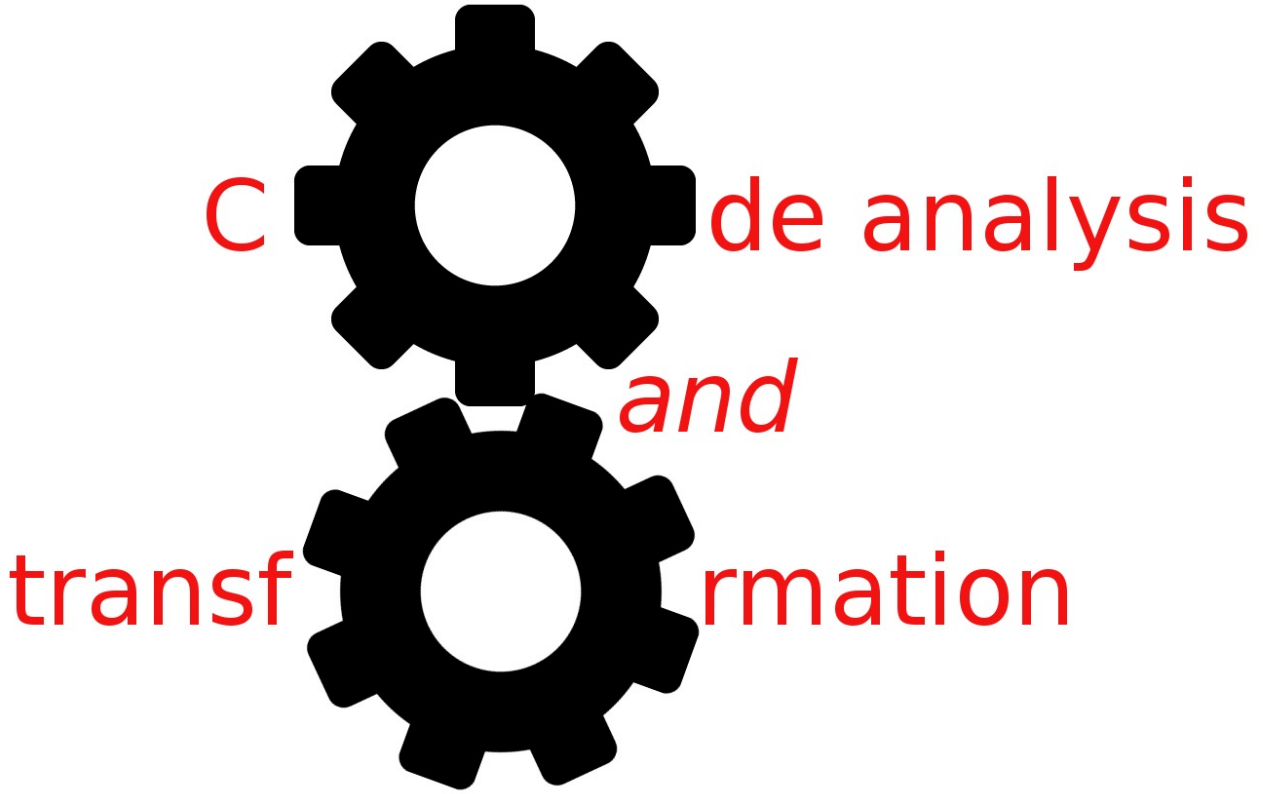

Loop normalizations

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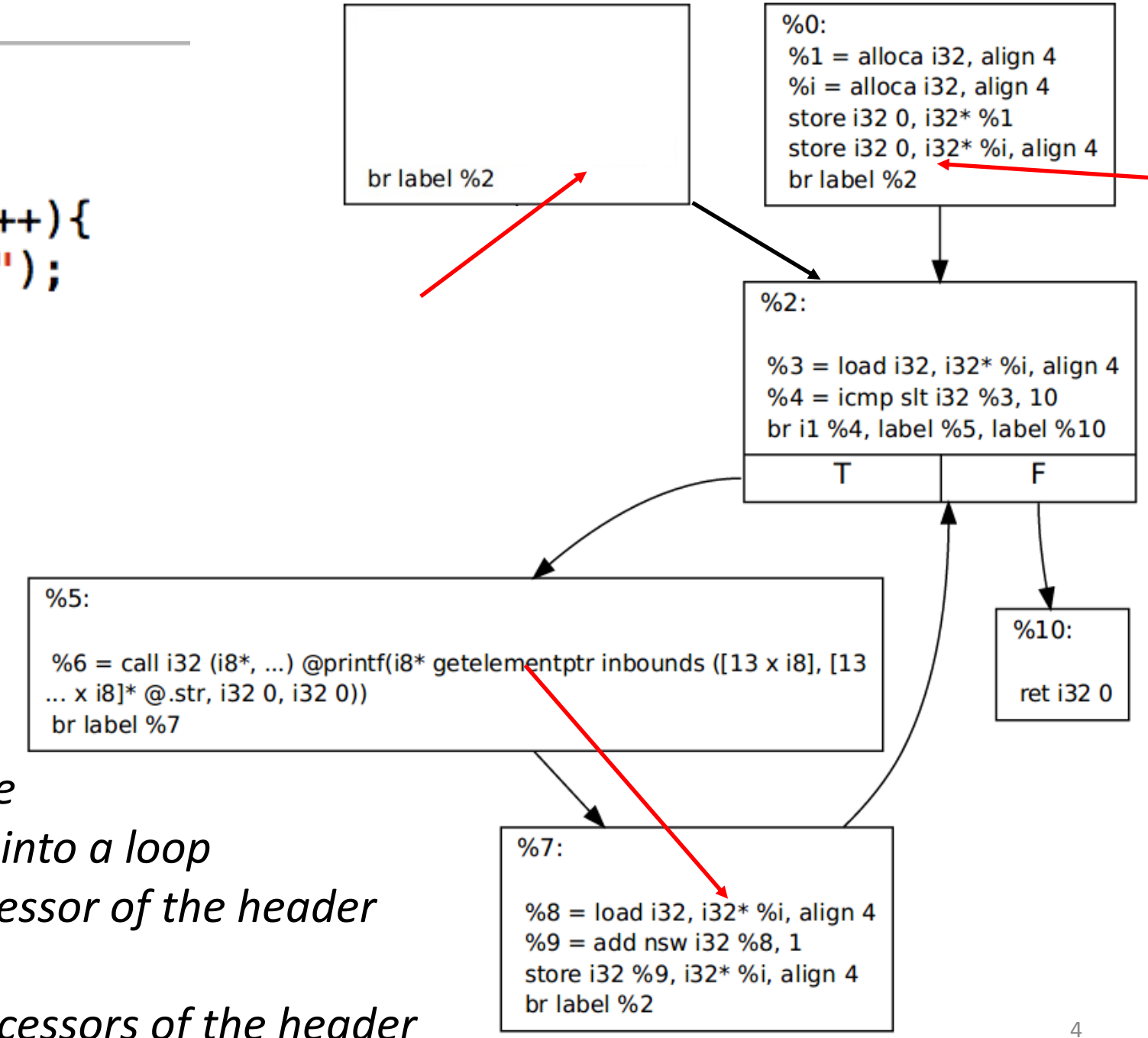
Outline

- Canonical form
- Loop-closed SSA form
- Other forms

Let’s look at a problem that loop normalizations will solve

```c
#include <stdio.h>

int main (){
  for (int i=0; i < 10; i++){
    printf("Hello world\n");
  }
  return 0;
}
```



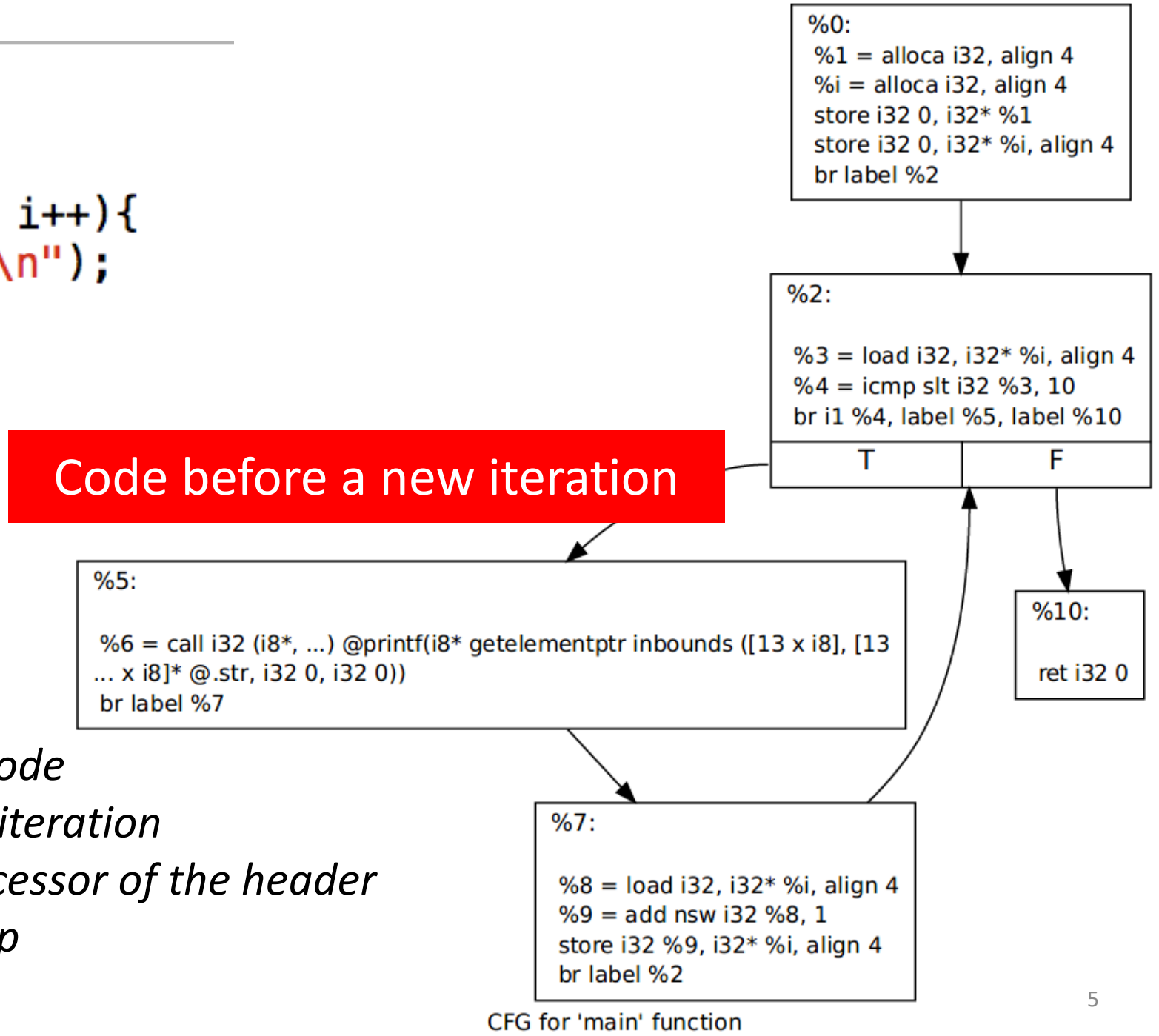
CFG for 'main' function

Let's say we want to add some code
to be executed just before jumping into a loop

- *(Incorrect) Add code to a predecessor of the header outside the loop*
- *(incorrect) Add code to all predecessors of the header*

```c
#include <stdio.h>

int main (){
  for (int i=0; i < 10; i++){
    printf("Hello world\n");
  }
  return 0;
}
```



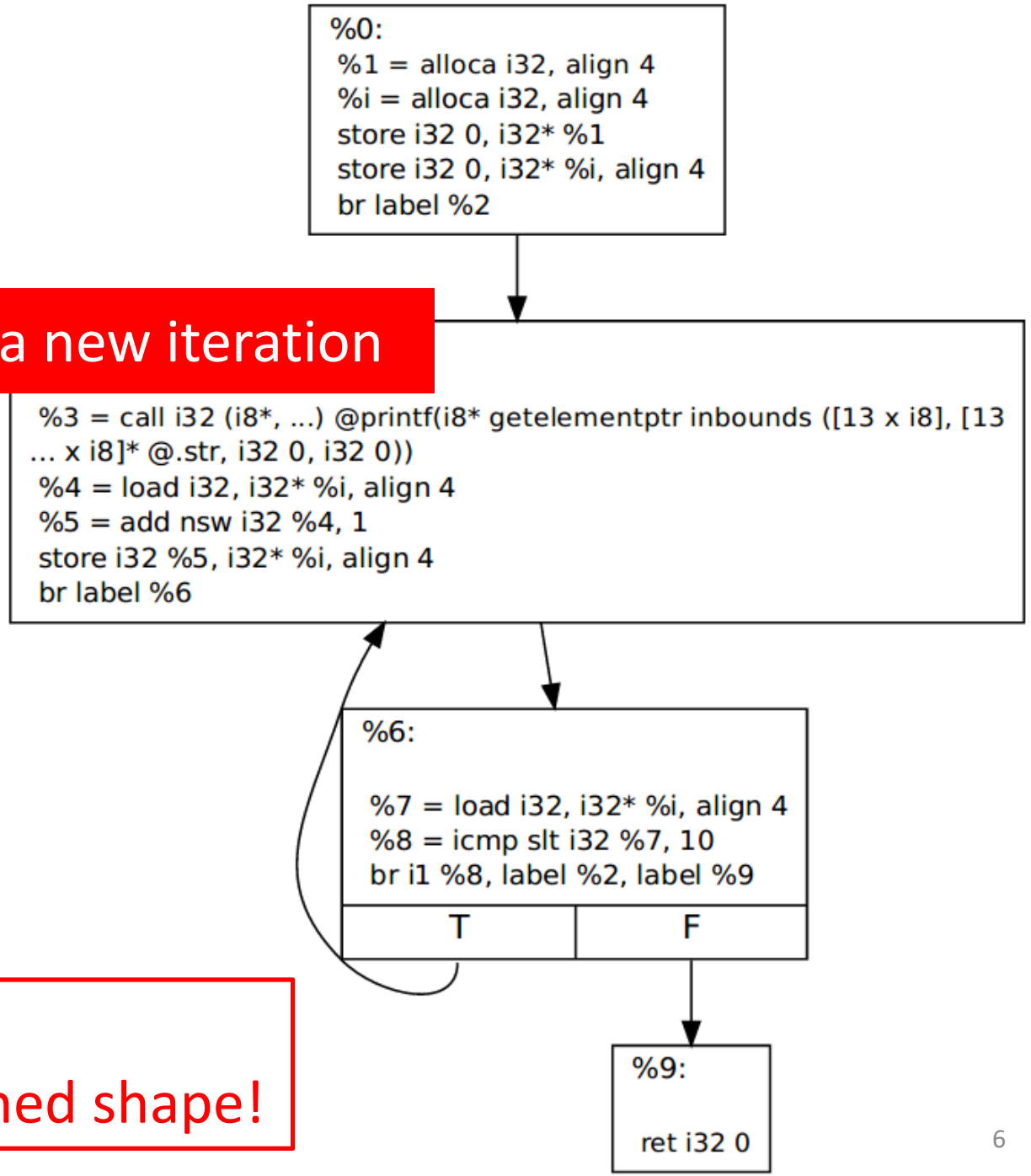
CFG for 'main' function

Let's say we want to add some code
to be executed just before every iteration
- (Incorrect) Add code to the successor of the header
that is within the loop

```c
#include <stdio.h>

int main (){
  i=0;
  do {
    printf("Hello worl
    i++;
  } while (i < 10);
  return 0;
}
```

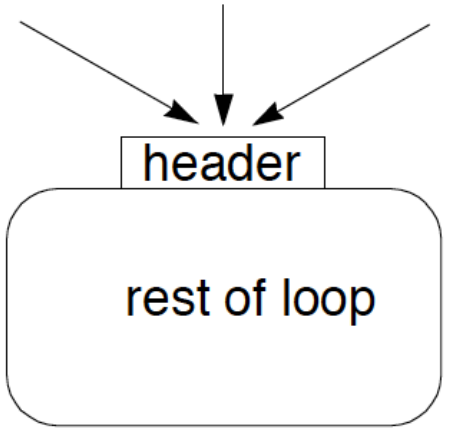
Code before a new iteration



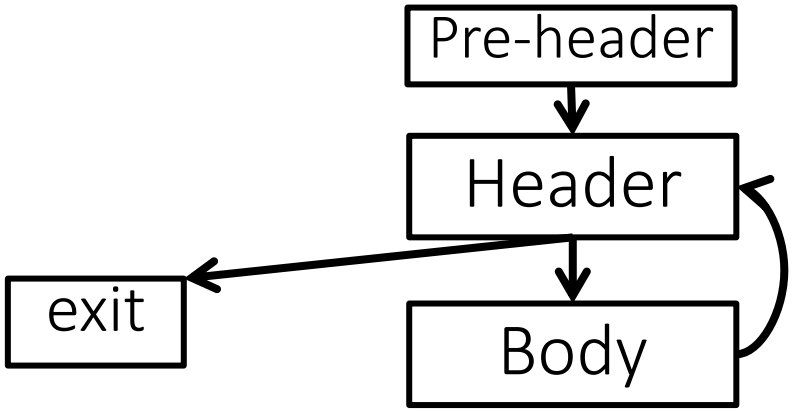
We need to normalize loops
so CATs can expect a single pre-defined shape!

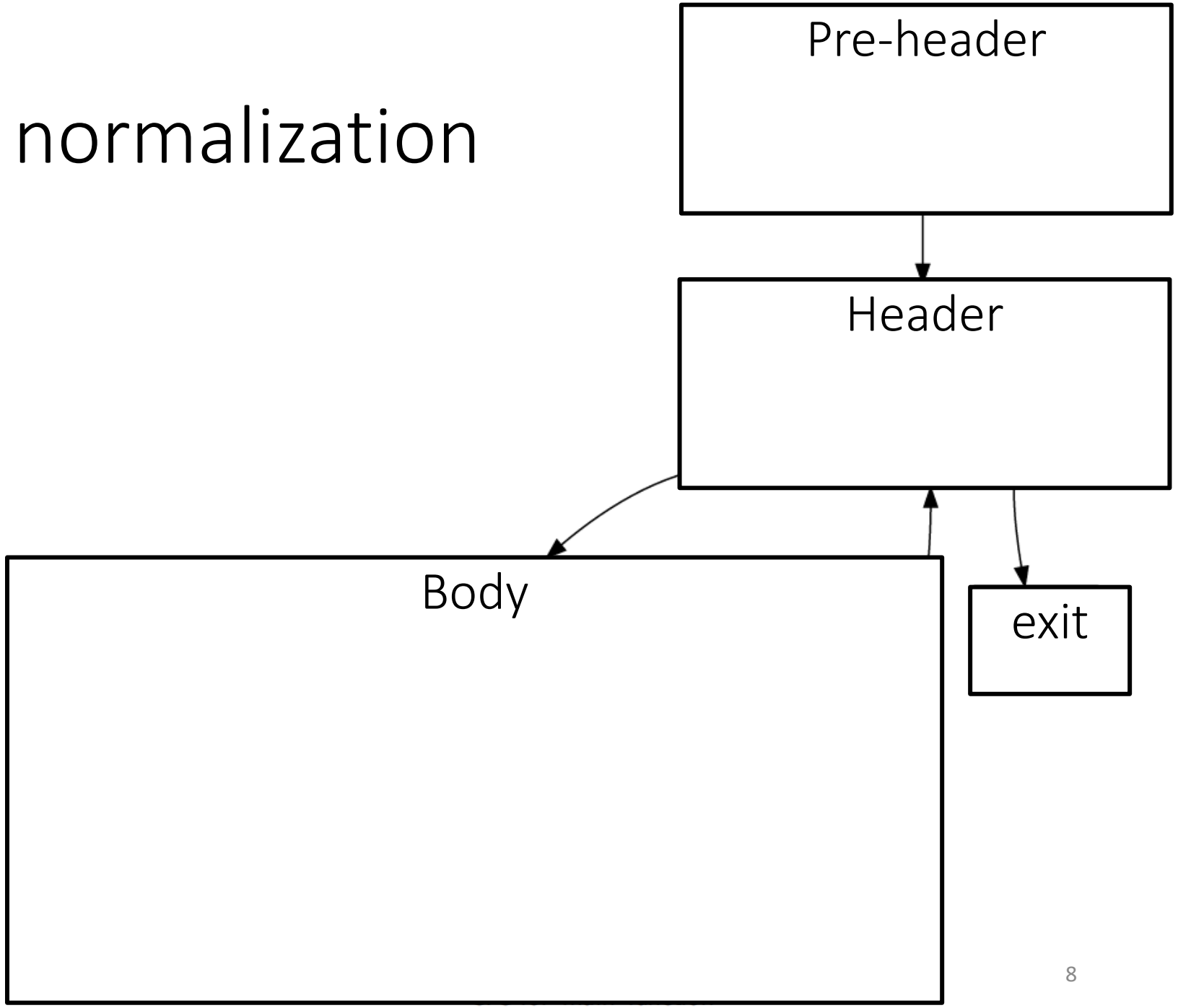
First normalization: adding a pre-header

- Optimizations often require code to be executed once before the loop
- Create a pre-header basic block for every loop

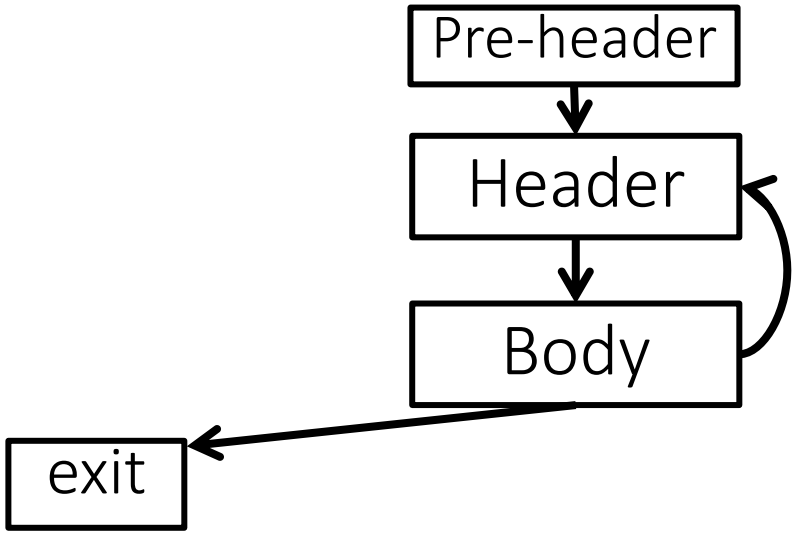


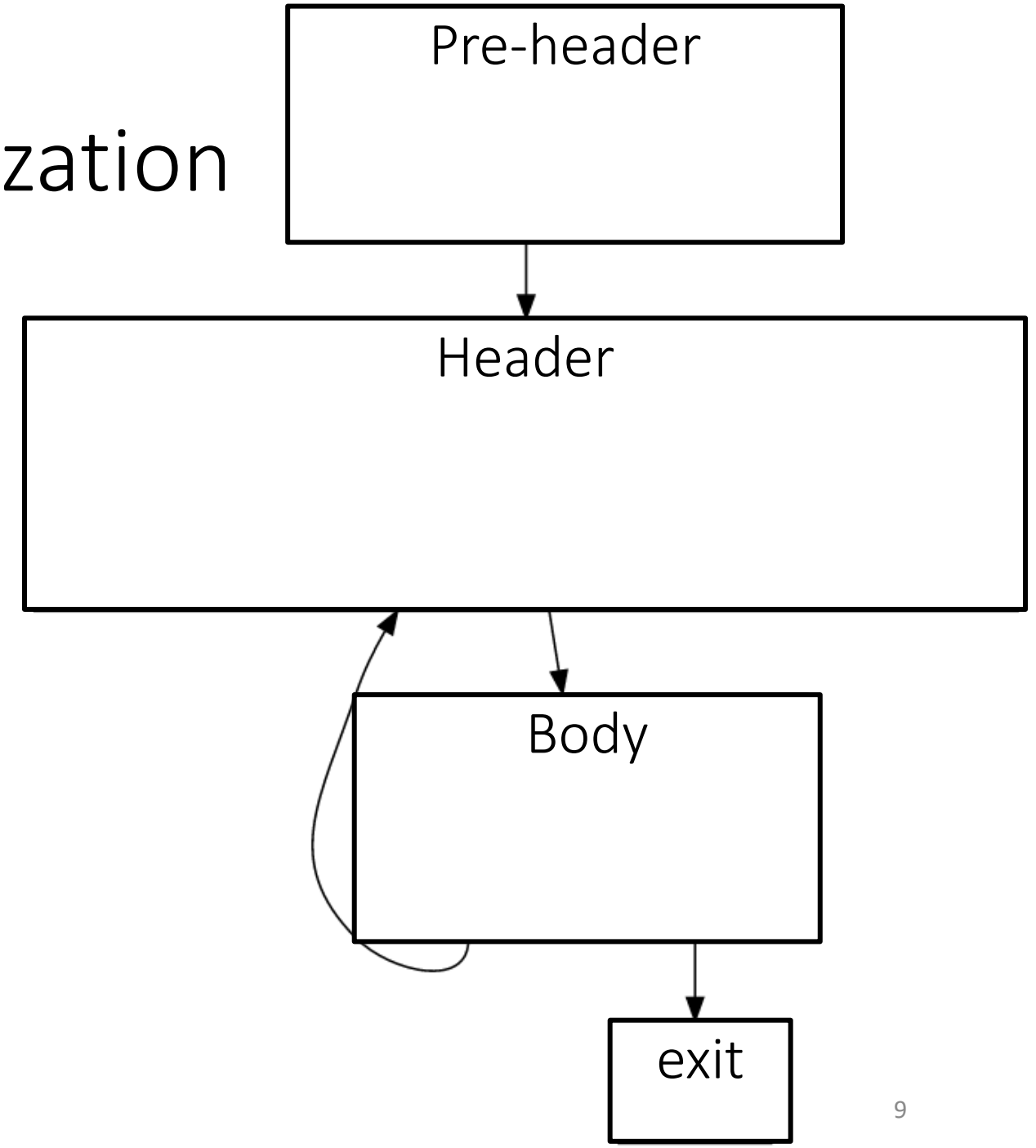
Common loop normalization





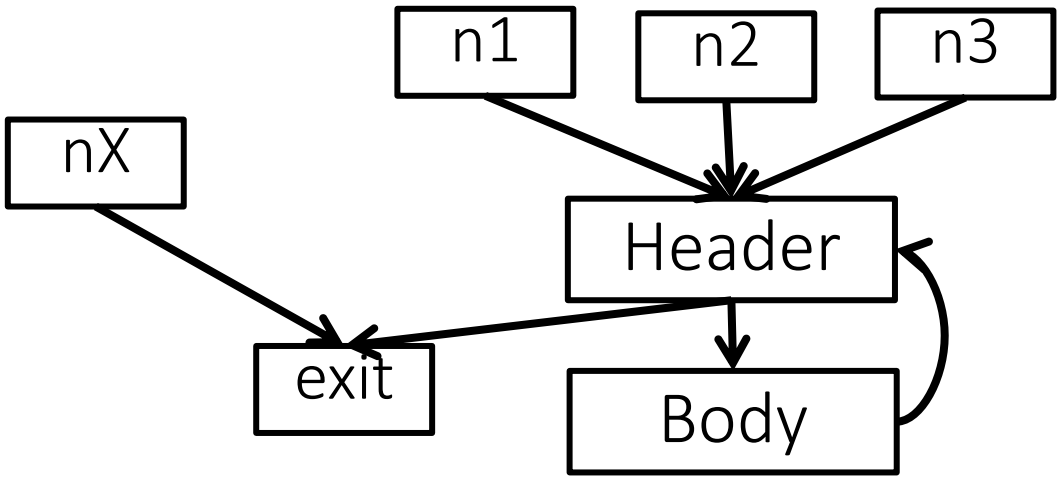
Common loop normalization





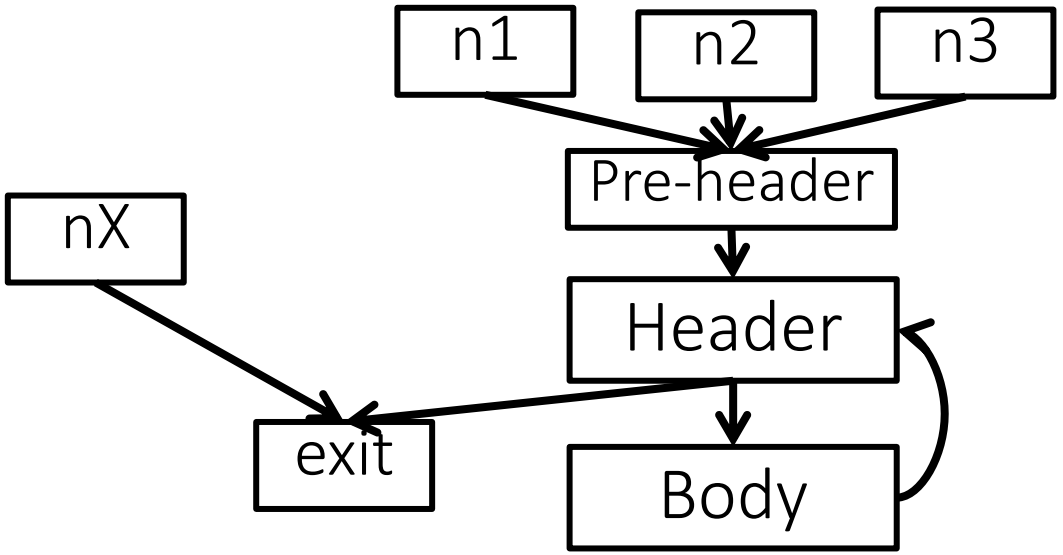
Loop normalization in LLVM

- The loop-simplify **pass normalize natural loops**
- **Output of** loop-simplify:
  - **Pre-header**: the only predecessor of the header



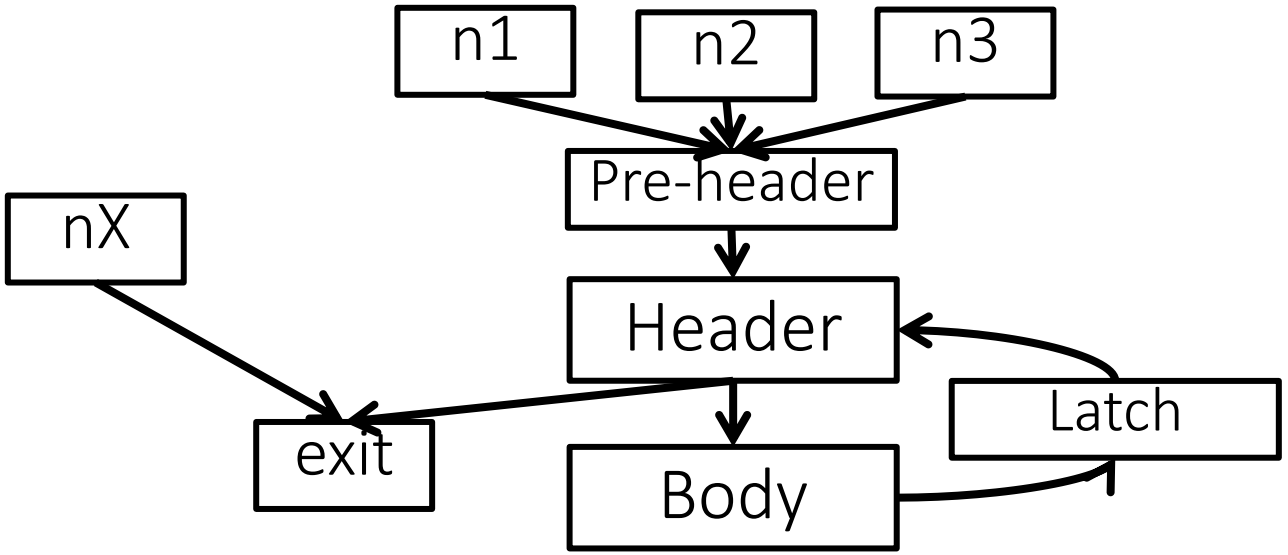
Loop normalization in LLVM

- The loop-simplify **pass normalize natural loops**
- Output of loop-simplify:
  - **Pre-header**: the only predecessor of the header
  - **Latch**: node executed just before starting a new loop iteration



Loop normalization in LLVM

- The loop-simplify **pass normalize natural loops**
- Output of loop-simplify:
  - **Pre-header**: the only predecessor of the header
  - **Latch**: single node executed just before starting a new loop iteration
  - **Exit node**: ensures it is dominated by the header



Loop normalization in LLVM

- The loop-simplify **pass normalize natural loops**
- Output of loop-simplify:
  - **Pre-header**: the only predecessor of the header
  - **Latch**: single node executed just before starting a new loop iteration
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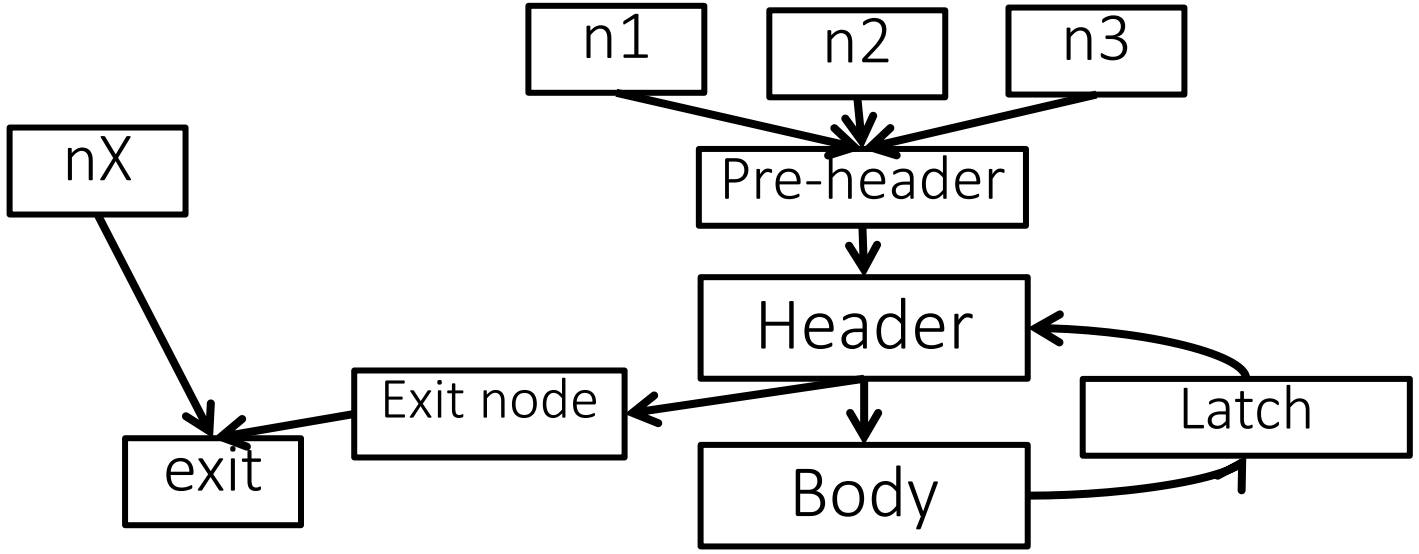
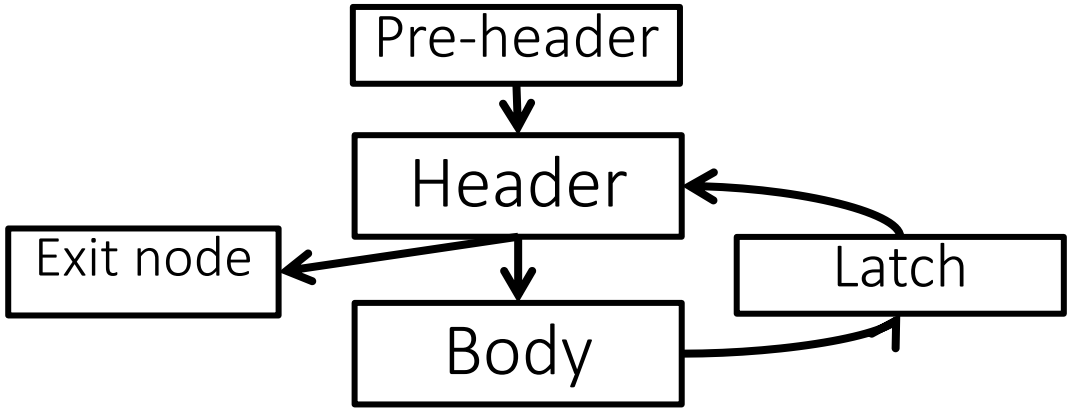


Loop normalization in LLVM

- **Pre-header** llvm::Loop:getLoopPreheader()
- **Header** llvm::Loop::getHeader()
- **Latch** llvm::Loop::getLoopLatch()
- **Exit** llvm::Loop::getExitBlocks()

```
opt -loop-simplify bitcode.bc -o normalized.bc
```



Canonical loop

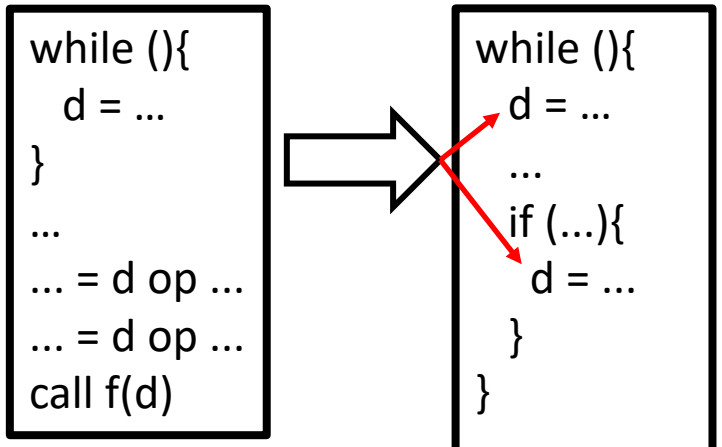
Outline

- Canonical form
- Loop-closed SSA form
- Other forms

Further normalizations in LLVM

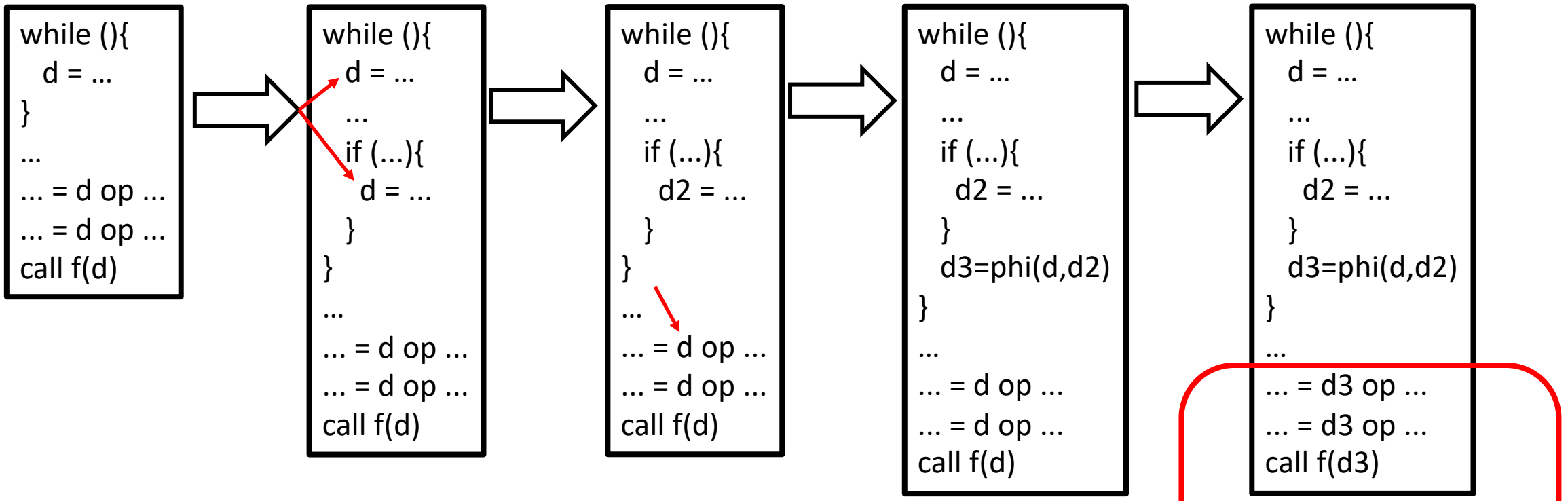
- Loop representation can be further normalized:
  - *loop-simplify* normalize the shape of the loop
  - What about definitions in a loop?
- Problem: updating code in loop might require to update code outside loops for keeping SSA

Loop pass example



A pass needs to add a conditional definition of d

Loop pass example



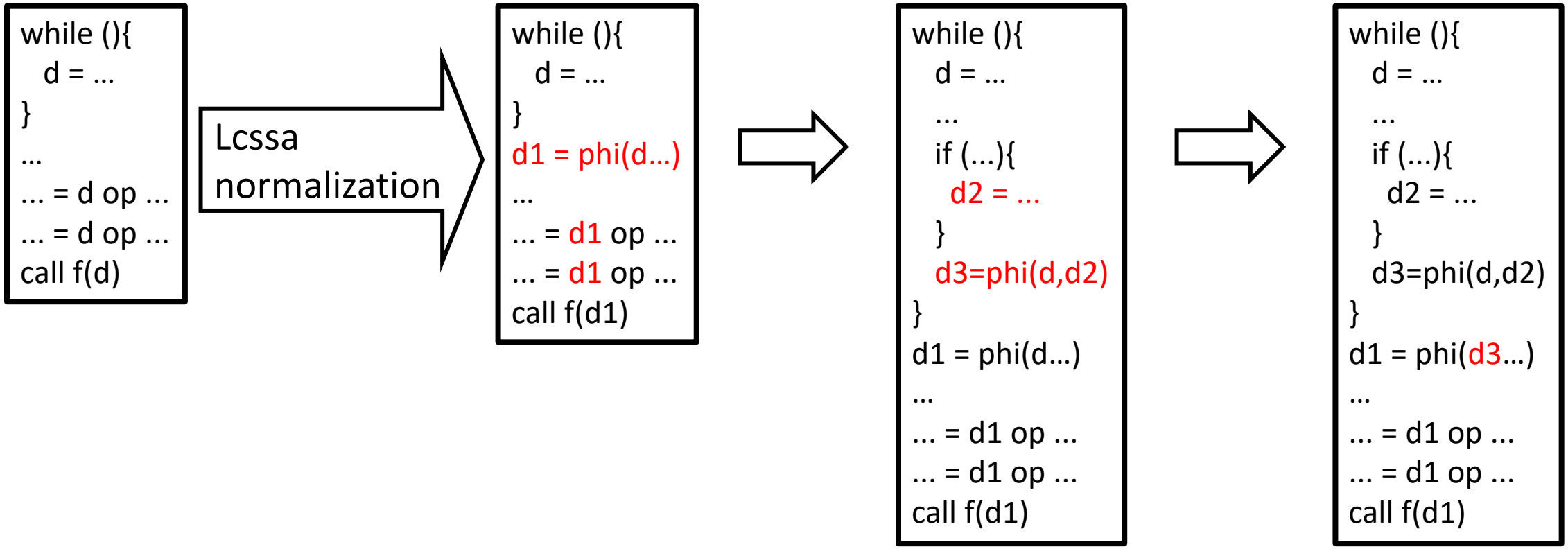
This is not in SSA anymore: we must fix it

Changes to code outside our loop

Further normalizations in LLVM

- Loop representation can be further normalized:
  - *loop-simplify* normalize the shape of the loop
  - What about definitions in a loop?
- Problem: updating code in loop might require to update code outside loops for keeping SSA
  - Keeping SSA form is expensive with loops
  - Loop-closed SSA form: no var is used outside of the loop in that it is defined
  - lcssa insert phi instruction at loop boundaries for variables defined in a loop body and used outside
    - Outside code only refers to these PHIs
  - Isolation between optimization performed in and out the loop
  - Faster keeping the SSA form
    - Propagation of code changes outside the loop blocked by phi instructions

Loop pass example



Loop-closed SSA form in LLVM

```
opt -lcssa bitcode.bc -o transformed.bc
```

```
llvm::Loop::isLCSSAForm(DT)
```

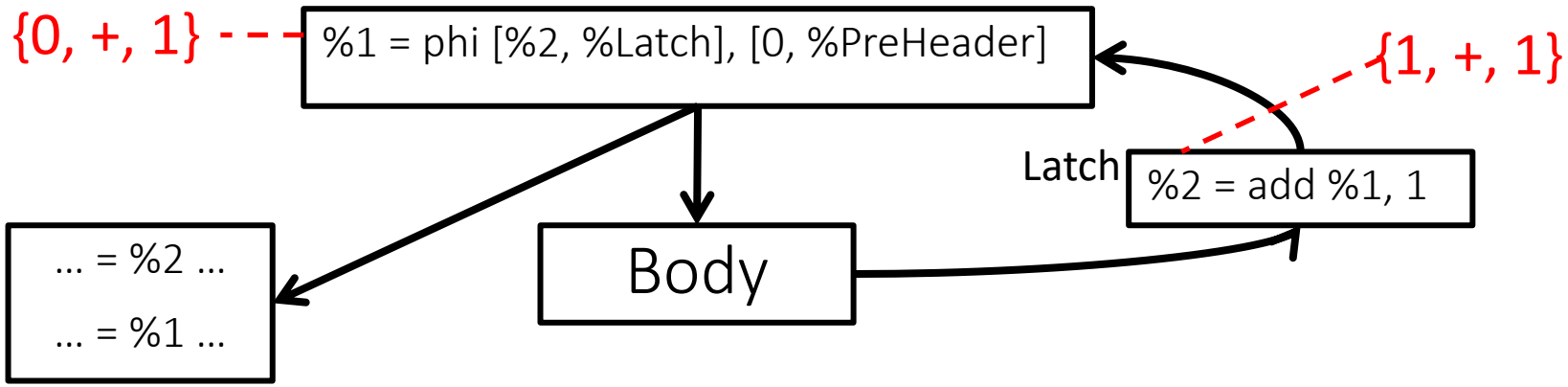
```
formLCSSA(…)
```

Outline

- Canonical form
- Loop-closed SSA form
- Other forms

Further normalizations in LLVM

- Scalar evolution normalization



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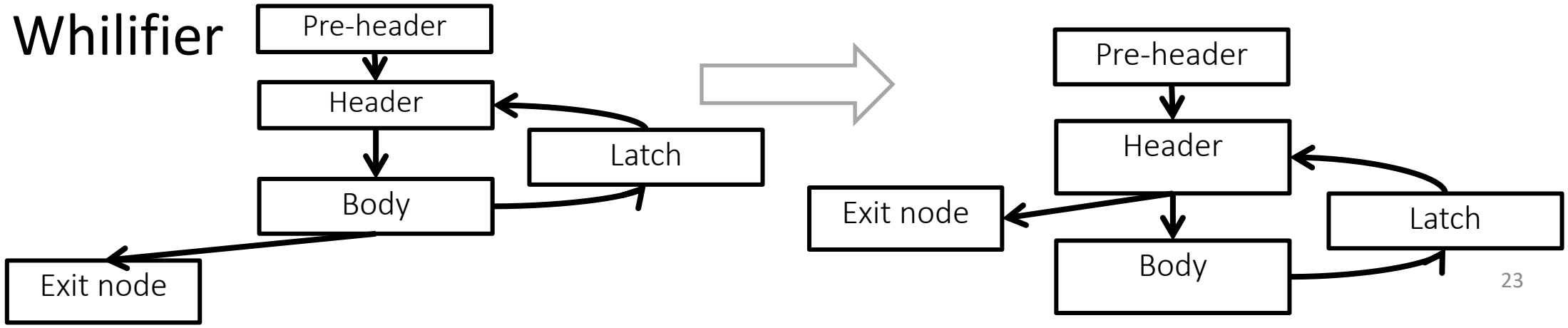

Always have faith in your ability

Success will come your way eventually

Best of luck!