Language Extensions
for MATLAB

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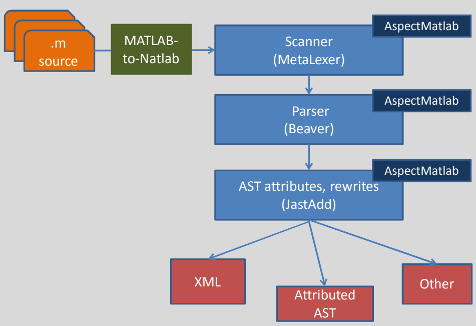
Overview

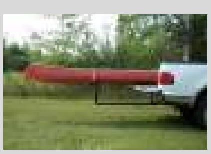
- How does one make language extensions for MATLAB using McLab?
- MetaLexer
- Aspects for MATLAB
- ["Types" for MATLAB]

McLab Extensible Front-end

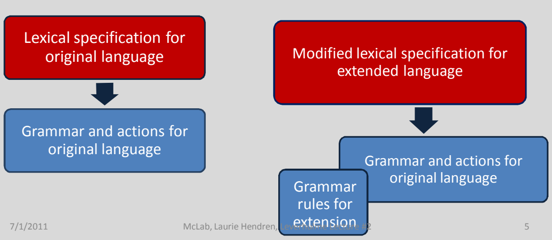


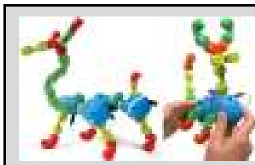
MetaLexer

- Modular Lexer Generator
- M.Sc. thesis, Andrew Casey
- AOSD 2011
- www.sable.mcgill.ca/metalexer

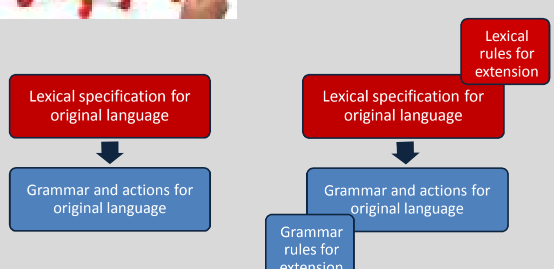


Given a front-end specification for a language (i.e. MATLAB), current method to implement a front-end for an extension of that language (i.e. AspectMatlab)?





Desired Modular MetaLexer Approach



We also want to be able to combine lexical specifications for diverse languages.

- Java + HTML
- Java + Aspects (AspectJ)
- Java + SQL
- MATLAB + Aspects (AspectMatlab)

Scanning AspectJ

```
package foo;

aspect Aspect {
    before() : (execution(* Clazz.* (..)) || if(Clazz.flag)) {
        System.out.println("Hello");
    }

    class Clazz {
        static boolean flag = false;

        public static void foo() {
            flag = !flag;
        }
    }
}
```

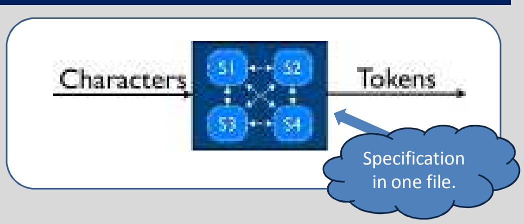

Would like to be able to reuse and extend lexical specification modules

- Nested C-style comments
- Javadoc comments
- Floating-point constants
- URL
- regular expressions
- …

First, let's understand the traditional lexer tools (lex, flex, jflex).

- programmer specifies regular expressions + actions
- tools generate a finite automaton-based implementation
- states are used to handle different language contexts

JFlex Lexing Structure



- **Lexing rules associated with a state.**
- **Changing states associated with action code.**

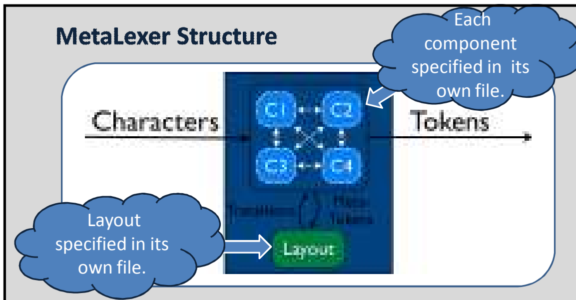

```
%%
%class Lexer
 Identifier  = [: jletter :]  [: jletterdigit :]*
 ...
%state STRING
%%
<YYINITIAL> {
  "abstract"       { return symbol(sym.ABSTRACT); }
  { Identifier }   { return symbol(sym.IDENTIFIER); }
  \"               { string.setLength(0); yybegin(STRING); }
  ...
}

<STRING> {
  \"               { yybegin(YYINITIAL); return ...; }
  [^\n\r\"\\]+     { string.append( yytext() ); }
  \\t              { string.append('\t'); }
  ...
}
```

Current (ugly) method for extending jflex specifications - copy&modify

- Copy jflex specification.
- Insert new scanner rules into copy.
  - Order of rules matters!
- Introduce new states and action logic for converting between states.

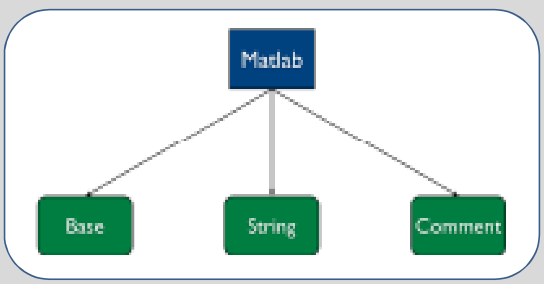
- Principled way of weaving new rules into existing rules.
- Modular and abstract notion of state and changing between states.

MetaLexer Structure

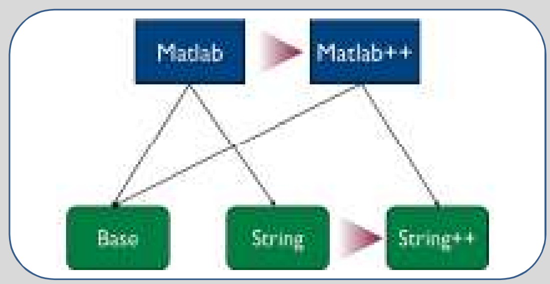


- Components define lexing rules associated with a state, rules produce meta-tokens.
- Layout defines transitions between components, state changes by meta-lexer (regular expressions + matching pairs of start/end symbols).

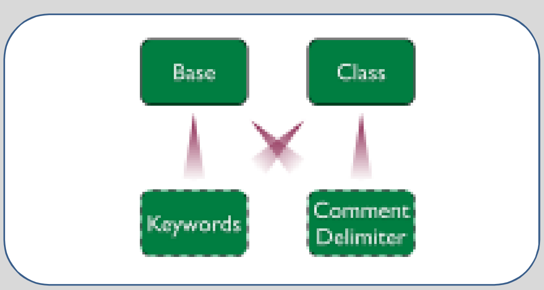
Example Structure of a MetaLexer Specification for MATLAB



Extending a MetaLexer Specification for Matlab

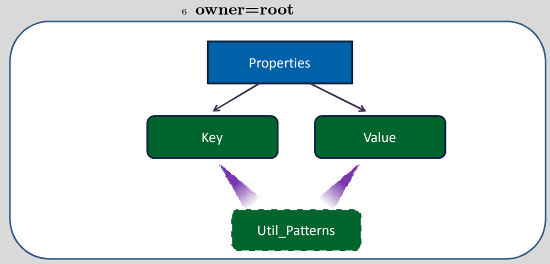


Sharing component specifications with MetaLexer



Scanning a properties file

```
#some properties
name=properties
date=2009/09/21

#some more properties
owner=root
```



util_properties.mlc helper component

```
%component util_patterns
%helper

lineTerminator = [\r\n] | "\r\n"
otherWhitespace = [ \t\f\b]
 identifier  = [a-zA-Z][a-zA-Z0-9_]*
comment = #[^\r\n]*
```


key.mlc component

```
%component key
%extern "Token symbol(int)"
%extern "Token symbol(int, String)"
%extern "void error(String) throws LexerException"

%%

%%inherit util_patterns
{lineTerminator} {: /*ignore*/ :}
{otherWhitespace} {: /*ignore*/ :}
"=" {: return symbol(ASSIGN); :} ASSIGN
%:
{ identifier } {: return symbol(KEY, yytext()); :}
{comment} {: /*ignore*/ :}
%:
<<ANY>> {: error("Unexpected char '"+yytext()+"'"); :}
<<EOF>> {: return symbol(EOF); :}
```

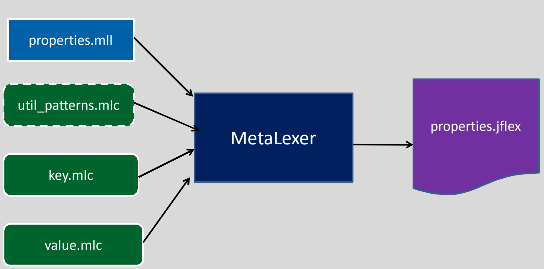

value.mlc component

```
%component value
%extern "Token symbol(int, String, int,  int ,  int ,  int)"
%append{
      return symbol(VALUE, text, startLine, startCol,
                                            endLine, endCol);
%append}

%%

%%inherit util_patterns
{lineTerminator} {: :} LINE_TERMINATOR
%:
%:
<<ANY>> {: append(yytext()); :}
<<EOF>> {: :} LINE_TERMINATOR
```


properties.mll layout

```
package properties;
%%
import static  properties.TokenTypes.*;
%%
%layout properties
%option public "%public"
 ...
%lexthrow "LexerException"
%component key
%component value
%start key
%%
%%embed
%name key_value
%host key
%guest value
%start ASSIGN
%end LINE_TERMINATOR
```

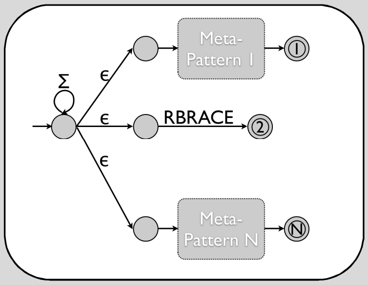

MetaLexer is implemented and available: www.sable.mcgill.ca/metalexer



Key problems to solve:

- How to implement the meta-token lexer?
- How to allow for insertion of new components, replacing of components, adding new embeddings (metalexer transitions).
- How to insert new patterns into components at specific points.

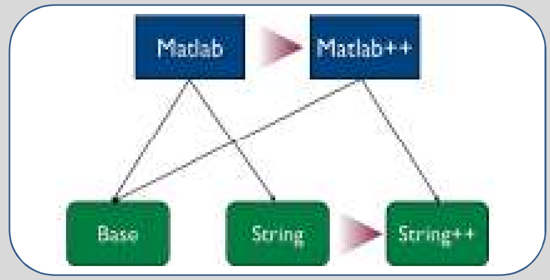
Implementing the meta-token lexer



Recognize a meta-pattern, i.e. when to go to a new component and when to return.

Recognize the matching suffix.

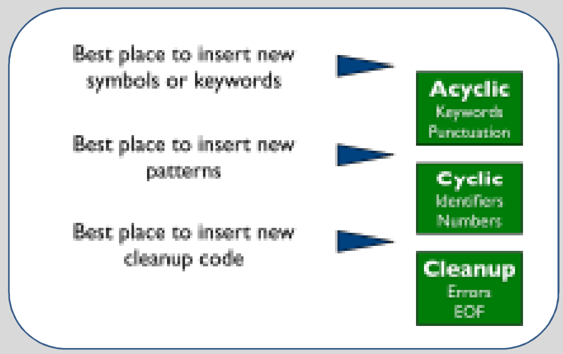
Implementing inheritance (structured weaving).



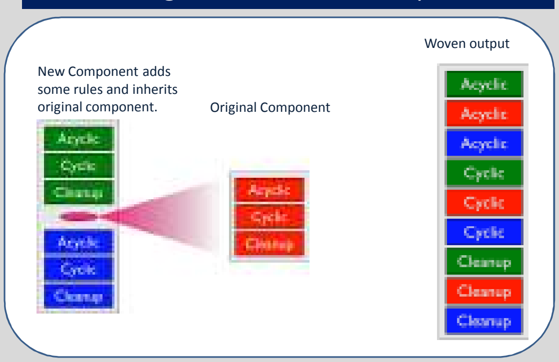
Implementing MetaLexer layout inheritance

- **Layouts can inherit other layouts**
- **%inherit directive put at the location at which the inherited transition rules (embeddings) should be placed.**
- **each %inherit directive can be followed by:**
  - **%unoption**
  - **%replace**
  - **%unembed**
  - **new embeddings**

Implementing MetaLexer component inheritance



Weaving in an inherited component



Results:

Applied to three projects with complex scanners:

- **AspectJ (abc and extensions)**
- **Matlab (Annotations and AspectMatlab extensions)**
- **MetaLexer**

AspectJ and Extensions

```
%%embed
%name perclause
%host aspect_decl
%guest pointcut
%start [PERCFLOW PERCFLOWBELOW PERTARGET
        PERTHIS] LPAREN
%end RPAREN
%pair LPAREN, RPAREN

%%embed
%name pointcut
%host java, aspect
%guest pointcut
%start POINTCUT
%end SEMICOLON
```


MetaLexer scanner implemented in MetaLexer

- 1st version of MetaLexer written in JFlex, one for components and one for layouts.
- 2nd version implemented in MetaLexer, many shared components between the component lexer and the layout lexer.

Related Work for MetaLexer

- Ad-hoc systems with separate scanner/ LALR parser
  - Polyglot
  - JastAdd
  - abc
- Recursive-descent scanner/parser
  - ANTLR and systems using ANTLR
- Scannerless systems
  - Rats! (PEGs)
- Integrated systems
  - Copper (modified LALR parser which communicates with DFA-based scanner)

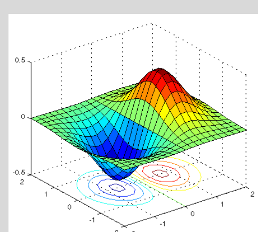
Metalexer Conclusions

- MetaLexer allows one to specify modular and extensible scanners suitable for any system that works with JFlex.
- Two main ideas: meta-lexing and component/layout inheritance.
- Used in large projects such as abc, McLab and MetaLexer itself.
- Available at: www.sable.mcgill.ca/metalexer

AspectMatlab

- Simple Aspect-Oriented extension to MATLAB
- M.Sc. thesis, Toheed Aslam
- Analysis by Jesse Doherty, applications by Anton Dubrau, extensions by Olivier Savary-Belanger
- AOSD 2010
- www.sable.mcgill.ca/mclab

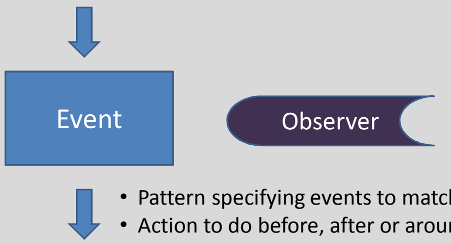
Why AspectMatlab?



- Test the McLab framework for extensibility
- Bring a simple and relevant version of AOP to scientists.

- simple language constructs
- focus on arrays and loops

What is an Aspect?



- Pattern specifying events to match.
- Action to do before, after or around the matched events.
- Action can use context information from the matched event.

Example: Profiling Array Sparsity

```
0 0 0 9 0 0 0 0 0 0
0 0 0 0 0 0 5 0 0 0
0 1 0 0 0 0 0 3 0 0
0 0 0 0 4 0 0 0 0 0
0 0 7 0 0 0 0 0 0 0
```

- Capture the sparsity and size at each operation on the whole array.
- Capture the number of indexed references to each array.
- Print out a summary for each array, allowing the programmer to identify good candidates to implement as sparse arrays.

Background - MATLAB Class

```
classdef myClass
  properties
     …
  end

  methods
     …
  end
end
```

data
count = 0;

helper functions
function x=getCount(this)
  x = this.count;
end

Aspect Definition

```
aspect myAspect
   properties
      …
   end
   methods
      …
   end
   patterns
      …
   end
   actions
      …
   end
end
```

data
count = 0;

helper functions
function x=getCount(this)
  x = this.count;
end

pointcuts
foocalls : call(foo);

advice
foocounter : before foocalls
  this.count = this.count + 1;
end

Function and Operator Patterns

```
patterns
   pCallFoo : call(foo);
   pExecBar : execution(bar);

   pCallFoo2args : call(foo(*,*));
   pExecutionMain : mainexecution();
end
```

```
patterns
   plusOp : op(+);
   timesOp : op(.*) || op(*);
   matrixOps: op(matrix);
   allButMinus: op(all) & ~op(-);
end
```


Array Patterns

also,
new value

a(i) = b(j,k)

Context Info
name
indices
object (value)
line number
location
file name

```
patterns
   pSetX : set(a);
   pGetX : get(b);

   arraySet : set(*);
   arrayWholeGet : get(*());
   arrayIndexedGet : get(*(..));
end
```

Loop Patterns

```
t1 = [1,3,5,7,9,...,n];
for   t2 = 1:numel(t1)
   i = t1(t2);
   ...
   ...
   ...
end
```

```
patterns
   pLoopI : loop(i);
   pLoopHeadI : loophead(i);
   pLoopBodyI : loopbody(i);
end
```


Scope Patterns

```
patterns
   pWithinFoo : within(function, foo);
   pWithinBar : within(script, bar);
   pWithinMyClass : within(class, myClass);
   pWithinLoops : within(loops, *);
   pWithinAllAbc : within(*, abc);
end
```


Compound Patterns

- Logical combinations of primitive patterns

```
patterns
   pCallFoo  : call(foo) & within(loops, *);
   pGetOrSet : (get(*) | set(*)) & within(function, bar);
end
```


Before & After Actions

```
actions
   aCountCall : before pCall
      this.count = this.count + 1;
      disp('calling a function');
   end

   aExecution : after executionMain
      total = this.getCount();
      disp(['total calls: ', num2str(total)]);
   end
end
```


Context Exposure

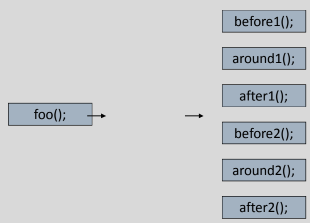
```
actions
   aCountCall : before pCall : (name, args)
      this.count = this.count + 1;
      disp(['calling ',name,' with args(',args, ')']);
   end

   aExecution : after executionMain : (file)
      total = this.getCount();
      disp(['total calls in ',file,': ',num2str(total)]);
   end
end
```


Around Actions

```
actions
   actcall : around pCallFoo : (args)
      disp(['before foo call with args(', args , ')']);
      proceed();
      disp(['after foo call with args(', args , ')']);
   end
end
```

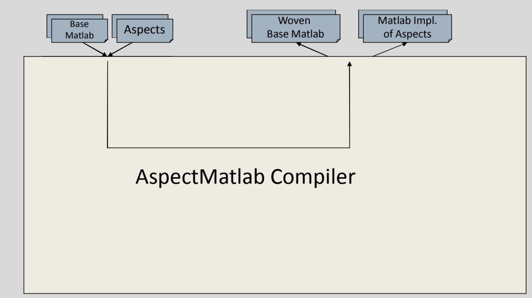
```
actions
   actcall : around pCallFoo : (args)
      % proceed not called, so varargout is set
      varargout{1} = bar(args{1}, args{2});
   end
end
```

Actions Weaving Order

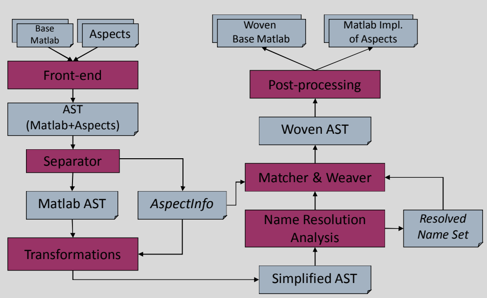



```
actions
  before1 : before pCallFoo
  …
  around1 : around pCallFoo
  …
  after1 : after pCallFoo
  …
  before2 : before pCallFoo
  …
  around2 : around pCallFoo
  …
  after2 : after pCallFoo
  …
end
```


Compiler Structure

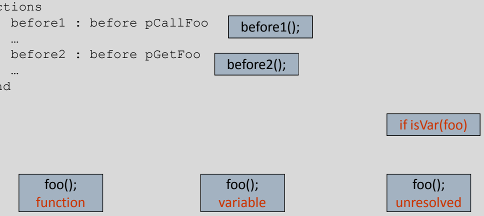


Compiler Structure



Name Resolution Analysis

```
patterns
  pCallFoo : call(foo);
  pGetFoo : get(foo);
end
actions
  before1 : before pCallFoo
  …
  before2 : before pGetFoo
  …
end
```



Scientific Use Cases

- Domain-Specific Profiling of Programs
  - Tracking array sparsity
  - Tracking array size-growing operations
  - Counting floating-point operations
- Extending Functionality
  - Interpreting loop iteration space
  - Adding units to computations

Related Work for AspectMatlab

- AspectJ *(Kiczales et al., ECOOP '01)*
  - abc *(The de Moor and Hendren gang, AOSD '05)*
  - Array pointcuts *(Chen et al., JSES '07)*
  - Loop pointcuts *(Harbulot et al., AOSD '06)*
- AspectCobol *(Lammel et al., AOSD '05)*
- Domain-Specific Aspects in Matlab *(Cardoso et al., DSAL workshop held at AOSD '10)*

Conclusions

- McLab supports extensions to MATLAB
- We developed MetaLexer to support modular and extensible lexers, and then used it in McLab.
- We designed and implemented AspectMatlab as an exercise in using McLab for extensions, and also to provide simple and relevant AOP for scientists.

Typing Aspects

- Types for MATLAB, somewhat in the spirit of aspects.
- Designed by what programmers might want to say.
- Checked at run-time, but some static analysis could be done.

Simple Example MATLAB function

```
function [ r ] = Ex1( n )
% Ex1(n) creates a vector of n values containing
%   the values [sin(1), sin(2), ..., sin(n)]
  for i=1:n
    r(i) = sin(i);
  end
end
```

```
>> Ex1(3)
ans = 0.8415    0.9093    0.1411

>> Ex1(2.3)
ans = 0.8415    0.9093
```



```
>> Ex1(int32(3))
??? Undefined function or method 'sin' for input
    arguments of type 'int32'.
Error in ==> Ex1 at 5
  r(i) = sin(i);

>> Ex1('c')
??? For colon operator with char operands, first
    and last operands must be char.
Error in ==> Ex1 at 4
  for i=1:n

>> Ex1(@sin)
??? Undefined function or method '_colonobj' for
    input arguments of type 'function_handle'.
Error in ==> Ex1 at 4
  for i=1:n
```



```
>> Ex1(complex(1,2))
Warning: Colon operands must be real scalars.
> In Ex1 at 4
ans = 0.8415

>> Ex1(true)
Warning: Colon operands should not be logical.
> In Ex1 at 4
ans = 0.8415

>> Ex1([3,4,5])
ans = 0.8415    0.9093    0.1411
```


MATLAB prorammers often expect certain types

```
function y = sturm(X,BC,F,G,R)
% STURM Solve the Sturm-Liouville equation:
%   d( F*dY/dX )/dX - G*Y = R using linear finite elements.
% INPUT:
%   X - a one-dimensional grid-point array of length N.
%   BC - is a 2 by 3 matrix [A1, B1, C1 ; An, Bn, Cn]
...
% Alex Pletzer: pletzer@pppl.gov (Aug. 97/July 99).
...
```

```
1 function [ r ] = Ex1( n )
2 % Ex1(n) creates a vector of n values containing
3 %   the values [sin(1), sin(2), ..., sin(n)]
4   atype('n','scalar of Float');
5   for i=1:n
6     r(i) = sin(i);
7   end
8   atype('r','array [n.value] of n.basetype');
9 end
```

```
>> Ex1(3)
ans = 0.8415    0.9093    0.1411

>> Ex1('c')
Type error in Ex1.m, Line 4: Expecting 'n' to have
type 'scalar of float', but got the type
'scalar of char'.
```

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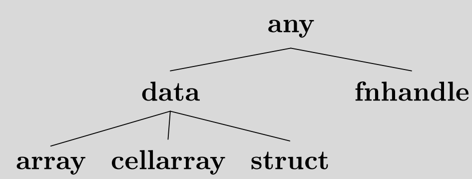
High-level types in MATLAB



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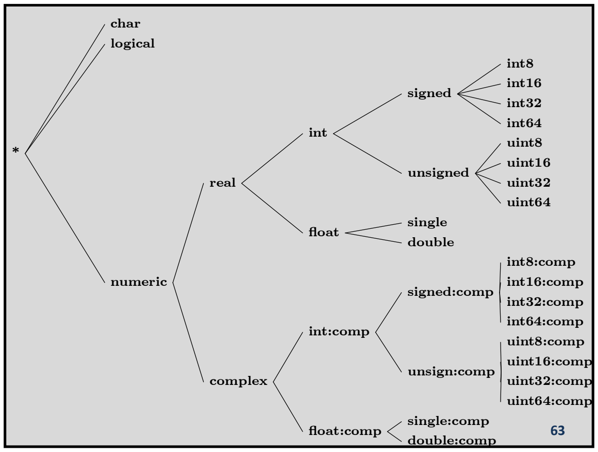

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Simple Example

```
function [ r ] = foo( a, b, c, d )
  atype('a', 'array [...] of int');
  atype('b', 'array[*,*]');
  atype('c', 'array[*,*,...]) of complex');
  atype('d', 'scalar of uint32');
  % ...
  % body of foo
  % ...
  atype('r','array[a.dims] of int');
end
```

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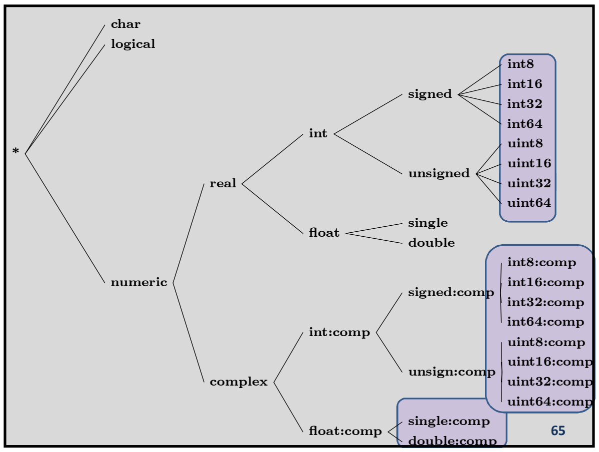

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Capturing reflective information

```
function [ r ] = foo( a )
  atype('a','any');
  % ...
  % body of foo
  % ...
  atype('r','a.type');
end
```

- a.type
- a.value
- a.dims
- a.basetype

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Capturing dimensions and basetype

```
function [ r ] = foo( a, b )
  atype('a','array[<n>,<m>] of real');
  atype('b','array[a.m,<p>] of a.basetype');
  % ...
  % body of foo
  % ...
  atype('r','array[a.m,b.p] of a.basetype');
end
```

- <n> can be used as a dimension spec
- value of n is instantiated from the runtime dimension
- repeated use in same atype statement implies equality

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