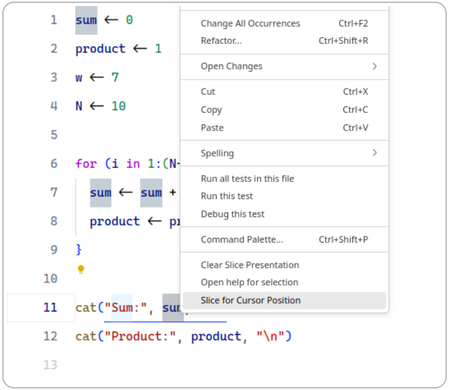
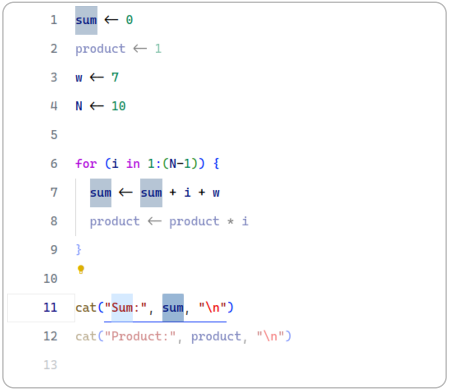


```
sum ← 0
product ← 1
w ← 7
N ← 10

for (i in 1:(N-
  sum ← sum +
  product ← pı
}

cat("Sum:", sur
cat("Product:", product, "\n")
```



```
sum ← 0
product ← 1
w ← 7
N ← 10

for (i in 1:(N-1)) {
  sum ← sum + i + w
  product ← product * i
}

cat("Sum:", sum, "\n")
cat("Product:", product, "\n")
```

# *flowR*: A Program Slicer for the R Programming Language

deRSE ’24 | Ulm University | Florian Sihler and Prof. Matthias Tichy | March 6, 2024

Software Engineering
Programming Languages

# The R Programming Language

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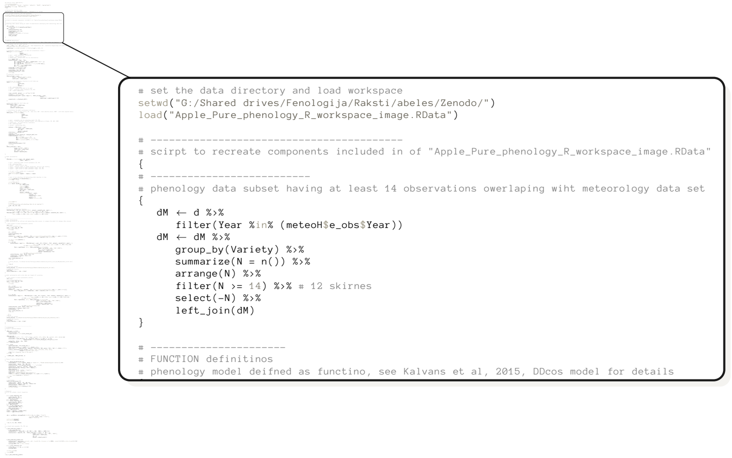

```
# set the data directory and load workspace
setwd("G:/Shared drives/Fenologija/Raksti/abeles/Zenodo/")
load("Apple_Pure_phenology_R_workspace_image.RData")

# -----------------------------------------
# scirpt to recreate components included in of "Apple_Pure_phenology_R_workspace_image.RData"
{
# --------------------------
# phenology data subset having at least 14 observations owerlaping wiht meteorology data set
{
   dM ← d %>%
      filter(Year %in% (meteoH$e_obs$Year))
   dM ← dM %>%
      group_by(Variety) %>%
      summarize(N = n()) %>%
      arrange(N) %>%
      filter(N >= 14) %>% # 12 skirnes
      select(-N) %>%
      left_join(dM)
}

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# FUNCTION definitinos
# phenology model deifned as functino, see Kalvans et al, 2015, DDcos model for details
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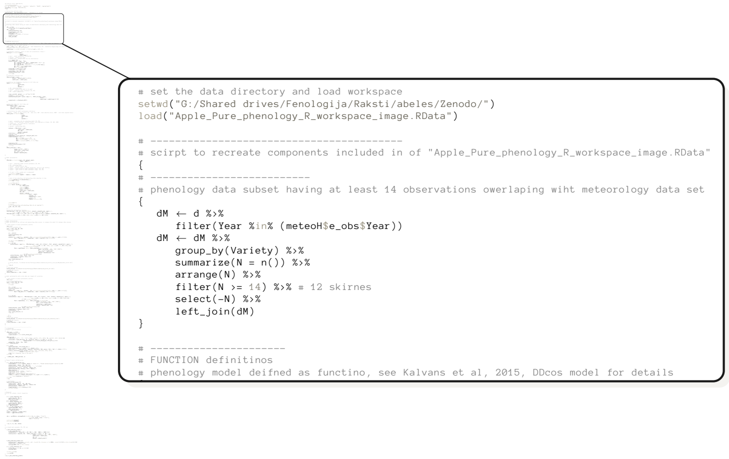

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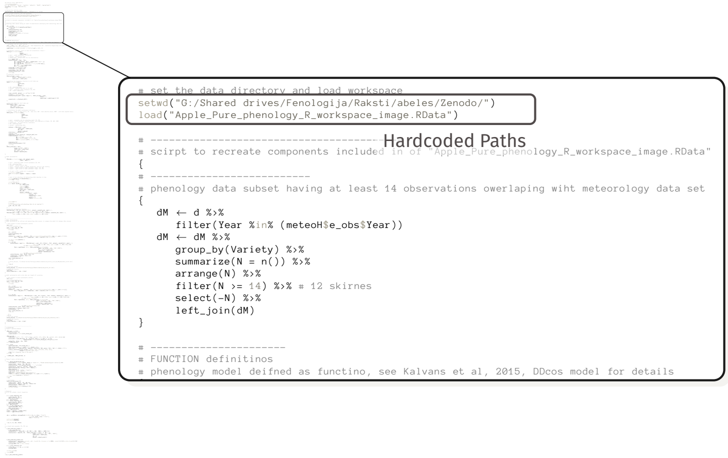

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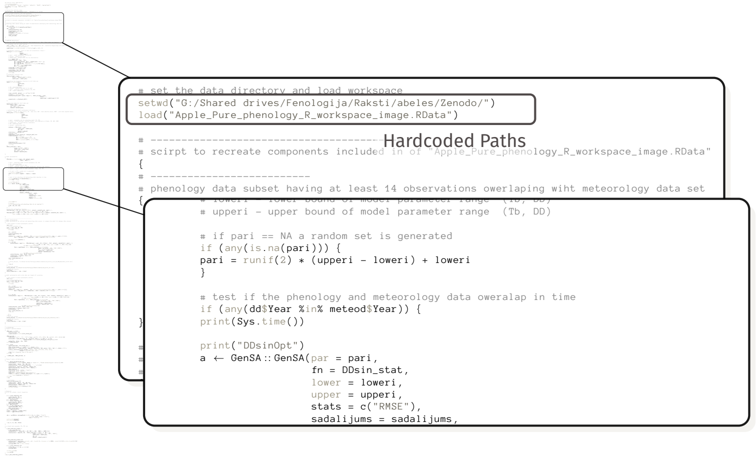

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Hardcoded Paths

```
        # loweri - lower bound of model parameter range  (Tb, DD)
        # upperi - upper bound of model parameter range  (Tb, DD)

        # if pari == NA a random set is generated
        if (any(is.na(pari))) {
        pari = runif(2) * (upperi - loweri) + loweri
        }

        # test if the phenology and meteorology data oweralap in time
        if (any(dd$Year %in% meteod$Year)) {
        print(Sys.time())

        print("DDsinOpt")
        a ← GenSA::GenSA(par = pari,
                         fn = DDsin_stat,
                         lower = loweri,
                         upper = upperi,
                         stats = c("RMSE"),
                         sadalijums = sadalijums,
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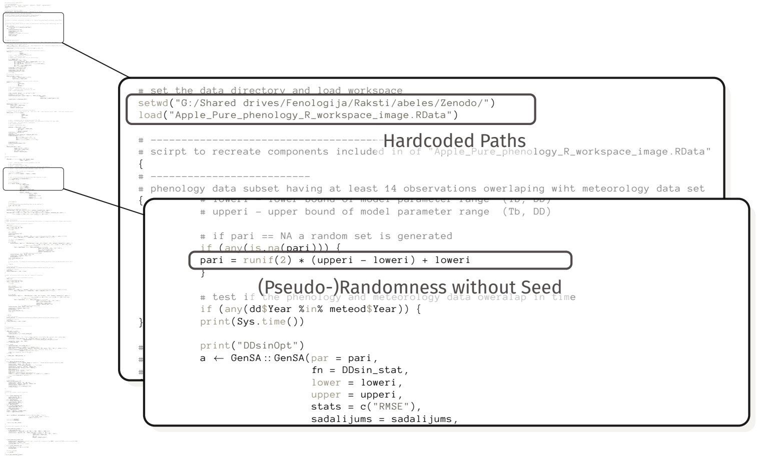

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(Pseudo-)Randomness without Seed

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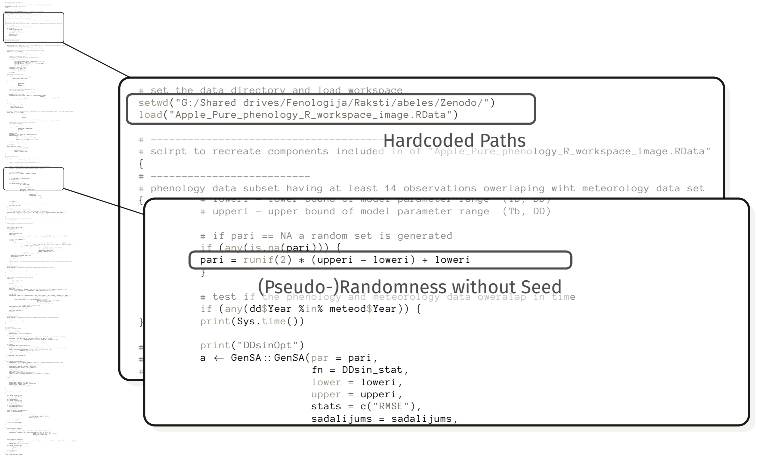
**74 % even fail to complete![2]**



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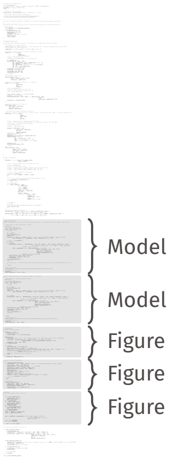

Model

Model

Figure

Figure

Figure

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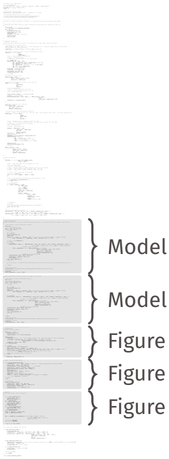

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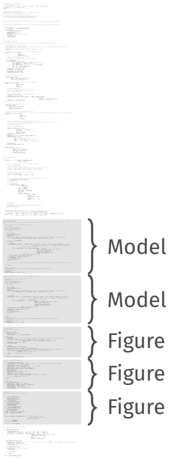

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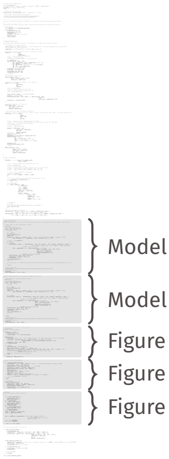

- Several analyses in one script
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- Hard to extract/re-use parts

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```
[9] pull.cat ← function(x) {
       bins ← 5
       increments ← (range(x)[2] - range(x)[1])/(bins - 1)
       to_return ← seq(range(x)[1], range(x)[2], increments)
       return(to_return)
    }

    up.cat ← function(new_bins) {
       up_bins = new_bins
       body(pull.cat)[[2]] ↞ substitute(bins ← up_bins)
    }
```

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  - Dependency analysis
  - Creation of call-graphs

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  - Syntax-highlighting and auto-completion
  - Reference tracing & Refactorings (rename)

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  - Style & syntax errors
  - Potential semantic errors

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  - Dependency analysis
  - Creation of call-graphs

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  - ~~Dependency analysis~~ ← Only top scope
  - Creation of call-graphs

# R Scripts …

# R Scripts …

1. fail to replicate

# R Scripts . . .

1. fail to replicate
2. do too much

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Better Software, Better Research

# R Scripts …

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Better Software, Better Research

# The Goal of flowR

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- Interested in a single figure

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# The Goal of flowR

- Interested in a single figure
- ≈ *70 %* reduction

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# The Architecture

[10] Sihler, “Constructing a static program slicer for R programs” (2023, Ulm University)
[11] Weiser, “Program Slicing” (1984, IEEE Transactions on Software Engineering)

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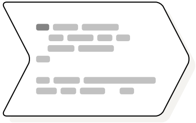

Parse

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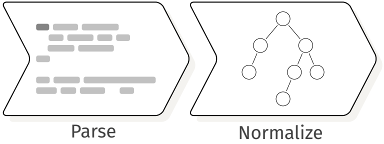

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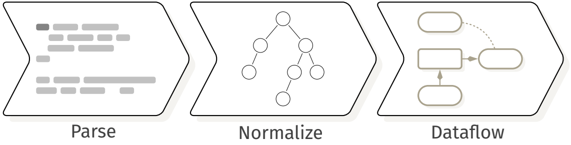

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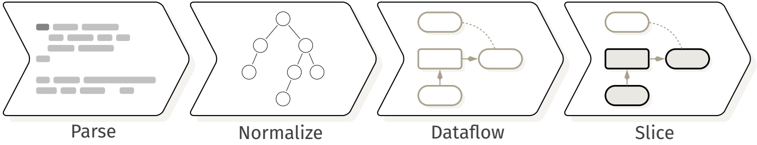

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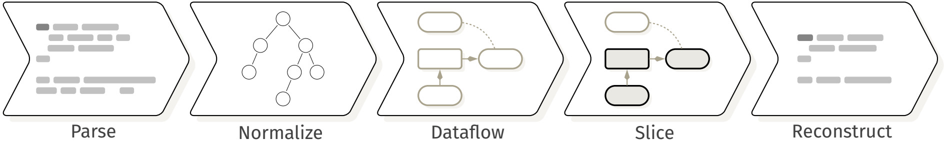

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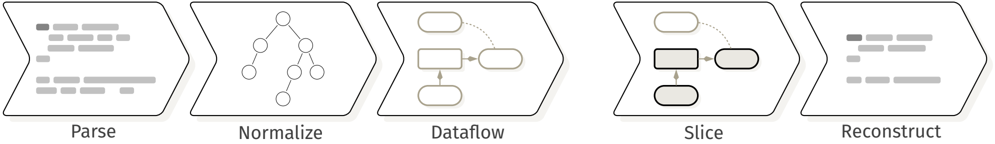

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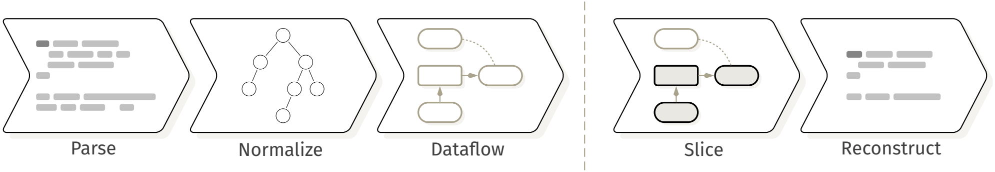

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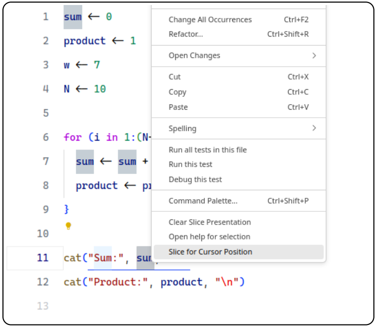

```
sum ← 0
product ← 1
w ← 7
N ← 10

for (i in 1:(N-
  sum ← sum +
  product ← pr
}

cat("Sum:", sum
cat("Product:", product, "\n")

```

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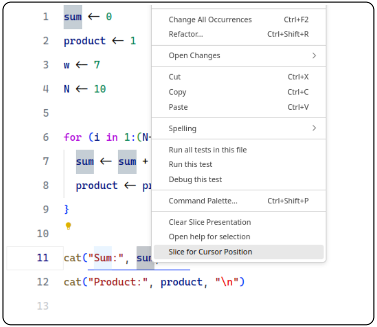

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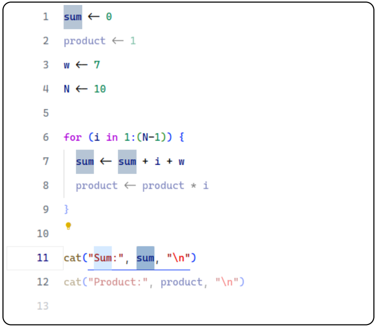

```
sum ← 0
product ← 1
w ← 7
N ← 10

for (i in 1:(N-1)) {
  sum ← sum + i + w
  product ← product * i
}

cat("Sum:", sum, "\n")
cat("Product:", product, "\n")
```

# Using flowR

- github.com/Code-Inspect/flowr
- github.com/Code-Inspect/vscode-flowr
- hub.docker.com/r/eagleoutice/flowr
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### Server

```
{
  "type": "request-file-analysis",
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  "content":   "x←1;␣x*y"
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```
const s = new SteppingSlicer({
  shell, tokenMap,
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const slice =
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## REPL

```
R> :parse "x←1; x*y"
exprlist
⊢ expr
|  ⊢ expr
|  |  └ SYMBOL "x" (1:1)
[...]

R> :dataflow* "x ← 1; x * y"
https://mermaid.live/edit#base64:eyJj...
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```
docker run -it --rm eagleoutice/flowr
```

# Appendix

# The R Code Static Analysis Landscape

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| | goal | method | impl. lang. | op. assignments | func. assignments | value trace (a.i., …) | controlflow | non-std. eval. | special operators | function calls | libraries | quotation | reflection | side effects | static scope | dynamic scope | type inference | pointer analysis | external files | pre-processors | hooks | FFI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [12] {CodeDepends} | static analysis | AST visitor | R | ● | ○ | | | ○ | ○ | ○ | ○ | | | ○ | ● | | | | | | | |
| [13] {codetools} | static analysis | AST visitor | R | ● | ○ | ○ | ○ | ○ | ○ | ○ | | ○ | | | ● | | | | | | | |
| [14] {checkglobals} | missing libs. | AST visitor | R, C | ● | ○ | | | ○ | ○ | ○ | ○ | ○ | | | ○ | | | | | | | ○ |
| ~~[15] {rstatic}~~ | ~~static analysis~~ | ~~AST visitor~~ | ~~R~~ | ● | | ○ | ● | | ○ | | | | | | ● | | | | | | | |
| [16] {CodeAnalysis} | static analysis | AST visitor | R | ● | ○ | ○ | ● | ○ | ○ | ○ | ○ | ○ | | | ● | | ○ | | ○ | | | |
| ~~[17] {RTypeInference}~~ | ~~type inference~~ | ~~AST visitor~~ | ~~R~~ | ● | | ○ | ● | | ○ | | | | | | ● | | ● | | | | | |
| [18] {pkgstats} | package insight | ctags & gtags | R, C++ | ○ | | | | | ○ | ○ | | | | | ○ | | | | | | | |
| [19] {globals} | distributed env. | AST visitor | R | ● | | ○ | ○ | ○ | ○ | ○ | | ○ | | | ● | | | | | | | |
| ~~[20] {Rclean}~~ | ~~debug/refactor~~ | ~~PDG traversal~~ | ~~R~~ | ● | ○ | | | ○ | ○ | ○ | ○ | | | | ● | | | | | | | |
| [21] {lintr} | linting | XPath, visitor | R | ● | ○ | | ○ | | ○ | | ○ | | | | ● | | | | | | | |
| [22] {SimilaR} | plagiarism | PDG, visitor | R, C++ | ○ | | | ○ | | | ○ | | | | | ● | | | | | | | |
| [23] {rco} | optimization | AST visitor | R | ● | | ● | ○ | | | | | | | | ● | | | | | | | |
| [24] {cyclocomp} | code complexity | AST visitor | R | | | | ○ | | | | | | | | ● | | | | | | | |
| [25] {flow} | visualize, debug | AST visitor | R, C | ○ | | | ● | | ○ | | ○ | ○ | | | | | | | ○ | | | |
| [26] {PaRe} | code review | Regex | R | ○ | | | ○ | | | ○ | | | | | | | | | | | | |
| ~~[27] {dfgraph}~~ | ~~static analysis~~ | ~~AST visitor~~ | ~~R~~ | ○ | | | ○ | | | ○ | | | | | | | | | | | | |
| ~~[28] {rflowgraph}~~ | ~~call graph~~ | ~~AST visitor~~ | ~~R~~ | | | | | | | ○ | ○ | | | | | | | | | | | |
| [29] {languageserver} | editor support | XPath, visitor | R, C | ● | ○ | | | | | ○ | ○ | | | | ● | | | | | | | |
| [30] RStudio | editor support | AST visitor | Java, C++, TS, … | ● | ○ | | | | | ○ | ○ | | | | ● | | | | | | | |
| ~~[31] ROSA~~ | ~~optimization~~ | ~~visitor~~ | ~~C++, R~~ | ● | | | ○ | | | ○ | | | ○ | | ● | | ● | ○ | | | | |
| ~~[32] Random~~ | ~~abstract int.~~ | ~~trace & visitor~~ | ~~R~~ | ○ | ○ | ○ | ○ | | | | ○ | | | | ○ | | | | | | | |
| [4] RaaS | reproducibility | AST visitor | Python, R | ● | ○ | | | ○ | ○ | ○ | ○ | | | | ● | | | | | | | |
| [33] GNU R | execute R | bytecode | C, Fortran, R | ● | ○ | ● | ○ | ○ | ● | ○ | | ○ | | | ● | | | | | | | |
| ~~[34] FastR~~ | ~~execute R~~ | ~~AST visitor~~ | ~~Java, C, R, …~~ | ● | | ○ | | | ○ | ○ | ○ | | | | ● | | | | | | | |
| [35] Ř | execute R | SSA, bytecode | C++, R, C, … | ● | ● | ● | ● | ○ | ● | ○ | | ○ | | | ● | ○ | ● | | | | | |
| [36] renjin | execute R | SSA, CFG | R, Java, C, … | ● | ○ | ○ | ● | | ○ | ○ | | | | ○ | ● | | ● | | | | | |
| ~~[37] pqR~~ | ~~execute R~~ | ~~bytecode~~ | ~~C, R, …~~ | ● | ○ | ● | ○ | ○ | ● | ○ | | ○ | | | ● | | | | | | | |
| ~~[38] MRO~~ | ~~execute R~~ | ~~bytecode~~ | ~~R, C, Fortran, …~~ | ● | ○ | ○ | ○ | | | | | | | | | | | | | | | |
| ~~[39] RCC~~ | ~~transpile C~~ | ~~CFG, bytecode~~ | ~~C/C++, Fortran, R, …~~ | ● | | ● | ○ | ○ | | ○ | | | | ○ | ● | | | | | | | |

# Performance Measurements

- We generated *every* possible variable of interest

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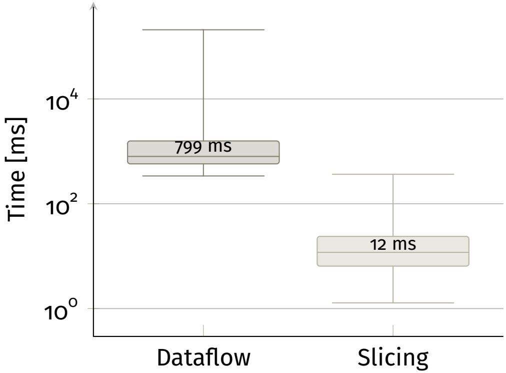

99th percentile

# Performance Measurements

- We generated *every* possible variable of interest
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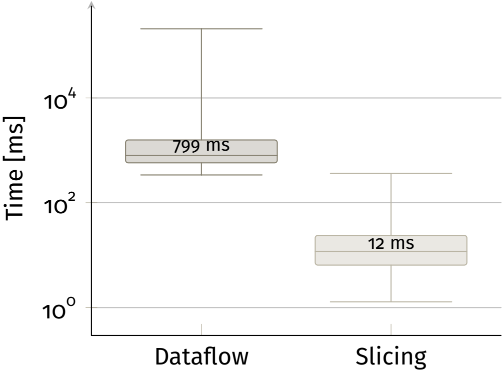

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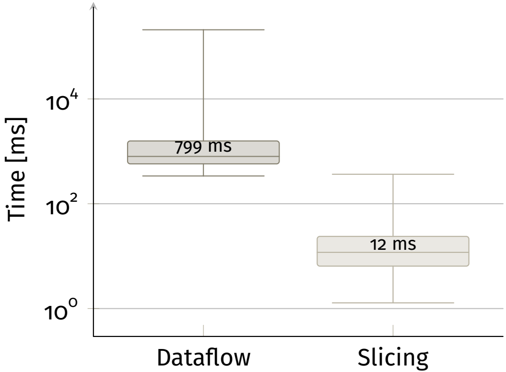
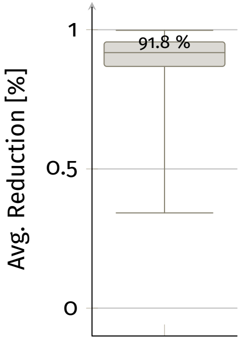
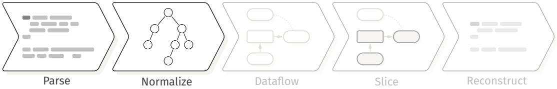




99th percentile

# Parse & Normalize



[40] R Core Team, *R Language Definition* (2023)

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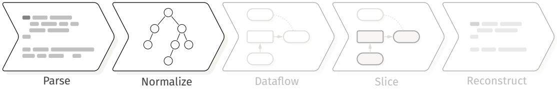

```
parse(text="if(TRUE) x else y")
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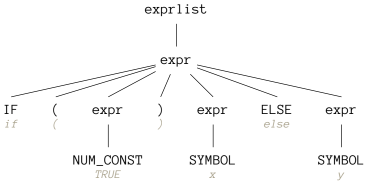

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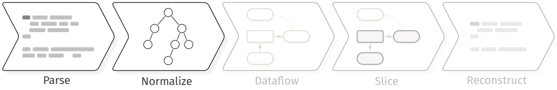

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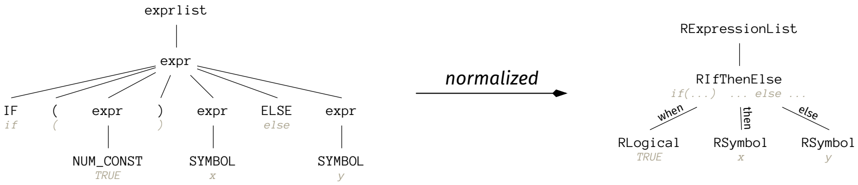

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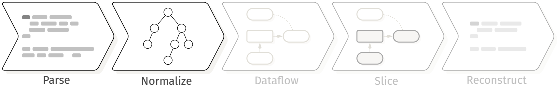

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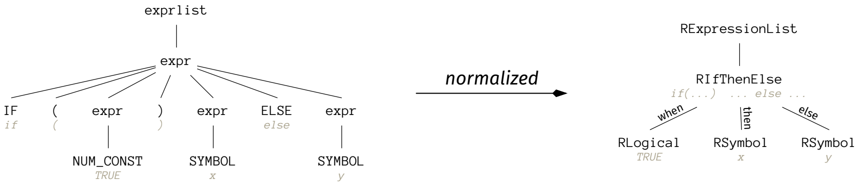

- Normalizing constants, namespacing, operators, …

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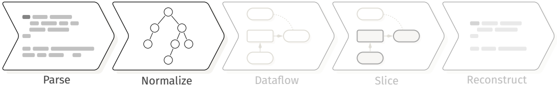

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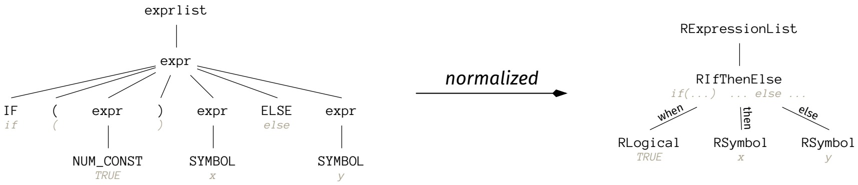
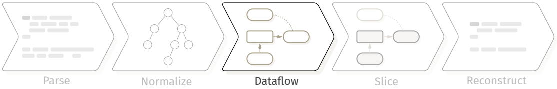


- Normalizing constants, namespacing, operators, ...
- We use the “R language definition”[40] as a basis

[40] R Core Team, *R Language Definition* (2023)

# Dataflow



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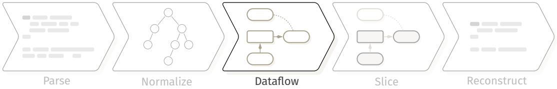

$x_0 \leftarrow 21$

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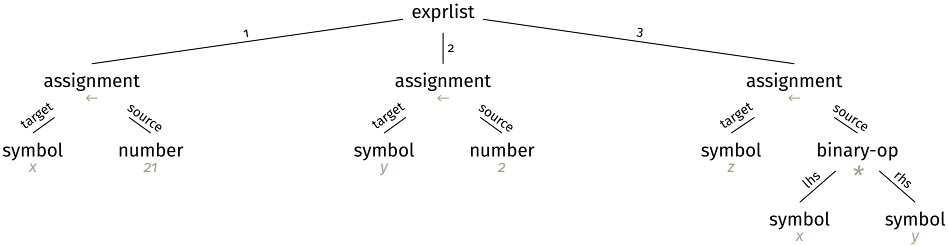

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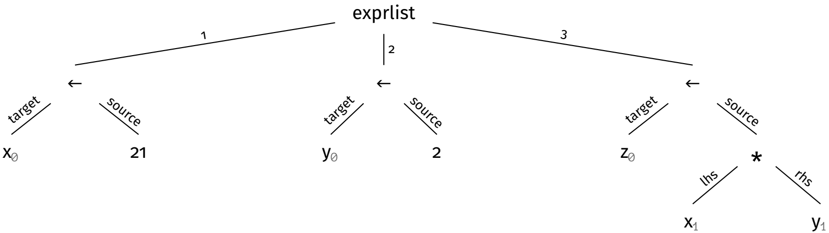

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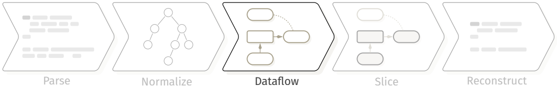

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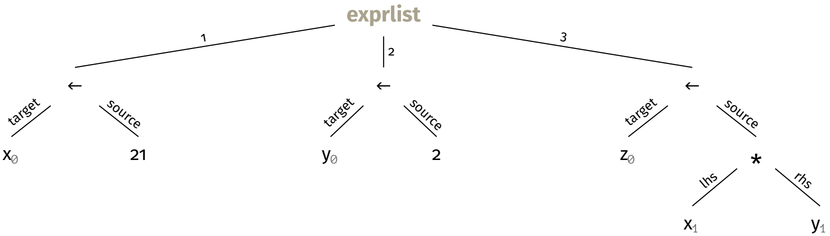

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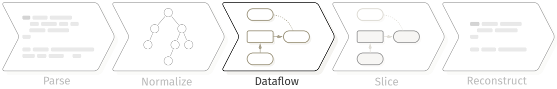

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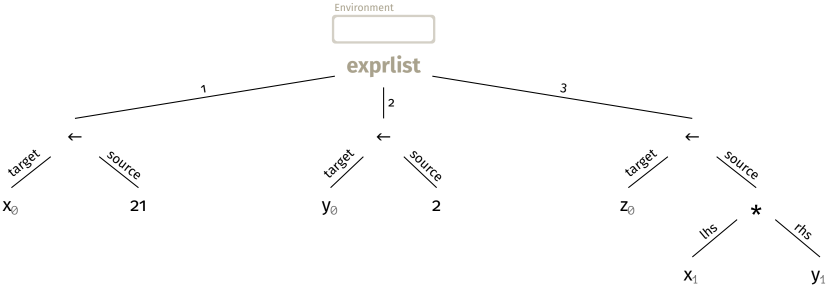

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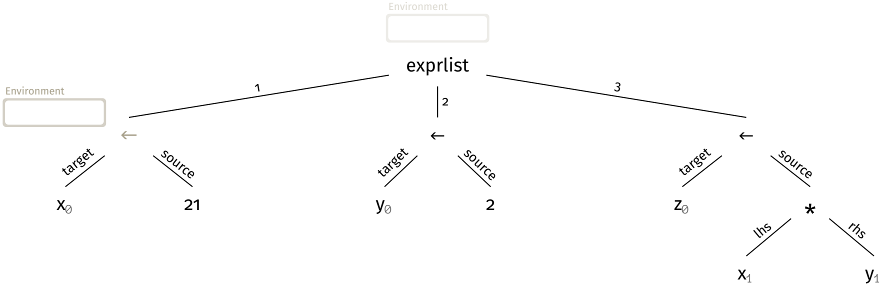

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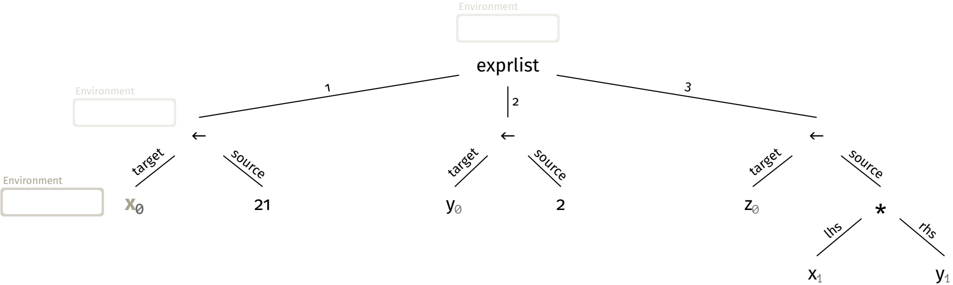

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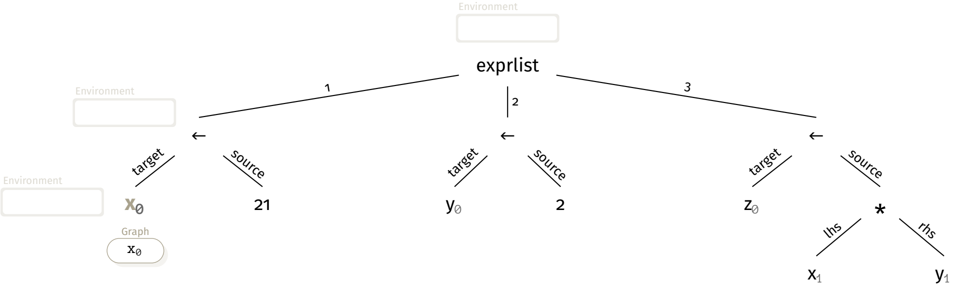

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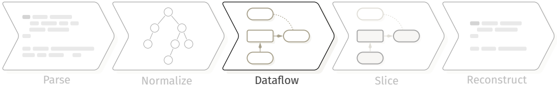

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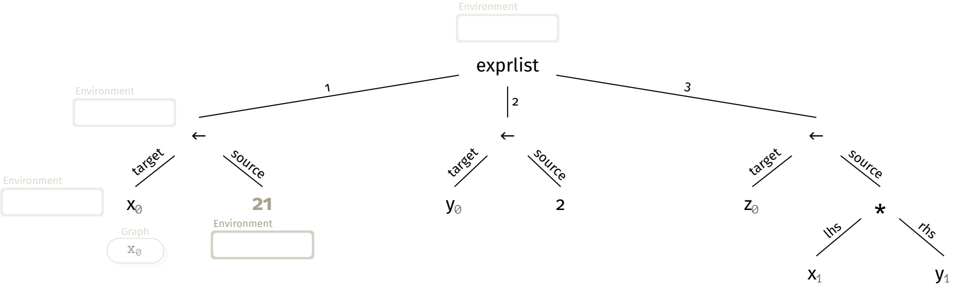

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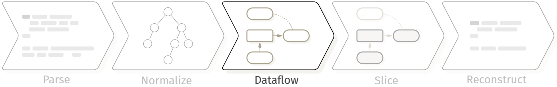

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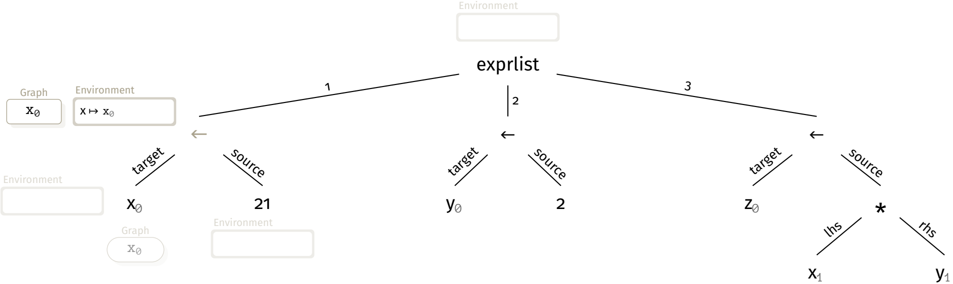

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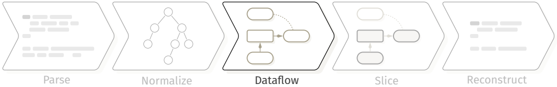

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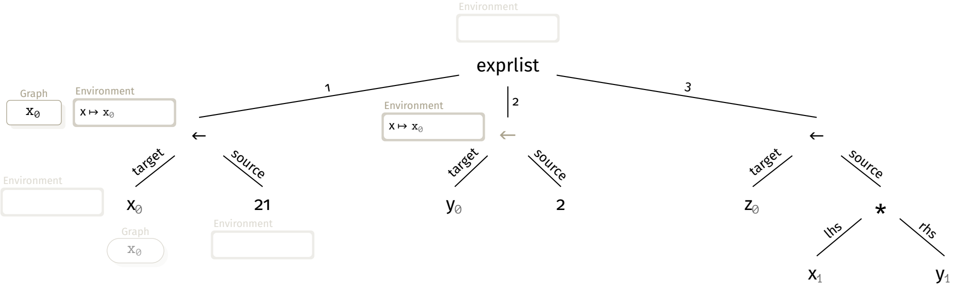

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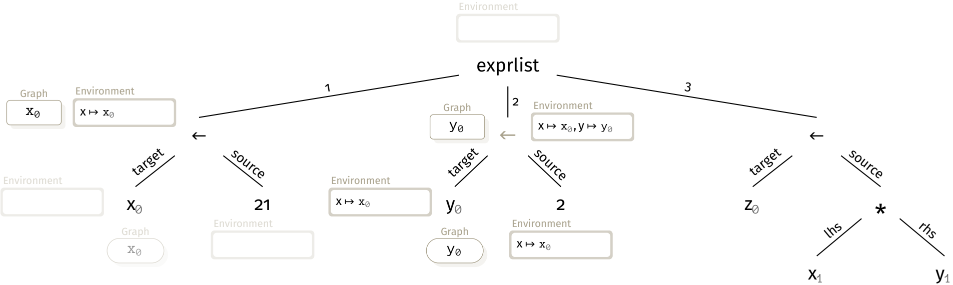

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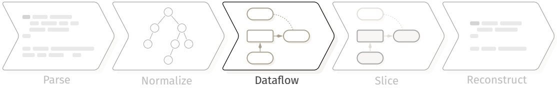

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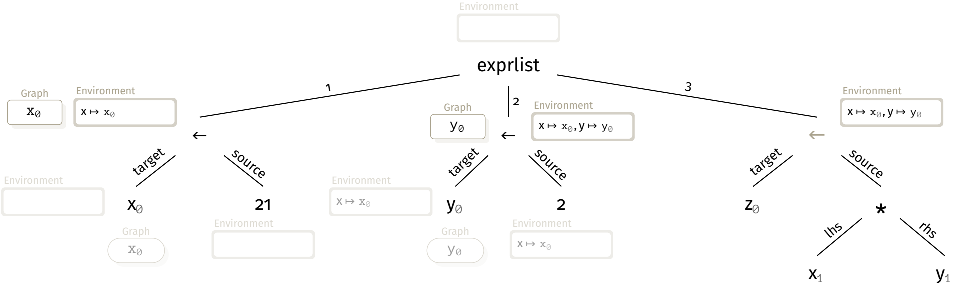

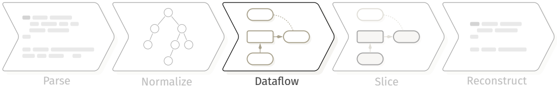

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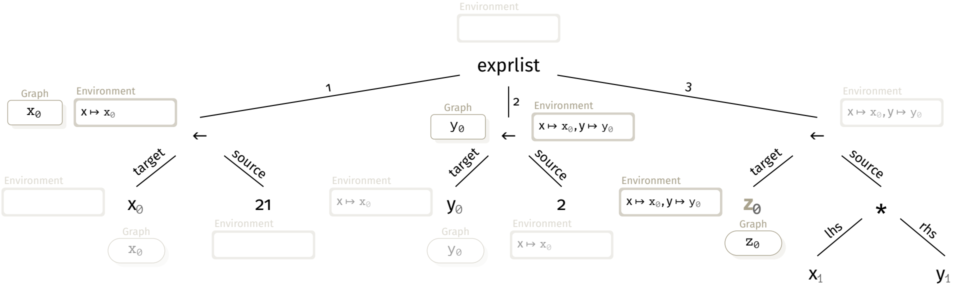

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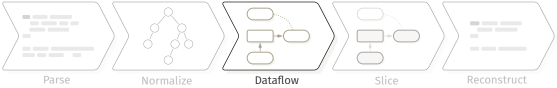

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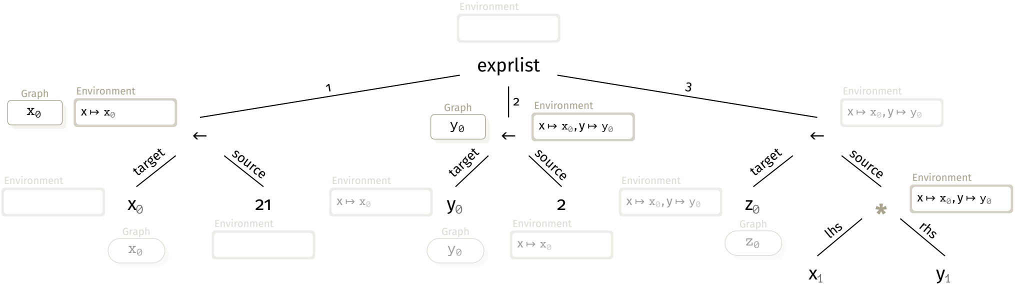

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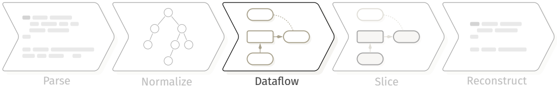

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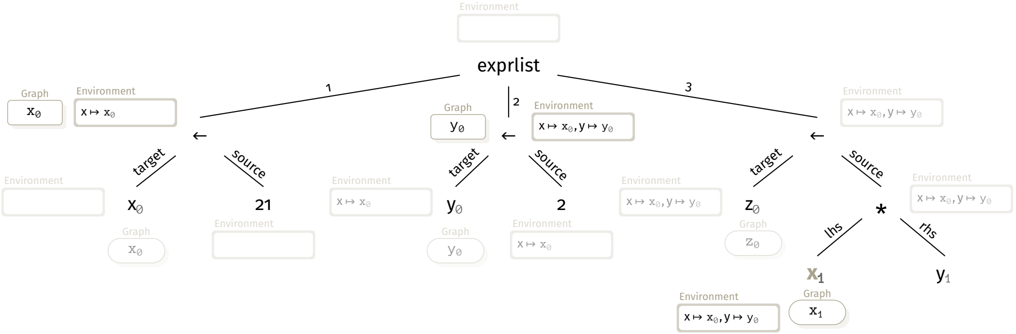

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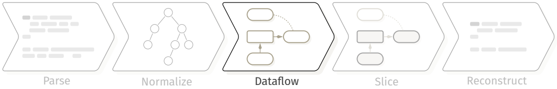

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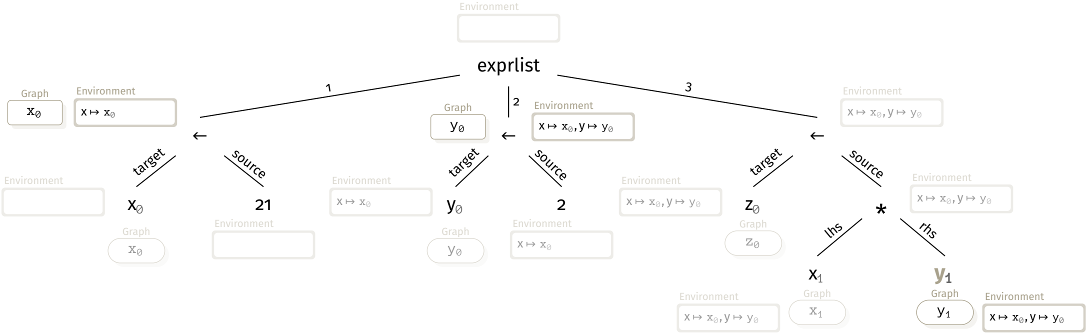

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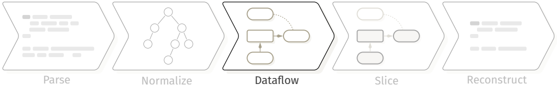

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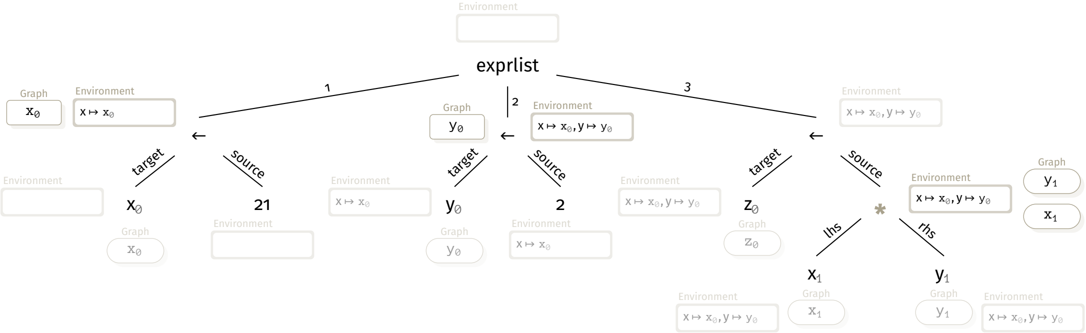

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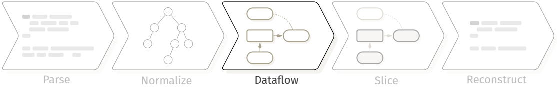

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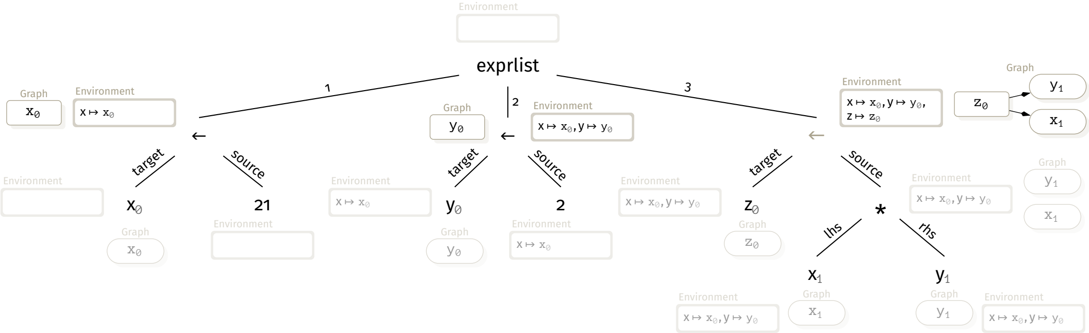

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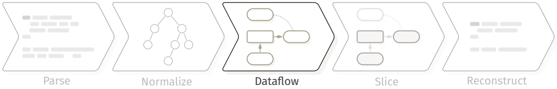

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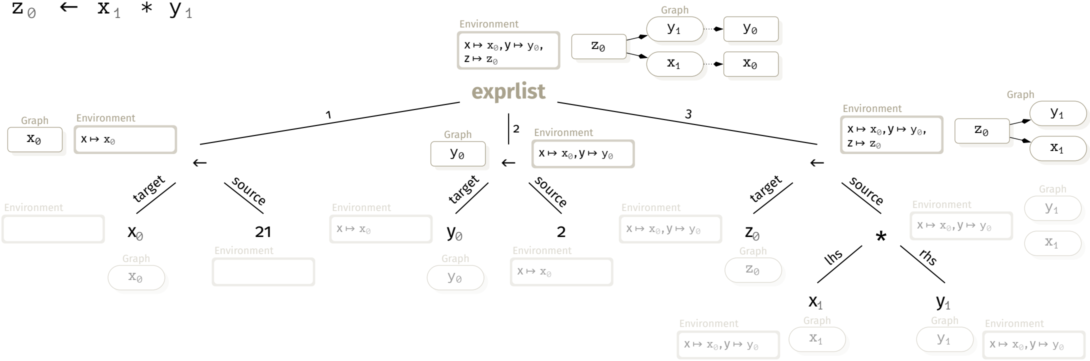
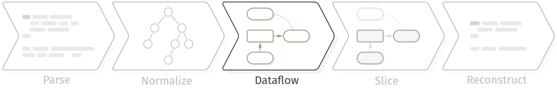


# Resulting Dataflow



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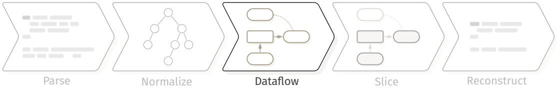
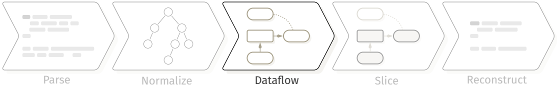


```
a ← 3
a ← x * m

if(m > 3) {
  a ← 5
}

b ← a + c
```

# Resulting Dataflow



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$a_0 \leftarrow 3$
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if($m_1 > 3$) {
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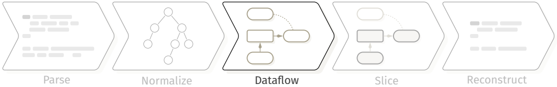

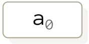

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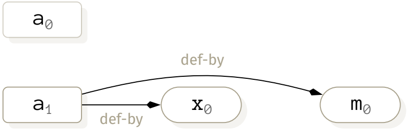

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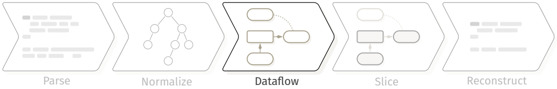

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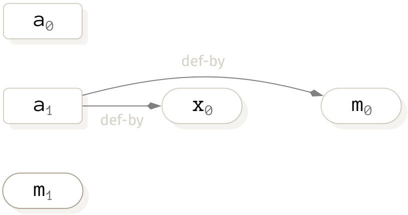

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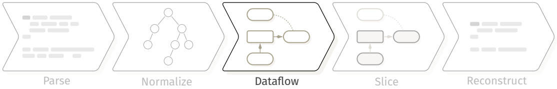

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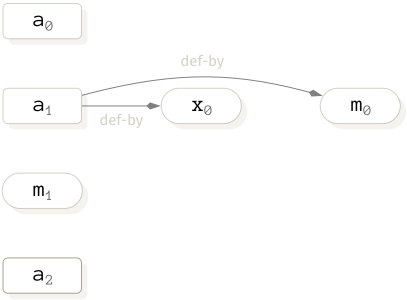

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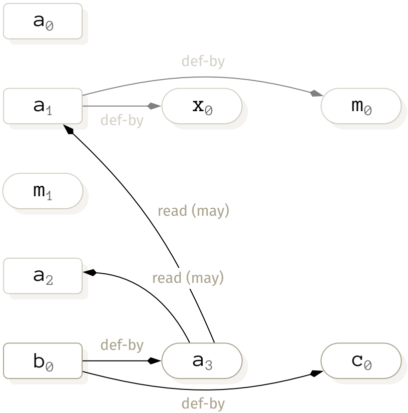

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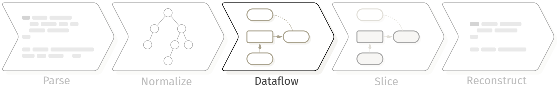

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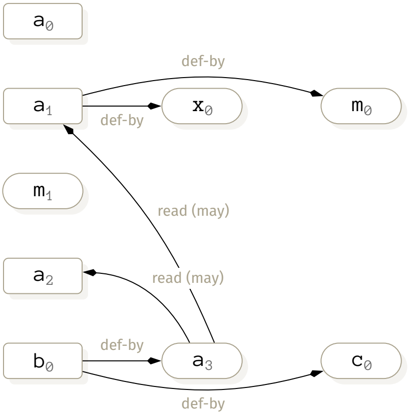
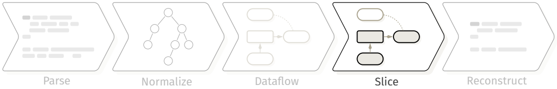


# Slicing, I



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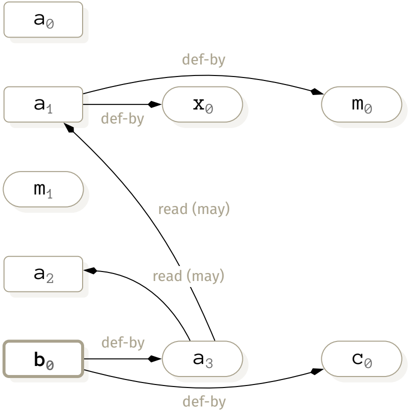

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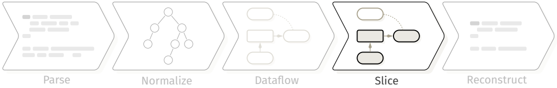

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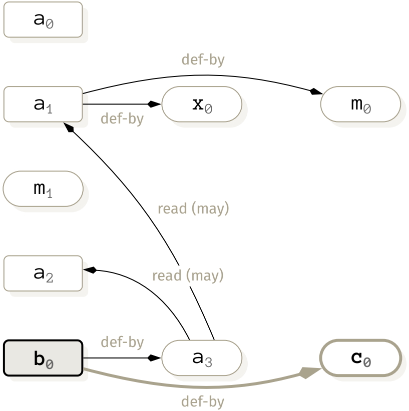

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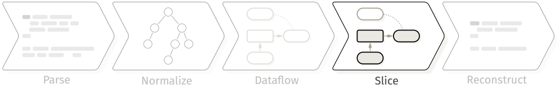

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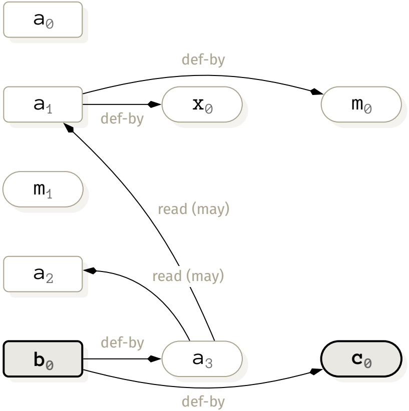

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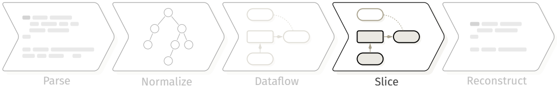

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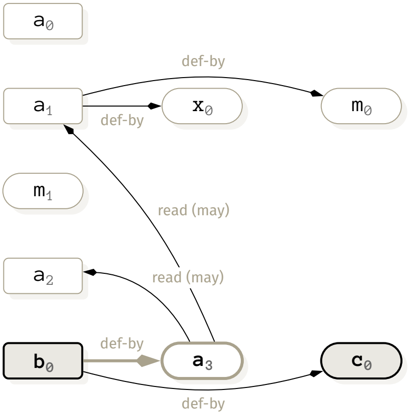

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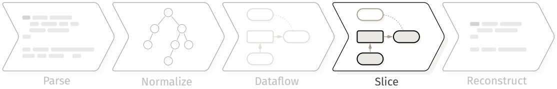

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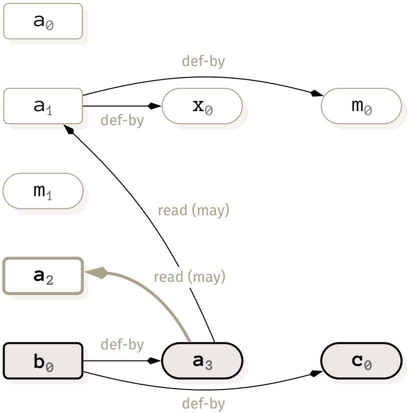

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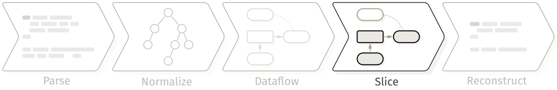

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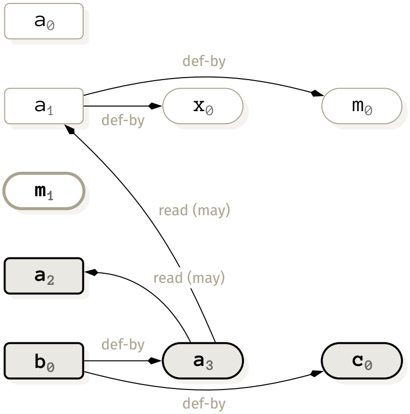

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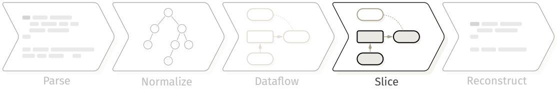


$a_0 \leftarrow 3$

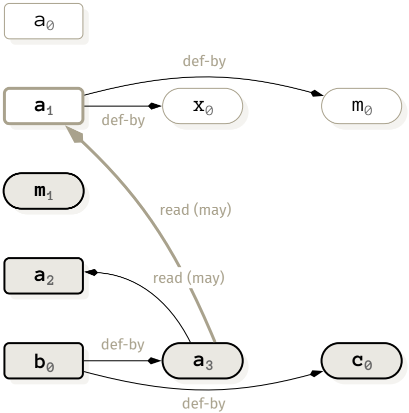
$a_1 \leftarrow x_0 * m_0$

$\text{if}(m_1 > 3)\ \{$

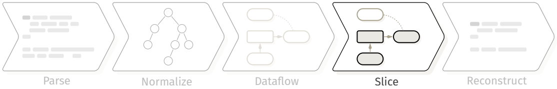
$\quad a_2 \leftarrow 5$

$\}$

$\underline{b}_0 \leftarrow a_3 + c_0$



# Slicing, I



$a_0 \leftarrow 3$

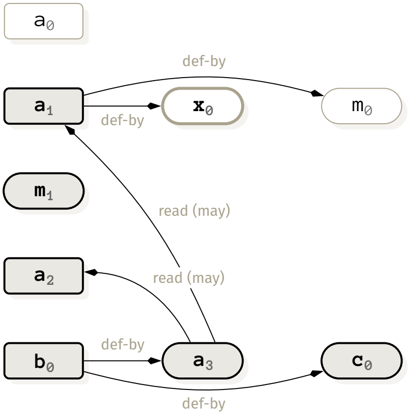
$a_1 \leftarrow x_0 * m_0$

$\texttt{if}(m_1 > 3)\ \{$

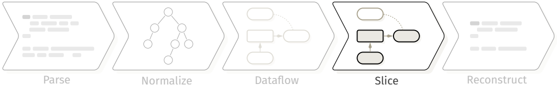
$\quad a_2 \leftarrow 5$

$\}$

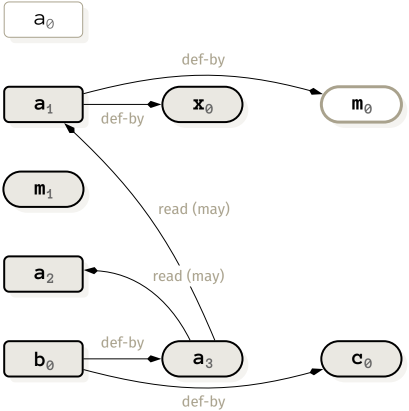
$\underline{b}_0 \leftarrow a_3 + c_0$



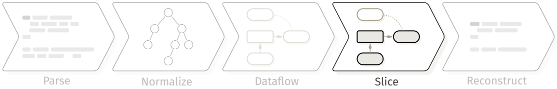
# Slicing, I



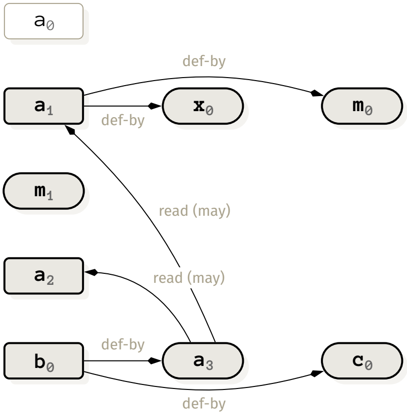
```
a_0 ← 3
a_1 ← x_0 * m_0

if(m_1 > 3) {
  a_2 ← 5
}

b_0 ← a_3 + c_0
```



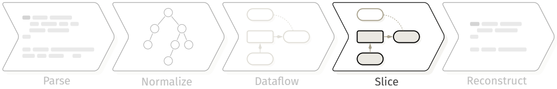
# Slicing, I



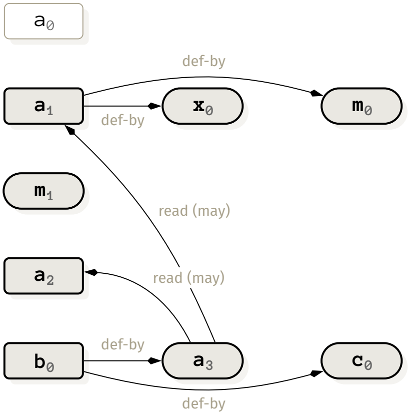
```
a_0 ← 3
a_1 ← x_0 * m_0

if(m_1 > 3) {
  a_2 ← 5
}

b_0 ← a_3 + c_0
```



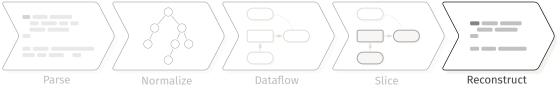
# Slicing, I



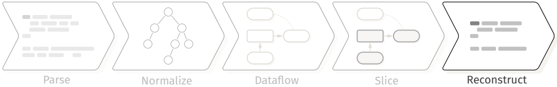
```
$a_0 \leftarrow 3$
$a_1 \leftarrow x_0 * m_0$

if($m_1$ > 3) {
  $a_2 \leftarrow 5$
}

$\underline{b}_0 \leftarrow a_3 + c_0$
```



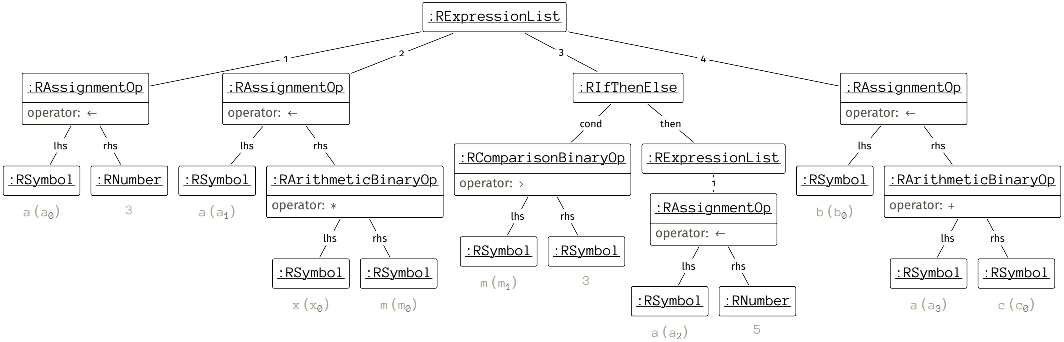
# Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct

# Slicing, II

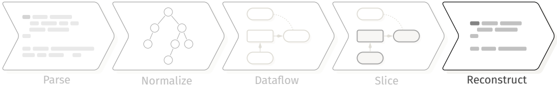


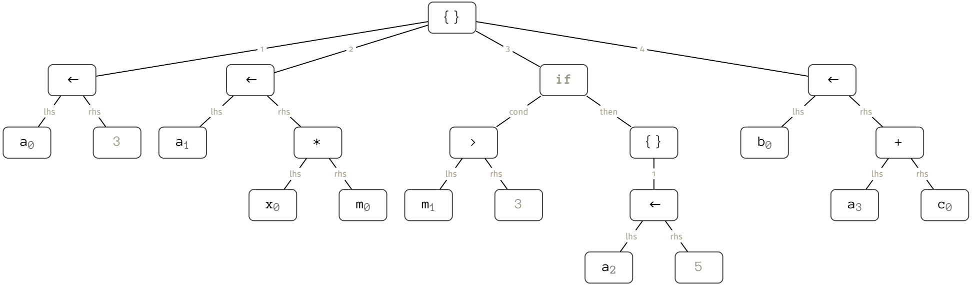
Parse
Normalize
Dataflow
Slice
Reconstruct



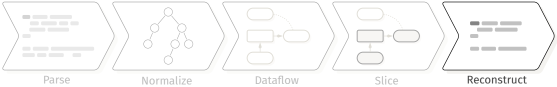
:RExpressionList
1
2
3
4
:RAssignmentOp
operator: ←
lhs
rhs
:RSymbol
a (a_0)
:RNumber
3
:RAssignmentOp
operator: ←
lhs
rhs
:RSymbol
a (a_1)
:RArithmeticBinaryOp
operator: ∗
lhs
rhs
:RSymbol
x (x_0)
:RSymbol
m (m_0)
:RIfThenElse
cond
then
:RComparisonBinaryOp
operator: >
lhs
rhs
:RSymbol
m (m_1)
:RSymbol
3
:RExpressionList
1
:RAssignmentOp
operator: ←
lhs
rhs
:RSymbol
a (a_2)
:RNumber
5
:RAssignmentOp
operator: ←
lhs
rhs
:RSymbol
b (b_0)
:RArithmeticBinaryOp
operator: +
lhs
rhs
:RSymbol
a (a_3)
:RSymbol
c (c_0)

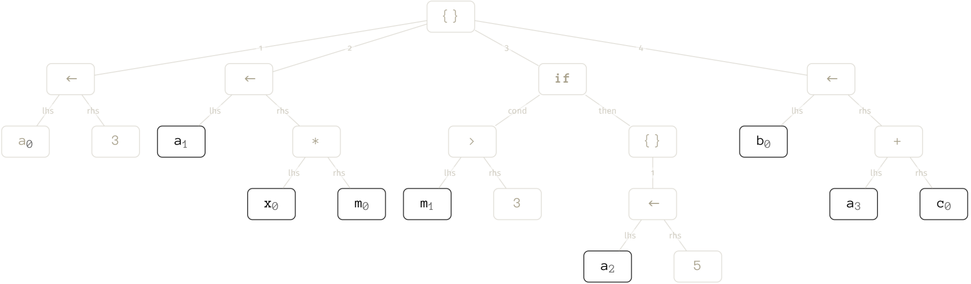
# Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct

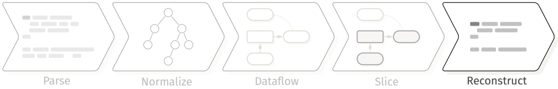

{ }
1
2
3
4
←
lhs
rhs
$a_0$
3
←
lhs
rhs
$a_1$
*
lhs
rhs
$x_0$
$m_0$
if
cond
then
>
lhs
rhs
$m_1$
3
{ }
1
←
lhs
rhs
$a_2$
5
←
lhs
rhs
$b_0$
+
lhs
rhs
$a_3$
$c_0$

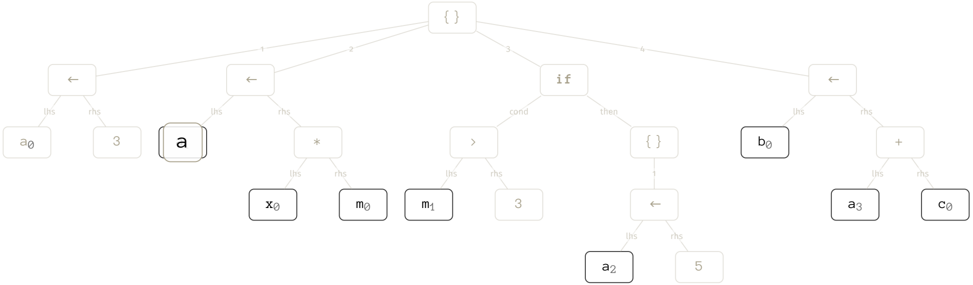
# Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct

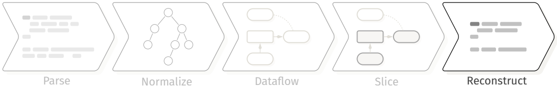

{ }
1
2
3
4
←
←
if
←
lhs
rhs
lhs
rhs
cond
then
lhs
rhs
a∅
3
a1
*
>
{ }
b∅
+
lhs
rhs
lhs
rhs
1
lhs
rhs
x∅
m∅
m1
3
←
a3
c∅
lhs
rhs
a2
5

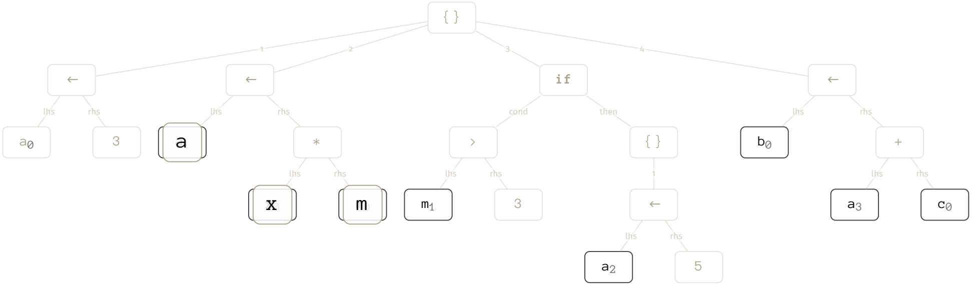
# Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct

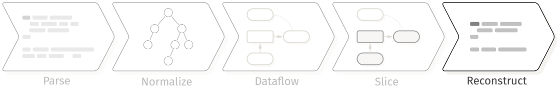

{ }
1
2
3
4
←
←
if
←
lhs
rhs
lhs
rhs
cond
then
lhs
rhs
$a_\emptyset$
3
a
*
>
{ }
$b_\emptyset$
+
lhs
rhs
lhs
rhs
1
lhs
rhs
$x_\emptyset$
$m_\emptyset$
$m_1$
3
←
$a_3$
$c_\emptyset$
lhs
rhs
$a_2$
5

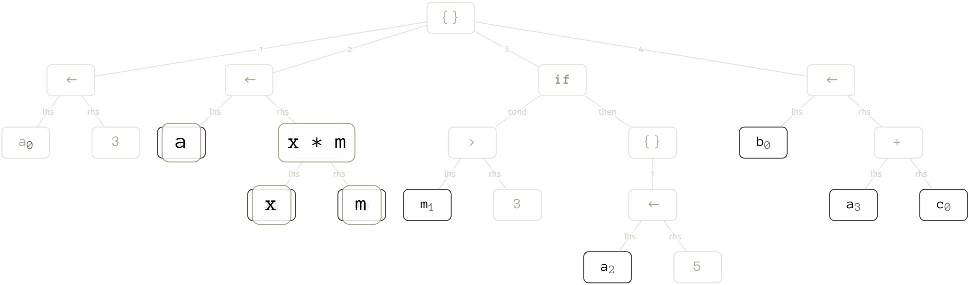
# Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct

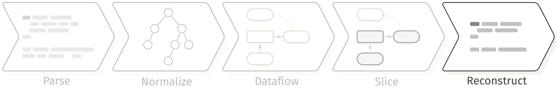

{ }
1
2
3
4
←
←
if
←
lhs
rhs
lhs
rhs
cond
then
lhs
rhs
$a_\emptyset$
3
a
*
>
{ }
$b_\emptyset$
+
lhs
rhs
lhs
rhs
1
lhs
rhs
x
m
$m_1$
3
←
$a_3$
$c_\emptyset$
lhs
rhs
$a_2$
5

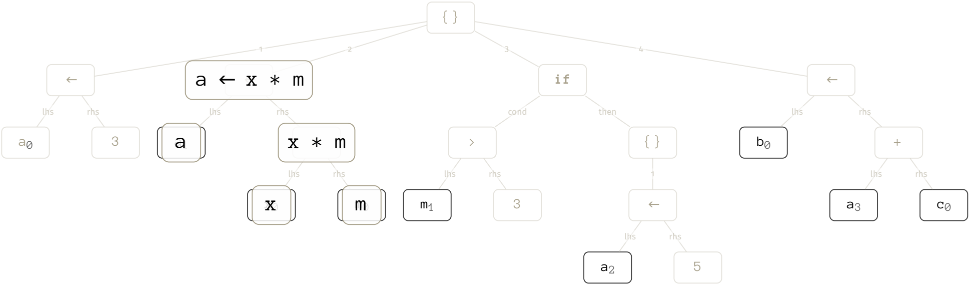
# Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct

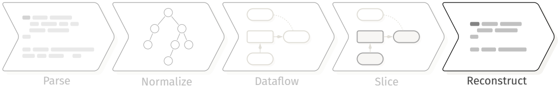

{ }
1
2
3
4
←
←
if
←
lhs
rhs
a∅
3
a
x * m
x
m
cond
then
>
m1
3
{ }
1
←
a2
5
b∅
+
a3
c∅

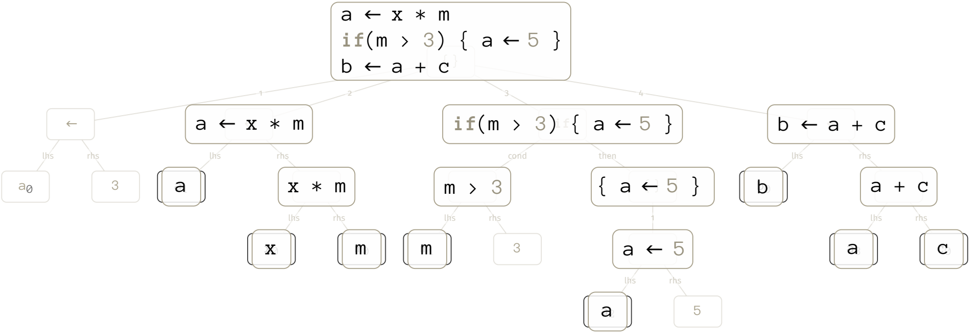
# Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct


{ }
1
2
3
4
←
a ← x * m
if
←
lhs
rhs
a∅
3
a
x * m
cond
then
>
{ }
b∅
+
x
m
m1
3
←
a3
c∅
a2
5

# Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct


a ← x * m
if(m > 3) { a ← 5 }
b ← a + c
1
2
3
4
←
lhs
rhs
a₀
3
a ← x * m
lhs
rhs
a
x * m
lhs
rhs
x
m
if(m > 3) { a ← 5 }
cond
then
m > 3
lhs
rhs
m
3
{ a ← 5 }
1
a ← 5
lhs
rhs
a
5
b ← a + c
lhs
rhs
b
a + c
lhs
rhs
a
c

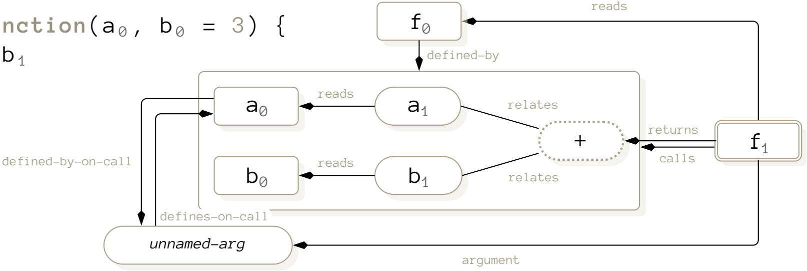
# There Is More…

# There Is More…

```
f_0 ← function(a_0, b_0 = 3) {
   a_1 + b_1
}
f_1(39)
```

# There Is More…

```
f_0 ← function(a_0, b_0 = 3) {
    a_1 + b_1
}
f_1(39)
```



# Definition-Retrieval

```
paste(
   "(*|descendant-or-self::exprlist/*)[self::FUNCTION or self::OP-LAMBDA]/
       following-sibling::SYMBOL_FORMALS[text() = '{token_quote}' and @line1 <= {
       row}]",
   "(*|descendant-or-self::exprlist/*)[LEFT_ASSIGN[preceding-sibling::expr[count
       (*)=1]/SYMBOL[text() = '{token_quote}' and @line1 <= {row}] and following-
       sibling::expr[@start > {start} or @end < {end}]]]",
   "(*|descendant-or-self::exprlist/*)[RIGHT_ASSIGN[following-sibling::expr[count
       (*)=1]/SYMBOL[text() = '{token_quote}' and @line1 <= {row}] and preceding-
       sibling::expr[@start > {start} or @end < {end}]]]",
   "(*|descendant-or-self::exprlist/*)[EQ_ASSIGN[preceding-sibling::expr[count(*)=
       1]/SYMBOL[text() = '{token_quote}' and @line1 <= {row}] and following-
       sibling::expr[@start > {start} or @end < {end}]]]",
   "forcond/SYMBOL[text() = '{token_quote}' and @line1 <= {row}]",
sep = "|")
```

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