C⚙de analysis

and

transf⚙rmation

Constant Optimizations

Simone Campanoni
simone.campanoni@northwestern.edu

NORTHWESTERN UNIVERSITY
1851

Outline

- Constant propagation
- Constant folding
- Algebraic simplification

Constant propagation: problem definition

Given a program, we would like to know
for every point in that program,
which variables have constant values, and which ones do not.

A variable has a constant value at a certain point in the CFG
if every execution that reaches that point
sees that variable holding the same constant value.

We are now going to implement
constant propagation automatically
and by relying only on reaching definition

i: x = 0
j: N = N + 1
k: Z = $\underline{x}$ + N

Reaching definition summary

- Reaching definition data-flow analysis computes IN[i] and OUT[i] for every instruction i
- IN[i] (OUT[i]) includes definitions that reach just before (just after) instruction i
- Each IN/OUT set contains a mapping for every variable in the program to a “value”

Constant propagation

- For a use of variable v by instruction n

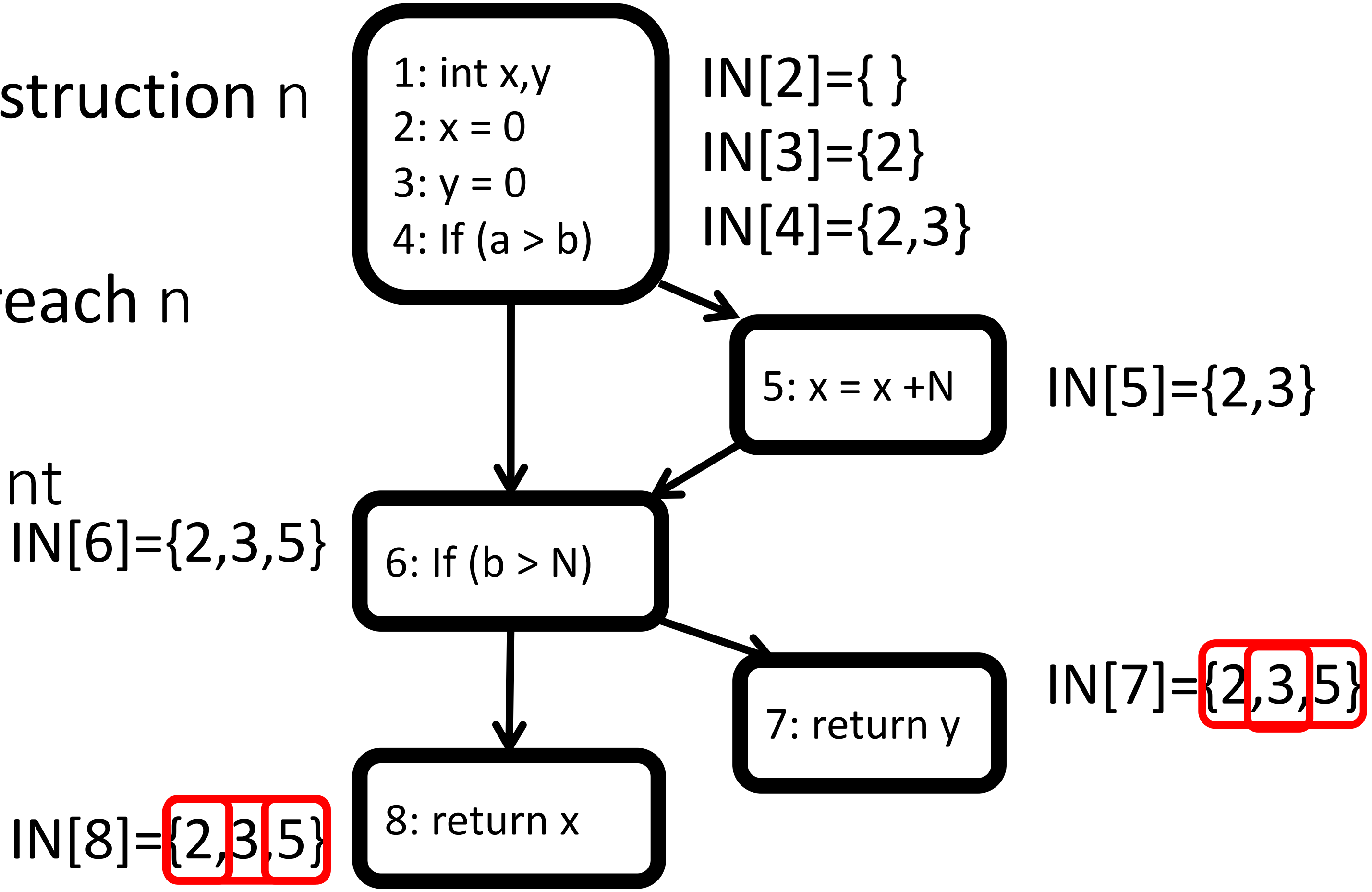
n: x = … v …

- If the definitions of v that reach n are all of the form

d: v = c //c is a generic constant

- then replace
  the uses of v in n with c

Do you see any problem?



1: int x,y
2: x = 0
3: y = 0
4: If (a > b)

IN[2]={ }
IN[3]={2}
IN[4]={2,3}

5: x = x +N

IN[5]={2,3}

IN[6]={2,3,5}

6: If (b > N)

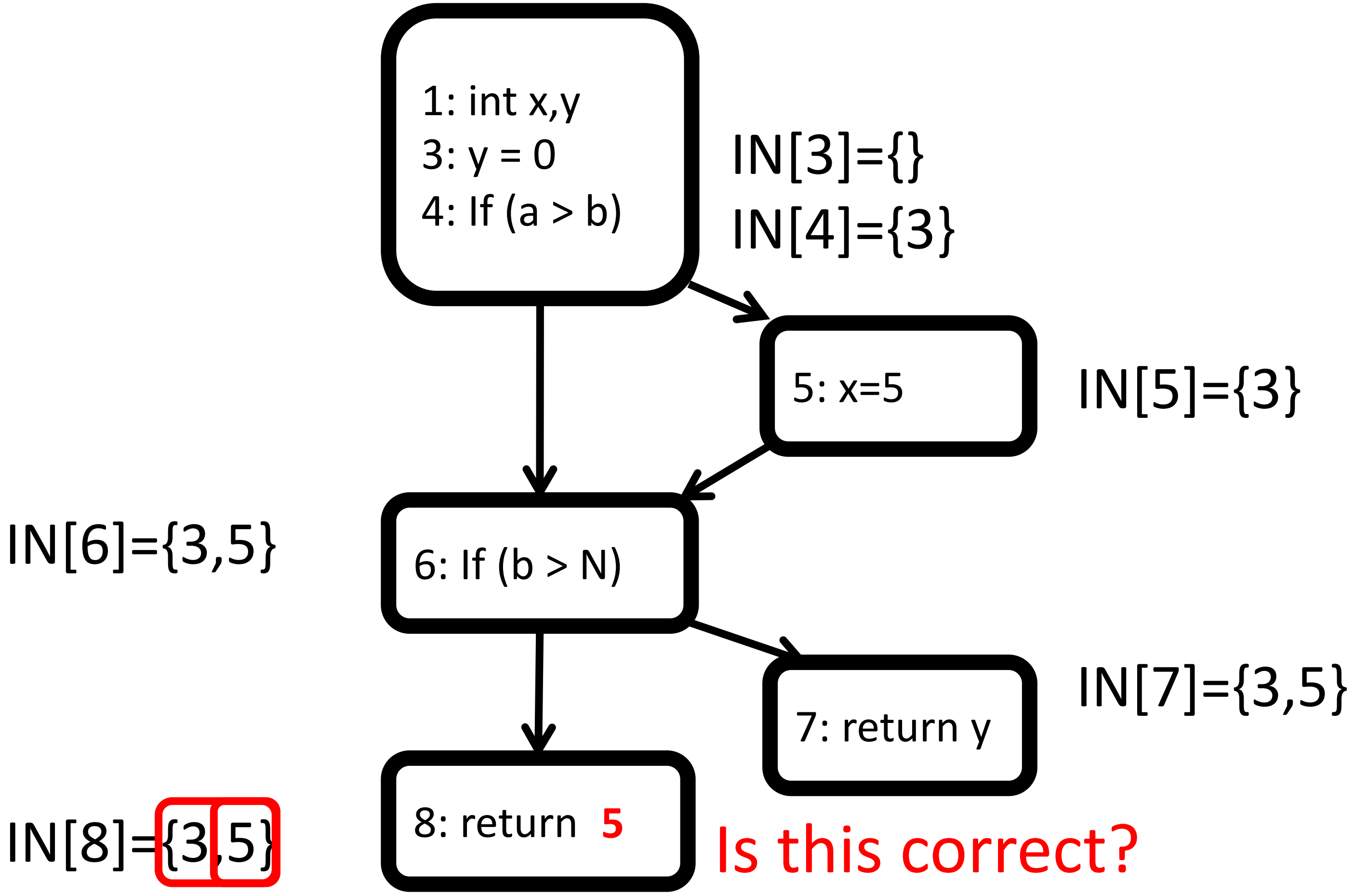
7: return y

IN[7]={2,3,5}

IN[8]={2,3,5}

8: return x

Constant propagation problem?



Is this correct?

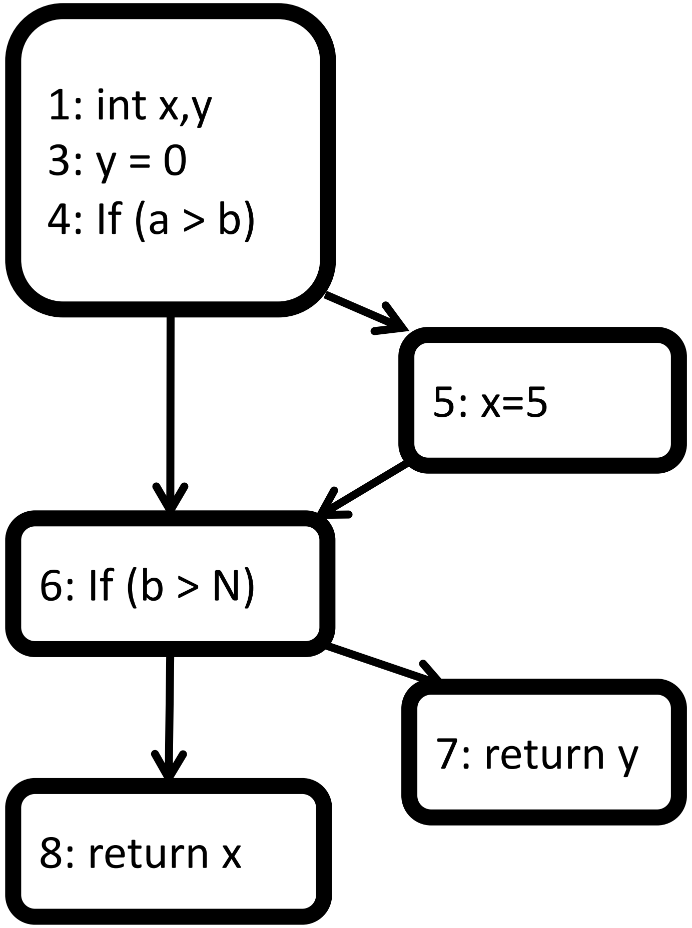
Undefined behavior: a funny interpretation

- **Undefined behavior** is the result of executing a program whose behavior is unpredictable

- Undefined behavior results in whatever compilers want the program being compiled to do

  even *to make demons fly out of your nose*
  - Undefined behavior is often referred to as *nasal demons*

Constant propagation problem?



Better solutions?

- Customize reaching definitions
- New analysis

Constant propagation for CAT

- Undefined values enable optimizations
- What about in the CAT language?
- CATData CAT_new (int64_t value);

SSA simplifies transformations

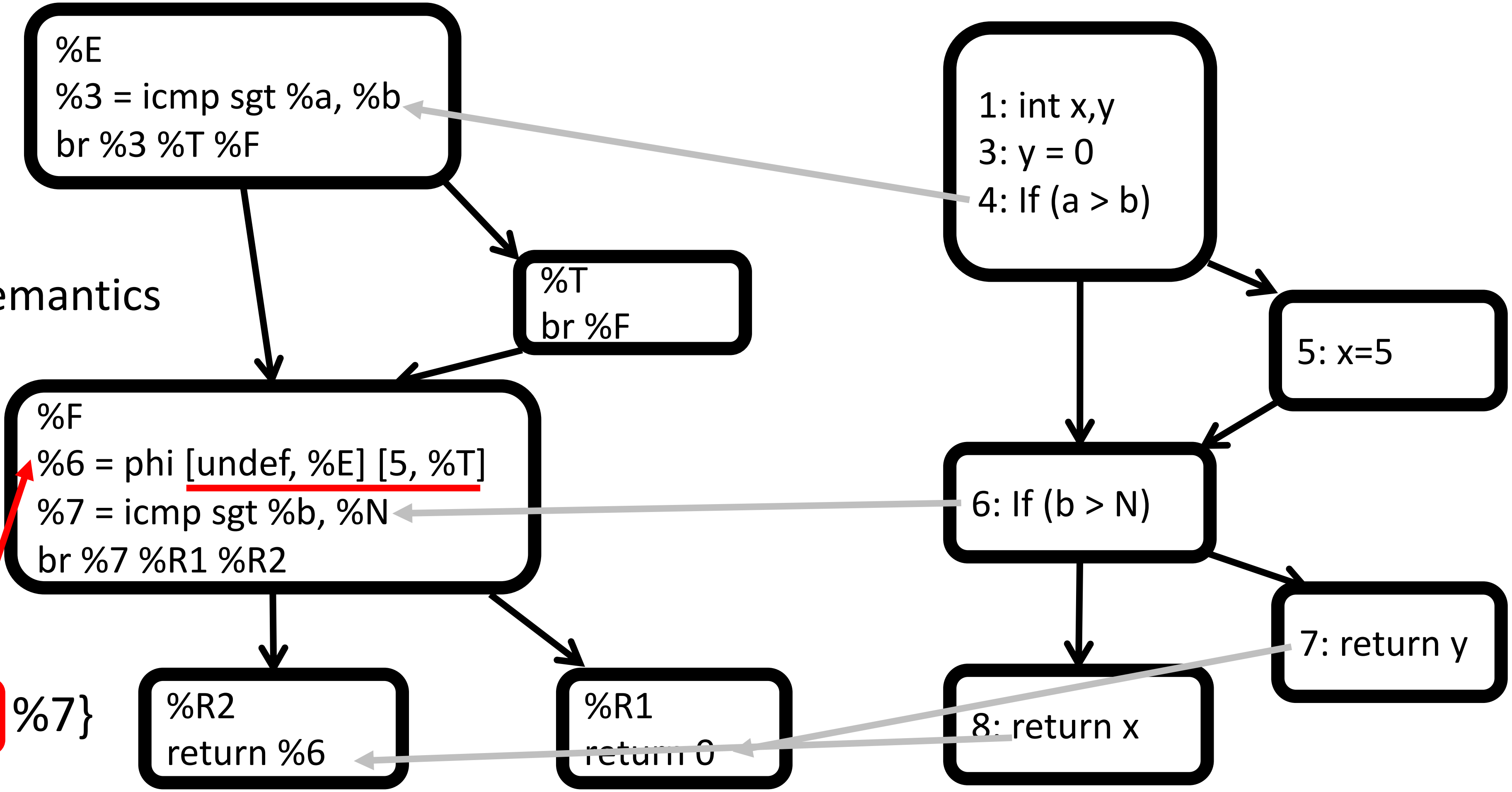
- We learned constant propagation that relies on reaching definition
  - This transformation is correct for both SSA and non-SSA IRs

- Can we have a faster constant propagation for SSA IRs?
  - Yes
  - Let’s first apply the previous constant propagation to an SSA IR to understand how to make it faster

Constant propagation in SSA (in LLVM)

If you want the conventional CP semantics

- Skip undef



```
%E
%3 = icmp sgt %a, %b
br %3 %T %F
```

```
%T
br %F
```

```
%F
%6 = phi [undef, %E] [5, %T]
%7 = icmp sgt %b, %N
br %7 %R1 %R2
```

```
%R2
return %6
```

```
%R1
return 0
```

```
1: int x,y
3: y = 0
4: If (a > b)
```

```
5: x=5
```

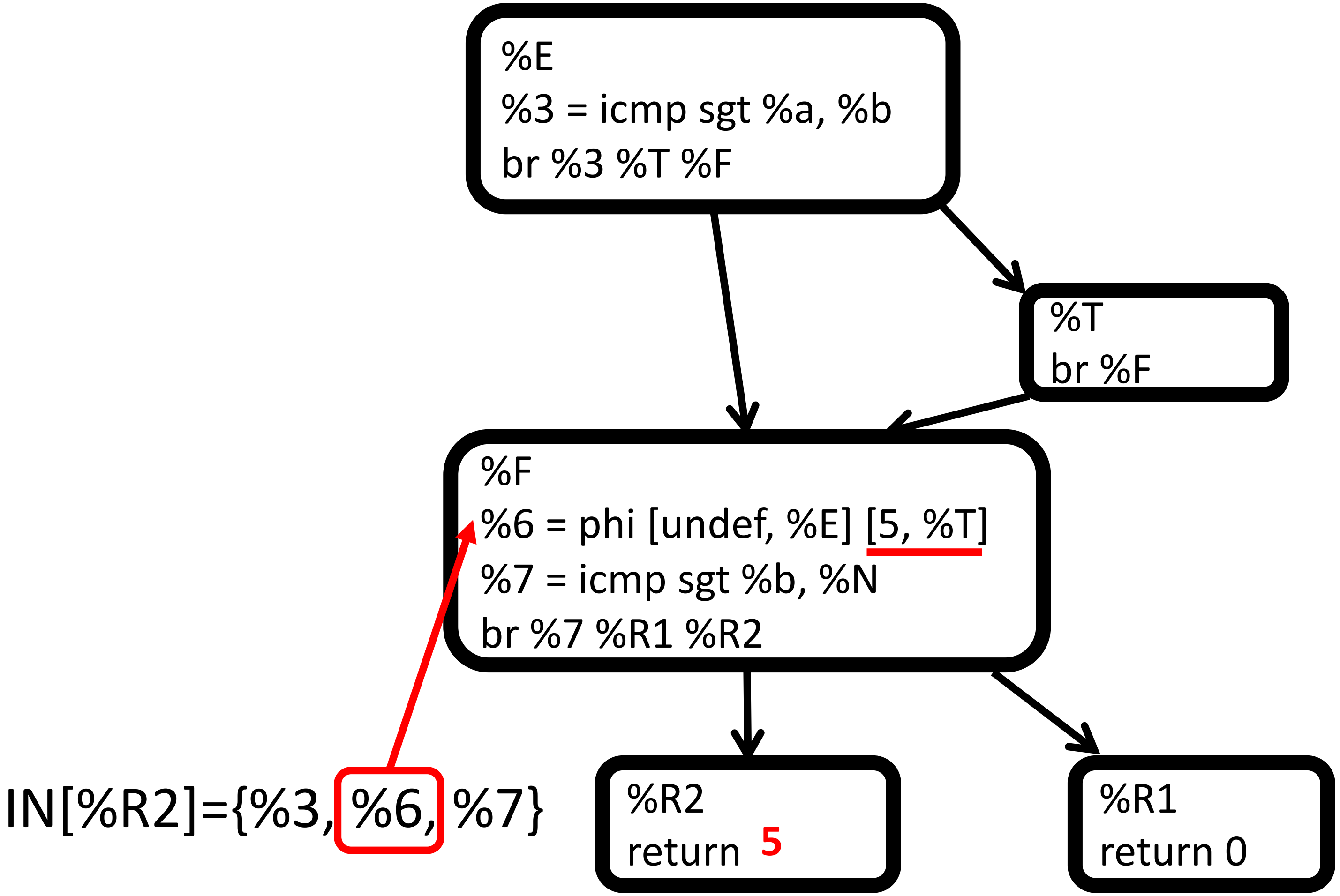
```
6: If (b > N)
```

```
7: return y
```

```
8: return x
```

IN[%R2]={%3, $\boxed{\%6,}$ %7}

(Unnecessary thanks to SSA)
Constant propagation in SSA (in LLVM)



```
%E
%3 = icmp sgt %a, %b
br %3 %T %F
```

```
%T
br %F
```

```
%F
%6 = phi [undef, %E] [5, %T]
%7 = icmp sgt %b, %N
br %7 %R1 %R2
```

```
%R2
return 5
```

```
%R1
return 0
```

IN[%R2]={%3, %6, %7}

Outline

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- Constant folding

- Algebraic simplification

Constant folding

Definition:
This transformation evaluates constant expressions at compile time so they do not need to be computed at runtime

```
int a = 3 + 2;
myF(a);
```

Constant folding
for C variables

```
int a = 5;
myF(a);
```

```
%a = add 3, 2
call @myF(%a)
```

Constant folding
for LLVM IR variables

```
call @myF(5)
```

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Algebraic simplification

- **Definition**:
  Algebraic simplification uses algebraic properties of operators or particular operand combinations to simplify expressions

- **Example**:

```
int b = a + 0;
```

Algebraic simplification

```
int b = a;
```

```
%b = add a, 0
call @myF(%b)
```

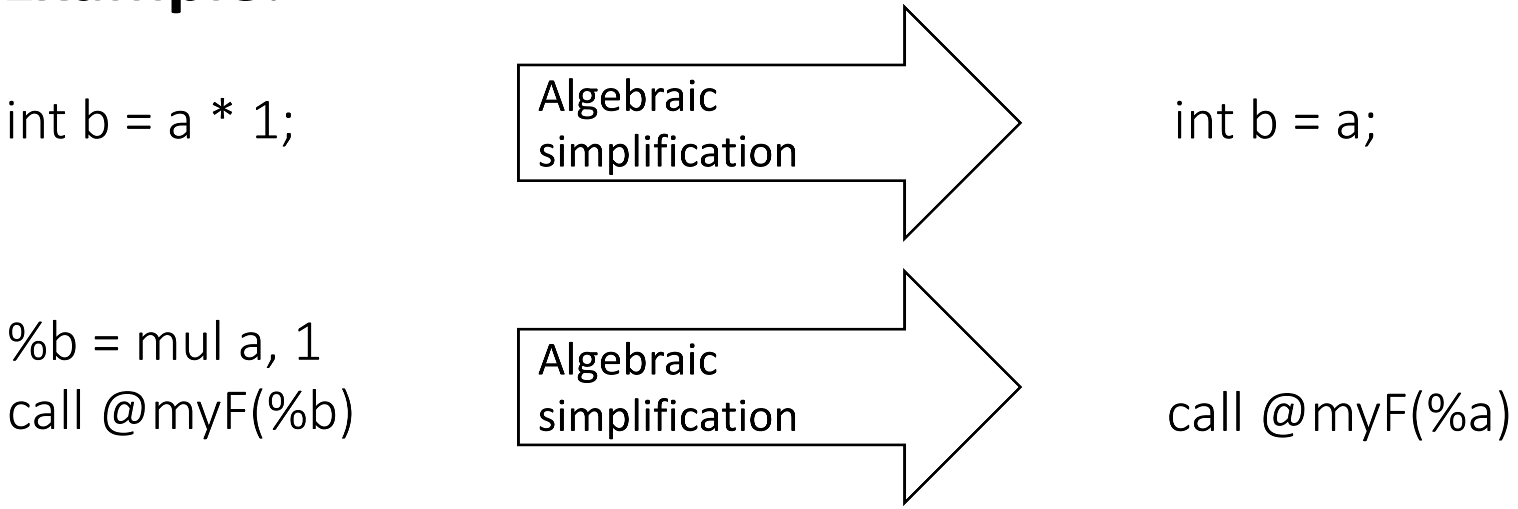
Algebraic simplification

```
call @myF(%a)
```

Algebraic simplification

- **Definition**:
  Algebraic simplification uses algebraic properties of operators or particular operand combinations to simplify expressions

- **Example**:



```
int b = a * 1;
```

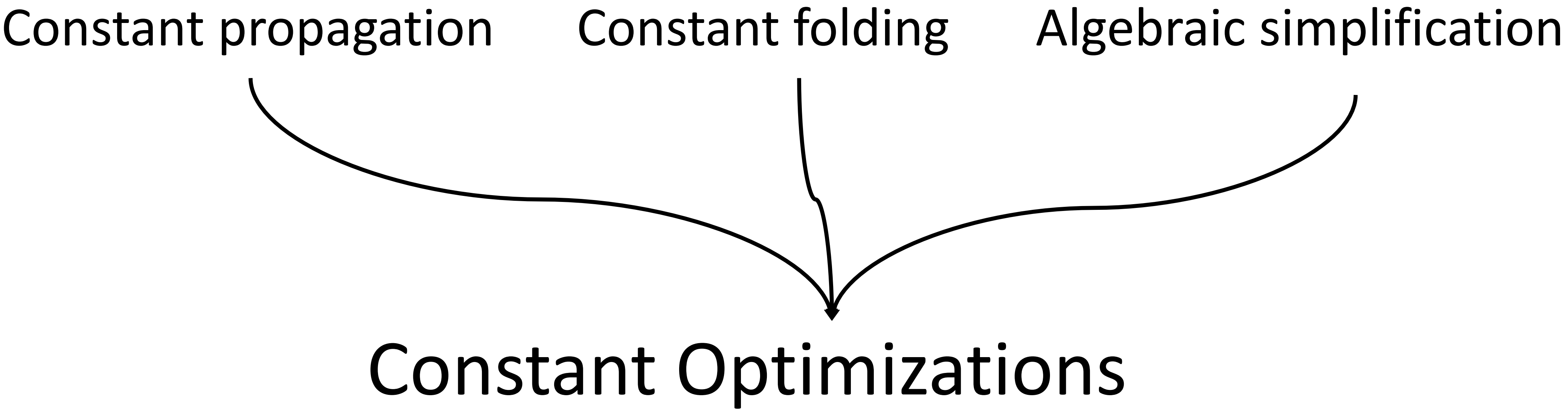
Algebraic simplification

```
int b = a;
```

```
%b = mul a, 1
call @myF(%b)
```

Algebraic simplification

```
call @myF(%a)
```



Constant propagation

Constant folding

Algebraic simplification

Constant Optimizations

Always have faith in your ability

Success will come your way eventually

Best of luck!