



Open-Source C++ Support for KLEE

Felix Rath, Klaus Wehrle

<https://comsys.rwth-aachen.de>

KLEE'21 Workshop, 2021-06-11

- Since KLEE 2.0: General support for many C++ programs (libc++ support)

- Since KLEE 2.0: General support for many C++ programs (libc++ support)
- Since KLEE 2.2: C++ exception handling supported

- Since KLEE 2.0: General support for many C++ programs (libc++ support)
- Since KLEE 2.2: C++ exception handling supported
- Successfully used it on:

- Since KLEE 2.0: General support for many C++ programs (libc++ support)
- Since KLEE 2.2: C++ exception handling supported
- Successfully used it on:
 - ▶ Z3 - Theorem prover by Microsoft Research

- Since KLEE 2.0: General support for many C++ programs (libc++ support)
- Since KLEE 2.2: C++ exception handling supported
- Successfully used it on:
 - ▶ Z3 - Theorem prover by Microsoft Research
 - ▶ RE2 - Regular expression library by Google

- Since KLEE 2.0: General support for many C++ programs (libc++ support)
- Since KLEE 2.2: C++ exception handling supported
- Successfully used it on:
 - ▶ Z3 - Theorem prover by Microsoft Research
 - ▶ RE2 - Regular expression library by Google
 - ▶ jtc - JSON query & manipulation tool

- Since KLEE 2.0: General support for many C++ programs (libc++ support)
- Since KLEE 2.2: C++ exception handling supported
- Successfully used it on:
 - ▶ Z3 - Theorem prover by Microsoft Research
 - ▶ RE2 - Regular expression library by Google
 - ▶ jtc - JSON query & manipulation tool
- Publicly available

- Since KLEE 2.0: General support for many C++ programs (libc++ support)
- Since KLEE 2.2: C++ exception handling supported
- Successfully used it on:
 - ▶ Z3 - Theorem prover by Microsoft Research
 - ▶ RE2 - Regular expression library by Google
 - ▶ jtc - JSON query & manipulation tool
- Publicly available
 - ▶ Related work: KLOVER [Li et al., CAV 2011]

- What is required to support C++ in KLEE?

- What is required to support C++ in KLEE?
- Frontend compiler

- What is required to support C++ in KLEE?
- Frontend compiler
 - ▶ Lowers C++ to LLVM IR

- What is required to support C++ in KLEE?
- Frontend compiler
 - ▶ Lowers C++ to LLVM IR
 - ▶ clang++

- **What is required to support C++ in KLEE?**
- **Frontend compiler**
 - ▶ Lowers C++ to LLVM IR
 - ▶ clang++
 - ▶ Fully lowers classes, inheritance, templates, closures, etc.

- **What is required to support C++ in KLEE?**
- **Frontend compiler**
 - ▶ Lowers C++ to LLVM IR
 - ▶ clang++
 - ▶ Fully lowers classes, inheritance, templates, closures, etc.
- **Standard library & runtime**

- **What is required to support C++ in KLEE?**
- **Frontend compiler**
 - ▶ Lowers C++ to LLVM IR
 - ▶ clang++
 - ▶ Fully lowers classes, inheritance, templates, closures, etc.
- **Standard library & runtime**
 - ▶ `std::cout`, `std::vector` etc.

- **What is required to support C++ in KLEE?**
- **Frontend compiler**
 - ▶ Lowers C++ to LLVM IR
 - ▶ clang++
 - ▶ Fully lowers classes, inheritance, templates, closures, etc.
- **Standard library & runtime**
 - ▶ std::cout, std::vector etc.
 - ▶ We use LLVM's libc++ & libc++abi (threads disabled)

- **What is required to support C++ in KLEE?**
- **Frontend compiler**
 - ▶ Lowers C++ to LLVM IR
 - ▶ clang++
 - ▶ Fully lowers classes, inheritance, templates, closures, etc.
- **Standard library & runtime**
 - ▶ std::cout, std::vector etc.
 - ▶ We use LLVM's libc++ & libc++abi (threads disabled)
 - ▶ Requires a libc

- **What is required to support C++ in KLEE?**
- **Frontend compiler**
 - ▶ Lowers C++ to LLVM IR
 - ▶ clang++
 - ▶ Fully lowers classes, inheritance, templates, closures, etc.
- **Standard library & runtime**
 - ▶ std::cout, std::vector etc.
 - ▶ We use LLVM's libc++ & libc++abi (threads disabled)
 - ▶ Requires a libc
 - ▶ Additional support required: Exception handling

- **What is required to support C++ in KLEE?**
- **Frontend compiler**
 - ▶ Lowers C++ to LLVM IR
 - ▶ clang++
 - ▶ Fully lowers classes, inheritance, templates, closures, etc.
- **Standard library & runtime**
 - ▶ std::cout, std::vector etc.
 - ▶ We use LLVM's libc++ & libc++abi (threads disabled)
 - ▶ Requires a libc
 - ▶ Additional support required: Exception handling
- **LLVM support**

- **What is required to support C++ in KLEE?**

- **Frontend compiler**

- ▶ Lowers C++ to LLVM IR
- ▶ clang++
- ▶ Fully lowers classes, inheritance, templates, closures, etc.

- **Standard library & runtime**

- ▶ std::cout, std::vector etc.
- ▶ We use LLVM's libc++ & libc++abi (threads disabled)
- ▶ Requires a libc
- ▶ Additional support required: Exception handling

- **LLVM support**

- ▶ Previously unimplemented instructions, etc.

- C++ exception handling based on the Itanium C++ ABI

- **C++ exception handling based on the Itanium C++ ABI**
 - ▶ Unwinding: Platform specific, language independent

- **C++ exception handling based on the Itanium C++ ABI**
 - ▶ Unwinding: Platform specific, language independent
 - ▶ C++-rules: Platform independent, language specific

- **C++ exception handling based on the Itanium C++ ABI**
 - ▶ Unwinding: Platform specific, language independent
 - ▶ C++-rules: Platform independent, language specific
- **KLEE implementation compatible**

- **C++ exception handling based on the Itanium C++ ABI**
 - ▶ Unwinding: Platform specific, language independent
 - ▶ C++-rules: Platform independent, language specific
- **KLEE implementation compatible**
- **Unwinding is C++-independent**

- **C++ exception handling based on the Itanium C++ ABI**
 - ▶ Unwinding: Platform specific, language independent
 - ▶ C++-rules: Platform independent, language specific
- **KLEE implementation compatible**
- **Unwinding is C++-independent**
- **Can be reused by other languages**

- **C++ exception handling based on the Itanium C++ ABI**
 - ▶ Unwinding: Platform specific, language independent
 - ▶ C++-rules: Platform independent, language specific
- **KLEE implementation compatible**
- **Unwinding is C++-independent**
- **Can be reused by other languages**
 - ▶ New personality function needed

- **C++ exception handling based on the Itanium C++ ABI**
 - ▶ Unwinding: Platform specific, language independent
 - ▶ C++-rules: Platform independent, language specific
- **KLEE implementation compatible**
- **Unwinding is C++-independent**
- **Can be reused by other languages**
 - ▶ New personality function needed
- **Symbolic exception values supported**

- Tried on three-open source C++ projects

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- jtc

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- **jtc**
 - ▶ ~32.5% instr. cov.

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- **jtc**
 - ▶ ~32.5% instr. cov.
 - ▶ Found three new bugs, and one uncaught exception

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- **jtc**
 - ▶ ~32.5% instr. cov.
 - ▶ Found three new bugs, and one uncaught exception
- **RE2**

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- **jtc**
 - ▶ ~32.5% instr. cov.
 - ▶ Found three new bugs, and one uncaught exception
- **RE2**
 - ▶ ~28.6% instr. cov.

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- **jtc**
 - ▶ ~32.5% instr. cov.
 - ▶ Found three new bugs, and one uncaught exception
- **RE2**
 - ▶ ~28.6% instr. cov.
 - ▶ No bugs found

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- **jtc**
 - ▶ ~32.5% instr. cov.
 - ▶ Found three new bugs, and one uncaught exception
- **RE2**
 - ▶ ~28.6% instr. cov.
 - ▶ No bugs found
- **Z3**

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- **jtc**
 - ▶ ~32.5% instr. cov.
 - ▶ Found three new bugs, and one uncaught exception
- **RE2**
 - ▶ ~28.6% instr. cov.
 - ▶ No bugs found
- **Z3**
 - ▶ ~0.3% instr. cov.

- Tried on three-open source C++ projects
- 10 runs, 1 hour each, KLEE 2.2
- **jtc**
 - ▶ ~32.5% instr. cov.
 - ▶ Found three new bugs, and one uncaught exception
- **RE2**
 - ▶ ~28.6% instr. cov.
 - ▶ No bugs found
- **Z3**
 - ▶ ~0.3% instr. cov.
 - ▶ New bug found: `fclose (m_file)` where `m_file` is `NULL`

- Open-source C++ support for KLEE

- Open-source C++ support for KLEE
- Required components

- **Open-source C++ support for KLEE**
- **Required components**
 - ▶ Frontend compiler, standard library & compiler runtime, LLVM support

- **Open-source C++ support for KLEE**
- **Required components**
 - ▶ Frontend compiler, standard library & compiler runtime, LLVM support
- **Exception handling in C++**

- **Open-source C++ support for KLEE**
- **Required components**
 - ▶ Frontend compiler, standard library & compiler runtime, LLVM support
- **Exception handling in C++**
- **Language independent unwinding**

- Open-source C++ support for KLEE
- Required components
 - ▶ Frontend compiler, standard library & compiler runtime, LLVM support
- Exception handling in C++
- Language independent unwinding
- Applicable to real-world programs

- Open-source C++ support for KLEE
- Required components
 - ▶ Frontend compiler, standard library & compiler runtime, LLVM support
- Exception handling in C++
- Language independent unwinding
- Applicable to real-world programs
- Thanks to: Lukas Wölfer, Julian Büning, Martin Nowack, Timotej Kapus, Cristian Cadar

- Open-source C++ support for KLEE
- Required components
 - ▶ Frontend compiler, standard library & compiler runtime, LLVM support
- Exception handling in C++
- Language independent unwinding
- Applicable to real-world programs
- Thanks to: Lukas Wölfer, Julian Büning, Martin Nowack, Timotej Kapus, Cristian Cadar
- Try it out on your project!