Inspired by Java String Analyser**
- **Value Flow Graph extended with *Switch* nodes**
- **Context-sensitive constant propagation**

***Hotspot → VFG → Strings***

# Precision Evaluation

- **Compare precision of JSA and OLSA**
- **Subjects**

  Small test programs developed for JSA testing
- **Test program features**

  Single hotspot

  Hard-coded inputs
- **Ground truth obtained by executing test programs**

# Unit Test Results

**T** – computed string set

**G** – ground truth string set

**R(T)** – **T** is fully resolved

**U(T)** – **T** is unresolved (fully or partially)

| | OLSA | JSA |
|---|---|---|
| ***Complete:*** $T = G$ | 15% | 32% |
| ***Disjoint:*** $T \cap G = \emptyset \wedge U(T)$ | 53% | 34% |
| ***Incorrect:*** $T \cap G = \emptyset \wedge R(T)$ | 15% | 4% |
| ***Over-approximation:*** $G \subset T$ | 8% | 28% |
| ***Partial:*** $T \cap G \neq \emptyset$ | 7% | 1% |
| ***Under-approximation:*** $T \subset G$ | 2% | 1% |

# Reflection Analysis Results

- **Compute `java.class.forName` arguments**
- **17 DaCapo programs (20 – 700 KLOC)**

| | Programs | Runtime (sec) | Resolved |
|---|---|---|---|
| ***OSLA*** | 17 | 2 | 60% |
| ***JSA*** | 5 | 1020 | 39% |

- **Precision (over 5 programs) is similar (except 1 result)**

# Key Reasons of Imprecision

- User input (!)
- Semantics of string-manipulating functions
- Analysis of containers (e.g., arrays)
- Handling of loops and recursion calls
- Field-sensitivity

# Scalability Evaluation

- **17 DaCapo programs (3,058 KLOC combined)**
- **Only OLSA and JSA failed**
- **Different hotspot configurations**

  *Lightweight* (reflection)

  *Default* (I/O functions)

  *Heavyweight* (any string argument)
- **Results (string resolution)**

  Resolved, Partial, Unresolved

# DaCapo Results: Oracle Labs String Analyser

| Configuration | Runtime (sec) | Hotspots | Resolved | Unresolved | Partial |
|---|---|---|---|---|---|
| ***Lightweight*** | 2.13 | 318 | 60% | 9% | 30% |
| ***Default*** | 8.77 | 4,304 | 39% | 40% | 40% |
| ***Heavyweight*** | 221.94 | 156,502 | 18% | 61% | 21% |

# Conclusions

- **JSA is more precise but fails on large codebases**
- **OLSA scales well to large programs, even in extreme cases**
- **For reflection analysis, lightweight constant propagation could be as precise as regular expression generating techniques**

  Precision depends on analysed code features

# Thank you!