LabMate: Supporting Types for Matlab

Conor McBride[1], Georgi Nakov[1], Fredrik Nordvall Forsberg[1], André Videla[1], Alistair Forbes[2], Keith Lines[2]

[1]University of Strathclyde, UK
[2]National Physical Laboratory, UK

IMEKO 2024 XXIV World Congress
August 27, 2024

The Problem

- Much science and engineering software is written in MATLAB.
  - May contain errors and bugs, as with any software.

The Problem

- Much science and engineering software is written in MATLAB.
  - May contain errors and bugs, as with any software.
- Developers often leave comments about how their data should be interpreted, e.g., units of measure for quantities.

The Problem

- Much science and engineering software is written in MATLAB.
  - May contain errors and bugs, as with any software.
- Developers often leave comments about how their data should be interpreted, e.g., units of measure for quantities.
- However MATLAB is oblivious to these high-level comments, and instead performs low-level checks during execution.

Our Plan

Can we do better?

- Make these developer comments formal.

Our Plan

Can we do better?

- Make these developer comments formal.
- . . . and create a tool to make use of them — LabMate.
  - Keep existing MATLAB code and toolchains; no need to switch to a new language.

Our Plan

Can we do better?

- Make these developer comments formal.
- . . . and create a tool to make use of them — LabMate.
  - Keep existing MATLAB code and toolchains; no need to switch to a new language.
- Distill the essence of the developer comments in LabMate's expressive type system.
  - A set of logical rules that assign domains of admissible values to program expressions.

Our Plan

Can we do better?

- Make these developer comments formal.
- . . . and create a tool to make use of them — LabMate.
  - Keep existing MATLAB code and toolchains; no need to switch to a new language.
- Distill the essence of the developer comments in LabMate's expressive type system.
  - A set of logical rules that assign domains of admissible values to program expressions.
- LabMate is meant to be used while writing the code to get instant feedback and guidance — do not delay until execution.

How does LabMate Work?

- LabMate is a program transducer: reads Matlab code with formal comments, and outputs a modified version of the input.

How does LabMate Work?

- LabMate is a program transducer: reads Matlab code with formal comments, and outputs a modified version of the input.
- These formal comments are directives — they start with %<.

How does LabMate Work?

- LabMate is a program transducer: reads Matlab code with formal comments, and outputs a modified version of the input.
- These formal comments are directives — they start with %<.
- Input the program:

```
%> rename n x
n = 5;
display(n);
```

How does LabMate Work?

- LabMate is a program transducer: reads Matlab code with formal comments, and outputs a modified version of the input.
- These formal comments are directives — they start with %<.
- Input the program:

```
%> rename n x
n = 5;
display(n);
```

this is an input directive to rename a variable

How does LabMate Work?

- LabMate is a program transducer: reads Matlab code with formal comments, and outputs a modified version of the input.
- These formal comments are directives — they start with %<.
- Input the program:

```
%> rename n x
n = 5;
display(n);
```

- Run LabMate to get:

```
%< LabMate 0.2.0.1
%< renamed n x
x = 5;
display(x);
```

How does LabMate Work?

- LabMate is a program transducer: reads Matlab code with formal comments, and outputs a modified version of the input.
- These formal comments are directives — they start with %<.
- Input the program:

```
%> rename n x
n = 5;
display(n);
```

- Run LabMate to get:

```
%< LabMate 0.2.0.1
%< renamed n x
x = 5;
display(x);
```

LabMate response to the input directive

How does LabMate Work?

- LabMate is a program transducer: reads Matlab code with formal comments, and outputs a modified version of the input.
- These formal comments are directives — they start with %<.
- Input the program:

```
%> rename n x
n = 5;
display(n);
```

- Run LabMate to get:

```
%< LabMate 0.2.0.1
%< renamed n x
x = 5;
display(x);
```

Mark the file as processed by LabMate

Matrix Types

- Matrices feature heavily in MATLAB code.

Matrix Types

- Matrices feature heavily in MATLAB code.
- LABMATE supports type annotations for matrices:

```
%> A :: [ 1 x 2 ] int
A = [ 3 4 ]
%> B :: [ 2 x 4 ] int
B = [ 1 1 1 1
      5 6 7 8 ]
C = A * B
```

Matrix Types

- Matrices feature heavily in MATLAB code.
- LABMATE supports type annotations for matrices:

```
%> A :: [ 1 x 2 ] int
A = [ 3 4 ]
%> B :: [ 2 x 4 ] int
B = [ 1 1 1 1
      5 6 7 8 ]
C = A * B
```

type annotations
at declaration of A

Matrix Types

- Matrices feature heavily in MATLAB code.
- LABMATE supports type annotations for matrices:

```
%> A :: [ 1 x 2 ] int
A = [ 3 4 ]
%> B :: [ 2 x 4 ] int
B = [ 1 1 1 1
      5 6 7 8 ]
C = A * B
```

type annotations
at declaration of B

Matrix Types

- Matrices feature heavily in MATLAB code.
- LABMATE supports type annotations for matrices:

```
%> A :: [ 1 x 2 ] int
A = [ 3 4 ]
%> B :: [ 2 x 4 ] int
B = [ 1 1 1 1
      5 6 7 8 ]
C = A * B
```

- We can ask for type information:

```
%> typeof C
%< C :: [Matrix 1 4 int]
```

Matrix Types

- Matrices feature heavily in MATLAB code.
- LABMATE supports type annotations for matrices:

```
%> A :: [ 1 x 2 ] int
A = [ 3 4 ]
%> B :: [ 2 x 4 ] int
B = [ 1 1 1 1
      5 6 7 8 ]
C = A * B
```

- We can ask for type information:

```
%> typeof C
%< C :: [Matrix 1 4 int]
```

query for the type of C

Matrix Types

- Matrices feature heavily in MATLAB code.
- LABMATE supports type annotations for matrices:

```
%> A :: [ 1 x 2 ] int
A = [ 3 4 ]
%> B :: [ 2 x 4 ] int
B = [ 1 1 1 1
      5 6 7 8 ]
C = A * B
```

- We can ask for type information:

```
%> typeof C
%< C :: [Matrix 1 4 int]
```

LabMate can infer the dimensions

Matrix Types

- Matrices feature heavily in MATLAB code.
- LABMATE supports type annotations for matrices:

```
%> A :: [ 1 x 2 ] int
A = [ 3 4 ]
%> B :: [ 2 x 4 ] int
B = [ 1 1 1 1
      5 6 7 8 ]
C = A * B
```

- We can ask for type information:

```
%> typeof C
%< C :: [Matrix 1 4 int]
```

- . . . and can easily spot incompatible sizing:

```
D = B * A
%> typeof D
%< The expression D is quite a puzzle
```

Matrix Types

- Matrices feature heavily in MATLAB code.
- LABMATE supports type annotations for matrices:

```
%> A :: [ 1 x 2 ] int
A = [ 3 4 ]
%> B :: [ 2 x 4 ] int
B = [ 1 1 1 1
      5 6 7 8 ]
C = A * B
```

- We can ask for type information:

```
%> typeof C
%< C :: [Matrix 1 4 int]
```

- . . . and can easily spot incompatible sizing:

```
D = B * A
%> typeof D
%< The expression D is quite a puzzle
```

LabMate can point out an error with D

Matrix Types

- LabMate processes arbitrary Matlab code.
  - LabMate does not rely on constants, variables work as well.

Matrix Types

- LabMate processes arbitrary Matlab code.
  - LabMate does not rely on constants, variables work as well.

```
function B = f(A)
  %> B :: [ 1 x 3 ] int
  B = [ 1 A ]

  %> typeof A
  %< A :: [Matrix 1 2 int]
end

A = 'hello'
%> typeof A
%< A :: string
```

Matrix Types

- LabMate processes arbitrary Matlab code.
  - LabMate does not rely on constants, variables work as well.

```
function B = f(A)
  %> B :: [ 1 x 3 ] int
  B = [ 1 A ]

  %> typeof A
  %< A :: [Matrix 1 2 int]
end

A = 'hello'
%> typeof A
%< A :: string
```

LabMate infers type of A from the annotation on B

Matrix Types

- LabMate processes arbitrary Matlab code.
  - LabMate does not rely on constants, variables work as well.

```
function B = f(A)
  %> B :: [ 1 x 3 ] int
  B = [ 1 A ]

  %> typeof A
  %< A :: [Matrix 1 2 int]
end

A = 'hello'
%> typeof A
%< A :: string
```

distinguishes and tracks Matlab scope

Dimensions and Quantities

- LabMate has support for arbitrary quantities.

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })
```

Dimensions and Quantities

- LabMate has support for arbitrary quantities

define some base set of dimensions

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })
```

Dimensions and Quantities

- LabMate has support for arbitrary quantities

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })
```

and a canonical unit of measure

Dimensions and Quantities

- LabMate has support for arbitrary quantities.

can be arbitrary group expression over V

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })
```

Dimensions and Quantities

- LabMate has support for arbitrary quantities.

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })
```

Dimensions and Quantities

- LabMate has support for arbitrary quantities.

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })

%<{
kg = 1;
%<}
```

Dimensions and Quantities

- LabMate has support for arbitrary quantities.

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })

%<{
kg = 1;
%<}
```

this is a “magic” response that LabMate emits

Dimensions and Quantities

- LabMate has support for arbitrary quantities.

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })

%<{
kg = 1;
%<}
```

Dimensions and Quantities

- LabMate has support for arbitrary quantities.

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })

%<{
kg = 1;
%<}
```

- We can then use the unit of measure for quantities:

```
y = 5*kg
%> typeof y
%< y :: Quantity (Enum [`Mass, `Time])
%<                    {`Mass}
```

Dimensions and Quantities

- LabMate has support for arbitrary quantities.

```
%> dimensions V for Q over `Mass, `Time
%> unit kg :: Q({ `Mass })

%<{
kg = 1;
%<}
```

- We can then use the unit of measure for quantities:

```
y = 5*kg
%> typeof y
%< y :: Quantity (Enum [`Mass, `Time])
%<                    {`Mass}
```

turn a value of a dimensionless type into a quantity

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.
- A common scenario when working with matrices of quantities:

```
%> dimensions V for Q over `L, `M, `T
%> unit metre :: Q({ `L })
%> unit kg :: Q({ `M })
%> unit sec :: Q({ `T })
```

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.
- A common scenario when working with matrices of quantities:

```
%> dimensions V for Q over `L, `M, `T
%> unit metre :: Q({ `L })
%> unit kg :: Q({ `M })
%> unit sec :: Q({ `T })
```

- Work in progress: LABMATE support for such matrices

```
% > A :: [ i <- [{} {`T}]
%         x j <- [{} {`L}]
%         ] Q({`M * j / i})
A = [ 2*kg          5*kg*metre
      3*kg/sec      4*kg*metre/sec]
```

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.
- A common scenario when working with matrices of quantities:

```
%> dimensions V for Q over `L, `M, `T
%> unit metre :: Q({ `L })
%> unit kg :: Q({ `M })
%> unit sec :: Q({ `T })
```

- Work in progress: LABMATE support for such matrices

```
% > A :: [ i <- [{} {`I}]
%         x j <- [{} {`L}]
%         ] Q({`M * j / i})
A = [ 2*kg          5*kg*metre
      3*kg/sec      4*kg*metre/sec]
```

The cell type Q depends on i and j

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.
- A common scenario when working with matrices of quantities:

```
%> dimensions V for Q over `L, `M, `T
%> unit metre :: Q({ `L })
%> unit kg :: Q({ `M })
%> unit sec :: Q({ `T })
```

- Work in progress: LatMath support for such matrices

Index i tells us something about the rows

```
% > A :: [ i <- [{} {`T}]
%          x j <- [{} {`L}]
%          ] Q({`M * j / i})
A = [ 2*kg          5*kg*metre
      3*kg/sec      4*kg*metre/sec]
```

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.
- A common scenario when working with matrices of quantities:

```
%> dimensions V for Q over `L, `M, `T
%> unit metre :: Q({ `L })
%> unit kg :: Q({ `M })
%> unit sec :: Q({ `T })
```

- Work in progress: LabMate support for such matrices

Index j disambiguates the columns

```
% > A :: [ I <- [{} {`I}]
%          x j <- [{} {`L}]
%          ] Q({`M * j / i})
A = [ 2*kg          5*kg*metre
      3*kg/sec      4*kg*metre/sec]
```

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.
- A common scenario when working with matrices of quantities:

```
%> dimensions V for Q over `L, `M, `T
%> unit metre :: Q({ `L })
%> unit kg :: Q({ `M })
%> unit sec :: Q({ `T })
```

- Work in progress: LABMATE support for such matrices

```
% > A :: [ i <- [{} {`T}]
%         , j <- [{} {`L}]
%   :: Q({ 'M * {} / {} })
% ] Q({ `M * j / i})
A = [ 2*kg          5*kg*metre
      3*kg/sec      4*kg*metre/sec]
```

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.
- A common scenario when working with matrices of quantities:

```
%> dimensions V for Q over `L, `M, `T
%> unit metre :: Q({ `L })
%> unit kg :: Q({ `M })
%> unit sec :: Q({ `T })
```

- Work in progress: LABMATE support for such matrices

```
% > A :: [ i <- [{} {`T}]
%         x j <- [{} {`L}]
%         ] Q({`M * `L / {}})
A = [ 2*kg          5*kg*metre
      3*kg/sec      4*kg*metre/sec]
```

:: Q({ ‘M * ‘L / {} })

Dimensional Consistency for Matrices

- Most MATLAB programs do not work on uniform matrices: type of the entry $e_{i,j}$ might depend on the indices i and j.
- A common scenario when working with matrices of quantities:

```
%> dimensions V for Q over `L, `M, `T
%> unit metre :: Q({ `L })
%> unit kg :: Q({ `M })
%> unit sec :: Q({ `T })
```

- Work in progress: LABMATE support for such matrices

```
% > A :: [ i <- [{} {`T}]
%          x j <- [{} {`L}]
%          ] Q({`M * j / i})
A = [ 2*kg                5*kg*metre
      3*kg/sec    4*kg*metre/sec]
```

:: Q({ 'M * 'L / 'T })

Implementation Details

- MATLAB programs are modelled as trees of commands, rather than sequence of commands.

Implementation Details

- MATLAB programs are modelled as trees of commands, rather than sequence of commands.
  - Type information is propagated (consistently) throughout the tree; can put type annotations after variable declarations.

Implementation Details

- MATLAB programs are modelled as trees of commands, rather than sequence of commands.
  - Type information is propagated (consistently) throughout the tree; can put type annotations after variable declarations.
  - Not every annotation is needed; document the interesting ones.

Implementation Details

- MATLAB programs are modelled as trees of commands, rather than sequence of commands.
  - Type information is propagated (consistently) throughout the tree; can put type annotations after variable declarations.
  - Not every annotation is needed; document the interesting ones.
- MATLAB expressions are translated to LABMATE internal core type theory.

Implementation Details

- MATLAB programs are modelled as trees of commands, rather than sequence of commands.
  - Type information is propagated (consistently) throughout the tree; can put type annotations after variable declarations.
  - Not every annotation is needed; document the interesting ones.
- MATLAB expressions are translated to LABMATE internal core type theory.
  - Matrix types are parametrised over 5 parameters with dependencies between them.

Implementation Details

- MATLAB programs are modelled as trees of commands, rather than sequence of commands.
  - Type information is propagated (consistently) throughout the tree; can put type annotations after variable declarations.
  - Not every annotation is needed; document the interesting ones.
- MATLAB expressions are translated to LABMATE internal core type theory.
  - Matrix types are parametrised over 5 parameters with dependencies between them.
  - Quantities are modelled as the free Abelian group over a base set of dimensions.

Implementation Details

- MATLAB programs are modelled as trees of commands, rather than sequence of commands.
  - Type information is propagated (consistently) throughout the tree; can put type annotations after variable declarations.
  - Not every annotation is needed; document the interesting ones.
- MATLAB expressions are translated to LABMATE internal core type theory.
  - Matrix types are parametrised over 5 parameters with dependencies between them.
  - Quantities are modelled as the free Abelian group over a base set of dimensions.
  - The typechecker understands nontrivial algebraic properties.

Current Progress & Future Plans

- LabMate is under active development.
  - Available on GitHub, please get it in touch if interested.

Current Progress & Future Plans

- LabMate is under active development.
  - Available on GitHub, please get it in touch if interested.
- Work in the pipeline:
  - Uniqueness of representation: currently, a matrix with quantities can have more than one corresponding type; this might lead to odd behaviour during typechecking.

Current Progress & Future Plans

- LabMate is under active development.
  - Available on GitHub, please get it in touch if interested.
- Work in the pipeline:
  - Uniqueness of representation: currently, a matrix with quantities can have more than one corresponding type; this might lead to odd behaviour during typechecking.
  - Quality of life improvements: better messages and more readable responses from LabMate.

Current Progress & Future Plans

- LabMate is under active development.
  - Available on GitHub, please get it in touch if interested.
- Work in the pipeline:
  - Uniqueness of representation: currently, a matrix with quantities can have more than one corresponding type; this might lead to odd behaviour during typechecking.
  - Quality of life improvements: better messages and more readable responses from LabMate.
- We want to extend our coverage to loops and conditionals in the future.

Thanks for the attention!

Thanks for the attention!

Questions?