Turning Control Flow Graphs into Callgraphs

Transformation of partitioned codes for execution in heterogeneous architectures

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Outline

1. Heterogeneous High Performance Computing

2. Compilation toolchain

3. Code refactoring for execution in heterogeneous platforms

Outline

1. **Heterogeneous High Performance Computing**

2. Compilation toolchain

3. Code refactoring for execution in heterogeneous platforms

High Performance Computing & Embedded Systems

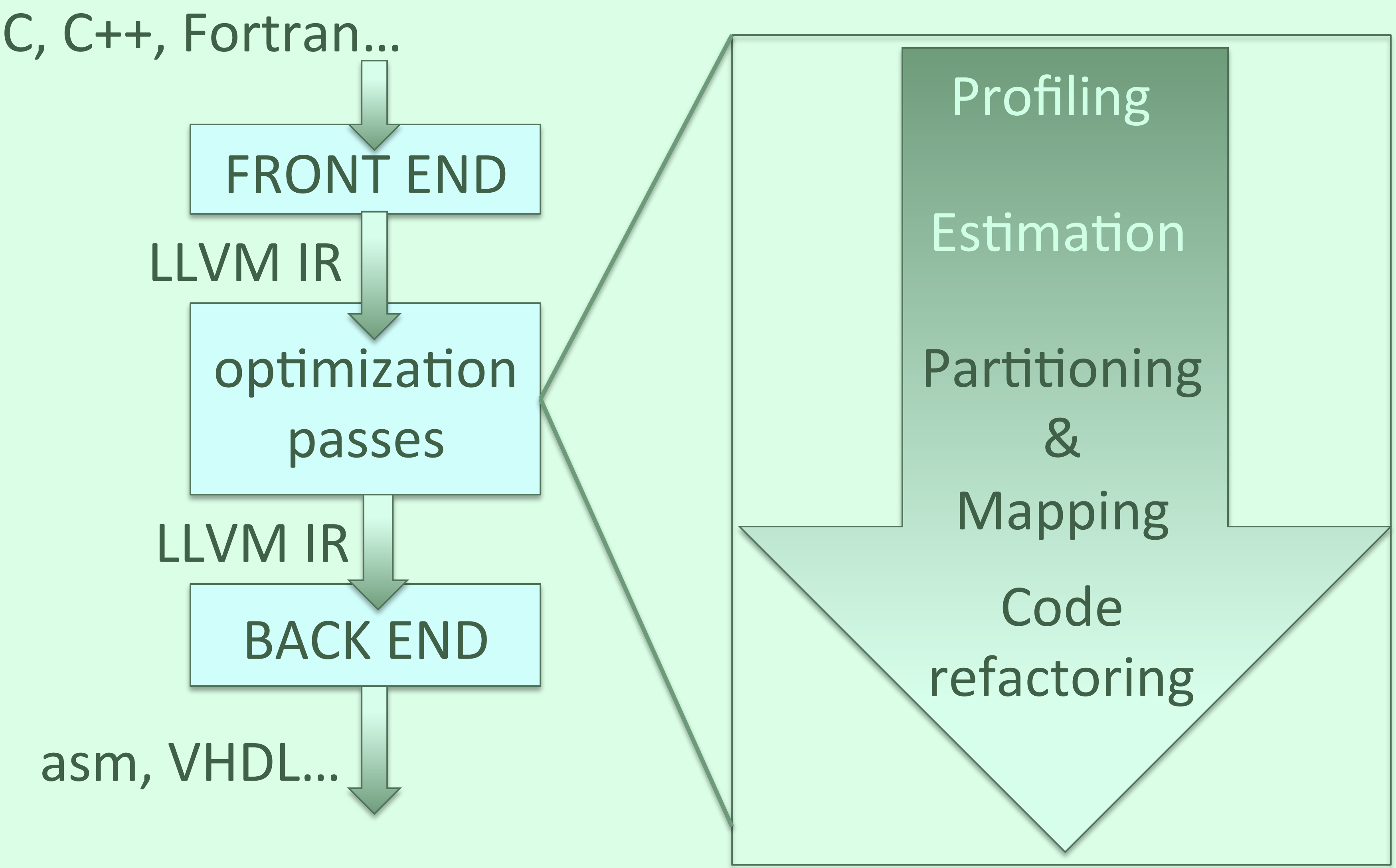
	Embedded	*HPC*
Type of processors	**Heterogeneous**	Homogeneous
Size	Small	**Massive**
Memory	Shared	**Distributed**

but getting closer every day…

Objectives

- A **code partitioner** for heterogeneous architectures.
- Easy to add **models for new devices and architectures**.
- Partitioning based on **software and hardware** characteristics.
- Communications generated for **distributed memory** systems.
- **Automatic parallelization**, both functional and data parallel.

The solution under research



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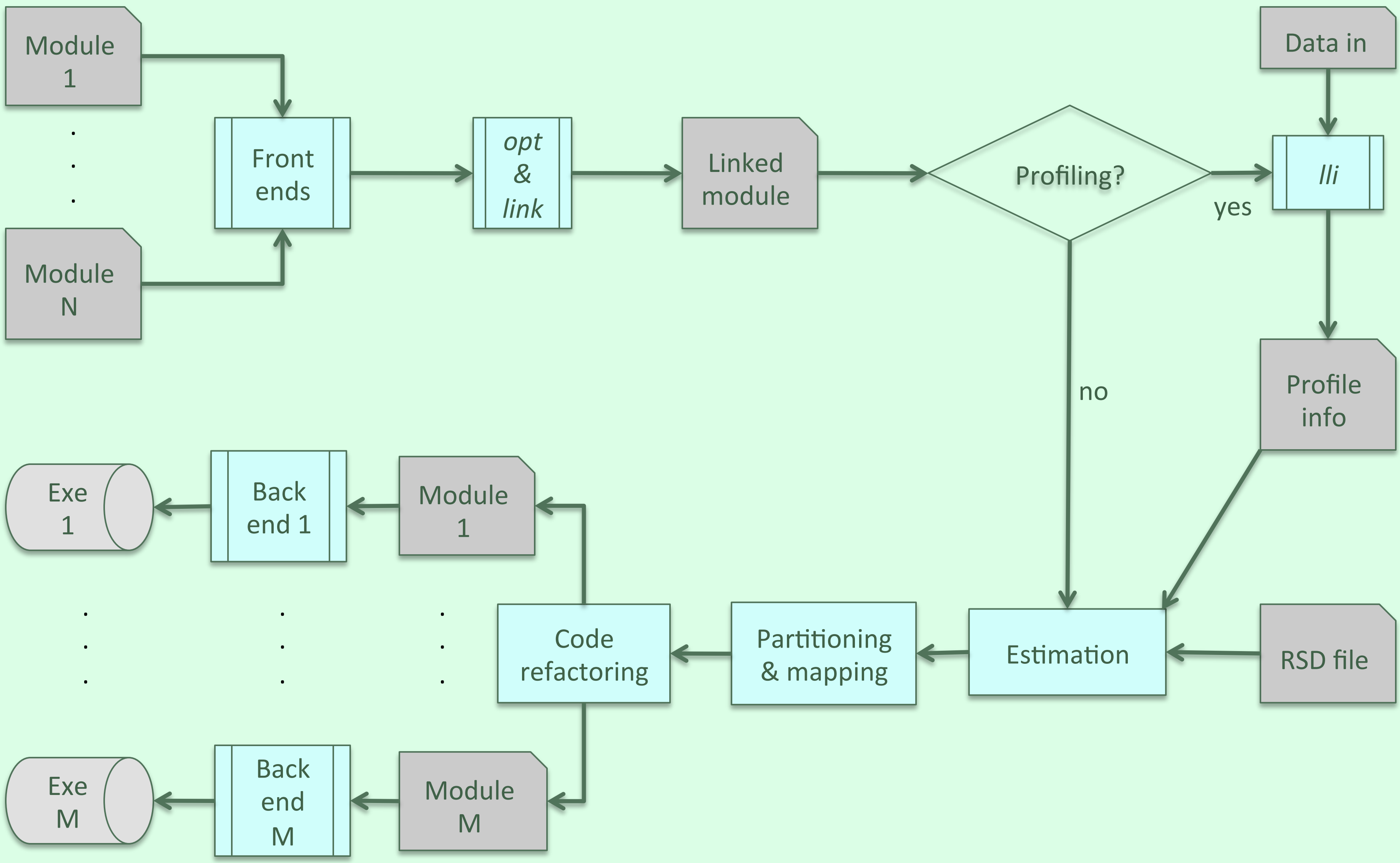
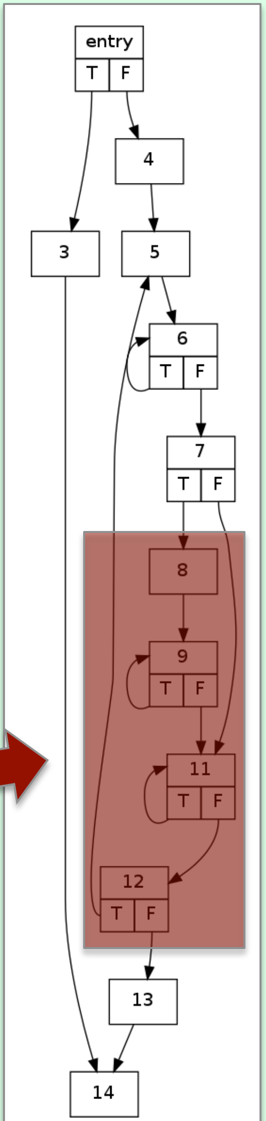
LLVM-based compilation toolchain



Partitioning & Mapping

```
[PartitioningPass] PARTITIONING OVERVIEW:
                 Initial exec time was 1.81e-07  s,
                 new is 1.06e-07
                 -- Speedup = 1.71e+00
[PartitionWriterPass] Generating partitioned code
PartitionWriterPass::runOnModule() -- Original
functions:
        odd with BBs:
                 entry --> CPU
        main with BBs:
                 entry --> CPU
                 3 --> CPU
                 4 --> CPU
                 beforeHeader --> CPU
                 5 --> CPU
                 6 --> CPU
                 7 --> CPU
                 8 --> CPU_SIMD
                 9 --> CPU_SIMD
                 11 --> CPU_SIMD
                 12 --> CPU_SIMD
                 13 --> CPU
                 14 --> CPU
                 afterHeader --> CPU
...
```



CFG for 'main' function

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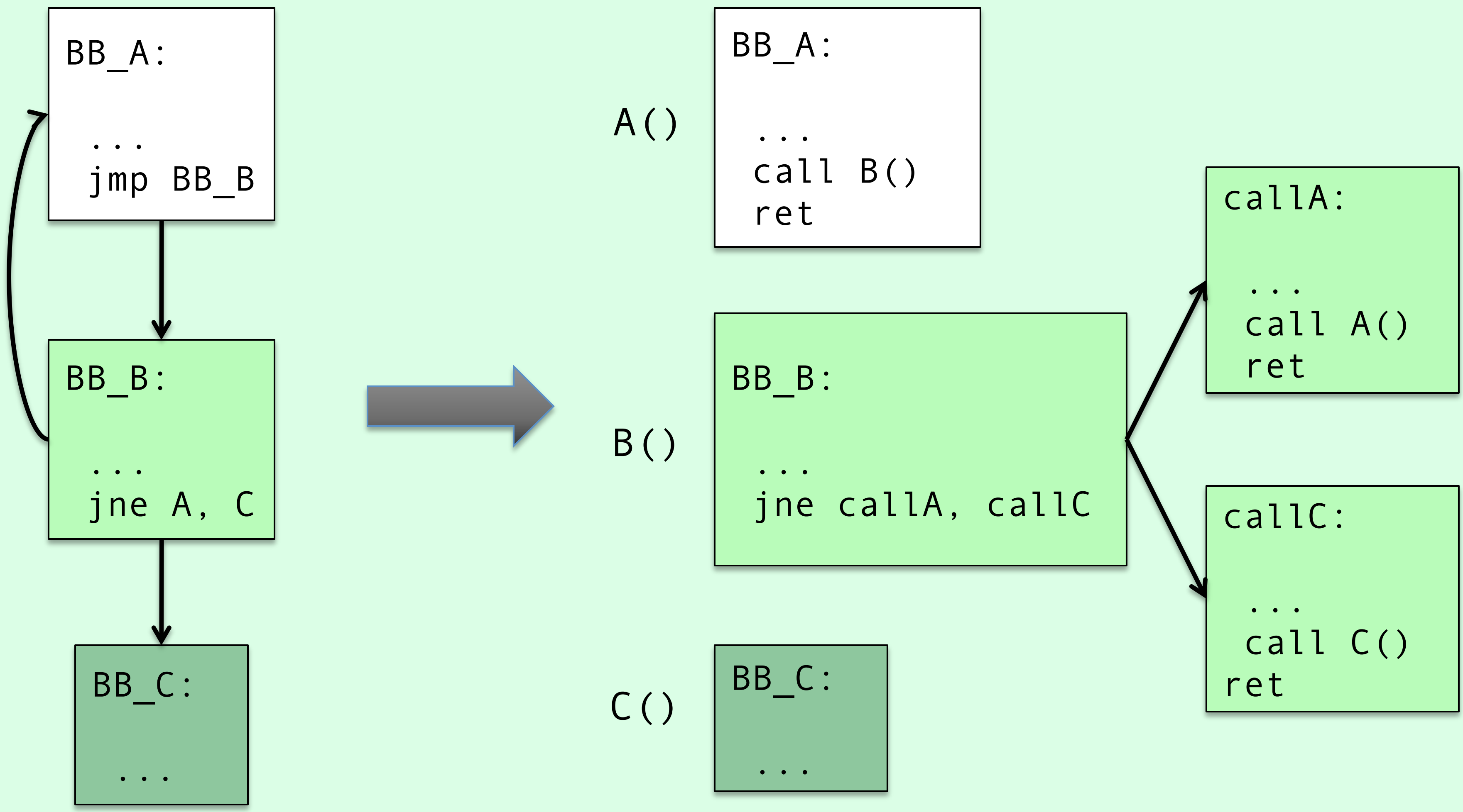
Function-based control flow



Refactoring methodology

duplicate constants

distribute globals

for every original function f

    initiatorList ← find initiators(f)

    create new functions(f, initiatorList)

    fix branches(initiatorList)

    fix phi nodes(initiatorList)

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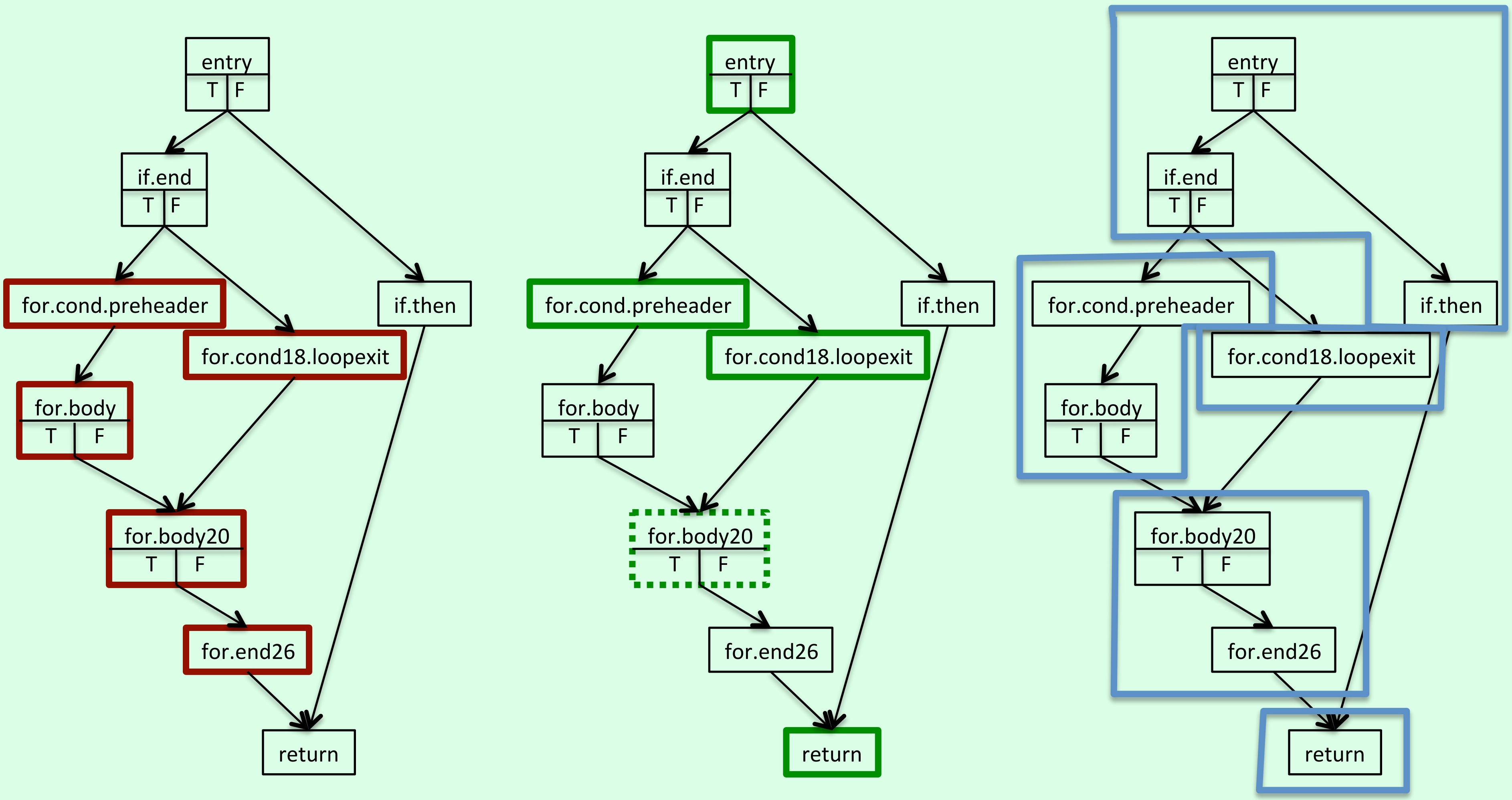
Initiator list ← find initiators(f)

Partitioning result | Initiators | Resulting functions



Refactoring methodology

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    initiatorList ← find initiators(f)

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    fix phi nodes(initiatorList)

create new functions (f, initiatorList)

MODULE 1

MODULE 2

```
i32 f(i8* %num)
```

```
BB_A:

 %3 = add i32 %2, 6
 jmp BB_B
```

DEV 1

```
BB_B:

 %4 = mul i32 %3, %3
 jne BB_A, BB_C
```

DEV 2

```
BB_C:

 ret call i32 @puts(%num)
```

```
declare i32 @puts(i8*)
```

Declare used functions in the destination module

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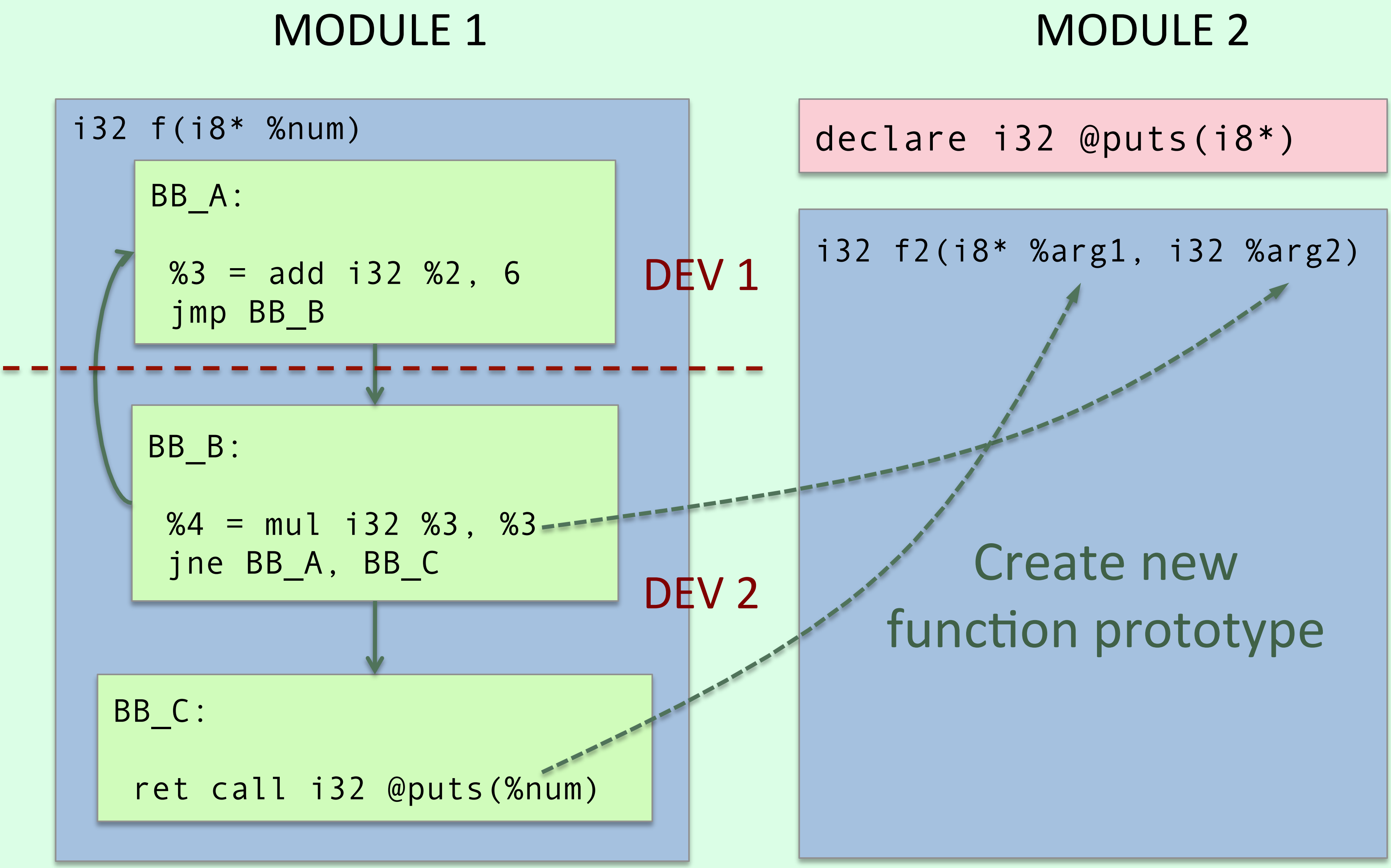
Splitting functions



create new functions (f, initiatorList)

MODULE 1

```
i32 f(i8* %num)

BB_A:

 %3 = add i32 %2, 6
 jmp BB_B
```

Move Basic Blocks

MODULE 2

```
declare i32 @puts(i8*)
```

```
i32 f2(i8* %arg1, i32 %arg2)

BB_B:

 %4 = mul i32 %3, %3
 jne BB_A, BB_C

BB_C:

 ret call i32 @puts(%num)
```

create new functions (f, initiatorList)

MODULE 1

```
i32 f(i8* %num)

BB_A:

 %3 = add i32 %2, 6
 jmp BB_B
```

Fix argument uses

MODULE 2

```
declare i32 @puts(i8*)
```

```
i32 f2(i8* %arg1, i32 %arg2)

BB_B:

 %4 = mul i32 %arg2, %arg2
 jne BB_A, BB_C

BB_C:

 ret call i32 @puts(%arg1)
```

Refactoring methodology

duplicate constants

distribute globals

for every original function f

initiatorList ← find initiators(f)

create new functions(f, initiatorList)

fix branches(initiatorList)

fix phi nodes(initiatorList)

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fix branches (initiatorList)

MODULE 1

```
i32 f(i8* %num)

BB_A:

 %3 = add i32 %2, 6
 %r = call i32 f2(%num, %3)
 ret %r
```

Replace old branches by function calls

MODULE 2

```
declare i32 @puts(i8*)
```

```
i32 f2(i8* %arg1, i32 %arg2)

BB_B:

 %4 = mul i32 %arg2, %arg2
 jne fcaller, BB_C

BB_C:

 ret call i32 @puts(%arg1)

fcaller:

 %r = call i32 f(%num, %3)
 ret %r
```

Refactoring methodology

duplicate constants

distribute globals

for every original function f

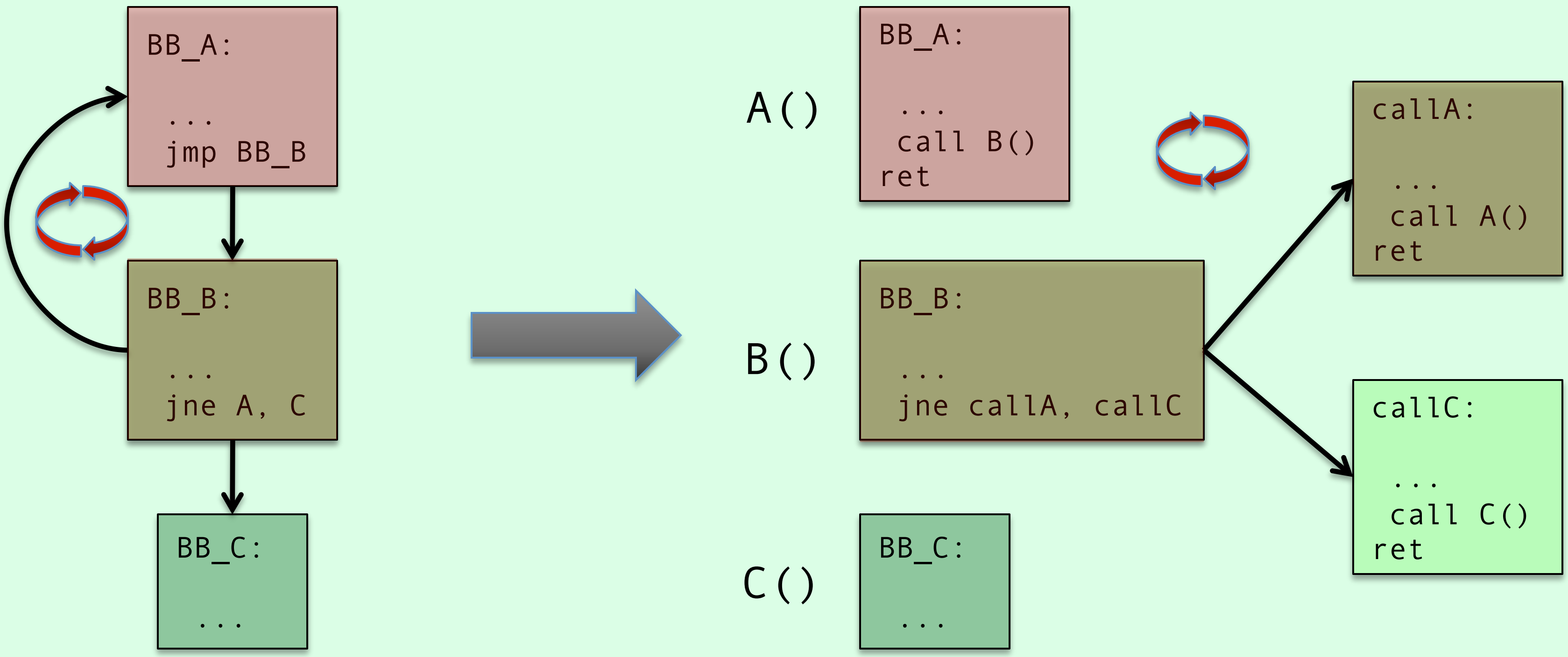
    initiatorList ← find initiators(f)

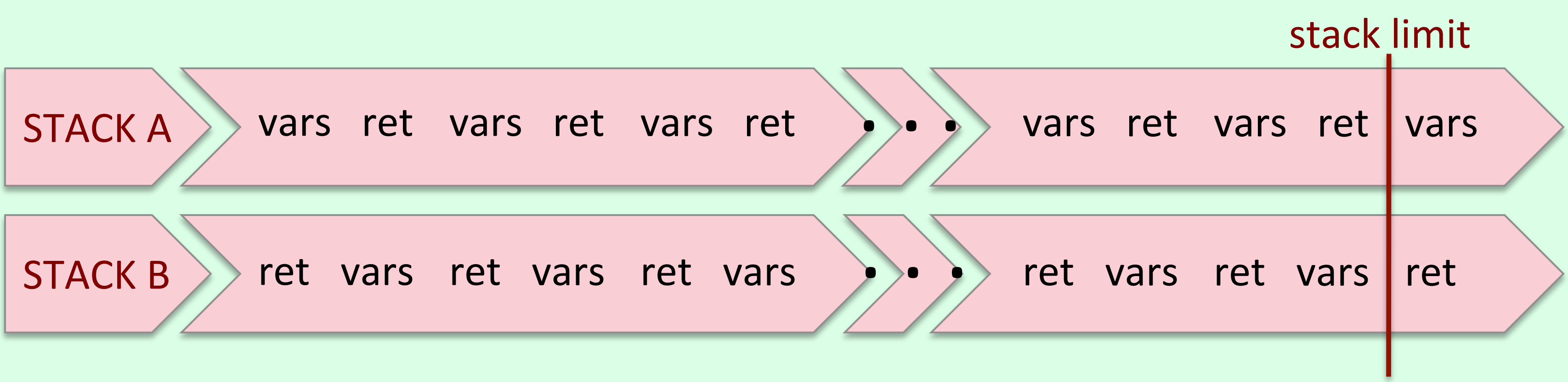
    create new functions(f, initiatorList)

    fix branches(initiatorList)

    fix phi nodes(initiatorList)

Loops generate recursive calls





Fixing loop recursion: a loop pass

```
header:

 %3 = add i32 %2, 6
 br label %latch
```

```
latch:

 %4 = mul i32 %3, %3
 %cond = icmp ne %4, 0
 br i1 %cond, label %header, label %exit
```

```
exit:

 ret call i32 @puts(%num)
```

```
preheader:

 %cmpRes = alloca i1
 store i1 true, i1* %cmpRes
 br label %header
```

```
header:

 %cond = load i1* %cmpRes
 br i1 %cond, label %postheader, label %”exit”
```

```
postheader:

 %3 = add i32 %2, 6
 jmp label %latch
```

```
latch:

 %4 = mul i32 %3, %3
 %cond = icmp ne %4, 0
 store i1 %cond, i1* cmpRes
 br label %header
```

```
exit:

 ret call i32 @puts(%num)
```

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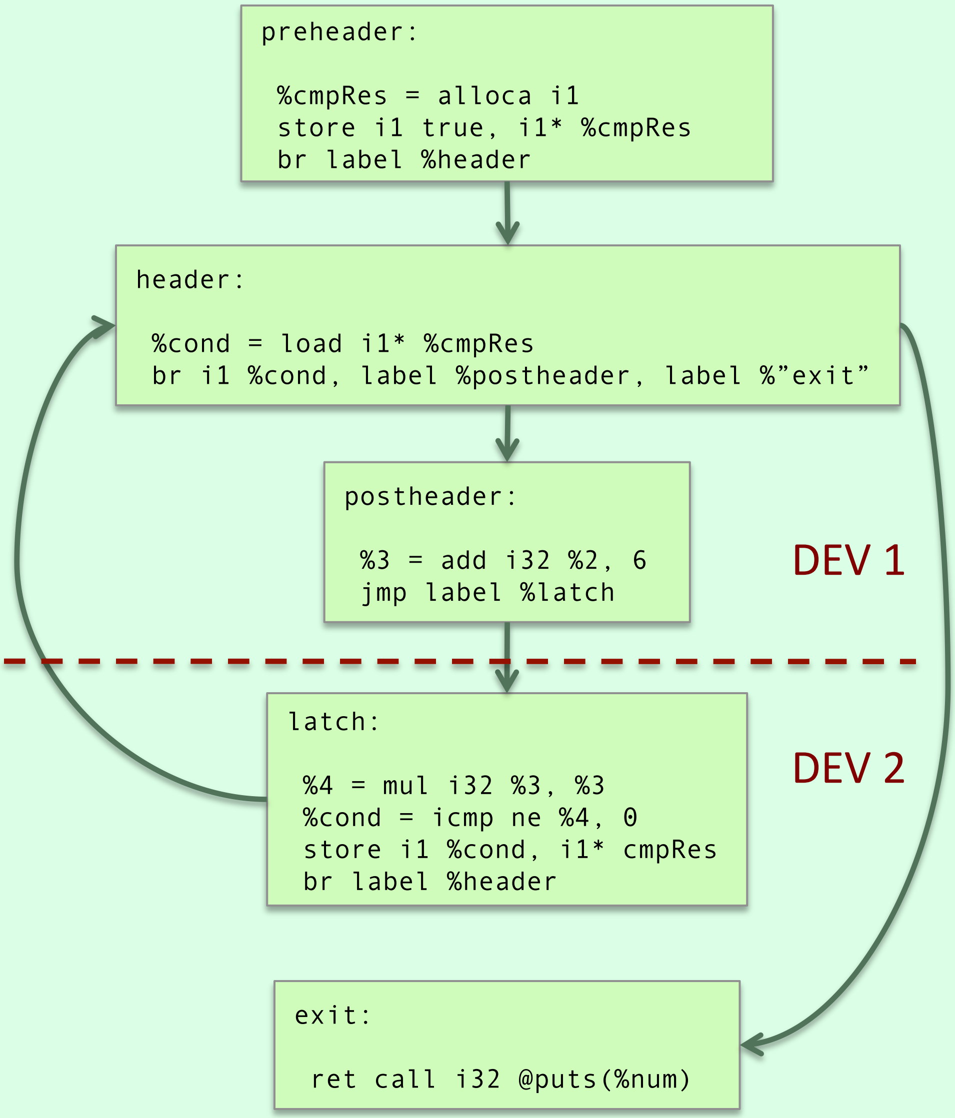
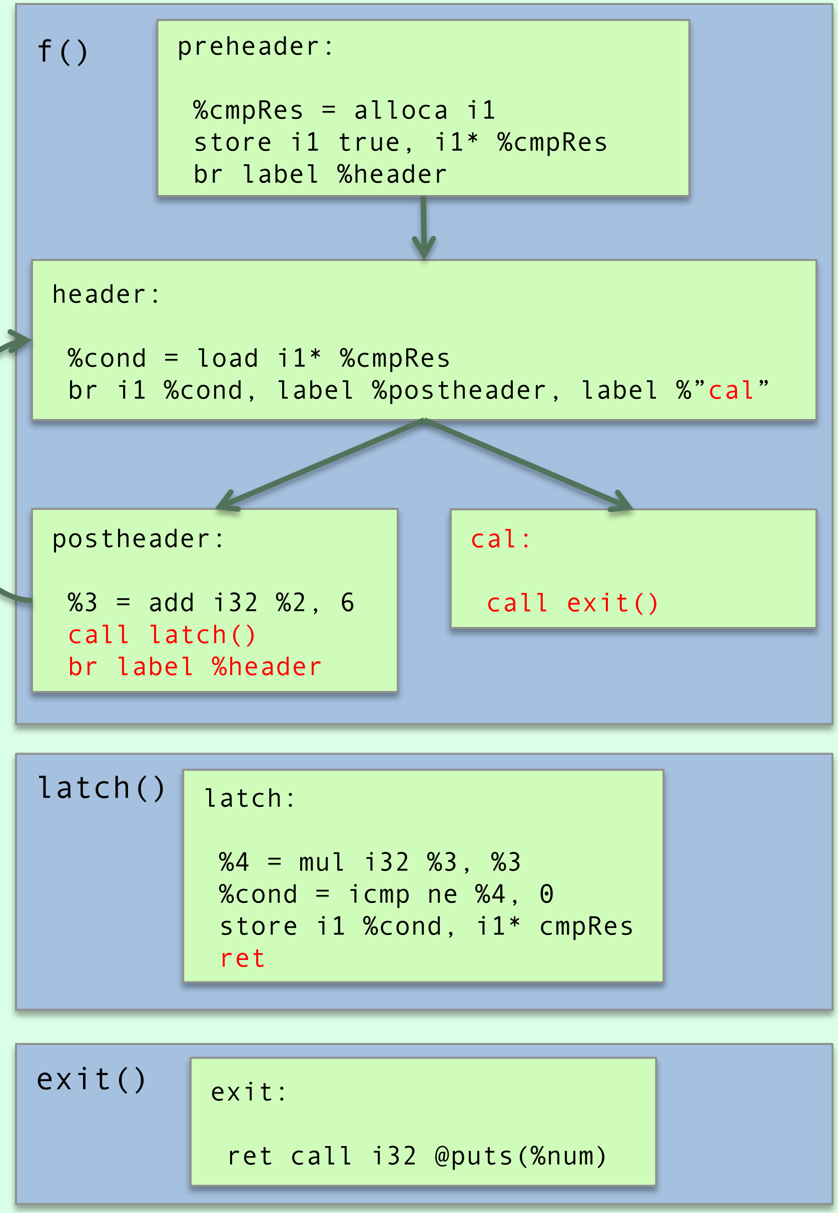
Fixing loop recursion: final code refactoring





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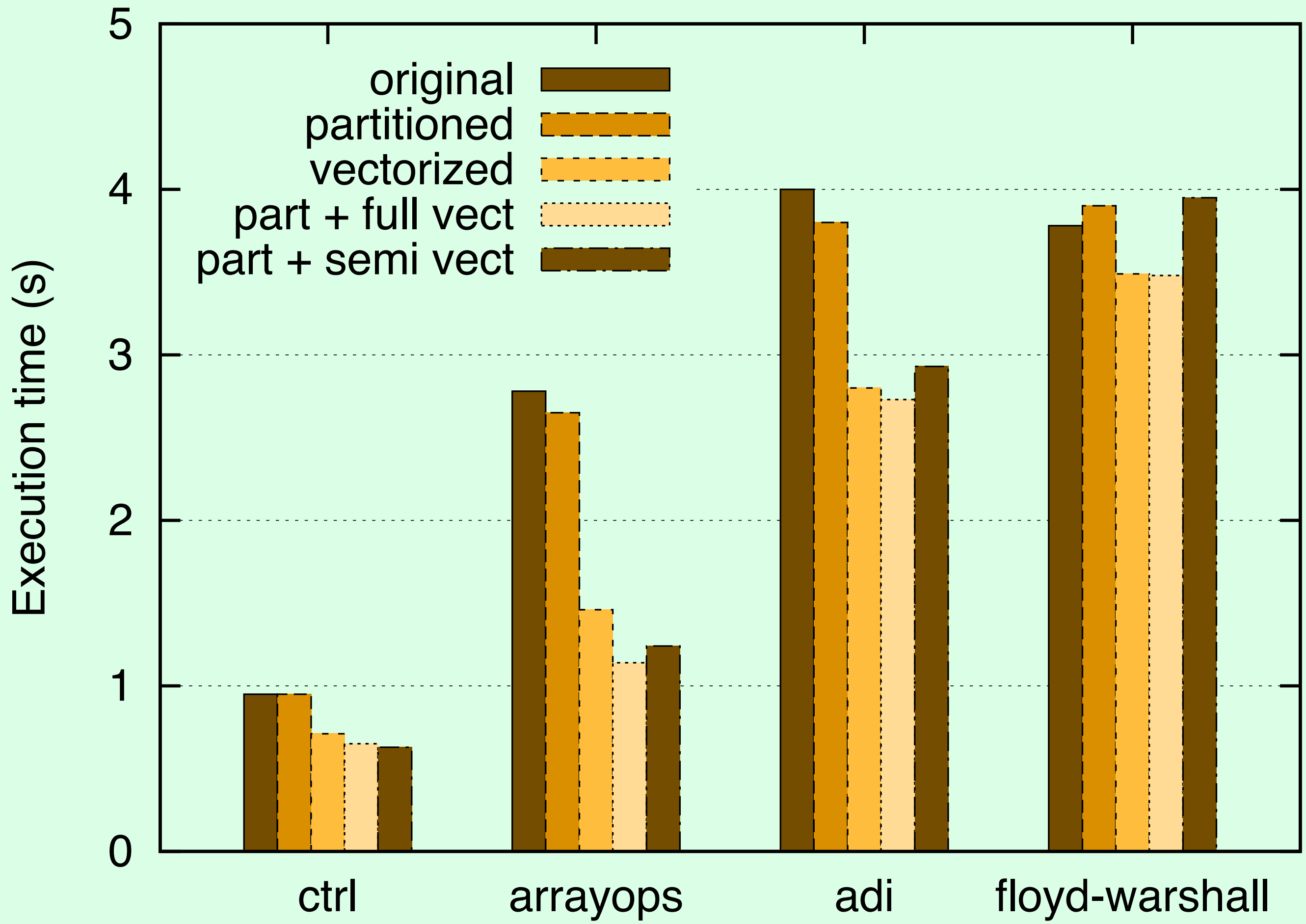
Output from the tool

```
Time profiling hello.ir
[HPCmap] Parsing module hello.ir...
[ReadArchPass] Parsing architecture ../architectures/CPU_SIMD.arch...
[EstimationPass] Estimating from profiling information...
[PartitioningPass] PARTITIONING OVERVIEW:
[PartitioningPass] Initial exec time was 1.81e-07  s, new is 1.06e-07  -- Speedup = 1.71e+00
[LoopRecursionBreakPass] Analyzing loop 5 <-> 12
[PartitionWriterPass] Generating partitioned code
PartitionWriterPass::runOnModule() -- Original module's functions:
            odd with BBs:
                        entry --> CPU
            main with BBs:
                        entry --> CPU
                        3 --> CPU
...
PartitionWriterPass::find_initiators() -- Inspecting function main()
            Trivial initiators:
                        5
                        8
            Entry block initiator: entry
            Nontrivial initiators:
                        14
...
PartitionWriterPass::create_new_Fs() -- Splitting up function main
            Function main1_CPU inserted in module CPU.part
            Moving BB 14 from function main to function main1_CPU
...
PartitionWriterPass::branches_to_fcalls() -- Fixing branches:
            to BB entry, moved to function main
            to BB 14, moved to function main1_CPU
PartitionWriterPass::fix_initiator_phis() -- Initiators:
            main2_CPU::5
                        2 phis updated
[PartitionWriterPass] Module CPU.part generated
[PartitionWriterPass] Module CPU_SIMD.part generated
Partitioned hello.ir
```

Preliminary results



Conclusions

- Compilation toolchain for heterogeneous architectures

- Code refactoring based on splitting functions into smaller ones.

- Removed recursion generated by loops being transformed into functions.

- The function call approach does not introduce a significant overhead so far.

Work in progress…

IN THE REFACTORING PASS

- Execute in a real architecture (one executable per device)
- Distributed memory
- Automatic communications

IN THE COMPLETE TOOLCHAIN

- Identification of parallelism
- Data partitioning
- Improve estimation, partitioning heuristics, profiling…

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[LoopRecursionBreakPass] Analyzing loop 9 <-> 9
[LoopRecursionBreakPass] DONE
[LoopRecursionBreakPass] Analyzing loop 6 <-> 6
[LoopRecursionBreakPass] DONE
[PartitionWriterPass] Genera
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                        9 --> CPU_SIMD
                        13 --> CPU
                        afterHeader --> CPU
            puts with BBs:
PartitionWriterPass::find_initiators() -- Inspecting function main()
            Trivial initiators:
                        5
                        11
            Entry block initiator: entry
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            Results:
            entry has initiator entry
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            5 has initiator 5
            11 has initiator 11
            12 has initiator 11
[PartitionWriterPass] Module CPU.part generated
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Turning CFGs into callgraphs

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Turning CFGs into callgraphs

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Turning CFGs into callgraphs