Qualcomm

Inliner in MLIR

Javed Absar, Principal Engineer
UK Reservoir Labs R&D
Qualcomm Technologies International, Ltd.

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Contents

- MLIR – highly versatile, extensible compiler infrastructure
- Inlining in MLIR world
- MLIR Inliner
- Conclusion

MLIR: versatile IR

Affine Dialect

```
func.func private @foo_0(%a : memref<10xf32>, %b : memref<10xf32>) {
  affine.for %i = 0 to 10 {
    %v0 = affine.load %b[%i] : memref<10xf32>
    %v1 = affine.load %a[%i] : memref<10xf32>
    %v2 = arith.addf %v0, %v1 : f32
    affine.store %v2, %b[%i] : memref<10xf32>
  }
  return
}
```

LLVM

```
9:                                    ; preds = %9, %6
  %10 = phi i64 [ 0, %6 ], [ %16, %9 ]
  %11 = getelementptr inbounds float, float* %0, i64 %10
  %12 = load float, float* %11, align 4, !tbaa !2
  %13 = getelementptr inbounds float, float* %1, i64 %10
  %14 = load float, float* %13, align 4, !tbaa !2
  %15 = fadd float %12, %14
  store float %15, float* %13, align 4, !tbaa !2
  %16 = add nuw nsw i64 %10, 1
  %17 = icmp eq i64 %16, %7
  br i1 %17, label %8, label %9
```

MLIR: Affine.for (ODS)

```
def AffineForOp : Affine_Op<"for",
    [AutomaticAllocationScope, ImplicitAffineTerminator, ConditionallySpeculatable,
     RecursiveMemoryEffects, DeclareOpInterfaceMethods<LoopLikeOpInterface,
     ["getSingleInductionVar", "getSingleLowerBound", "getSingleStep",
      "getSingleUpperBound"]>,
     DeclareOpInterfaceMethods<RegionBranchOpInterface,
     ["getSuccessorEntryOperands"]>]> {
  let summary = "for operation";
  let description = [{ …}];

  let arguments = (ins Variadic<AnyType>);
  let results = (outs Variadic<AnyType>:$results);
  let regions = (region SizedRegion<1>:$region);
  …
}
```

MLIR: Affine.for (Generic)

```
affine.for %i = 0 to 10 {
  %v0 = affine.load %b[%i] : memref<10xf32>
  %v1 = affine.load %a[%i] : memref<10xf32>
  %v2 = arith.addf %v0, %v1 : f32
  affine.store %v2, %b[%i] : memref<10xf32>
}
```

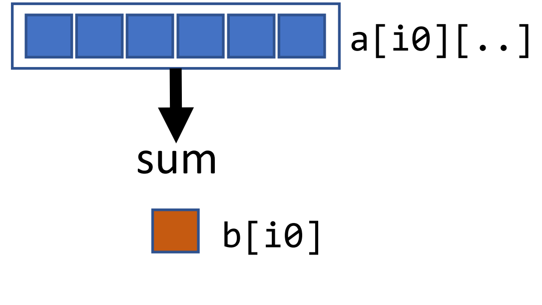
```
mlir-opt  -mlir-print-op-generic file.mlir
```

```
#map = affine_map<(d0) -> (d0)>
#map1 = affine_map<() -> (0)>
#map2 = affine_map<() -> (10)>
"builtin.module"() ({
  "func.func"() ({
  ^bb0(%arg0: memref<10xf32>, %arg1: memref<10xf32>):
    "affine.for"() ({
    ^bb0(%arg2: index):
      %0 = "affine.load"(%arg1, %arg2) {map = #map} : (memref<10xf32>, index) -> f32
      %1 = "affine.load"(%arg0, %arg2) {map = #map} : (memref<10xf32>, index) -> f32
      %2 = "arith.addf"(%0, %1) {fastmath = #arith.fastmath<none>} : (f32, f32) -> f32
      "affine.store"(%2, %arg1, %arg2) {map = #map} : (f32, memref<10xf32>, index) -> ()
      "affine.yield"() : () -> ()
    }) {lower_bound = #map1, step = 1 : index, upper_bound = #map2} : () -> ()
    "func.return"() : () -> ()
  }) {function_type = (memref<10xf32>, memref<10xf32>)
          -> (), sym_name = "foo_0", sym_visibility = "private"} : () -> ()
}) : () -> ()
```

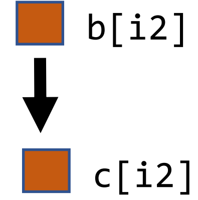
Inlining in MLIR world

```
func.func @foo(%a : memref<10x10xf32>, %b : memref<10xf32>, %c : memref<10xf32>) {
  func.call @foo_0(%a, %b) : (memref<10x10xf32>, memref<10xf32>) -> ()
  func.call @foo_1(%b, %c) : (memref<10xf32>, memref<10xf32>) -> ()
  return
}
```

```
func.func private @foo_0(%a : memref<10x10xf32>, %b : memref<10xf32>) {
  affine.for %i0 = 0 to 10 {
    affine.for %i1 = 0 to 10 {
      %v0 = affine.load %b[%i0] : memref<10xf32>
      %v1 = affine.load %a[%i0, %i1] : memref<10x10xf32>
      %v3 = arith.addf %v0, %v1 : f32
      affine.store %v3, %b[%i0] : memref<10xf32>
    }
  }
  return
}
```




```
func.func private @foo_1(%b : memref<10xf32>, %c : memref<10xf32>) {
  affine.for %i2 = 0 to 10 {
    %v4 = affine.load %b[%i2] : memref<10xf32>
    affine.store %v4, %c[%i2] : memref<10xf32>
  }
  return
}
```



Inlining in MLIR world

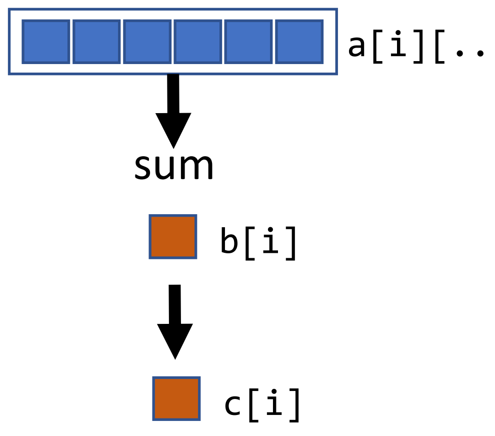
```
mlir-opt -inline='op-pipelines=func.func(canonicalize,cse)’ ex.mlir –o inlined.mlir
```

```
module {
  func.func @foo(%a: memref<10x10xf32>, %b: memref<10xf32>,
                 %c: memref<10xf32>) {
    affine.for %i = 0 to 10 {
      affine.for %j = 0 to 10 {
        %0 = affine.load %b[%i] : memref<10xf32>
        %1 = affine.load %a[%i, %j] : memref<10x10xf32>
        %2 = arith.addf %0, %1 : f32
        affine.store %2, %b[%i] : memref<10xf32>
      }
    }
    affine.for %i = 0 to 10 {
      %0 = affine.load %b[%i] : memref<10xf32>
      affine.store %0, %c[%i] : memref<10xf32>
    }
    return
  }
}
```

Inlining in MLIR world

```
mlir-opt  inlined.mlir  -pass-pipeline='builtin.module(func.func(affine-loop-fusion))'
```

```
module {
  func.func @foo(%a: memref<10x10xf32>, %b: memref<10xf32>,
                 %c: memref<10xf32>) {
    affine.for %i = 0 to 10 {
      affine.for %j = 0 to 10 {
        %1 = affine.load %b[%i] : memref<10xf32>
        %2 = affine.load %a[%i, %j] : memref<10x10xf32>
        %3 = arith.addf %1, %2 : f32
        affine.store %3, %b[%i] : memref<10xf32>
      }
      %0 = affine.load %b[%i] : memref<10xf32>
      affine.store %0, %c[%i] : memref<10xf32>
    }
    return
  }
}
```



How to Inline ? MLIR Interfaces

- Generic way of interacting with the IR
- Corner-stone of MLIR extensibility
- Provide information to the transformation/analysis pass
- Interfaces (properties of interest) defined by the transformation
- Transformation/Analyses in terms of interfaces

```
TestInterfaces, ArithOpsInterfaces,OpenMPOpsInterfaces,LLVMInterfaces, MatchInterfaces,
TransformInterfaces,TosaInterfaces, BuiltinAttributeInterfaces,SymbolInterfaces,
AffineMemoryOpInterfaces, LinalgInterfaces, VectorInterfaces, ShapedOpInterfaces,
CallInterfaces, CastInterfaces, DataLayoutInterfaces, …
```

DialectInlinerInterface

```
InliningUtils.h
```

```
/// This is the interface that must be implemented by the dialects of operations
/// to be inlined. This interface should only handle the operations of the …
class DialectInlinerInterface
    : public DialectInterface::Base<DialectInlinerInterface> {
public:
  //===----------------------------------------------------------------------===//
  // Analysis Hooks
  //===----------------------------------------------------------------------===//

  /// Returns true if the given operation 'callable', that implements the
  /// 'CallableOpInterface', can be inlined into the position given call…
  virtual bool isLegalToInline(Operation *call, Operation *callable,
                               bool wouldBeCloned) const;
   ...
  //===----------------------------------------------------------------------===//
  // Transformation Hooks
  //===----------------------------------------------------------------------===//
  virtual void handleTerminator(Operation *op, Block *newDest) const;
  ...
```

DialectInlinerInterface

LLVMInlining.cpp

```
struct LLVMInlinerInterface : public DialectInlinerInterface {
  using DialectInlinerInterface::DialectInlinerInterface;
  LLVMInlinerInterface(Dialect *dialect)
      : DialectInlinerInterface(dialect),
        // Cache set of StringAttrs for fast lookup in `isLegalToInline`.
        disallowedFunctionAttrs({
            StringAttr::get(dialect->getContext(), "noduplicate"),
            StringAttr::get(dialect->getContext(), "noinline"),
            StringAttr::get(dialect->getContext(), "optnone"),
            StringAttr::get(dialect->getContext(), "presplitcoroutine"),
            StringAttr::get(dialect->getContext(), "returns_twice"),
            StringAttr::get(dialect->getContext(), "strictfp"),
        }) {}
  bool isLegalToInline(Operation *call, Operation *callable,
                       bool wouldBeCloned) const final {
    auto callOp = dyn_cast<LLVM::CallOp>(call);
    if (!callOp) {
      LLVM_DEBUG(llvm::dbgs()
                 << "Cannot inline: call is not an LLVM::CallOp\n");
      return false;
    }
```

CallOp Interface

CallInterfaces.td

```
def CallOpInterface : OpInterface<"CallOpInterface"> {
  let description = [{ ...transfers control from one sub-routine to.. }];
  …
  let methods = [
    InterfaceMethod<[{Returns the callee of this call-like operation. …either a
        reference to a symbol, or a reference to a defined SSA value. }],
      "::mlir::CallInterfaceCallable", "getCallableForCallee"
    >,
    InterfaceMethod<[{… get the operands …to the callee. }],
      "::mlir::Operation::operand_range", "getArgOperands"
    >,
  ];
  let extraClassDeclaration = [{/// Resolve the callable operation for given callee
      Operation *resolveCallable(SymbolTableCollection *symbolTable = nullptr);
  }];
}
```

CallableOp Interface

CallInterfaces.td

```
def CallableOpInterface : OpInterface<"CallableOpInterface"> {
  let description = [{ … represents a potential sub-routine, and may
    be a target for those providing the CallOpInterface  }];
  …
  let methods = [
    InterfaceMethod<[{
        Returns the region on the current operation that is callable. This may
        return null in the case of an external callable object, e.g. an external
        function.
      }],
      "::mlir::Region *", "getCallableRegion"
    >,
    InterfaceMethod<[{
        The results types that the callable region produces when executed.
      }],
      "::llvm::ArrayRef<::mlir::Type>", "getCallableResults"
    >,
  ];
}
```

Using call interfaces

FuncOps.td

```
def CallOp : Func_Op<"call",
    [CallOpInterface, MemRefsNormalizable,
     DeclareOpInterfaceMethods<SymbolUserOpInterface>]> {
  let summary = "call operation";
  let description = [{... a direct call to a function ...
    Example:

    ```mlir
    %2 = func.call @my_add(%0, %1) : (f32, f32) -> f32
    ```
  }];

  let arguments = (ins FlatSymbolRefAttr:$callee, Variadic<AnyType>:$operands);
  let results = (outs Variadic<AnyType>);
  ...
}
```

Inline Legality

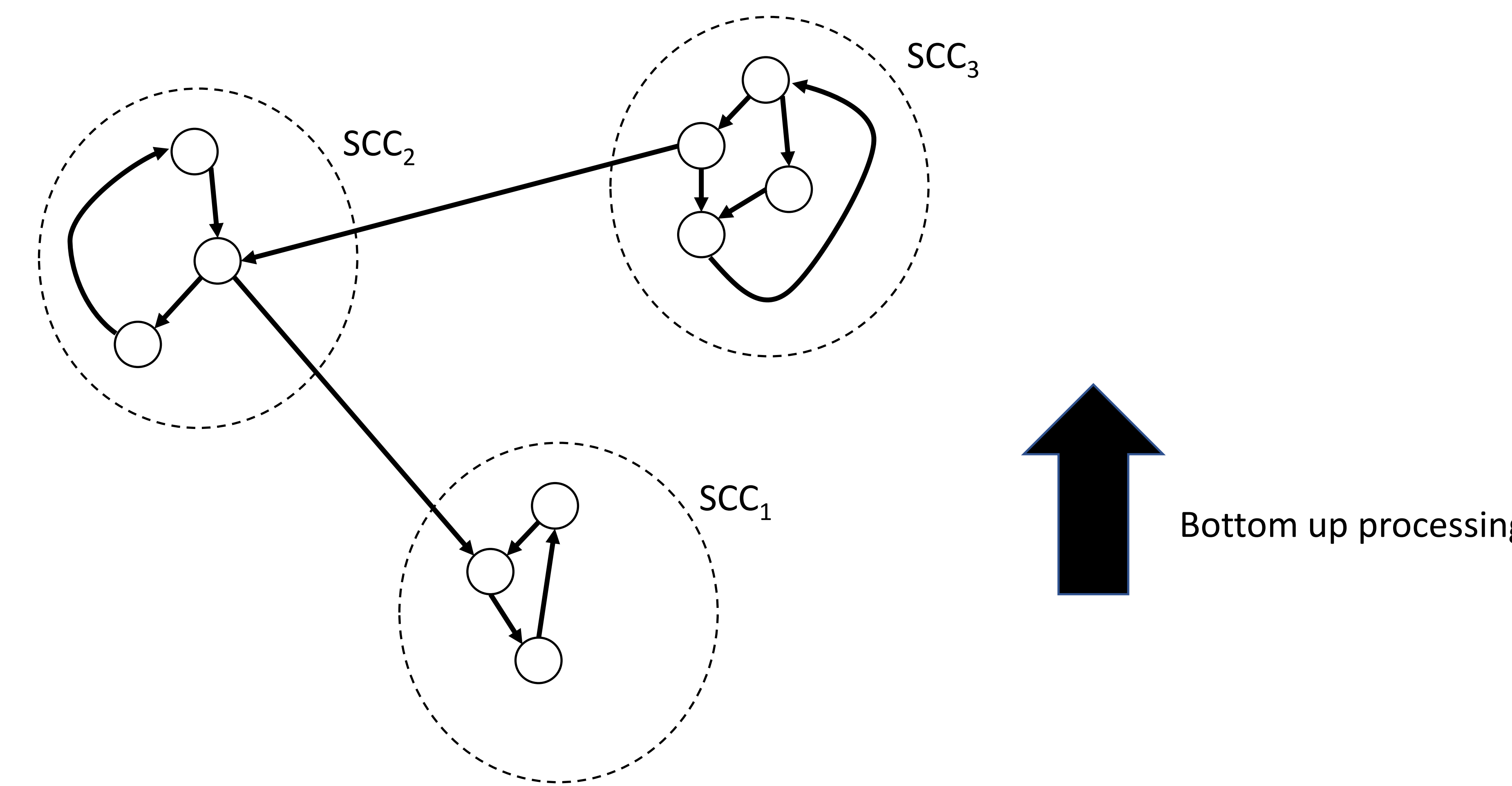
InliningUtils.h

```
/// Utility to check that all of the operations within 'src' can be inlined.
static bool isLegalToInline(InlinerInterface &interface, Region *src,
                            Region *insertRegion, bool shouldCloneInlinedRegion,
                            IRMapping &valueMapping) {
  for (auto &block : *src) {
    for (auto &op : block) {
      // Check this operation.
      if (!interface.isLegalToInline(&op, insertRegion,
                                     shouldCloneInlinedRegion, valueMapping)) {
        ...
        });
        return false;
      }
      // Check any nested regions.
      ...
}
```

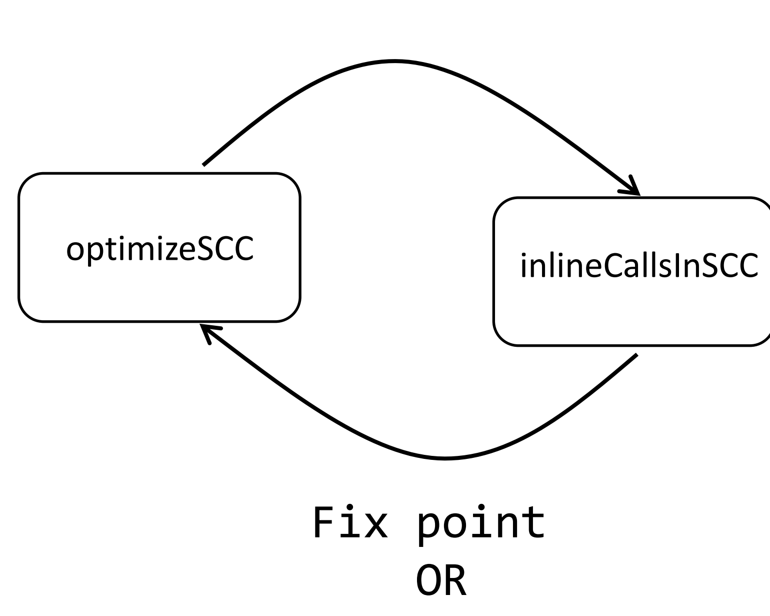
How to Inline ? MLIR Interfaces

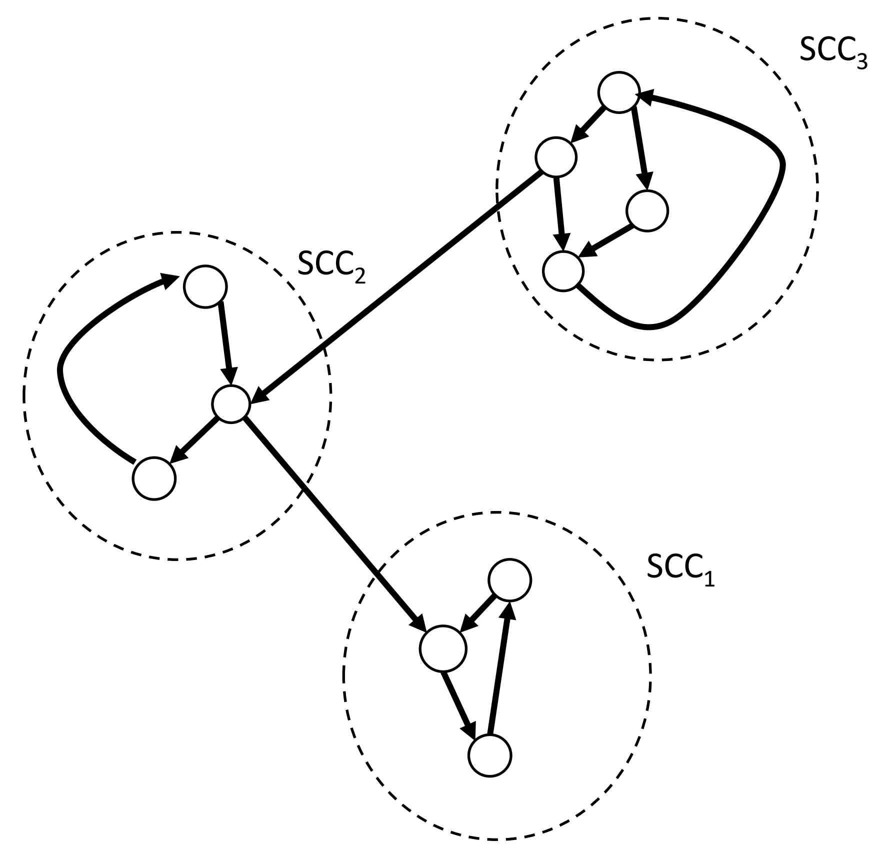
- Dialect Inliner Interface
- CallOp Interface
- CallableOp Interface

Inliner Implementation



Inliner in MLIR





Inline History

```
func.func @A(%x : i32) -> i32 {
  %res = func.call @B(%x) : (i32) -> i32
  return %res : i32
}

func.func @B(%x : i32) -> i32 {
  %res = func.call @C(%x) : (i32) -> i32
  return %res : i32
}

func.func @C(%x : i32) -> i32 {
  %cst_1 = arith.constant 1 : i32
  %y = arith.addi %x, %cst_1 : i32
  %res = func.call @A(%y) : (i32) -> i32
  return %res : i32
}
```

```
func @A( ) {
 C2: call @B
}
```

```
func @B( ) {
 C1: call @C
}
```

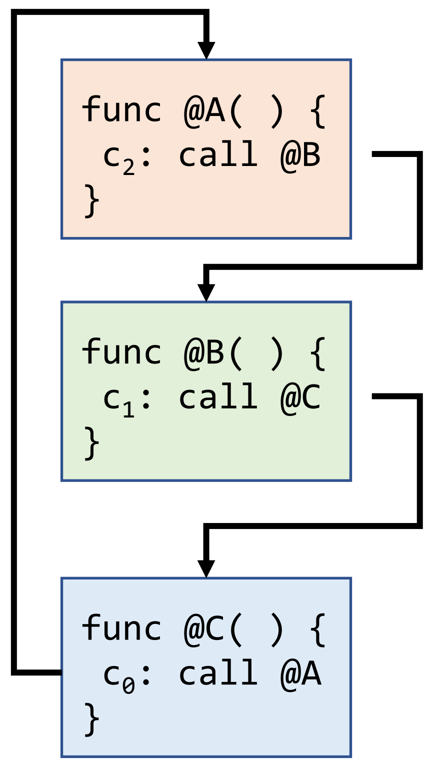
```
func @C( ) {
 C0: call @A
}
```

```
func.func @A(%x : i32) -> i32 {
  %res = func.call @B(%x) : (i32) -> i32
  return %res : i32
}

func.func @B(%x : i32) -> i32 {
  %res = func.call @C(%x) : (i32) -> i32
  return %res : i32
}

func.func @C(%x : i32) -> i32 {
  %cst_1 = arith.constant 1 : i32
  %y = arith.addi %x, %cst_1 : i32
  %res = func.call @A(%y) : (i32) -> i32
  return %res : i32
}
```

Inline History



Calls

c_0. call @A
c_1. call @C
c_2. call @B

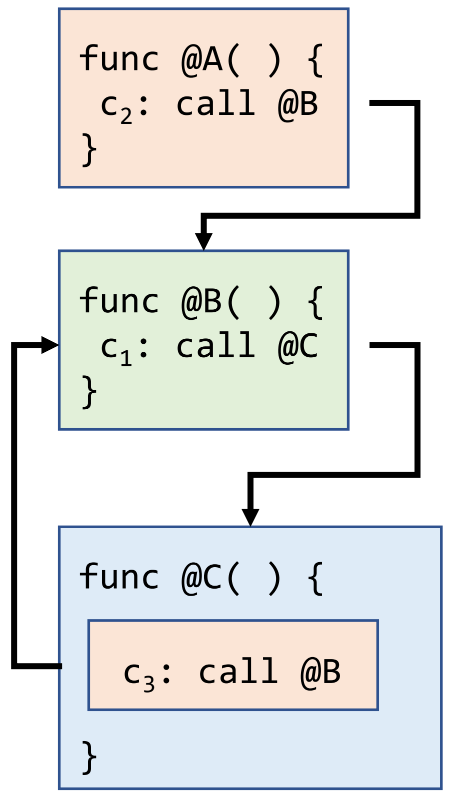
Call-History

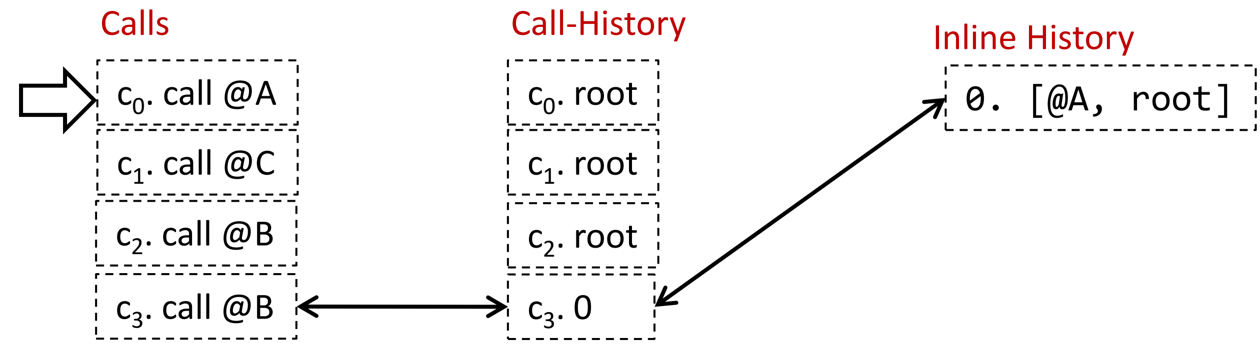
c_0. root
c_1. root
c_2. root

Inline History

```
* Inliner: Initial calls in SCC are: {
  0. %1 = func.call @A(%0) : (i32) -> i32,
  1. %0 = func.call @C(%arg0) : (i32) -> i32,
  2. %0 = func.call @B(%arg0) : (i32) -> i32,
}
```

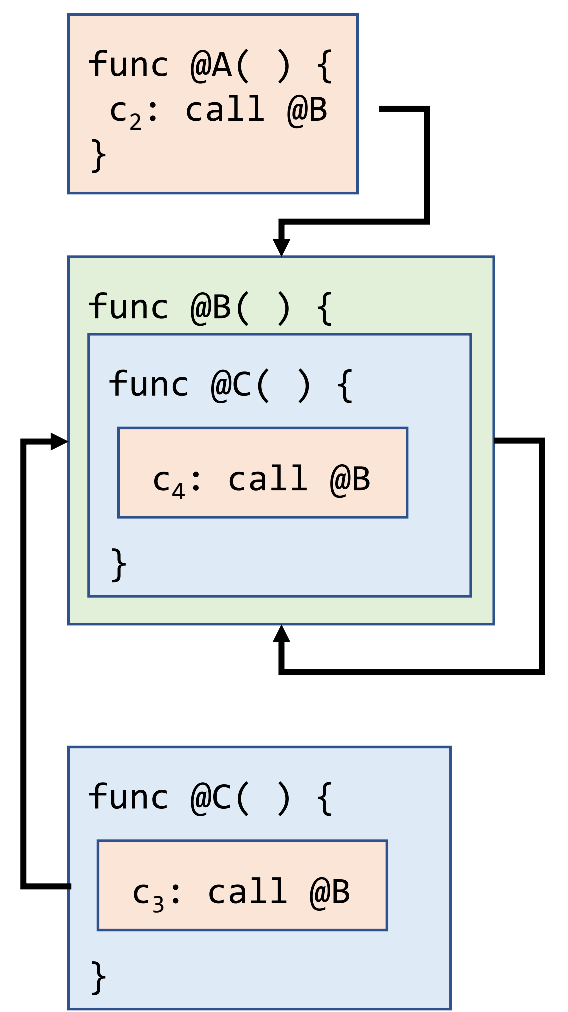
Inline History



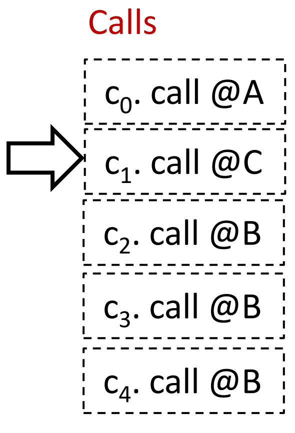



```
* Inlining call: 0. %1 = func.call @A(%0) : (i32) -> i32
* new inlineHistory entry: 0. [%1 = func.call @A(%0) : (i32) -> i32, root]
* new call 3 {%2 = func.call @B(%0) : (i32) -> i32}
   with historyID = 0, added due to inlining of
  call {%1 = func.call @A(%0) : (i32) -> i32}
 with historyID = root
```

Inline History



Calls



Call-History

- c_0. root
- c_1. root
- c_2. root
- c_3. 0
- c_4. 1

Inline History

- 0. [@A, root]
- 1. [@C, root]

```
* Inlining call: 1. %0 = func.call @C(%arg0) : (i32) -> i32
* new inlineHistory entry: 1. [%0 = func.call @C(%arg0) : (i32) -> i32, root]
* new call 4 {%2 = func.call @B(%1) : (i32) -> i32}
   with historyID = 1, added due to inlining of
  call {%0 = func.call @C(%arg0) : (i32) -> i32}
 with historyID = root
```

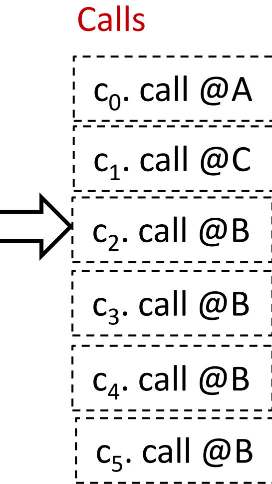
Inline History

```
func @A( ) {
  func @B( ) {
    func @C( ) {
      c5: call @B
    }
  }
}
```

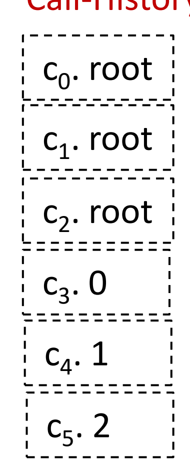
```
func @B( ) {
  func @C( ) {
    c4: call @B
  }
}
```

```
func @C( ) {
  c3: call @B
}
```

Calls



Call-History

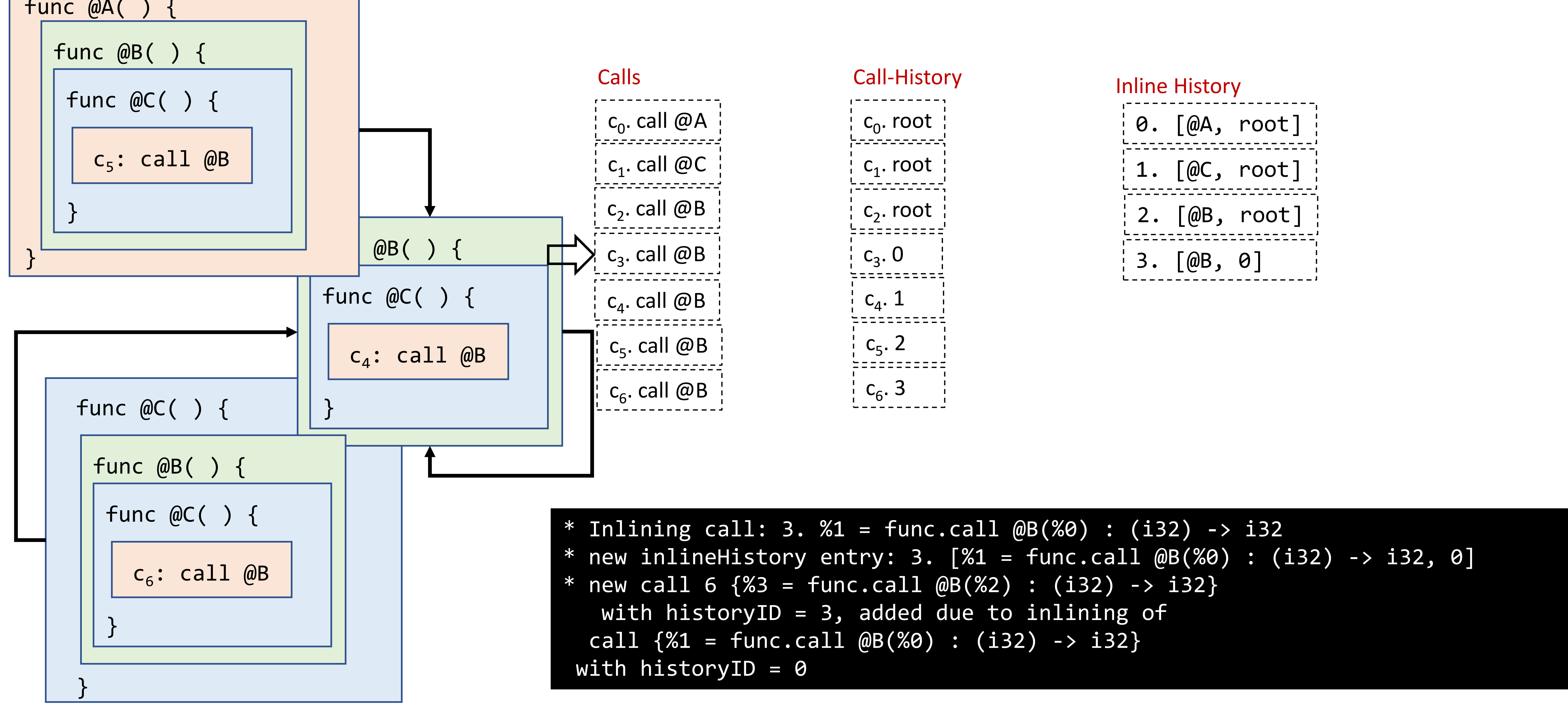


Inline History

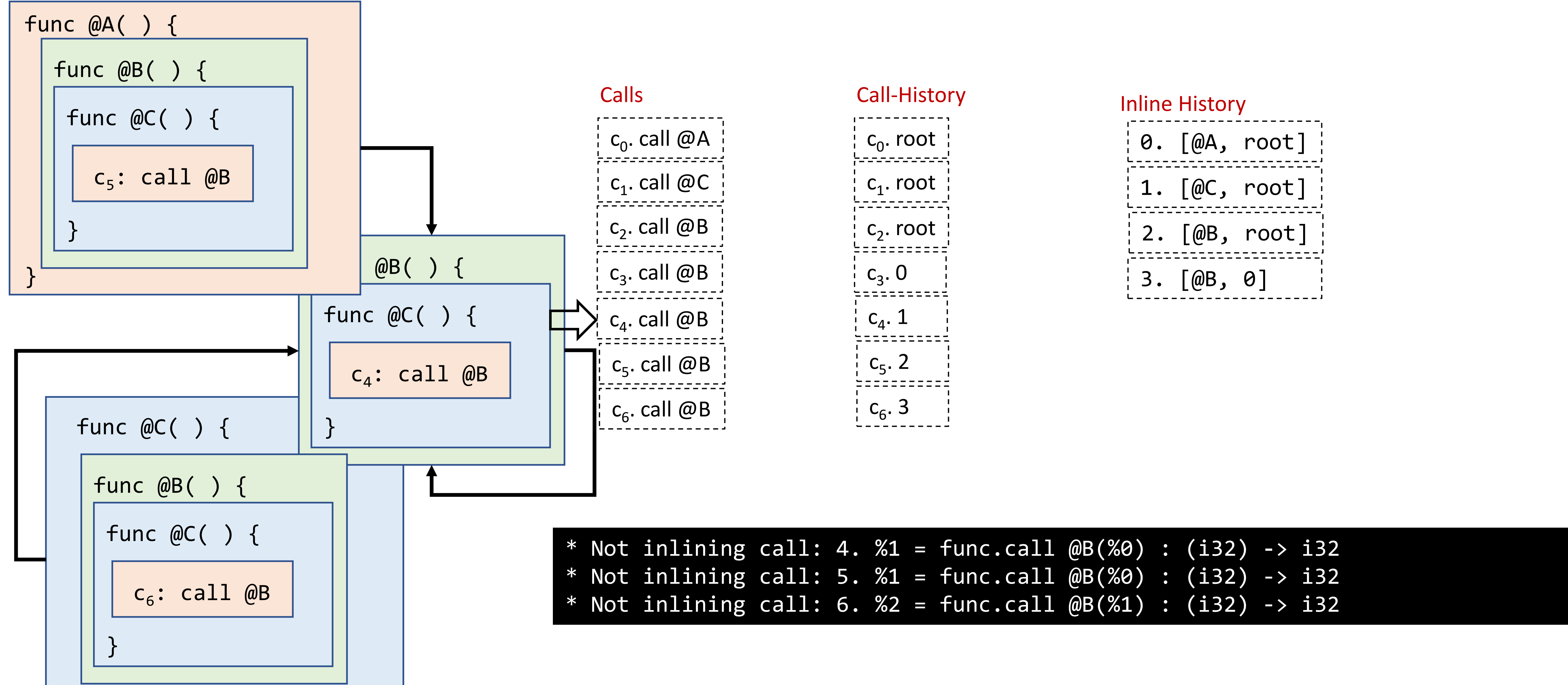
```
0. [@A, root]
1. [@C, root]
2. [@B, root]
```

```
* Inlining call: 2. %0 = func.call @B(%arg0) : (i32) -> i32
* new inlineHistory entry: 2. [%0 = func.call @B(%arg0) : (i32) -> i32, root]
* new call 5 {%2 = func.call @B(%1) : (i32) -> i32}
   with historyID = 2, added due to inlining of
  call {%0 = func.call @B(%arg0) : (i32) -> i32}
 with historyID = root
```

Inline History



Inline History



Inline History

func @A( ) {
func @B( ) {
func @C( ) {
c_5: call @B
}
}

@B( ) {
func @C( ) {
c_4: call @B
}

func @C( ) {
func @B( ) {
func @C( ) {
c_6: call @B
}
}

```
module {
  func.func @A(%arg0: i32) -> i32 {
    %c1_i32 = arith.constant 1 : i32
    %0 = arith.addi %arg0, %c1_i32 : i32
    %1 = call @B(%0) : (i32) -> i32
    return %1 : i32
  }
  func.func @B(%arg0: i32) -> i32 {
    %c1_i32 = arith.constant 1 : i32
    %0 = arith.addi %arg0, %c1_i32 : i32
    %1 = call @B(%0) : (i32) -> i32
    return %1 : i32
  }
  func.func @C(%arg0: i32) -> i32 {
    %c1_i32 = arith.constant 1 : i32
    %0 = arith.addi %arg0, %c1_i32 : i32
    %c1_i32_0 = arith.constant 1 : i32
    %1 = arith.addi %0, %c1_i32_0 : i32
    %2 = call @B(%1) : (i32) -> i32
    return %2 : i32
  }
}
```

Conclusion

- MLIR : versatile but some common transformations can be useful
- Inliner: works well across dialects
- Inlining Interface
- Details of Inliner operation

Thank you

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