nCompiler: generating C++ from R

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Contributors:

- Daniel Turek, Chris Paciorek, Nicholas Michaud (via contributions to nimble)
- James Duncan

useR!2019
Toulouse

https://github.com/nimble-dev/nCompiler

Outline

- History
- Goals
- Main abstractions, features and current status
- We welcome ideas and contributions.

History

- nCompiler started as an internal tool for nimble.

https://creazilla.com/nodes/1786-model-t-silhouette
https://creativecommons.org/licenses/by/4.0/

r-nimble.org

Core Team

Perry de Valpine (co-PI)

Chris Paciorek (co-PI)

Daniel Turek

Nicholas Michaud

Other contributors and collaborators:

- Duncan Temple Lang
- Jagadish Babu
- Ras Bodik
- Clifford Anderson-Bergman
- David Pleydell
- Lauren Ponisio
- Dao Nguyen
- Abel Rodriguez
- Claudia Wehrhan
- Fritz Obermeyer
- Sally Paganin

Numerical
Inference for statistical
Models using
Bayesian and
Likelihood
Estimation

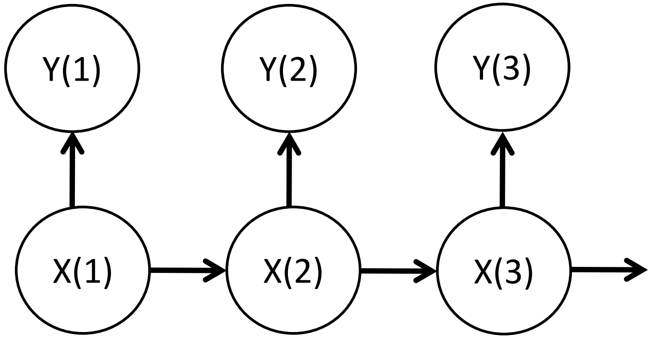
Funded in part by:

NSF

BERKELEY Institute for Data Science

What is NIMBLE?

Statistical model language:
New dialect of BUGS/JAGS.



+

Algorithm language
embedded in R

“nimble compiler”:
Generates C++ for each model and algorithm (e.g. MCMC)

De Valpine et al. 2017. Programming with Models: Writing Statistical Algorithms for General Model Structures with NIMBLE. Journal of Computational and Graphical Statistics. https://doi.org/10.1080/10618600.2016.1172487

History

- nCompiler started as an internal tool for nimble.
- The “nimble compiler” works pretty well!
- Maybe it could be a more general tool:
  - Gain C++ speed-ups without coding C++ directly.
  - Automatically get derivatives, parallelization, and serialization.
- It has some design limitations and concepts particular to nimble.
- nCompiler is a complete re-write with heavy borrowing from nimble.

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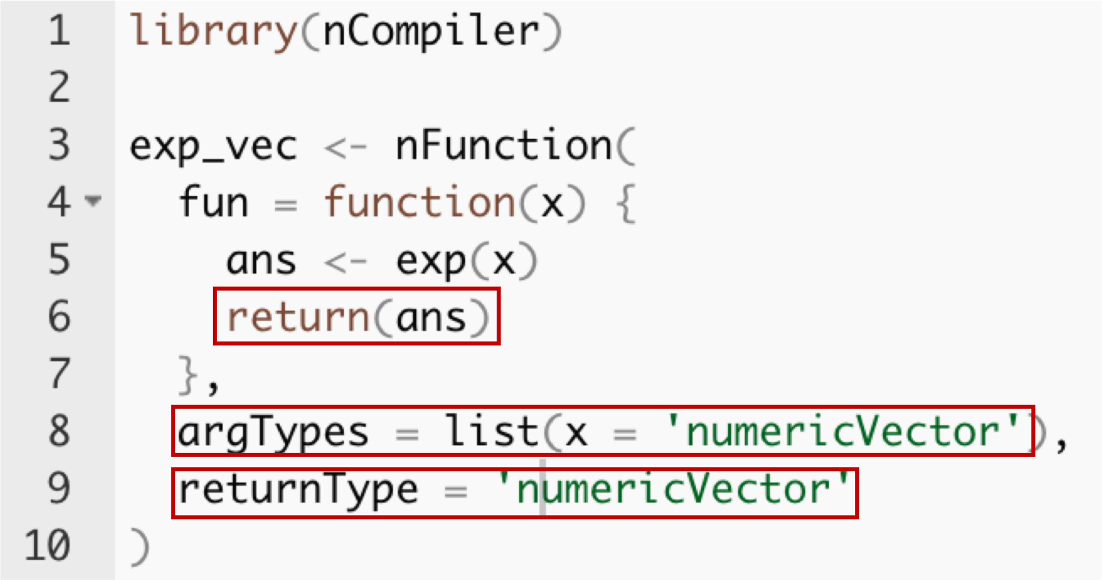
nFunction

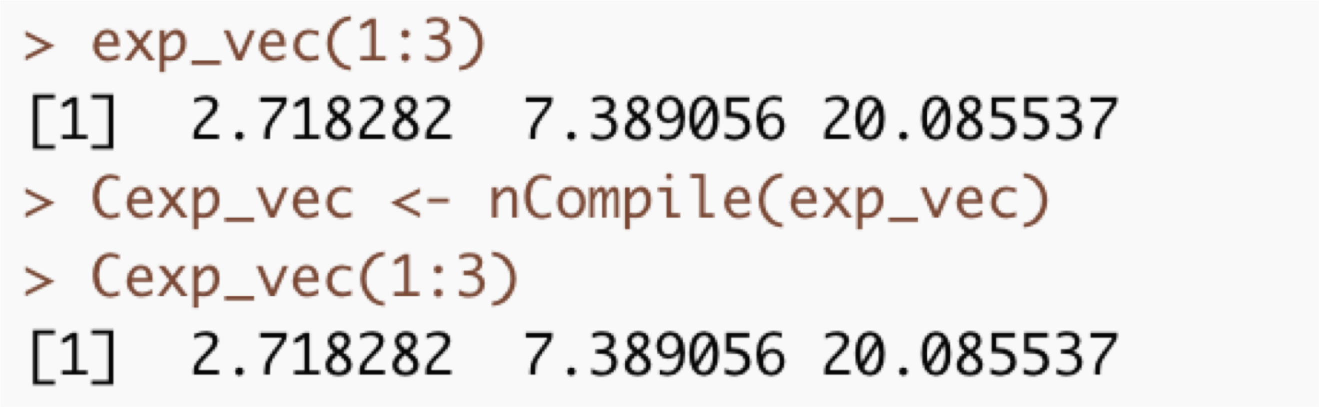


```
library(nCompiler)

exp_vec <- nFunction(
  fun = function(x) {
    ans <- exp(x)
    return(ans)
  },
  argTypes = list(x = 'numericVector'),
  returnType = 'numericVector'
)
```

explicit “return”

Argument and return type-declarations.



```
> exp_vec(1:3)
[1]  2.718282  7.389056 20.085537
> Cexp_vec <- nCompile(exp_vec)
> Cexp_vec(1:3)
[1]  2.718282  7.389056 20.085537
```

Everything runs uncompiled and compiled.

Goals

Keep what worked well:

- Code generation from R mathematical and distribution functions
- Automatic type determination based on declared inputs
- Coding embedded in R via new types of “function” and “class”
- Linear algebra via Eigen
- Algorithmic differentiation (AD) via CppAD (not released)
- Calls to external libraries or to R
- Basic flow control

Goals

Keep what worked well:

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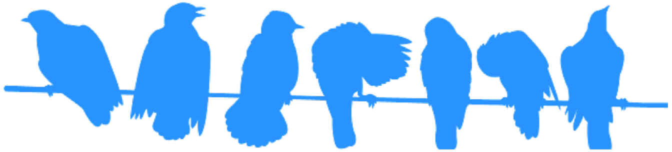
What to add or change:

- Clarify key abstractions: nFunction, nClass.
- Use Eigen more deeply and Eigen::Tensor for math with arbitrary arrays
- Ground-up support for:
  - Parallelization (Threading Building Blocks)
  - Serialization (saving and loading C++ objects) (Cereal).
  - Use in package development
- Easier integration with hand-written C++
- Better use/integration/compatibility with other tools (Rcpp family).
- Extensibility and developer tools



https://creazilla.com/nodes/2875-birds-on-a-wire-silhouette?tag_id=9
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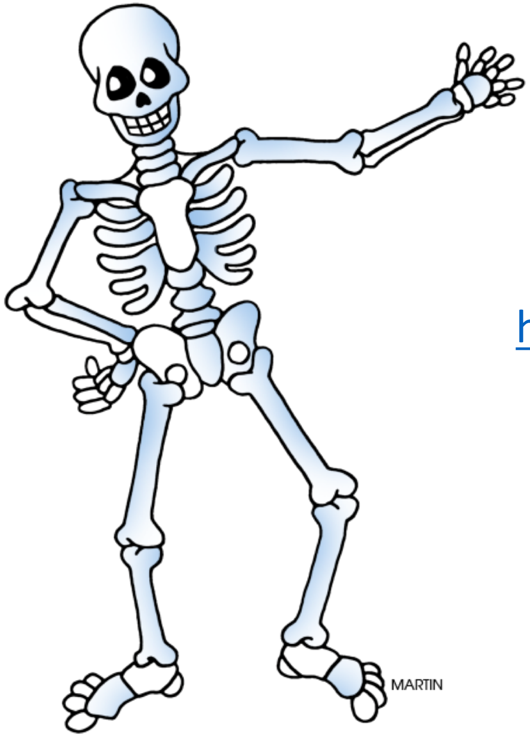
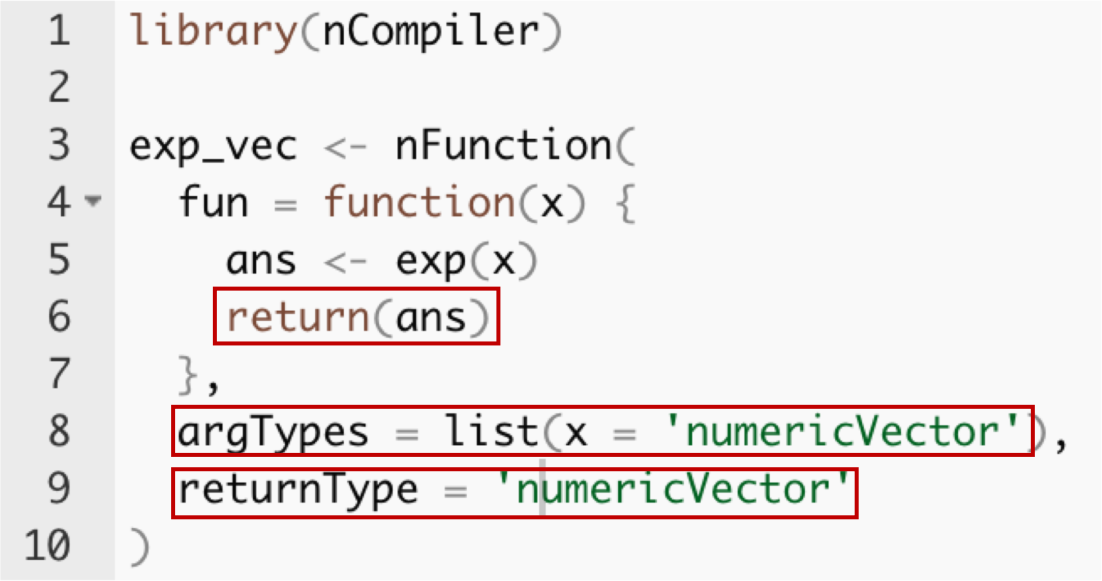
Current status: A working skeleton of all major components.



https://clipartimage.com/images/clipart-286921.html

https://github.com/nimble-dev/nCompiler

nFunction

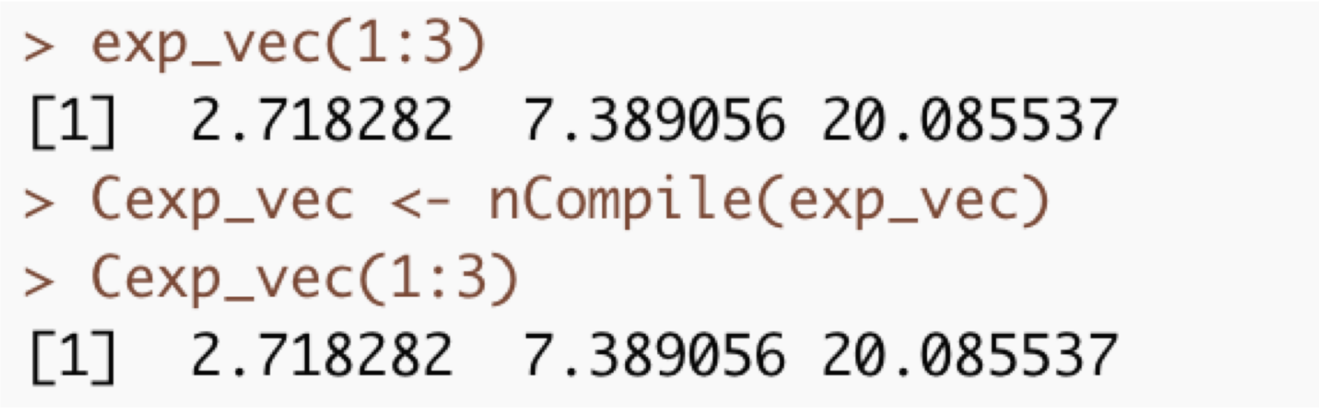


```
library(nCompiler)

exp_vec <- nFunction(
  fun = function(x) {
    ans <- exp(x)
    return(ans)
  },
  argTypes = list(x = 'numericVector'),
  returnType = 'numericVector'
)
```

explicit “return”

Argument and return type-declarations.



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> exp_vec(1:3)
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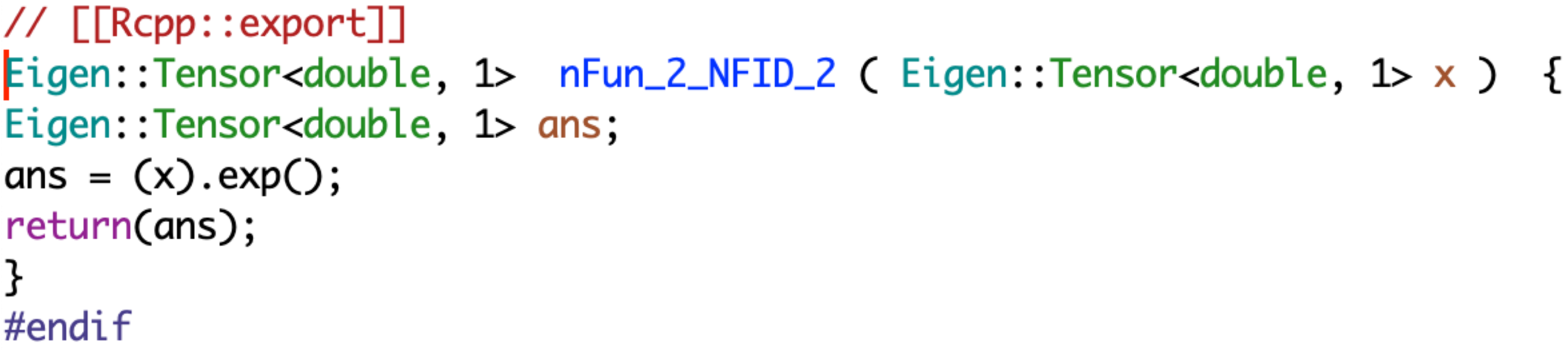
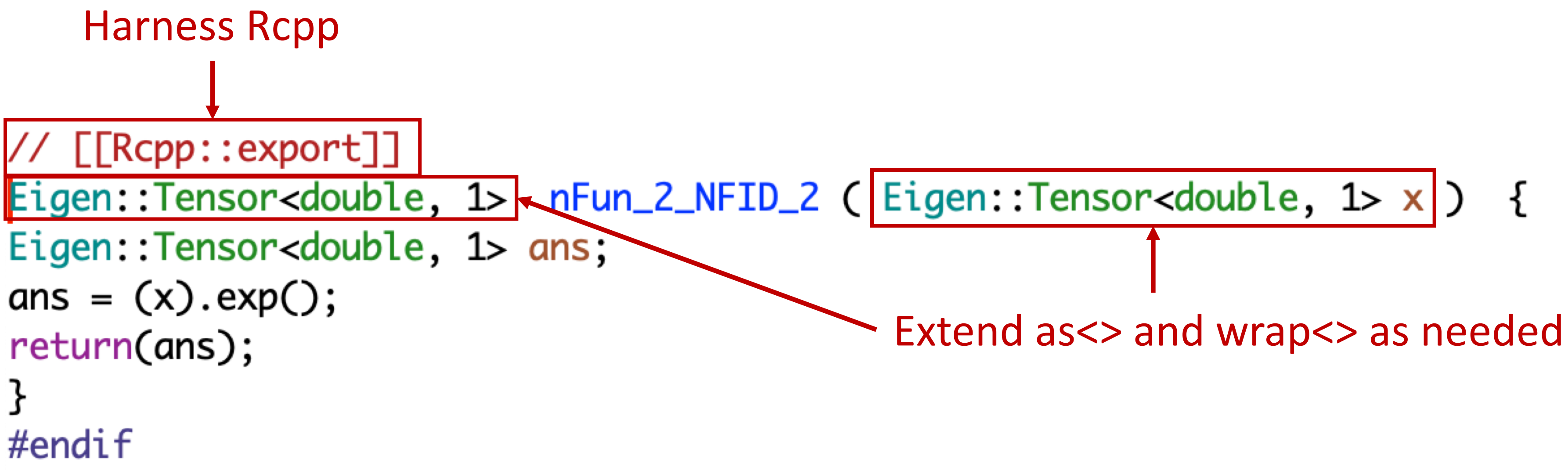
Everything runs uncompiled and compiled.



```
// [[Rcpp::export]]
Eigen::Tensor<double, 1>  nFun_2_NFID_2 ( Eigen::Tensor<double, 1> x )  {
Eigen::Tensor<double, 1> ans;
ans = (x).exp();
return(ans);
}
#endif
```



Harness Rcpp

```
// [[Rcpp::export]]
Eigen::Tensor<double, 1> nFun_2_NFID_2 ( Eigen::Tensor<double, 1> x ) {
Eigen::Tensor<double, 1> ans;
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return(ans);
}
#endif
```
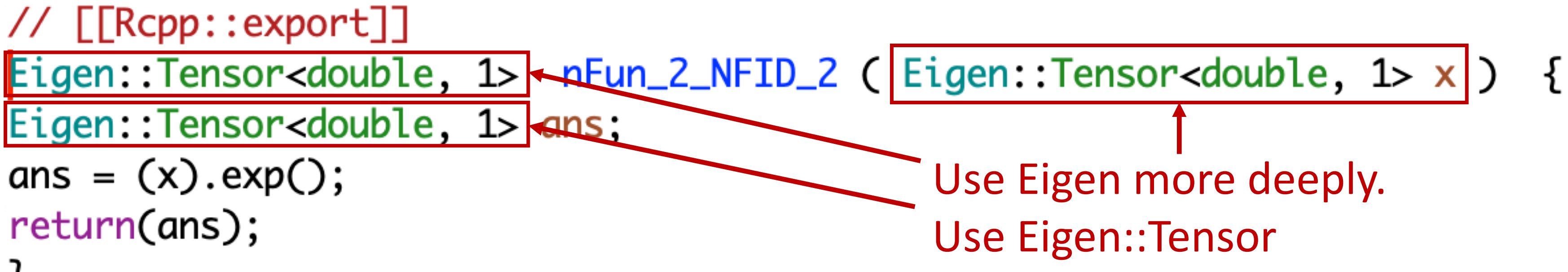

Extend as<> and wrap<> as needed



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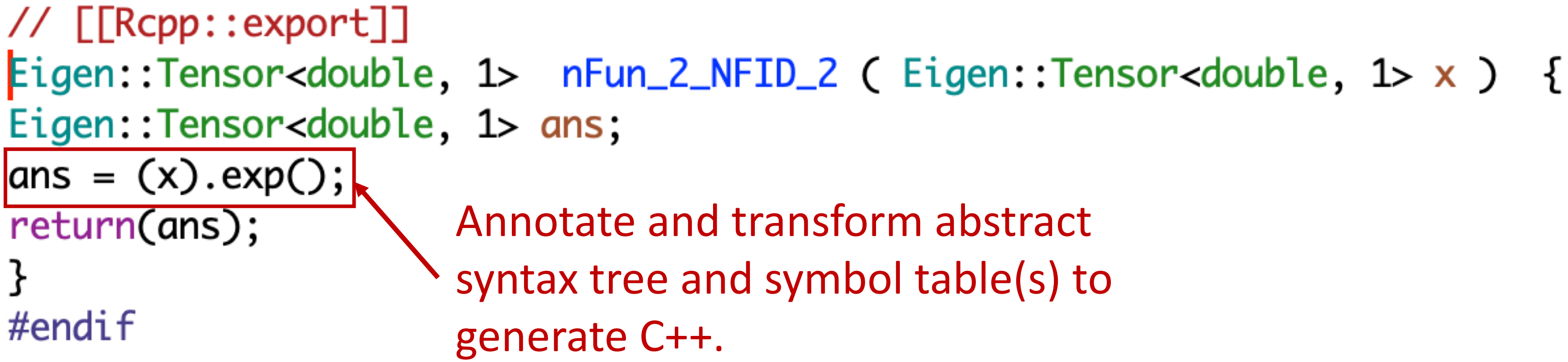
return(ans);
}
#endif
```

Use Eigen more deeply.

Use Eigen::Tensor

http://eigen.tuxfamily.org



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Eigen::Tensor<double, 1> ans;
ans = (x).exp();
return(ans);
}
#endif
```
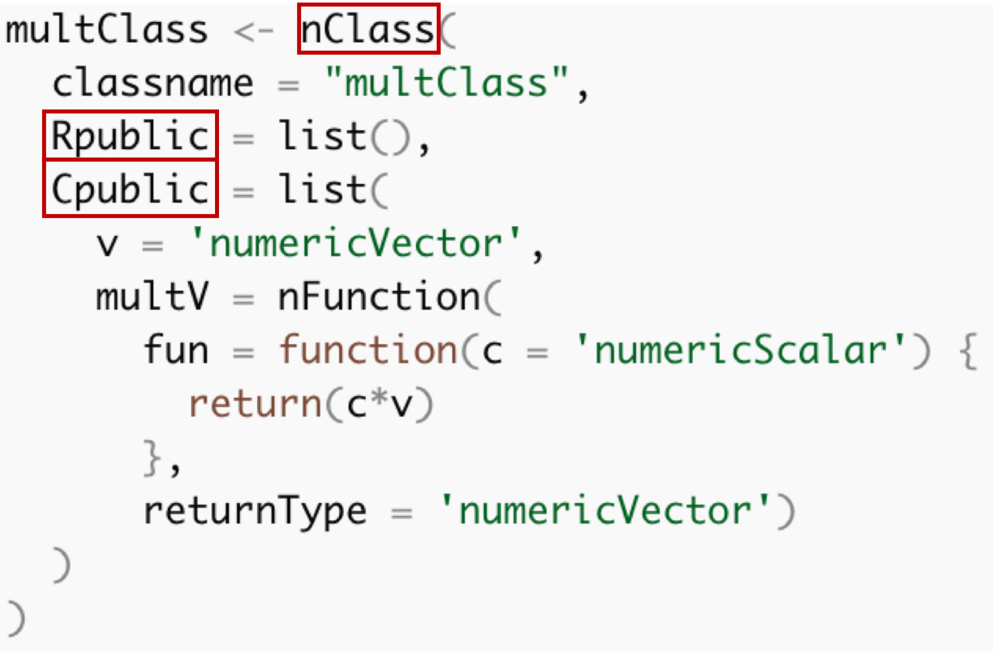
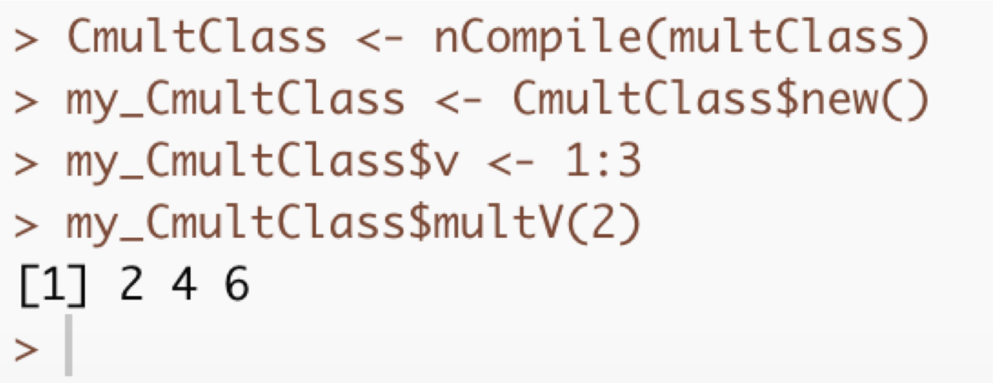

Annotate and transform abstract syntax tree and symbol table(s) to generate C++.

nClass



```
multClass <- nClass(
  classname = "multClass",
  Rpublic = list(),
  Cpublic = list(
    v = 'numericVector',
    multV = nFunction(
      fun = function(c = 'numericScalar') {
        return(c*v)
      },
      returnType = 'numericVector')
  )
)
```



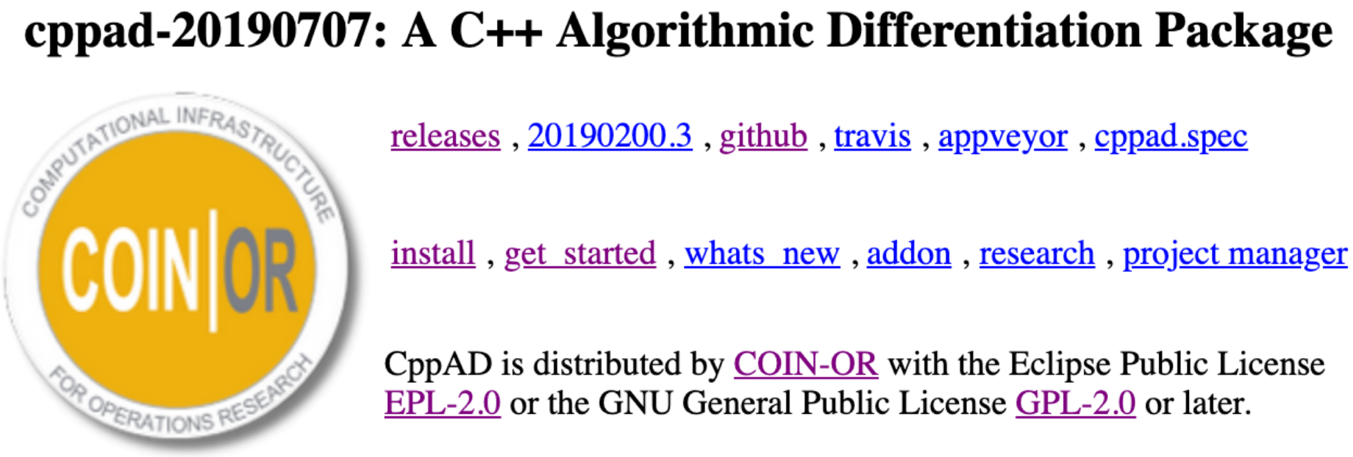
```
> CmultClass <- nCompile(multClass)
> my_CmultClass <- CmultClass$new()
> my_CmultClass$v <- 1:3
> my_CmultClass$multV(2)
[1] 2 4 6
> 
```

nClass generates a custom R6 class.

Rpublic implemented in R.

Cpublic implemented in C++.

AD: Algorithmic (or Automatic) Derivatives



cppad-20190707: A C++ Algorithmic Differentiation Package

releases , 20190200.3 , github , travis , appveyor , cppad.spec

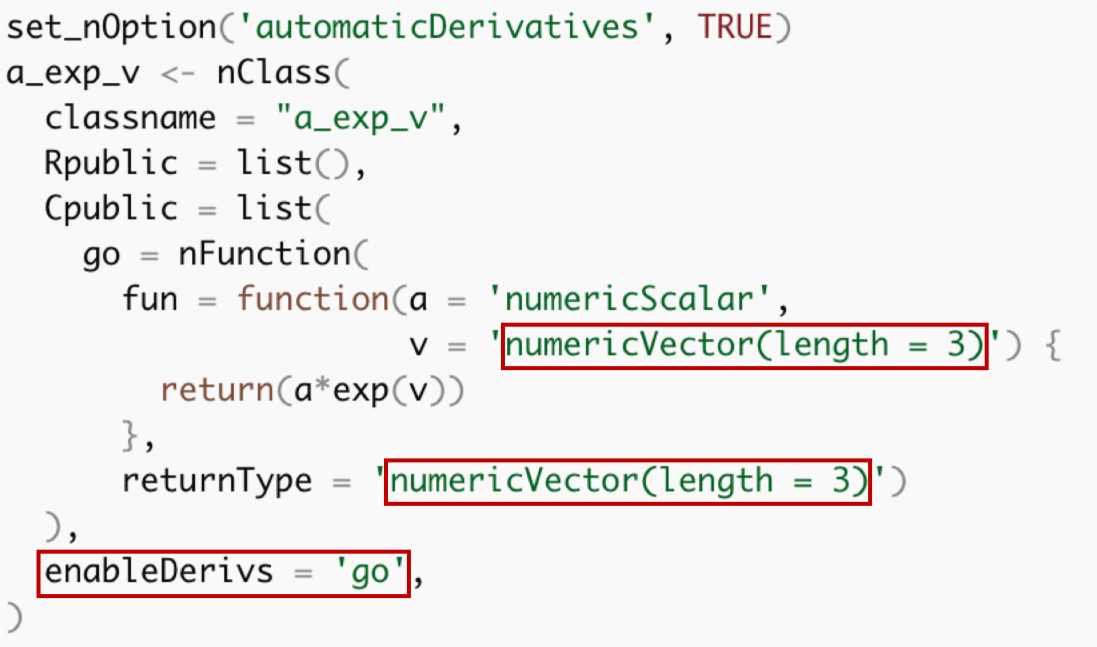
install , get_started , whats_new , addon , research , project manager

CppAD is distributed by COIN-OR with the Eclipse Public License EPL-2.0 or the GNU General Public License GPL-2.0 or later.

Also used by

- TMB (Kristensen, Bell, Skaug, Magnusson, Berg, Nielsen, Maechler, Michelot, Brooks, Forrence, Albertsen, & Monnahan). On CRAN.
- RcppEigenAD (Berridge, Crouchley & Grose). On CRAN.

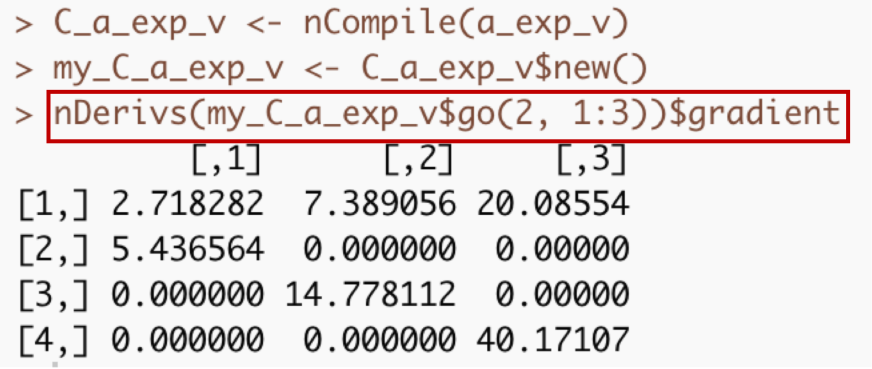
AD: Algorithmic (or Automatic) Derivatives



```r
set_nOption('automaticDerivatives', TRUE)
a_exp_v <- nClass(
  classname = "a_exp_v",
  Rpublic = list(),
  Cpublic = list(
    go = nFunction(
      fun = function(a = 'numericScalar',
                     v = 'numericVector(length = 3)') {
        return(a*exp(v))
      },
      returnType = 'numericVector(length = 3)')
  ),
  enableDerivs = 'go',
)
```

Fixed-length inputs and output

enableDerivs argument

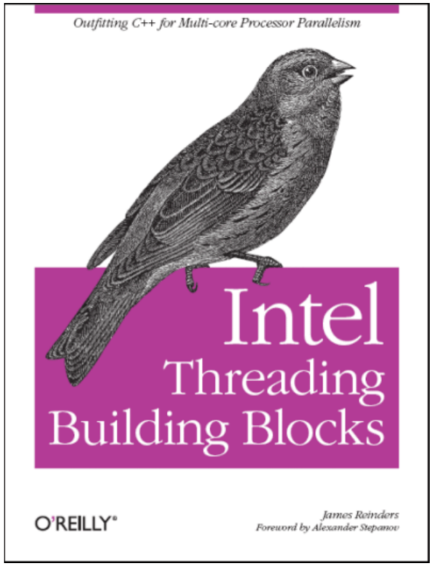


```
> C_a_exp_v <- nCompile(a_exp_v)
> my_C_a_exp_v <- C_a_exp_v$new()
> nDerivs(my_C_a_exp_v$go(2, 1:3))$gradient
         [,1]      [,2]     [,3]
[1,] 2.718282  7.389056 20.08554
[2,] 5.436564  0.000000  0.00000
[3,] 0.000000 14.778112  0.00000
[4,] 0.000000  0.000000 40.17107
```

Call via nDerivs

Jacobian:

Parallelization

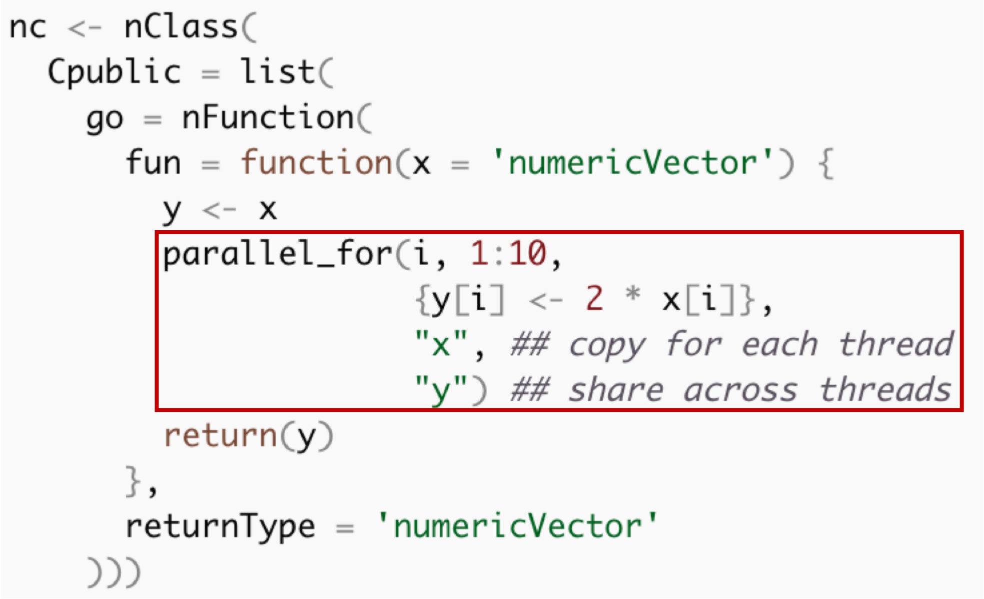

Outfitting C++ for Multi-core Processor Parallelism
Intel
Threading
Building Blocks
O'REILLY
James Reinders
Foreword by Alexander Stepanov

Also used by

RcppParallel

Allaire, Francois, Ushey, Vandenbrouck, Geelnard, RStudio, Intel, Microsoft
(On CRAN)

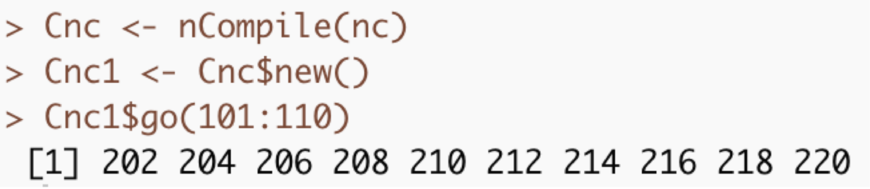
Parallelization



```r
nc <- nClass(
  Cpublic = list(
    go = nFunction(
      fun = function(x = 'numericVector') {
        y <- x
        parallel_for(i, 1:10,
                     {y[i] <- 2 * x[i]},
                     "x", ## copy for each thread
                     "y") ## share across threads
        return(y)
      },
      returnType = 'numericVector'
    )))
```

parallel_for (final syntax TBD)

Variables to copy or share across threads.

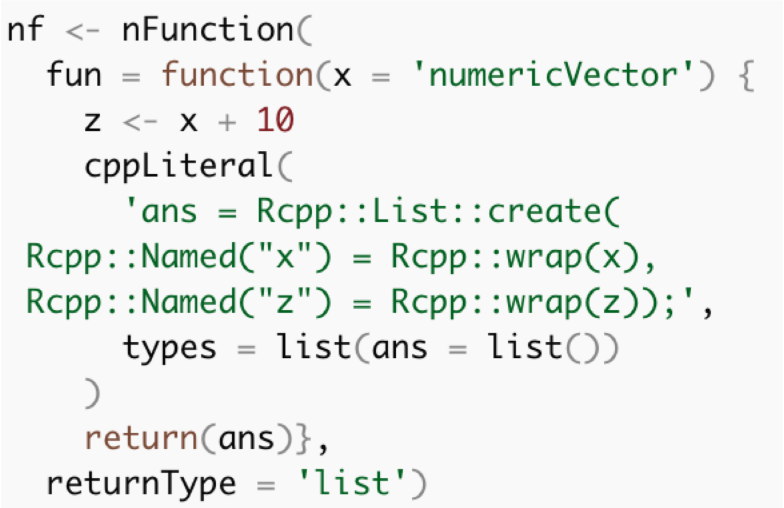


```
> Cnc <- nCompile(nc)
> Cnc1 <- Cnc$new()
> Cnc1$go(101:110)
 [1] 202 204 206 208 210 212 214 216 218 220
```

Argument passing

- By copy
- By reference
- By block reference

Mixing with other C++



```
nf <- nFunction(
  fun = function(x = 'numericVector') {
    z <- x + 10
    cppLiteral(
      'ans = Rcpp::List::create(
 Rcpp::Named("x") = Rcpp::wrap(x),
 Rcpp::Named("z") = Rcpp::wrap(z));',
      types = list(ans = list())
    )
    return(ans)},
  returnType = 'list')
```

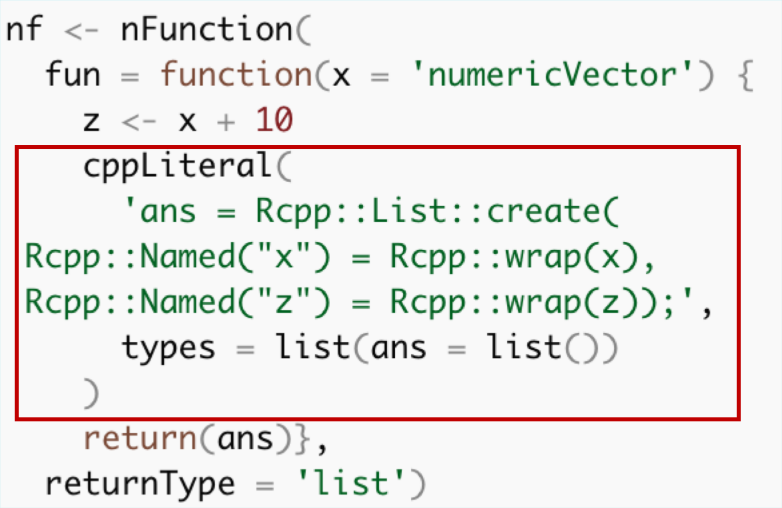
Using nCompiler code in packages

- Generate necessary R and C++ into package src and inst directories.

Argument passing

- By copy
- By reference
- By block reference

Mixing with other C++



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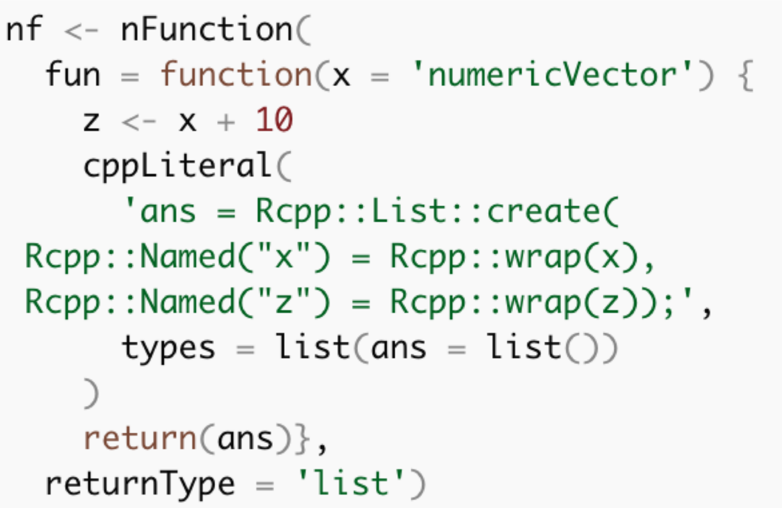

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      types = list(ans = list())
    )
    return(ans)},
  returnType = 'list')
```

Using nCompiler code in packages

- Generate necessary R and C++ into package src and inst directories.

Serialization for saving and loading compiled objects.

https://github.com/USCiLab/cereal

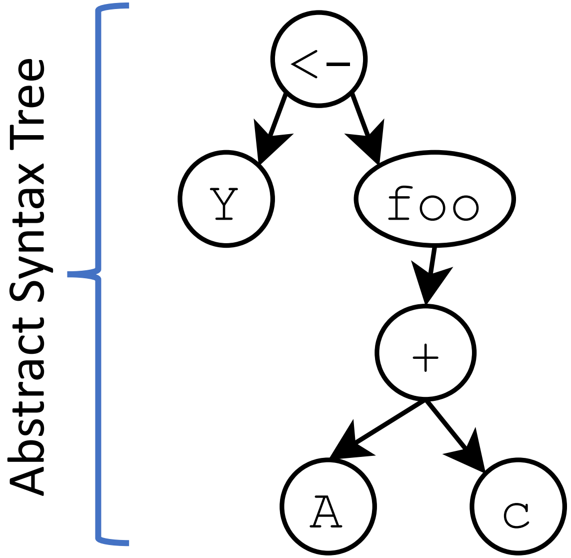
Also provided by

- Rcereal (Wu, Voorhees and Grant). On CRAN.

nCompiler generates Cereal code into nClass C++ code.

Extensibility

```
Y <- foo(A + c)
```



Compilation = clearly defined traversals and transformations of the tree.

Extensibility

```
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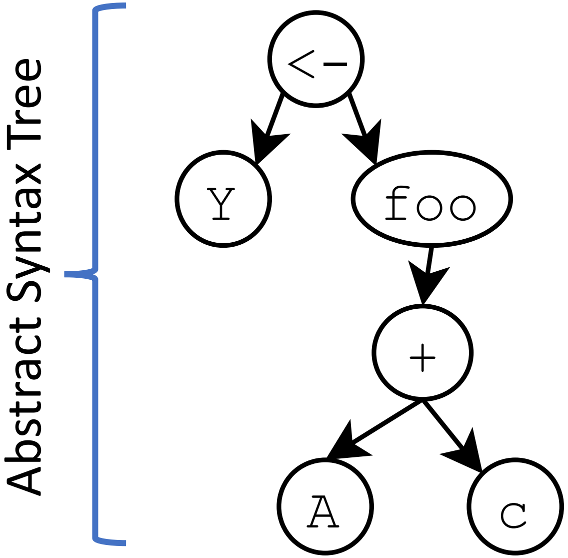
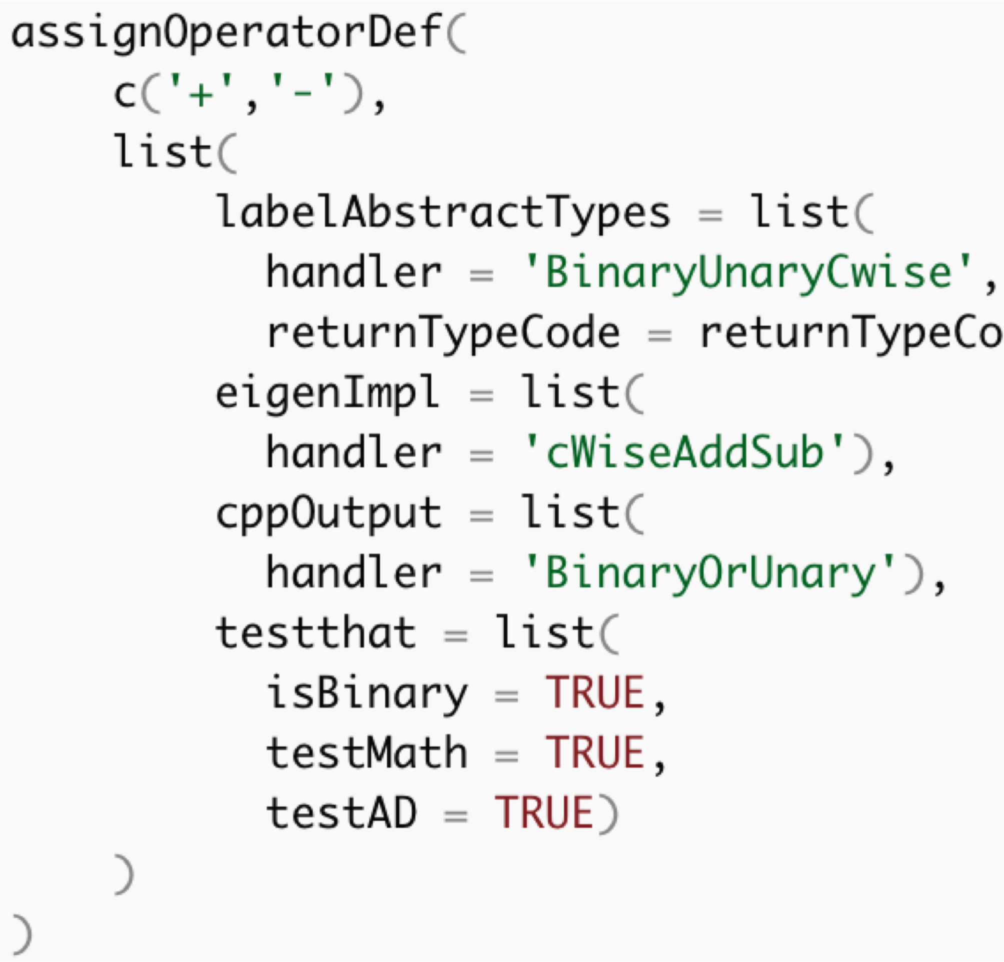
```



Compilation = clearly defined traversals and transformations of the tree.

How to handle `<-`, `foo`, or `+`?



```
assignOperatorDef(
    c('+','-'),
    list(
        labelAbstractTypes = list(
          handler = 'BinaryUnaryCwise',
          returnTypeCode = returnTypeCo
        eigenImpl = list(
          handler = 'cWiseAddSub'),
        cppOutput = list(
          handler = 'BinaryOrUnary'),
        testthat = list(
          isBinary = TRUE,
          testMath = TRUE,
          testAD = TRUE)
    )
)
```

Questions?

https://github.com/nimble-dev/nCompiler