Performance, Correctness, Exceptions: Pick Three

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Motivations

Static binary translation has a variety of possible uses:

- Support for legacy code.
- Performance improvement for legacy architectures.
- Instrumentation of code.

Goals

- Improve the performance of the translated binaries.
- Do not reinvent the wheel, use as much as possible *off-the-shelf* components.
- Be architecture independent, as the the whole `rev.ng` framework.

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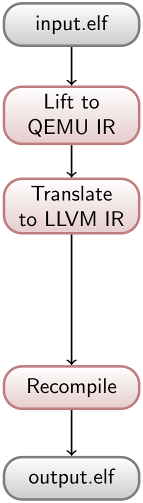
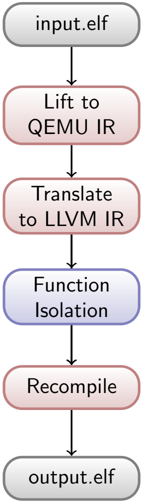
rev.ng

rev.ng


input.elf
Lift to QEMU IR
Translate to LLVM IR
Recompile
output.elf

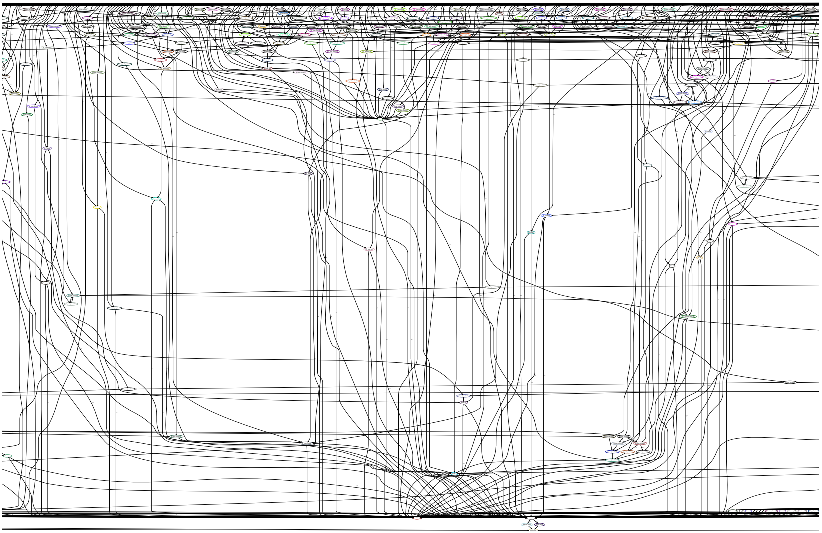
rev.ng


input.elf
Lift to QEMU IR
Translate to LLVM IR
Function Isolation
Recompile
output.elf

The root Function

- At the present time, the lifting phase places all the code recovered from the binary in a *single* (and often large) LLVM function, that we call `root`.

The root Function



The Dispatcher

- What about indirect branches or indirect function calls (e.g. `jmp rax`)?
- We need the *dispatcher*.

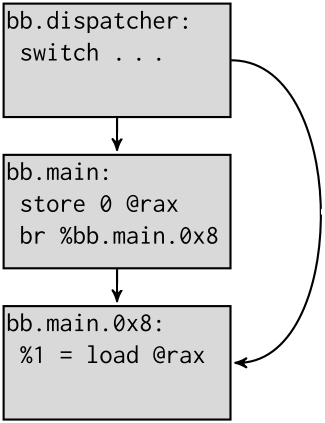
The Dispatcher

```
switch i64 @pc, label %dispatcher.default [
  i64 4194536, label %bb._init
  i64 4194542, label %bb._init.0x6
  i64 4194547, label %bb._init.0xb
  i64 4194560, label %bb._start
  i64 4194582, label %bb._start_c
  i64 4194614, label %bb._start.0x36
  i64 4194624, label %bb.deregister_tm_clones
  i64 4194645, label %bb.deregister_tm_clones.0x15
  i64 4194655, label %bb.deregister_tm_clones.0x1f
  i64 4194672, label %bb.deregister_tm_clones.0x30
  i64 4194688, label %bb.register_tm_clones
  i64 4194723, label %bb.register_tm_clones.0x23
  i64 4194733, label %bb.register_tm_clones.0x2d
  i64 4194744, label %bb.register_tm_clones.0x38
]
```

Current Limitations

- One mayor problem of the dispatcher is that every time we need to pass through it, we pay an *high cost* in terms of performance.
- The CFG of the `root` function contains a lot of unnecessary edges, and this leads to a *mazy* topology.
- This topology prevents a lot of `opt` optimizations.

Current Limitations


$$\begin{tikzcd}
\boxed{\texttt{bb.dispatcher: switch ...}} \arrow[d] \arrow[dd, bend left] \\
\boxed{\texttt{bb.main: store 0 @rax; br \%bb.main.0x8}} \arrow[d] \\
\boxed{\texttt{bb.main.0x8: \%1 = load @rax}}
\end{tikzcd}$$

```
bb.dispatcher:
 switch . . .

bb.main:
 store 0 @rax
 br %bb.main.0x8

bb.main.0x8:
 %1 = load @rax
```

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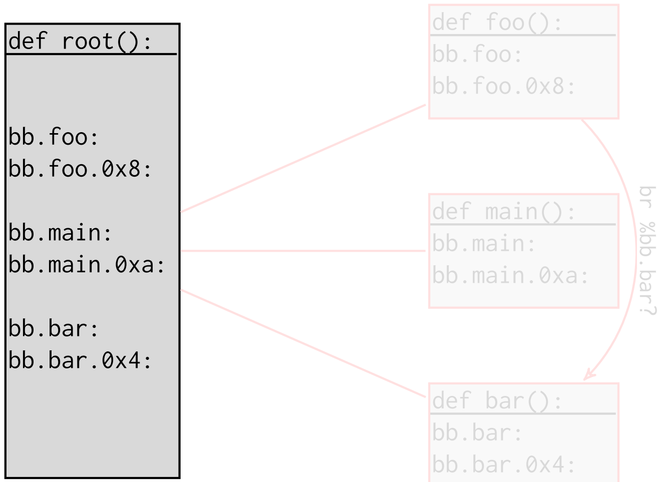
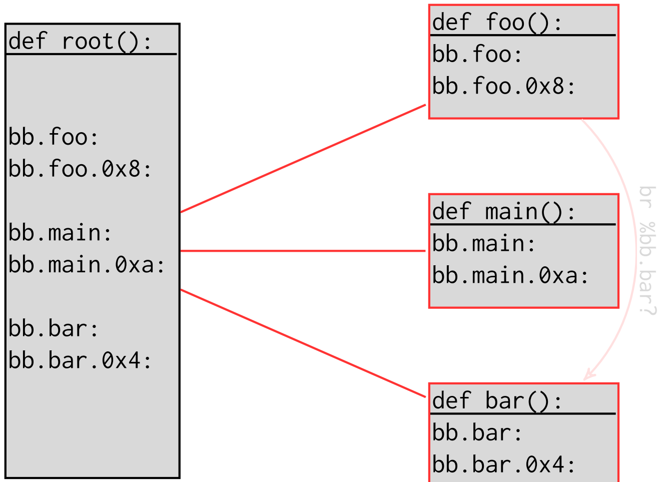
A naive approach

- The natural thing to do is try to *reconstruct* (with some approximations) the original *function layout*.
- Will things break? (Spoiler: yes, they will).

Bird View


def root():
bb.foo:
bb.foo.0x8:
bb.main:
bb.main.0xa:
bb.bar:
bb.bar.0x4:
def foo():
bb.foo:
bb.foo.0x8:
def main():
bb.main:
bb.main.0xa:
def bar():
bb.bar:
bb.bar.0x4:
br %bb.bar?

Bird View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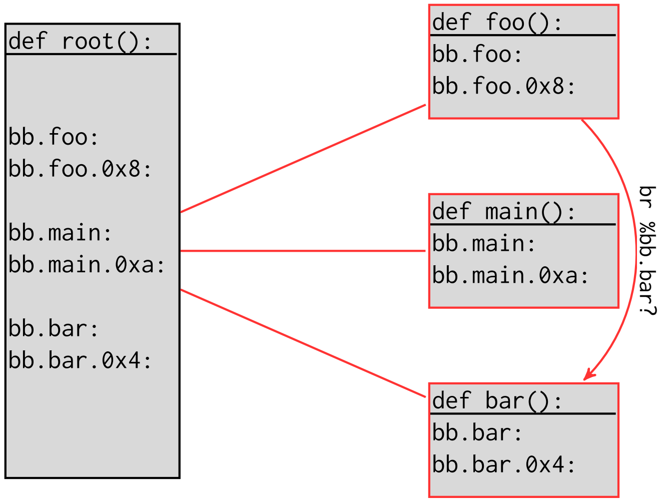
Bird View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bb.main:
bb.main.0xa:
def bar():
bb.bar:
bb.bar.0x4:
br %bb.bar?

- What if we make the isolated functions and the `root` function *coexist*?

Isolated and Non-Isolated Realms

We define these two *realms*:

Isolated Realm In this realm, we have a new LLVM function for each function discovered by the FBDA.

Non-Isolated Realm In this realm the original `root` function has been preserved, basically unaltered.

To the Isolated Realm and Back

- Transitioning to the isolated realm is easy, every time we find a basic block that is an *entry point* of a function, we call the corresponding isolated function in the isolated realm.
- The transition in the opposite direction is more complicated, our idea is to exploit the *exception handling mechanism* provided by LLVM.

To the Isolated Realm and Back

```
def root():
dispatcher:
 switch (pc):
  1 label %bb.foo
  2 label %bb.main
  3 label %bb.bar

bb.foo:
 invoke foo()

bb.main:
 invoke main()

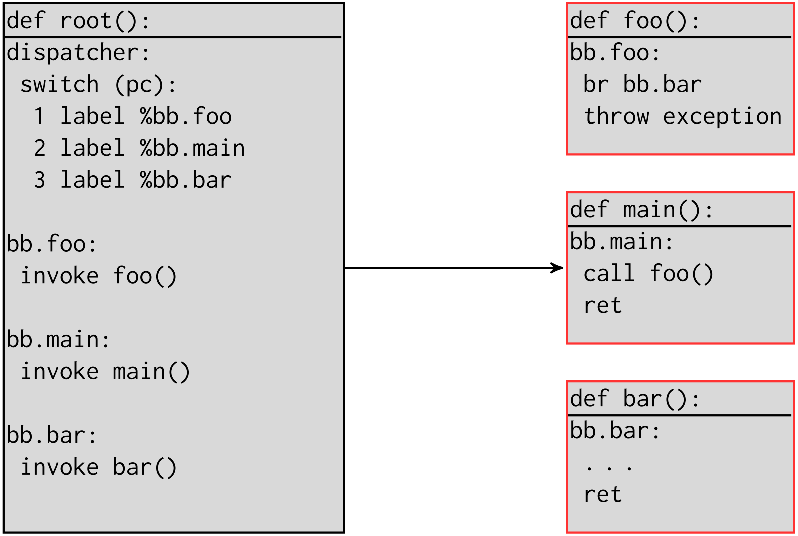
bb.bar:
 invoke bar()
```

```
def foo():
bb.foo:
 br bb.bar
 throw exception
```

```
def main():
bb.main:
 call foo()
 ret
```

```
def bar():
bb.bar:
 . . .
 ret
```

To the Isolated Realm and Back



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 throw exception
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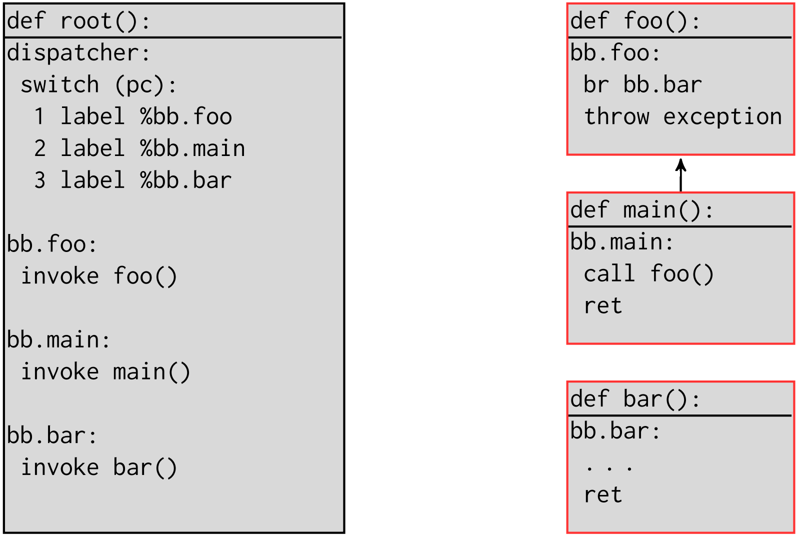
 call foo()
 ret
```

```
def bar():
bb.bar:
 . . .
 ret
```

To the Isolated Realm and Back



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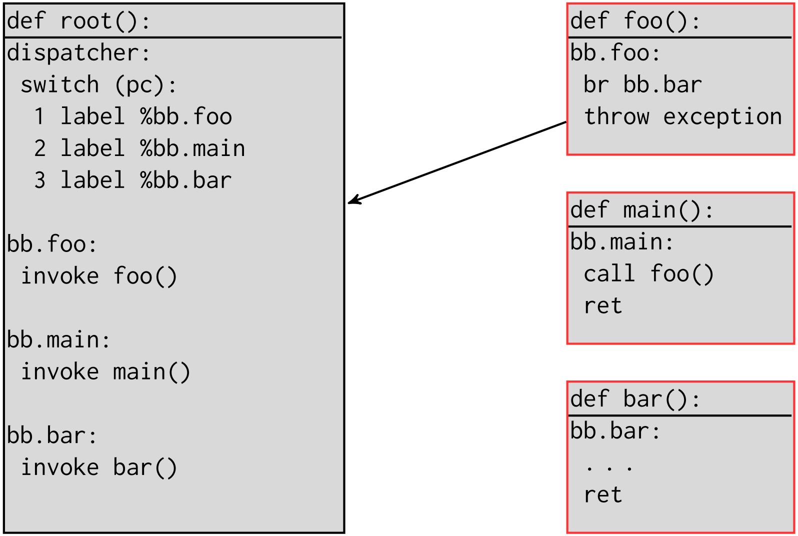
```
def foo():
bb.foo:
 br bb.bar
 throw exception
```

```
def main():
bb.main:
 call foo()
 ret
```

```
def bar():
bb.bar:
 . . .
 ret
```

To the Isolated Realm and Back



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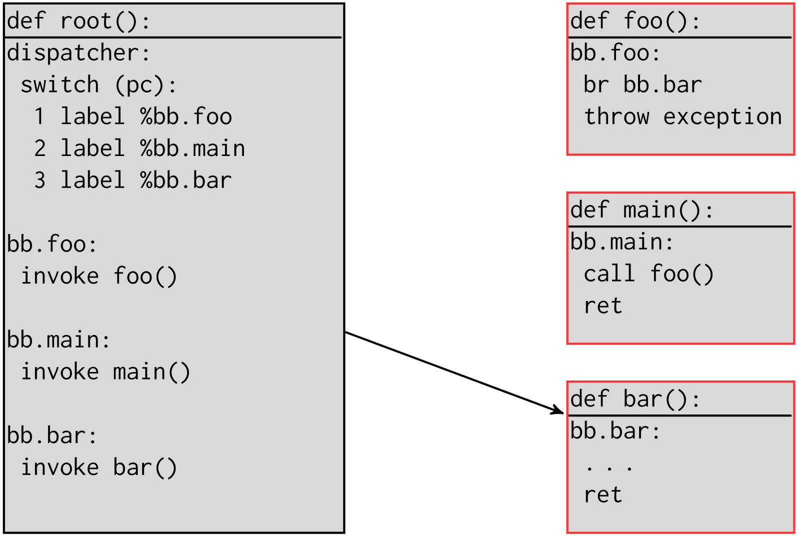
 throw exception
```

```
def main():
bb.main:
 call foo()
 ret
```

```
def bar():
bb.bar:
 . . .
 ret
```

To the Isolated Realm and Back



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  1 label %bb.foo
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bb.foo:
 invoke foo()

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 invoke main()

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 throw exception
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 call foo()
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```

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def bar():
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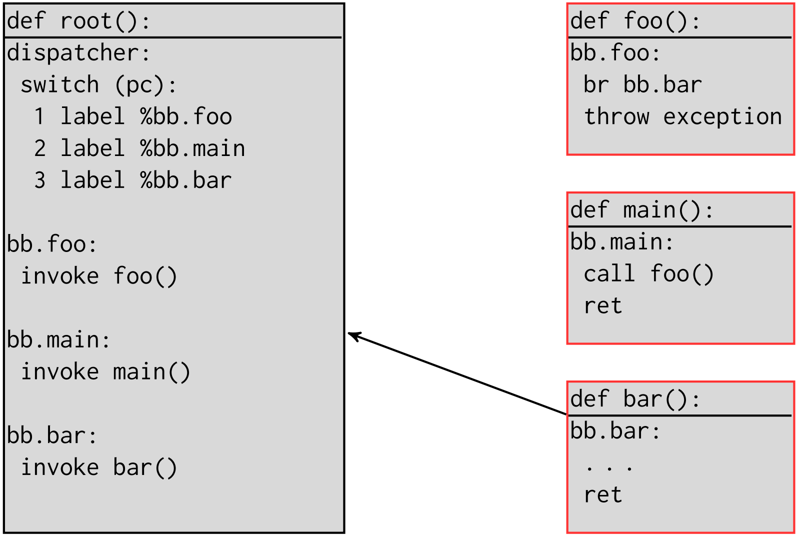
 . . .
 ret
```

To the Isolated Realm and Back



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def root():
dispatcher:
 switch (pc):
  1 label %bb.foo
  2 label %bb.main
  3 label %bb.bar

bb.foo:
 invoke foo()

bb.main:
 invoke main()

bb.bar:
 invoke bar()
```

```
def foo():
bb.foo:
 br bb.bar
 throw exception
```

```
def main():
bb.main:
 call foo()
 ret
```

```
def bar():
bb.bar:
 . . .
 ret
```

Exception Handling Mechanism

Our fallback mechanism is implemented using:

- The exception support provided by the LLVM framework.
- The stack unwinding mechanism via `libgcc`.

Function Isolation

- Function isolation is performed on the basis of the information provided by the Function Boundaries Detection Analysis pass.
- The accuracy of the FBDA is an important factor for performing an high quality function isolation.
- The quality of the function isolation determines how much the fallback-mechanism is actually employed.

Function Boundaries Analysis Limitations

- There are situations (e.g. exceptions in the original code), where the good (or even optimal) quality of the FBDA will not be sufficient.
- Our fallback mechanism guarantees that we can handle the execution in these situations.
- We handle exceptions with exceptions!

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Experimental Setup

- We used the SPECint 2006 benchmark suite.
- 4 configurations:
  - Native
  - QEMU
  - `rev.ng`
  - `rev.ng` with isolation

Experimental Results

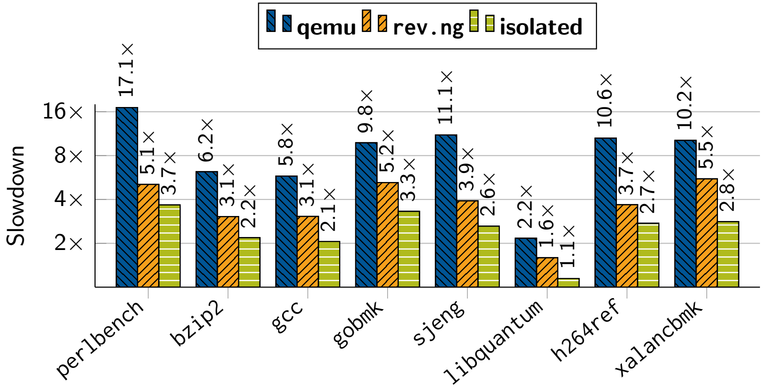

Figure: Slowdown of the different translation techniques compared to native code. Logarithmic scale. Lower is better.

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Future Work

- Recognize function parameters.
- Recognize return values.
- Promote global variables (registers) to local variables when possible.

Resources

- The function isolation feature has been implemented in `rev.ng` as a LLVM pass.
- The artifacts produced during the work, the code and the instructions to reproduce them are available at `https://rev.ng/gitlab/revng-bar-2019/artifacts`.
- If you are interested in more general instructions on how to get started with `rev.ng`, you can check the official website at `https://rev.ng/getting-started.html`.

Questions?

License

Backup Slides

Backup Slides

LLVM IR

```c
int counter;

int main(int argc) {
  if (argc > 5) {



    counter++;





  } else {
    myfunction();
  }


  return 1;

}
```

```llvm
@counter = common global i32 0

define i32 @main ( i32 %argc ) {
  %1 = icmp sgt i32 %argc , 5
  br i1 %1 , label %yes , label %no

yes :
  %2 = load i32 , i32 * @counter
  %3 = add i32 %2 , 1
  store i32 %3 , i32 * @counter
  br label %end

no :
  call void @otherfunction ()
  br label %end

end :
  ret i32 1

}
```

Exception Handling Mechanism

To do this, we mainly used the *exception handling* mechanism provided by LLVM. In our solution, this mechanism is in charge of recovering a potentially faulty situation, for example when static analysis cannot foresee the destination of a jump, taking care of redirecting the execution to a component that is in charge of understanding what to do next.

Exception Handling Mechanism

At the implementation level, for using exceptions we need to:

- Replace in the `root` function, each function entry basic block body with an `invoke` instruction (a peculiar `call` instruction) to the isolated function.
- In the isolated realm, each time we need to exit from the isolated function in an unexpected manner, throw an exception.
- Provide to LLVM a *personality function*, which is a function that is in charge of specifying the runtime behavior when an exception is thrown.

CSV

- `rev.ng` represents the current CPU state using the so called *CSV* (CPU state variable), which are LLVM *global variables*.
- In the general case, this is a great bottleneck for the performances (we need to go through memory).