Parfait Lessons Learnt

Cristina Cifuentes, Nathan Keynes, Manuel Valdiviezo*, John Gough, Diane Corney
Oracle Labs Australia
* Oracle Parfait
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To develop a static code analysis tool that is precise (>= 90% true positives) yet scalable to millions of lines of C/C++ code in a nightly run
The Parfait Design
2007
Built on Top of LLVM
## Snapshot of Parfait Results

### June 2009

<table>
<thead>
<tr>
<th>Kernel</th>
<th>Part</th>
<th>LOC</th>
<th>Buffer overrun</th>
<th>Bug density</th>
<th>Status</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpenSolaris UTS b105</td>
<td>Core</td>
<td>2.1M</td>
<td>15</td>
<td>0.0069</td>
<td>Being fixed</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Device drivers</td>
<td>1.2M</td>
<td>67</td>
<td>0.054</td>
<td>Being fixed</td>
<td></td>
</tr>
</tbody>
</table>

### September 2010

<table>
<thead>
<tr>
<th>ON</th>
<th>Part</th>
<th>LOC</th>
<th># bug types</th>
<th>Memory</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OpenSolaris ON</td>
<td>All</td>
<td>10.4M</td>
<td>9</td>
<td>10-20x .bc</td>
<td>90</td>
</tr>
</tbody>
</table>
The Bells and Whistles to Enable Tech Transfer

1. Trace witness for each bug report
2. Unique bug identity via hashes
3. Server to keep track of multiple runs
4. Server integration with bug tracking system
The Transfer

June 2012

- Parfait becomes an internal Oracle product
- Used internally by RDBMS, Solaris, OEL, TimesTen, ...

Used by thousands of developers within Oracle on a daily basis
New Language and Analysis Support

Focus on vulnerabilities rather than bugs

June 2013
- Start Java language support
- Analyses focus on vulnerabilities in the Java platform
- Used internally by Java Product Group

June 2015
- Start PL/SQL language support
- Analyses focus on web vulnerabilities
- To be used by JEE and cloud organisations
What Worked Well
Frontend

- “Loosening up” Clang
  - To support multiple C compilers and old versions of C
- Translation of language for analysis
  - Java, PL/SQL
- Multi-language support and reuse of analyses

Diagram:

- C/C++ Source → C/C++ Translator
- Java Source → Java Translator
- PL/SQL Source → PL/SQL Translator
- Translated languages → IR
• Demand-driven analysis scales well
  – Combined with extensive caching
  – Function summaries help

• Backwards reusable frameworks
  – Dataflow
  – Symbolic analysis

• Having abstractions align well with the code under analysis
  – E.g., bit-flag operations
Presentation Framework

- **Usability**
  - Server to keep track of multiple runs
  - Bug hashes to
    - compare results from different runs, and
    - group bugs
  - Trace witness for each bug report
• LLVM works well as the underlying infrastructure
  – IR
  – Analysis support
The In Between
• Layered analysis works but not fully used as originally planned
  – Most analyses have multiple exit points
  – Promotions of one bug type to another
Granularity of Analysis

- **Intermodule support**
  - Analysing one LLVM module at a time doesn’t work for large monolithic codebases
    - E.g., 200GB RAM to process one .bc file
  - Reuse of results of analysis of dynamic libraries linked into multiple binaries is needed

- **Incremental analysis at the LLVM module doesn’t work for everyone**
  - Some teams want incremental at subcomponent levels
Parfait Infrastructure

• Replicated work due to independent development of the analyses
• Bug hashes essential but hard to keep consistent
What Didn’t Work Well
Use of optimisations to simplify IR
– Removed in favour of useful bug reports

Requires data from the AST
– Needed for useful bug reports

Cannot represent dynamic features of languages
LLVM Infrastructure

- llvm-ld doesn’t scale well
- .bc format is not indexable
  - Now using file format that supports random access
- Support for other C compilers not of interest to the Clang community
Analysis

- Technical debt exposed when improving analysis code coverage
- Incomplete call graph due to function pointers and virtual calls
Usability and Development Organisation’s Workflow

- “Expensive” analyses are not deployed in production
  - If runtime is larger than allocated nightly integration window
Parfait for C/C++, Java and PL/SQL – Main Takeaways

**Worked Well**

- Scalability through demand-driven analyses + caching + function summaries
- Precision through unsoundness + heuristics
- Language translation for analysis
- Usability through user and organisational deployment experience

**Needs More Work**

- Extensibility only possible through handwritten C++
  - New languages
  - New analyses
- Infrastructure changes become challenging as time goes by
Many People Have Worked on Parfait Over the Years

- Cristina Cifuentes
- Bernhard Scholz
- Nathan Keynes
- Lian Li
- Chenyi Zhang
- Erica Mealy
- Michael Mounteney
- Simon Long
- Nathan Hawes
- Mike Van Emmerik
- Christian Hoermann
- Manuel Valdiviezo
- Andrew Browne
- Adam Heron
- Jimmy Ti
- Jacob Zimmermann
- Andrew Craik
- Brad Moody
- Ben Barham
- Douglas Teoh
- Duc Hoai Nguyen
- Edward Evans
- Dominic Ferreira
- Ijaz Faiz
- Ben Dean
- Ben Jones
- Daniel Dawson
- Adam Heron
- Kostyantyn Vorobyov
- Diane Corney
- John Gough
- Daniel Wainwright
- Nicholas Allen
- Brian Modra
- Matthew Johnson
- Paddy Krishnan
- Tomas Kotal
- Vince Chiang
- Lin Gao
- Richard Marks
- Minhtri Pham
- François Gauthier
- Alexander Jordan
- Vladimir Silchanka
- Tom King
- Ramon Millsteed
Parfait: scalable and precise bug detection for static languages
Integrated Cloud
Applications & Platform Services
Observation 1: some bugs are easy to find, others are hard to find
Observation 2: cheap program analyses can find easy bugs, expensive program analyses can find complex bugs
## Buffer Overflow Results Over Open Source OS Kernels

### June 2009

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<thead>
<tr>
<th>Kernel</th>
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</thead>
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<tr>
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<td>0.0069</td>
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<td>1.2M</td>
<td>67</td>
<td>0.054</td>
<td>Being fixed</td>
</tr>
<tr>
<td>Linux 2.6.29*</td>
<td>13</td>
<td>Core</td>
<td>1.6M</td>
<td>12</td>
<td>0.0073</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Device drivers</td>
<td>4.1M</td>
<td>85</td>
<td>0.020</td>
<td>Submitted</td>
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<tr>
<td>OpenBSD 4.4</td>
<td>2</td>
<td>Core</td>
<td>0.5M</td>
<td>3</td>
<td>0.0060</td>
<td>Fixed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Device drivers</td>
<td>0.8M</td>
<td>26</td>
<td>0.029</td>
<td>Fixed</td>
</tr>
</tbody>
</table>

* Linux has the benefit of two separate scans already made by Coverity over their kernel code
Common C Bugs Results Over OpenSolaris ON Code
November 2009 – September 2010

<table>
<thead>
<tr>
<th>time (mins)</th>
<th>100s bug reports</th>
<th>% false positives</th>
</tr>
</thead>
</table>

- **Usability release**
- **3 to 7 bug types**
- **1 analysis inter-proc**
- **Dataflow framework inter-proc**

<table>
<thead>
<tr>
<th>Version</th>
<th>MLOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3 (Nov)</td>
<td>9.5</td>
</tr>
<tr>
<td>0.3.1 (Jan)</td>
<td>10.3</td>
</tr>
<tr>
<td>0.3.2 (Apr)</td>
<td>10.4</td>
</tr>
<tr>
<td>0.3.3 (May)</td>
<td>10.4</td>
</tr>
<tr>
<td>0.3.4 (Sep)</td>
<td>10.4</td>
</tr>
</tbody>
</table>
Extensibility – Possible Solutions

Provide interface to Datalog

Provide interface to other languages
Memory Consumption

• Memory usage: 10x-20x size of .bc