# Implementing machine code optimizations for RISC-V

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# Shrink wrapping

```
foo:
  addi sp, sp, -16
  sw ra, 12(sp)
   ...
  beq a0, a1, .Lend

  call bar
   ...

.Lend:
   ...
  lw ra, 12(sp)
  addi sp, sp, 16
  ret
```

*‘ra’ used for call*

# Shrink wrapping

```
foo:
  addi sp, sp, -16
  sw ra, 12(sp)
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  call bar
  ...

.Lend:
  ...
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  ret
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## Shrink wrapping

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foo:
   addi sp, sp, -16
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   beq a0, a1, .Lend

   call bar
   ...

.Lend:
   ...
   lw ra, 12(sp)
   addi sp, sp, 16
   ret
```
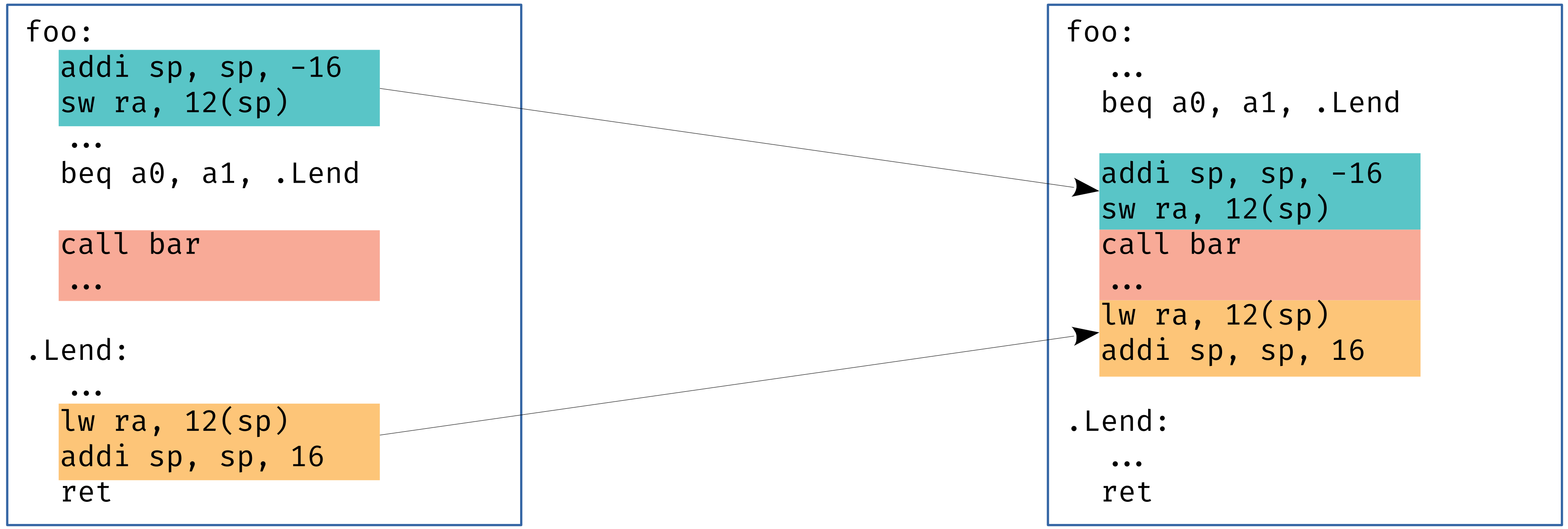

*Actually, ‘ra’ is only used if execution reaches this block…*

# Shrink wrapping



```
foo:
  addi sp, sp, -16
  sw ra, 12(sp)
  ...
  beq a0, a1, .Lend

  call bar
  ...

.Lend:
  ...
  lw ra, 12(sp)
  addi sp, sp, 16
  ret
```

```
foo:
  ...
  beq a0, a1, .Lend

  addi sp, sp, -16
  sw ra, 12(sp)
  call bar
  ...
  lw ra, 12(sp)
  addi sp, sp, 16

.Lend:
  ...
  ret
```

## Shrink wrapping

- Minimal changes necessary in RISC-V backend.
  - Remove 'shrink wrapping is not yet supported' assertion
  - Correctly calculate epilogue insertion point

```
  ...

  // If this is not a terminator, the actual insert location should be after the
  // last instruction.
  if (!MBBI->isTerminator())
    MBBI = std::next(MBBI);
```

# Save/restore

```
foo:
   addi sp, sp, -16
   sw ra, 12(sp)
   ...
   lw ra, 12(sp)
   addi sp, sp, 16
   ret

bar:
   addi sp, sp, -16
   sw ra, 12(sp)
   sw s0, 8(sp)
   ...
   lw s0, 8(sp)
   lw ra, 12(sp)
   addi sp, sp, 16
   ret

...
```

*Save and restore code may be needed a lot throughout a program, and can start to look very familiar.*

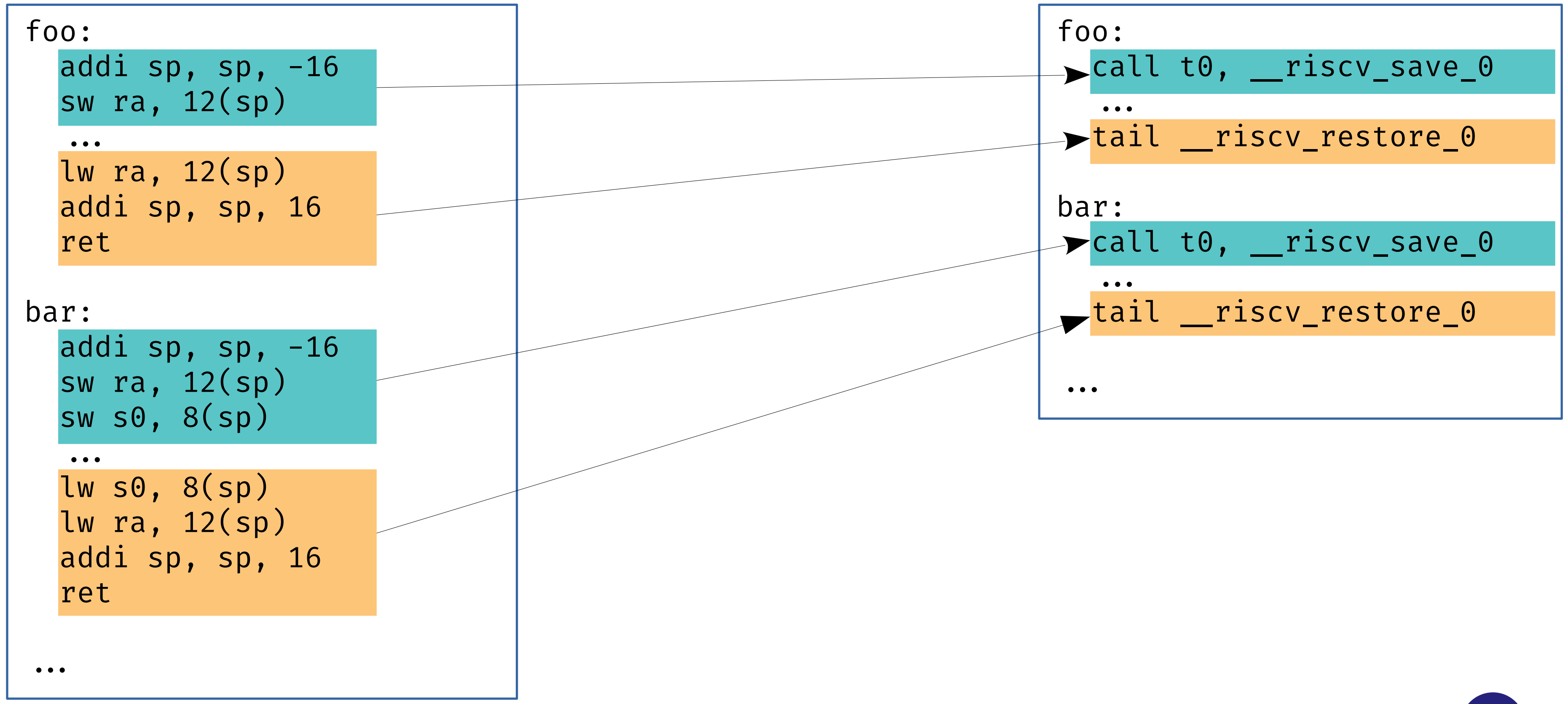
## Save/restore

```
…

__riscv_save_3:
__riscv_save_2:
__riscv_save_1:
__riscv_save_0:
  addi sp, sp, -16
  sw s2, 0(sp)
  sw s1, 4(sp)
  sw s0, 8(sp)
  sw ra, 12(sp)
  jr t0

…
```

*People have noticed this before. Minimized routines available in libgcc.*

```
…

__riscv_restore_3:
__riscv_restore_2:
__riscv_restore_1:
__riscv_restore_0:
  lw s2, 0(sp)
  lw s1, 4(sp)
  lw s0, 8(sp)
  lw ra, 12(sp)
  addi sp, sp, 16
  ret

…
```

# Save/restore



```
foo:
  addi sp, sp, -16
  sw ra, 12(sp)
  ...
  lw ra, 12(sp)
  addi sp, sp, 16
  ret

bar:
  addi sp, sp, -16
  sw ra, 12(sp)
  sw s0, 8(sp)
  ...
  lw s0, 8(sp)
  lw ra, 12(sp)
  addi sp, sp, 16
  ret

 ...
```

```
foo:
  call t0, __riscv_save_0
  ...
  tail __riscv_restore_0

bar:
  call t0, __riscv_save_0
  ...
  tail __riscv_restore_0

 ...
```

## Save/restore

- Save/restore is not a pass, but needs to be manually implemented.
  - For each register saved by libcall, indicate that it shouldn't have save/restore code automatically generated
  - Insert call via t0 to the save libcall at the beginning of the prologue
  - Insert tail call to the restore libcall at the end of the epilogue

## Save/restore

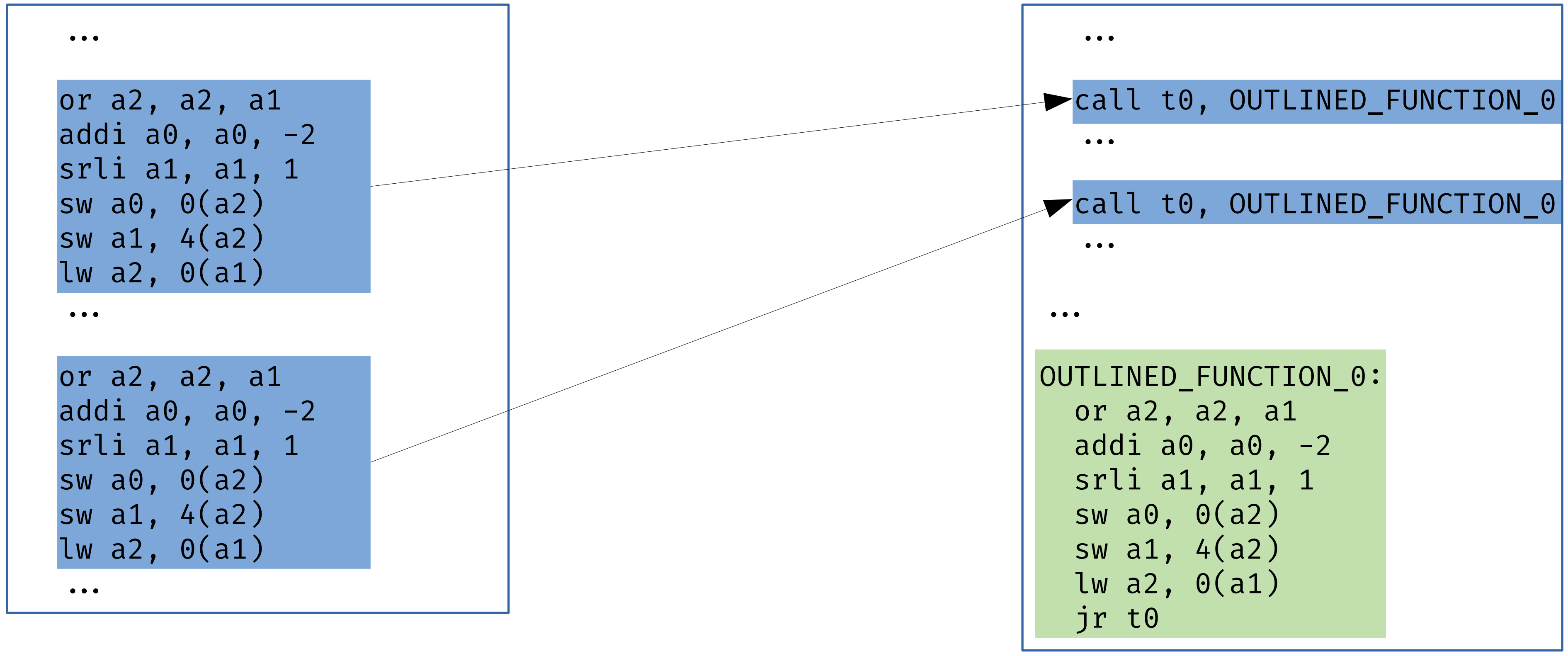
- Using libcalls introduces various complexities.
  - Inserting a tail call to a libcall means we cannot have any other tail calls in the function
  - A frame may now have additional stack adjustment within a libcall to keep track of

```
  ...

uint64_t StackSize = MFI.getStackSize();
uint64_t RealStackSize = StackSize + RVFI→getLibCallStackSize();
```

# Machine outlining

```
...

or a2, a2, a1
addi a0, a0, -2
srli a1, a1, 1
sw a0, 0(a2)
sw a1, 4(a2)
lw a2, 0(a1)
...

or a2, a2, a1
addi a0, a0, -2
srli a1, a1, 1
sw a0, 0(a2)
sw a1, 4(a2)
lw a2, 0(a1)
...
```

## Machine outlining



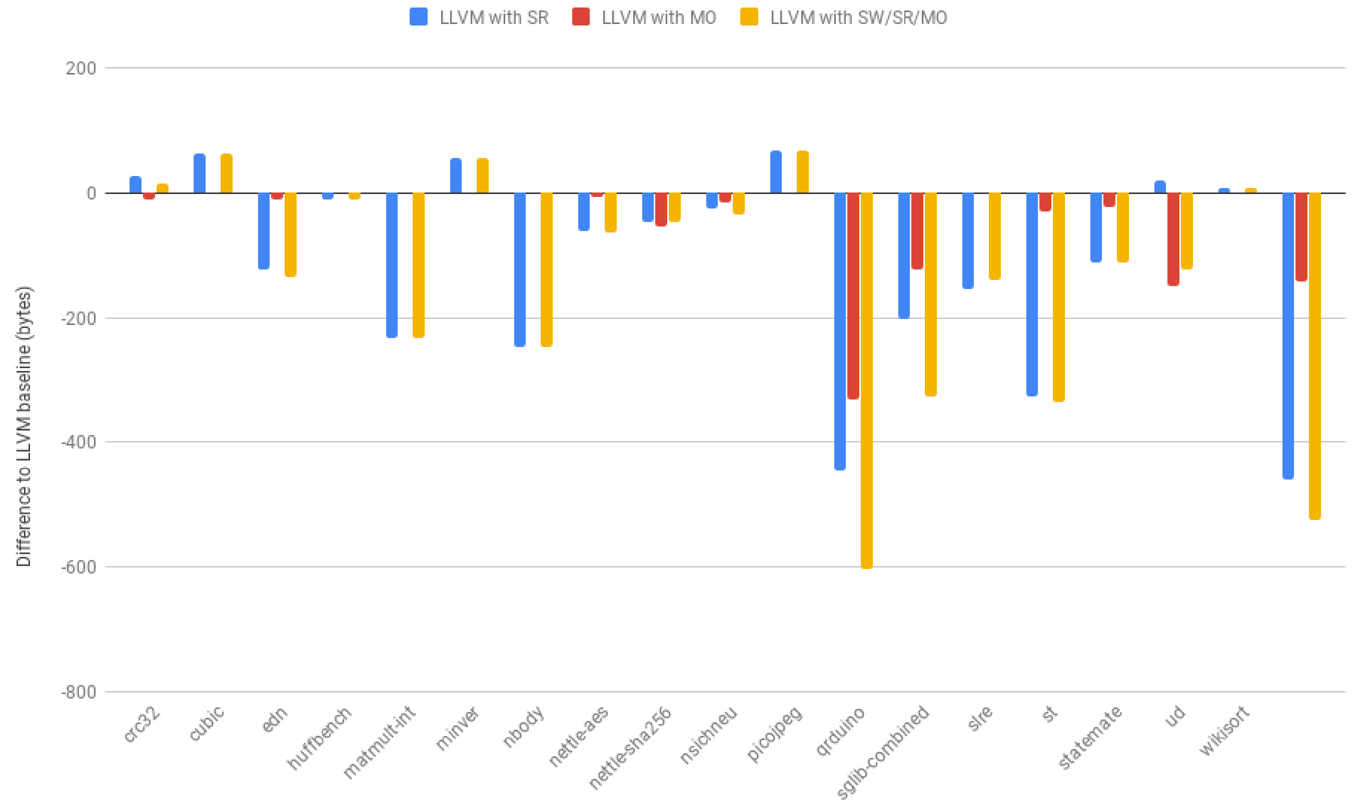
```
...

or a2, a2, a1
addi a0, a0, -2
srli a1, a1, 1
sw a0, 0(a2)
sw a1, 4(a2)
lw a2, 0(a1)
...

or a2, a2, a1
addi a0, a0, -2
srli a1, a1, 1
sw a0, 0(a2)
sw a1, 4(a2)
lw a2, 0(a1)
...
```

```
 ...

 call t0, OUTLINED_FUNCTION_0
 ...

 call t0, OUTLINED_FUNCTION_0
 ...

...

OUTLINED_FUNCTION_0:
  or a2, a2, a1
  addi a0, a0, -2
  srli a1, a1, 1
  sw a0, 0(a2)
  sw a1, 4(a2)
  lw a2, 0(a1)
  jr t0
```

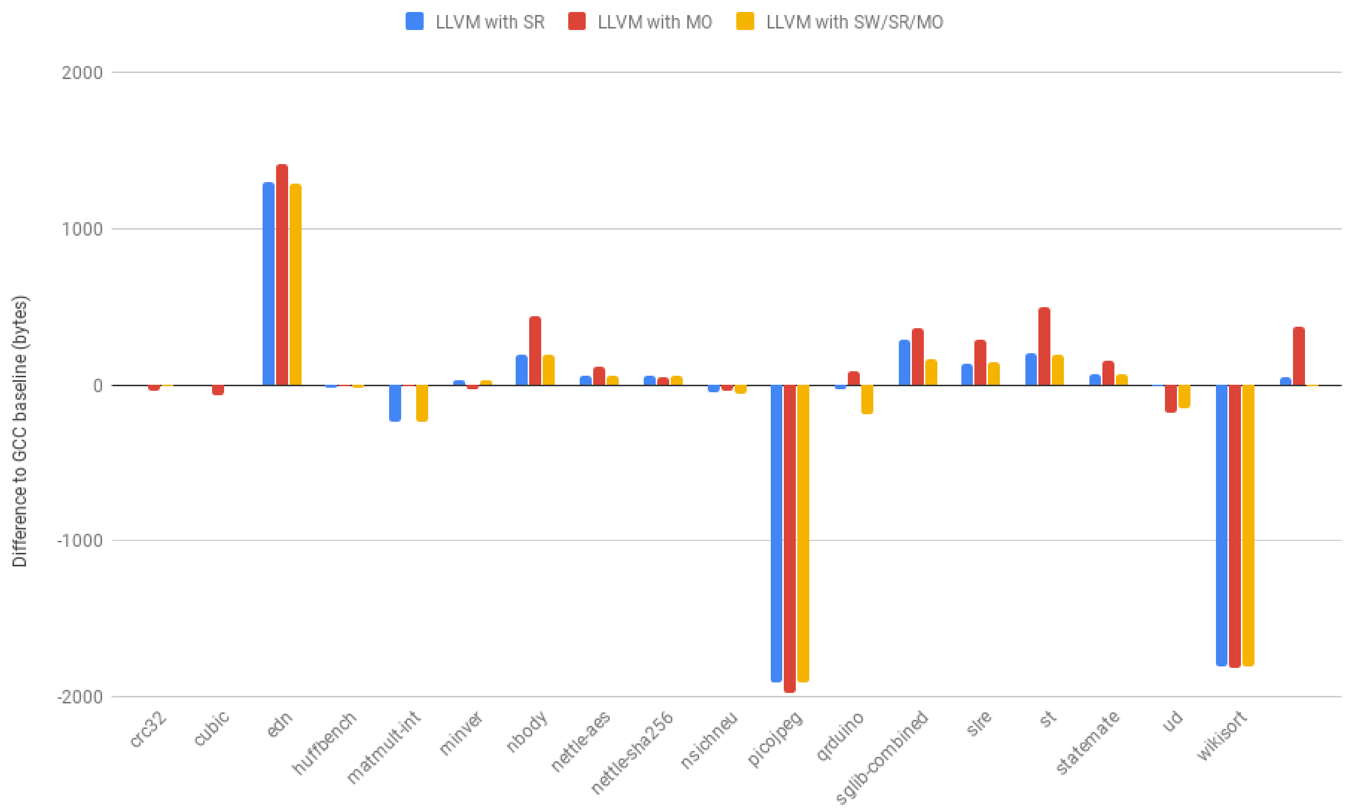
## Machine outlining

- Use target hooks to provide details to the machine outliner.
  - Which functions/basic blocks are safe to outline from?
  - Which instructions can be outlined?
  - What is the benefit of outlining a set of candidates?
- Build the outlined function, and insert calls
  - Same ‘call through t0’ approach as save/restore

# Results


LLVM with SR
LLVM with MO
LLVM with SW/SR/MO
200
0
-200
-400
-600
-800
Difference to LLVM baseline (bytes)
crc32
cubic
edn
huffbench
matmult-int
minver
nbody
nettle-aes
nettle-sha256
nsichneu
picojpeg
qrduino
sglib-combined
slre
st
statemate
ud
wikisort

# Results



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# Thank you!

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