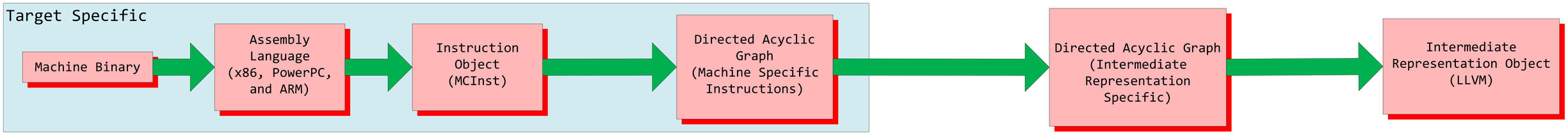
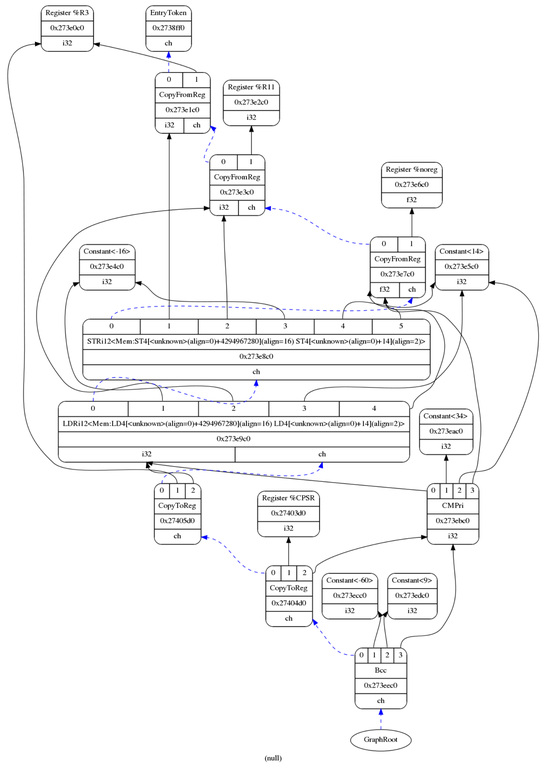
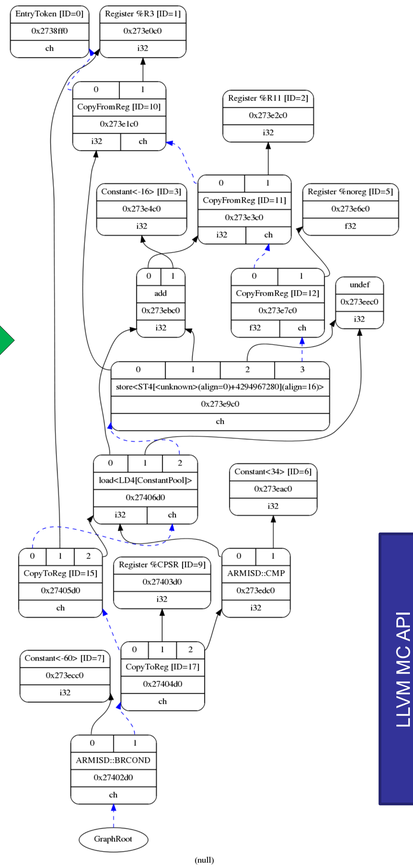
Fracture: Inverting LLVM's Target Independent Code Generator



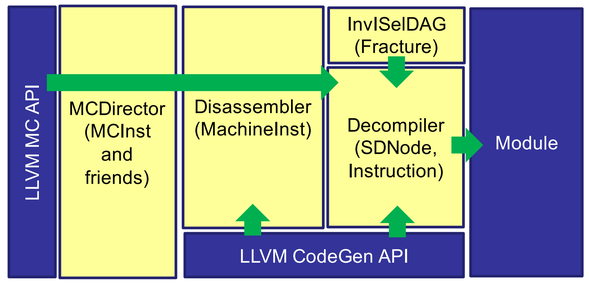

```
000000B8:   10 48 2D E9  push {r4, r11, lr}
000000BC:   08 B0 8D E2  add  r11, sp, #0x8
000000C0:   0C D0 4D E2  sub  sp, sp, #0xc
000000C4:   00 30 A0 E3  mov  r3, #0x0
000000C8:   10 30 0B E5  str  r3, [r11, #-16]
000000CC:   0A 00 00 EA  b    #0x28
```

```
%SP<def,tied1> = STMDB_UPD %SP<tied0>, pred:14,
                           pred:%noreg, %R4, %R11, %LR
%R11<def> = ADDri %SP, 8, pred:14, pred:%noreg, opt:%noreg
%SP<def> = SUBri %SP, 12, pred:14, pred:%noreg, opt:%noreg
%R3<def> = MOVi 0, pred:14, pred:%noreg, opt:%noreg
STRi12 %R3, %R11, 4294967280, pred:14, pred:%noreg
Bcc 40, pred:14, pred:%noreg
```






```
%0 = sub %SP, Constant<4>
store %R4, %0
%1 = sub %0, Constant<4>
store %R11, %1
%2 = sub %1, Constant<4>
store %LR, %2
%R11 = add %2, Constant<8>
%SP = sub %2, Constant<12>
%R3 = Constant<0>
%3 = add %R11, Constant<-16>
store %R3, %3
ARMISD::BRCOND Constant<40>
```



Technical Approach

- We mirrored the LLVM compilation process
  - This was sometimes easier, sometimes harder
    - Easy: Objects, graphs, etc already done
    - Hard: fighting LLVM API, decoding symbols/memory accesses, classic decompilation problems (which we haven't solved yet)
- Two major software components:
  - A "reverse" DAG manipulation table in TableGen
  - Libraries to handle LLVM API Interaction ("CodeInv")

Fracture TableGen Backend

- Borrowed a lot of code (modified some of it):

```
CodeGenDAGPatterns.h    CodeGenInstruction.cpp  CodeGenInstruction.h CodeGenIntrinsics.h
CodeGenMapTable.cpp     CodeGenRegisters.cpp        CodeGenRegisters.h    CodeGenSchedule.cpp
CodeGenSchedule.h     CodeGenTarget.cpp           CodeGenTarget.h       DAGISelMatcher.cpp
DAGISelMatcher.h      DAGISelMatcherEmitter.cpp      SDNodeInfo.cpp       SDNodeInfo.h
SetTheory.cpp      SetTheory.h         TGValueTypes.cpp   TableGen.cpp TableGenBackends.h
```

- CodeInvDAGPatterns
  - Helpers: InvTreePattern, InvTreePatternNode, InvTreePatternToMatch modeled after originals
  - Examines InOperandList and OutOperandList, then looks at Pattern and Fragments
  - No Glue, but kept chains

```
def SUBSri {
…
  dag OutOperandList = (outs GPR:$Rd);
  dag InOperandList = (ins GPR:$Rn, so_imm:$imm, pred:$p);
  list<dag> Pattern = [(set GPR:$Rd, CPSR, (anonymous.val.3663 GPR:$Rn, so_imm:$imm))];
…
def anonymous.val.3663 {
…
  dag Operands = (ops node:$LHS, node:$RHS);
  dag Fragment = (ARMsubc node:$LHS, node:$RHS);
…
```

```
/*6126*/  /*Scope*/ 30, /*->6157*/
/*6127*/    OPC_CheckOpcode, TARGET_VAL(ARM::SUBSri),
/*6130*/    OPC_MoveChild, 0,
/*6132*/    OPC_RecordNode,   // #0 = $Rn
/*6133*/    OPC_MoveParent,
/*6134*/    OPC_MoveChild, 1,
/*6136*/    OPC_CheckOpcode, TARGET_VAL(ISD::Constant),
/*6139*/    OPC_RecordNode,   // #1 = constant node
/*6140*/    OPC_MoveParent,
/*6141*/    OPC_MoveChild, 2,
/*6143*/    OPC_RecordNode,   // #2 = $p
/*6144*/    OPC_MoveParent,
/*6145*/    OPC_EmitNode, TARGET_VAL(ARMISD::SUBC), 0,
                1/*#VTs*/, MVT::i32, 2/*#Ops*/, 0, 1,  // Results = #3
/*6154*/    OPC_CompleteMatch, 1, 0,
            // Src: (SUBSri GPR:$Rn, (imm), pred:$p) - Complexity = ?
            // Dst: (ARMsubc GPR:$Rn, (imm))
```

- Notes:
  - Not optimized (OptimizeMatcher not called)
  - CPSR not in VT
  - Why care about predicate $p?
  - ARMISD::SUBC?

Ideas to Use Fracture

- Multiple code "views" (e.g., IDA Pro plugin) to see IR->MC when user doesn't know Target
- Use KLEE to analyze code
  - Lots of neat recent research could be applied here
  - Can use to solve indirect control transfer (ICT)
- Interpreter (lli) can run code
  - Extend to simulate entire embedded system if you can work out HW interaction
- Binary editor - retarget (for tractable programs), fix bugs, change functionality
- Decompiler (i.e., C-Backend)

Summary

- Modular (and fast?) conversion from machine code to IR
- Uses existing LLVM APIs and TableGen definitions
- Generic IR-based tools instead of one-off target specific solutions

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