```
1  sum ← 0
2  product ← 1
3  w ← 7
4  N ← 10
5
6  for (i in 1:(N-
7    sum ← sum +
8    product ← pr
9  }
10
11 cat("Sum:", sum
12 cat("Product:", product, "\n")
13
```

Change All Occurrences Ctrl+F2
Refactor... Ctrl+Shift+R
Open Changes
Cut Ctrl+X
Copy Ctrl+C
Paste Ctrl+V
Spelling
Run all tests in this file
Run this test
Debug this test
Command Palette... Ctrl+Shift+P
Clear Slice Presentation
Open help for selection
Slice for Cursor Position

```
1  sum ← 0
2  product ← 1
3  w ← 7
4  N ← 10
5
6  for (i in 1:(N-1)) {
7    sum ← sum + i + w
8    product ← product * i
9  }
10
11 cat("Sum:", sum, "\n")
12 cat("Product:", product, "\n")
13
```

flowR: A Program Slicer for the R Programming Language

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

The R Programming Language

- R is mainly designed for statistical computing[1]
  - Heavily used in research (e.g., social science)[2]
  - Ranks 6th on PYPL[3]
  - Over 20 000 packages on CRAN[1]
- Most users are from non-computer-science domains
- Several problems in practice[2, 4]
  - Replication
  - Program comprehension
  - Missing tool support
- Demand for software engineering practices[5]

[5] Thimbleby, "Improving Science That Uses Code" (2023, Oxford University Press)
[4] Wonsil et al., "Reproducibility as a Service" (2023, Software: Practice and Experience)
[3] https://pypl.github.io/ [archived]
[2] Trisovic et al., "A Large-Scale Study on Research Code Quality and Execution" (2022, Nature Publishing Group)
[1] https://cran.r-project.org/

R Scripts

We analyzed 4 083 R-files[7]

```
# 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)
}

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


[7] Sihler et al., "On the Anatomy of Real-World R Code for Static Analysis" (2024, MSR)
[6] Drudze et al., *Apple phenology data set and R script, related to publication "Full flowering phenology of apple tree (Malus domestica) in Pūre orchard, Latvia from 1959 to 2019"* (2021, Zenodo)

R Scripts Fail to Replicate

74 % even fail to complete![2]

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

Hardcoded Paths

```
# ----------------------------------------
# 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
{
```

```
        # 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
        }
```

(Pseudo-)Randomness without Seed

```
        # test if the phenology and meteorology data overlap at 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,
```


[2] Trisovic et al., "A Large-Scale Study on Research Code Quality and Execution" (2022, Nature Publishing Group)
[6] Drudze et al., *Apple phenology data set and R script, related to publication "Full flowering phenology of apple tree (Malus domestica) in Pūre orchard, Latvia from 1959 to 2019"* (2021, Zenodo)

R Scripts Do Too Much

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

[6] Drudze et al., *Apple phenology data set and R script, related to publication "Full flowering phenology of apple tree (Malus domestica) in Pūre orchard, Latvia from 1959 to 2019"* (2021, Zenodo)

R Scripts Are Hard to Analyze

```
[8] mod.proj_wc ← ecospat.ESM.Projection(ESM.modeling.output=mod,
        new.env=eval(parse(text = paste("env_",period,"_wc",sep=""))))
```

- String-based code evaluation

```
[9] pull.cat ← function(x) {
      bins ← up_bins # (e.g., 6)
      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)
    }
```

- Self-modifying code

[9] Robertson, *Social hierarchy reveals thermoregulatory trade- offs in response to repeated stressors* (2020, Zenodo) [L. 68ff]
[8] Ma et al., *Predicting range shifts of pikas (Mammalia, Ochotonidae) in China under scenarios incorporating land-use change, climate change, and dispersal limitations* (2021, Zenodo) [L. 135f]

R Misses Sophisticated Analysis Tools

- RStudio IDE posit.co
  - Syntax-highlighting and auto-completion
  - ~~Refactorings (rename, extract functions and variables)~~ ← Often wrong (simple heuristics)

- R language server github.com/REditorSupport
  - Syntax-highlighting and auto-completion
  - ~~Reference tracing & Refactorings (rename)~~ ← Often wrong (XPath-Expressions)

- {lintr} github.com/r-lib/lintr
  - Style & syntax errors
  - ~~Potential semantic errors~~

    ↑

    XPath-Expressions, packages

- {CodeDepends} github.com/duncantl/CodeDepends
  - ~~Dependency analysis~~ ← Only top scope
  - Creation of call-graphs

R Scripts ...

1. fail to replicate
2. **do too much**
3. are hard to analyze
4. are not well supported by tools

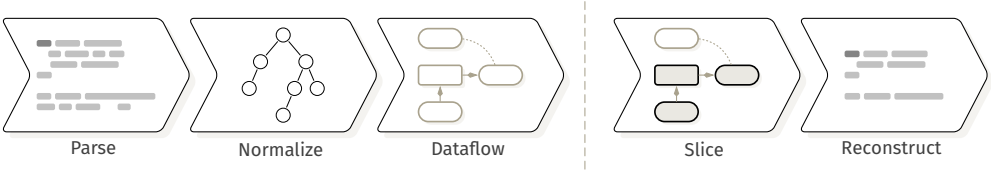
Better Software, Better Research

The Goal of flowR

- Interested in a single figure
- ≈ 70 % reduction

[6] Drudze et al., *Apple phenology data set and R script, related to publication "Full flowering phenology of apple tree (Malus domestica) in Pūre orchard, Latvia from 1959 to 2019"* (2021, Zenodo)

The Architecture

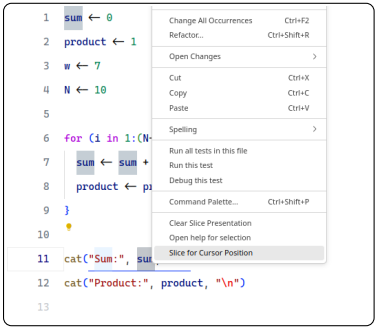


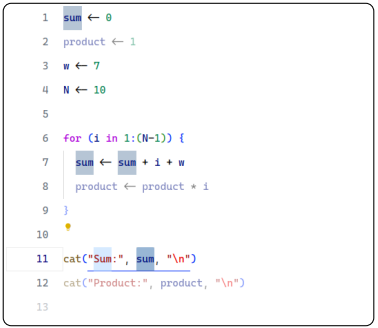
[10] Sihler, "Constructing a static program slicer for R programs" (2023, Ulm University)
[11] Weiser, "Program Slicing" (1984, IEEE Transactions on Software Engineering)

Visual Studio Code Integration

Rudimentary VSCode integration at:

github.com/Code-Inspect/vscode-flowr





Using flowR

github.com/Code-Inspect/flowr
github.com/Code-Inspect/vscode-flowr
hub.docker.com/r/eagleoutice/flowr
npmjs.com/package/@eagleoutice/flowr

Server

```
{
  "type": "request-file-analysis",
  "id":        "1",
  "filetoken": "123",
  "content":   "x←1;␣x*y"
}

{
  "type": "request-slice",
  "id":        "2",
  "filetoken": "123",
  "criterion": ["1@x"]
}
```

Library

```
const s = new SteppingSlicer({
  shell, tokenMap,
  request:
     requestFromInput("x←1; x*y"),
  criterion: ['1@x'],
})
const slice =
   await s.allRemainingSteps()
```

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...
```

```
docker run -it --rm eagleoutice/flowr
```

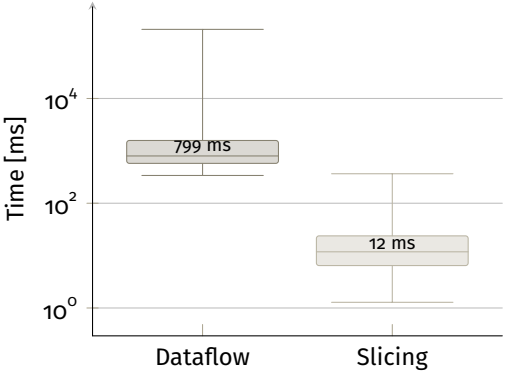
Appendix

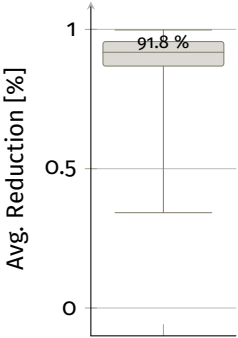
The R Code Static Analysis Landscape

	goal	method	impl. lang.	op. assignments	func. assignments	value trace(a1, ...)	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] R̃	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
- Dataflow results can be cached

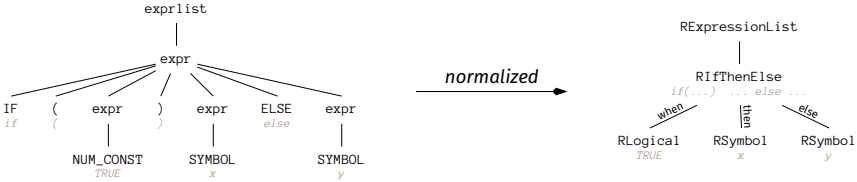




99th percentile

Parse & Normalize

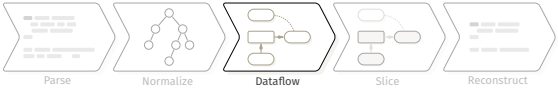

```
parse(text="if(TRUE) x else y")
```



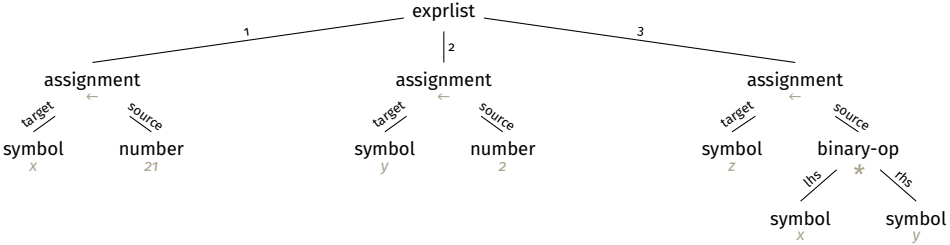
- Normalizing constants, namespacing, operators, …
- We use the "R language definition"[40] as a basis

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

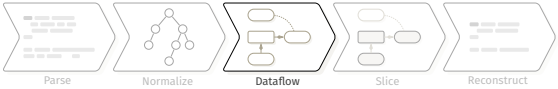
Dataflow



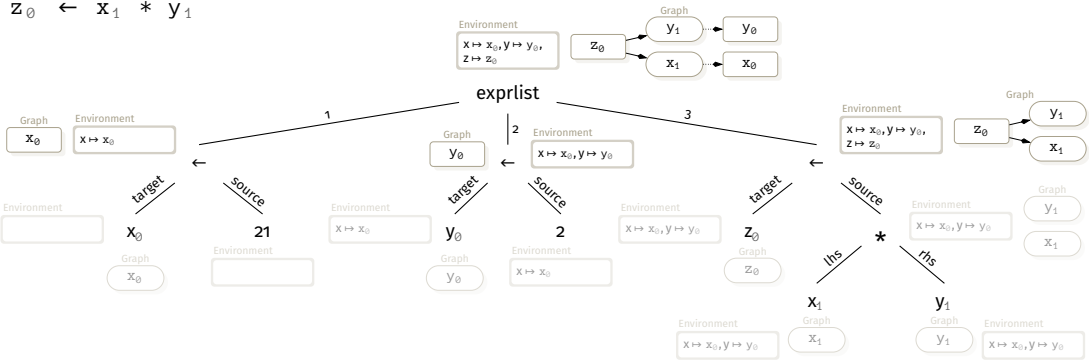
$x_0 \leftarrow 21$
$y_0 \leftarrow 2$
$z_0 \leftarrow x_1 * y_1$



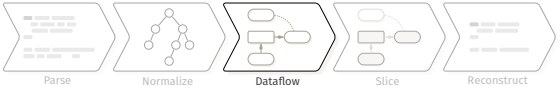
Dataflow



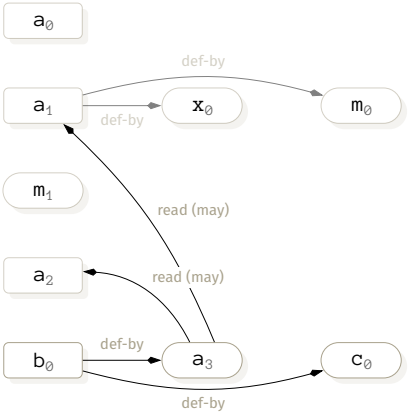
$x_0 \leftarrow 21$
$y_0 \leftarrow 2$
$z_0 \leftarrow x_1 * y_1$



Resulting Dataflow

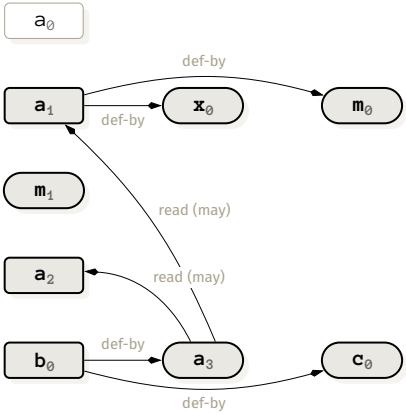



```
> a0 ← 3
  a1 ← x0 * m0

  if(m1 > 3) {
    a2 ← 5
  }

  b0 ← a3 + c0
```



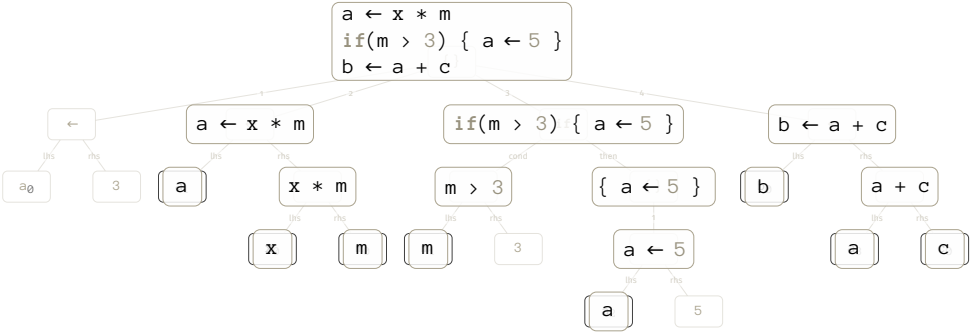
Slicing, I


```
a0 ← 3
a1 ← x0 * m0

if(m1 > 3) {
  a2 ← 5
}

b0 ← a3 + c0
```



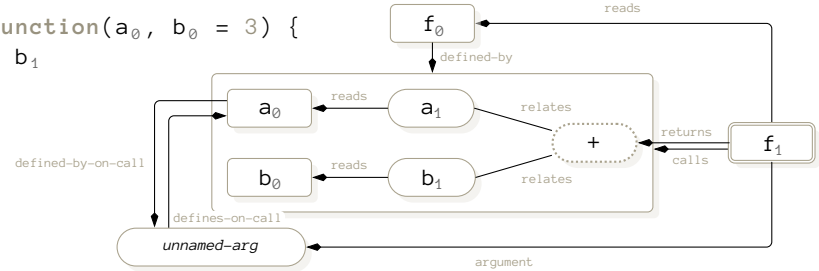
Slicing, II


Parse
Normalize
Dataflow
Slice
Reconstruct


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

There Is More…

```
f₀ ← function(a₀, b₀ = 3) {
    a₁ + b₁
}
f₁(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 = "|")
```

References I

[1] *The Comprehensive R Archive Network — cran.r-project.org*. 2024

[2] Ana Trisovic et al. “A Large-Scale Study on Research Code Quality and Execution”. 2022

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[9] Joshua Robertson. *Social hierarchy reveals thermoregulatory trade- offs in response to repeated stressors*. Oct. 2020

[10] Florian Sihler. “Constructing a static program slicer for R programs”. 2023

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[11] Mark Weiser. “Program Slicing”. July 1984

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[36] Alexander Bertram. “Renjin: A new r interpreter built on the jvm”. 2013

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[40] R Core Team. *R Language Definition*. 2023