C Programming Tools: Part 4

Building Lexers and Parsers

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June 2019

The handout and tarball are available on CATE and at:
`http://www.doc.ic.ac.uk/~dcw/c-tools-2019/lecture4/`

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- But what Little Language shall we use for our main example?

- A tiny Haskell subset called THS.

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- For example:

```
f :: Int -> Int
f x = x*2
abs x | x>0  = x
      | x==0 = 0
      | 0>x  = 0-x
fact x | x==1 = 1
       | x>1  = x * fact(x-1)
f(20) + abs(0-2)*fact(arg1)
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- In a break with strict Haskell-syntax, we'll decide that brackets on function calls like `abs(10)` are compulsory. Why? Because the lack of brackets confuses me:-)

- The basic lexical tokens we need are:
  - A few keywords ‘mod’, ‘Int’, ‘True’.
  - Various one-or-two character tokens (eg. ‘(’, ‘+’, ‘*’, ‘)’, ‘::’ etc).
  - Numeric constants (eg ‘2’ or ‘123’).
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  - Identifiers (eg 'fact' or 'x').
- With Lex, specify the tokens as regular expression/action pairs:

```
[ \t\n]+                /* ignore whitespace */;
mod                     return MOD;
Int                     return INTTYPE;
True                    return TRUEV;
::                      return COLONCOLON;
->                      return IMPLIES;
==                      return EQ;
=                       return IS;
>                       return GT;
!=                      return NE;
\+                      return PLUS;
-                       return MINUS;
\*                      return MUL;
\/                      return DIV;
\(                      return OPEN;
\)                      return CLOSE;
\|                      return GUARD;
[0-9]+                  return NUMBER;
[a-z][a-z0-9]*          return IDENT;
.                       return TOKERR;
```

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- See lexer.l in 01.ths-recogniser for the full Lex input file, containing the above plus some prelude. This file can be turned into C code via: lex -o lexer.c lexer.l.

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- See lexer.l in 01.ths-recogniser for the full Lex input file, containing the above plus some prelude. This file can be turned into C code via: lex -o lexer.c lexer.l.
- Our next task is to combine these tokens into THS programs via our grammar. The Yacc input file parser.y starts with a long prelude of plain C code:

```
%{
// some includes

extern int yylex(void);
extern int yylineno;
extern bool verbose;

int yyerrors = 0;

void yyerror(const char *str)
{
        fprintf(stderr, "Error on line %d: %s\n", yylineno, str);
        yyerrors++;
}

int yywrap( void ) { return 1; }
%}
```

- Next, parser.y defines all the tokens:

```
%token COLONCOLON IMPLIES EQ GT NE TRUEV PLUS MINUS MUL DIV MOD OPEN
       CLOSE GUARD IS INTTYPE TOKERR NUMBER IDENT
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  The generated parser will try to consume the entire input and parse it as a program.

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- Then we list the grammar rules that define the language, in BNF:

```
program      :  defns expr
             ;
defns        :  /* empty */
             | defns ftypedefn
             | defns fdefinition
             ;
ftypedefn    : IDENT COLONCOLON INTTYPE IMPLIES INTTYPE
             ;
fdefinition  : IDENT IDENT IS expr
             | IDENT IDENT guardrules
             ;
guardrules   : guard
             | guardrules guard
             ;
```

- The grammar rules continue, defining guarded expressions (guard), boolean expressions (bexpr) and arithmetic expressions (rules expr, term and factor):

```
guard       : GUARD bexpr IS expr
            ;
bexpr       : expr EQ expr
            | expr NE expr
            | expr GT expr
            | TRUEV
            ;
expr        : expr PLUS term
            | expr MINUS term
            | term
            ;
term        : term MUL factor
            | term DIV factor
            | term MOD factor
            | factor
            ;
factor      : NUMBER
            | OPEN expr CLOSE
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- Picking the top guard rule out as an example, it means that a guarded expression comprises a GUARD token (‘|’), followed by a boolean expression, followed by an IS token (‘=’), followed by an expression.

- Note that recursive rules in Yacc that match lists of items, eg:

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defns      : defns ftypedefn
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- Putting it all together, adding a main program that initializes the lexer, invokes the parser, and checks whether parsing is successful or not, and adding a Makefile, compile and link by typing make.
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- Our next THS version, in 02.ths-treebuilder, will build an Abstract Syntax tree during the parse!

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- Similarly, when we've matched an identifier - the longest possible alphanumeric sequence that isn't a keyword such as "mod" - the name of the identifier is in yytext. We strdup(yytext) to give ourselves a long-lived copy of the string, and store that in yylval.s - a char *s field in the mysterious yylval.

- Moving onto parser.y, there are many changes. First, the parser.y prelude includes rather more `#include` statements, then defines:

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program ast = NULL;
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  which is where the AST (the program) is stored after a successful parse. We'll see where the type program is defined shortly.

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- Next parser.y contains a `%union` declaration, which lists all possible types of data associated with tokens and grammar rules:

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%union
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        int       n;    char     *s;
        expr      e;    bexpr     b;
        guard     g;    guardlist gl;
        fdefn     f;    flist     fl;
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- The Lex prelude includes parser.h: this explains how yylval.n is an int, and yylval.s is a char *.

- Next, parser.y alters the definition of these two tokens:

```
%token <n> NUMBER
%token <s> IDENT
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This tells Yacc that a NUMBER token has an associated int n value, and that an IDENT token has an associated char *s value.

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- These AST types are defined in types.in - a *Datadec input file*:

```
arithop   =  plus or minus or times or divide or mod;
expr      =  num( int n )
          or id( string s )
          or call( string s, expr e )
          or binop( expr l, arithop op, expr r );
boolop    =  eq or ne or gt;
bexpr     =  truev
          or binop( expr l, boolop op, expr r );
guard     =  pair( bexpr cond, expr e );
guardlist =  nil or cons( guard hd, guardlist tl );
fdefn     =  triple( string fname, string param, fbody b );
fbody     =  one( expr e ) or many( guardlist l );
flist     =  nil or cons( fdefn hd, flist tl );
program   =  pair( flist l, expr e );
```

- Back in parser.y, we associate a specific field in the union with many, but not all, grammar rules:

```
%type <e> factor term expr
%type <g> guard
%type <f> fdefinition
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%type <b> bexpr
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- You will see that all the grammar rules have been annotated with the corresponding tree-building actions to take when the rules match:

```
program      :  defns expr       { ast = program_pair( $1, $2 ); }
             ;
defns        :  /* empty */      { $$ = flist_nil(); }
             | defns ftypedefn   { $$ = $1; /* ignore type defns */ }
             | defns fdefinition { $$ = flist_cons( $2, $1 ); }
             ;
ftypedefn    : IDENT COLONCOLON INTTYPE IMPLIES INTTYPE { free_string( $1 ); }
             ;
fdefinition  : IDENT IDENT IS expr    { $$ = fdefn_onerule( $1, $2, $4 ); }
             | IDENT IDENT guardrules { ... }
             ;
guardrules   : guard            { $$ = guardlist_cons($1, guardlist_nil()); }
             | guardrules guard { $$ = guardlist_push( $1, $2 ); }
             ;
```

- I'll explain the strange $n and $$ syntax shortly.

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  - $1 set to the value (if any) associated with the GUARD token,
  - $2 set to the value (if any) associated with the bexpr rule,
  - $3 set to the value (if any) associated with the IS token, and
  - $4 set to the value (if any) associated with the expr rule.

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- Here, only the bexpr and the expr have associated values, so we use $2 and $4 to build a guard: `guard_pair( $2, $4 )`.

- Picking one of our rules + actions out, we see:

```
guard       : GUARD bexpr IS expr { $$ = guard_pair( $2, $4 ); }
```

- If this rule matches, then the action is executed, with:
  - $1 set to the value (if any) associated with the GUARD token,
  - $2 set to the value (if any) associated with the bexpr rule,
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- Having built a new guard, parsing continues trying to parse a non-empty sequence of guards, and build them into a guard list. Guard lists get incorporated into function definitions, function definitions into a function list, the function list and the main expression into the program - and assigned to the ast variable.

- We said that recursive rules in Yacc, such as:

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- We modify the main program to print out the AST (if parsing is successful), add named constants (via the longhash module), and modify the Makefile to build everything, using **lex, yacc** and **datadec** to generate lexer.c, the parser module and the types module, using the **tmpl** and **proto** tools from the previous lecture to generate numerous small modules.

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- Compile and link by typing make. We end up with a THS parser and treebuilder ths2, in which we only write about 460 lines of code. Give it a try!

- 03.ths-semanticchecker adds semantic checking - in THS, this means checking that we define every function we call. In other languages, we'd have to check the number and types of actual parameters to each called function.
- How do we do semantic checks? A semantic checker either walks the AST, or builds and iterates over equivalent data structures.
- To reduce tree-walking, we enhanced parser.y to populate a hash called funchash as we parse functions, and a set called callset as we parse calls.
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- The semantic checker then iterates through the callset checking that each called function is present in the funchash.

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- Note that we also have to trap runtime errors such as division by zero and what happens if no guard evaluates to true.

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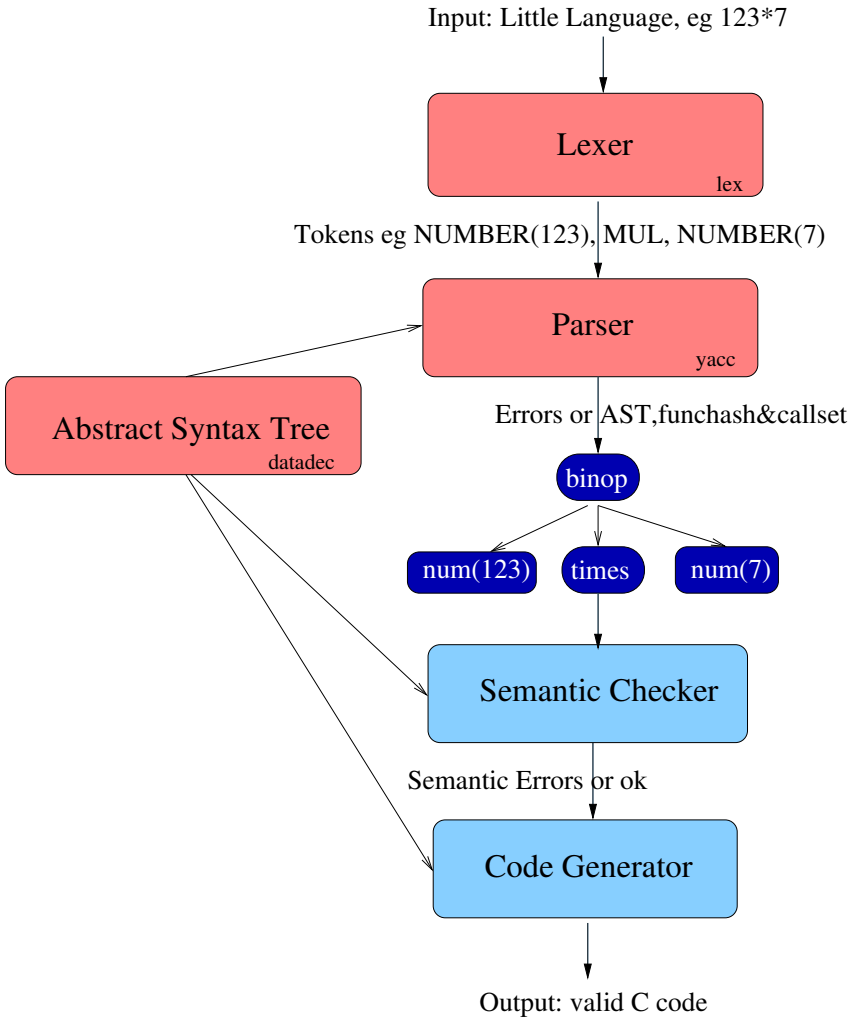

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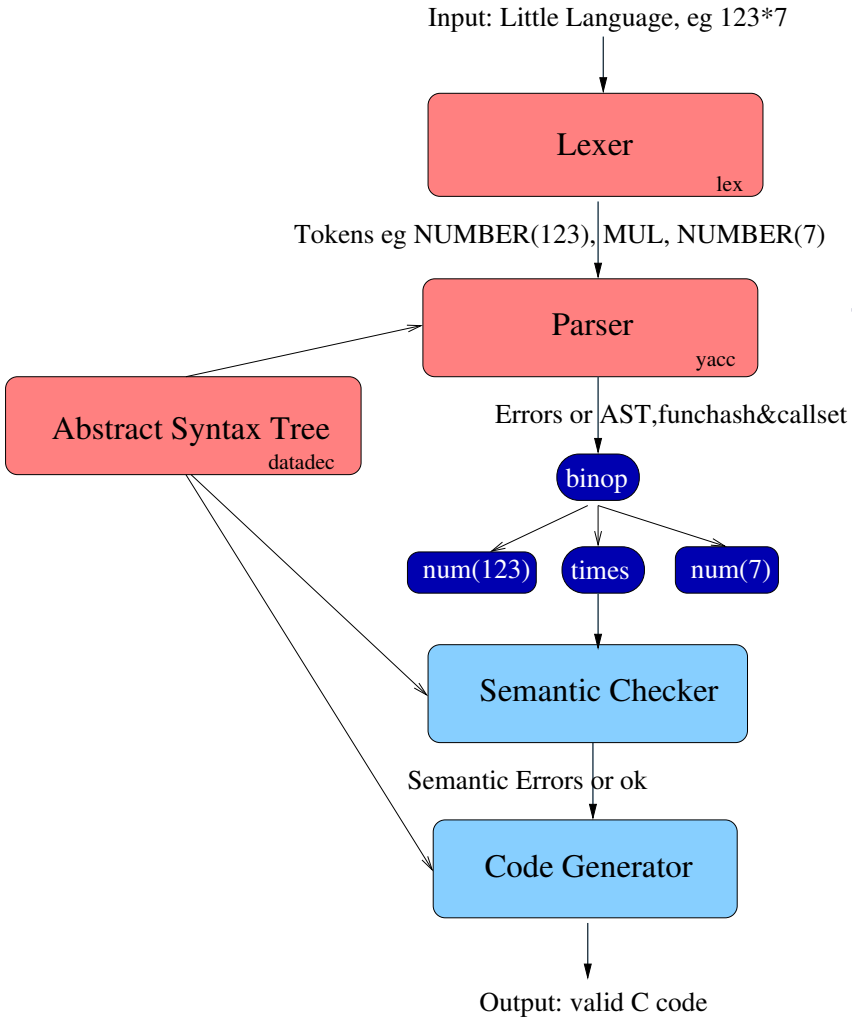

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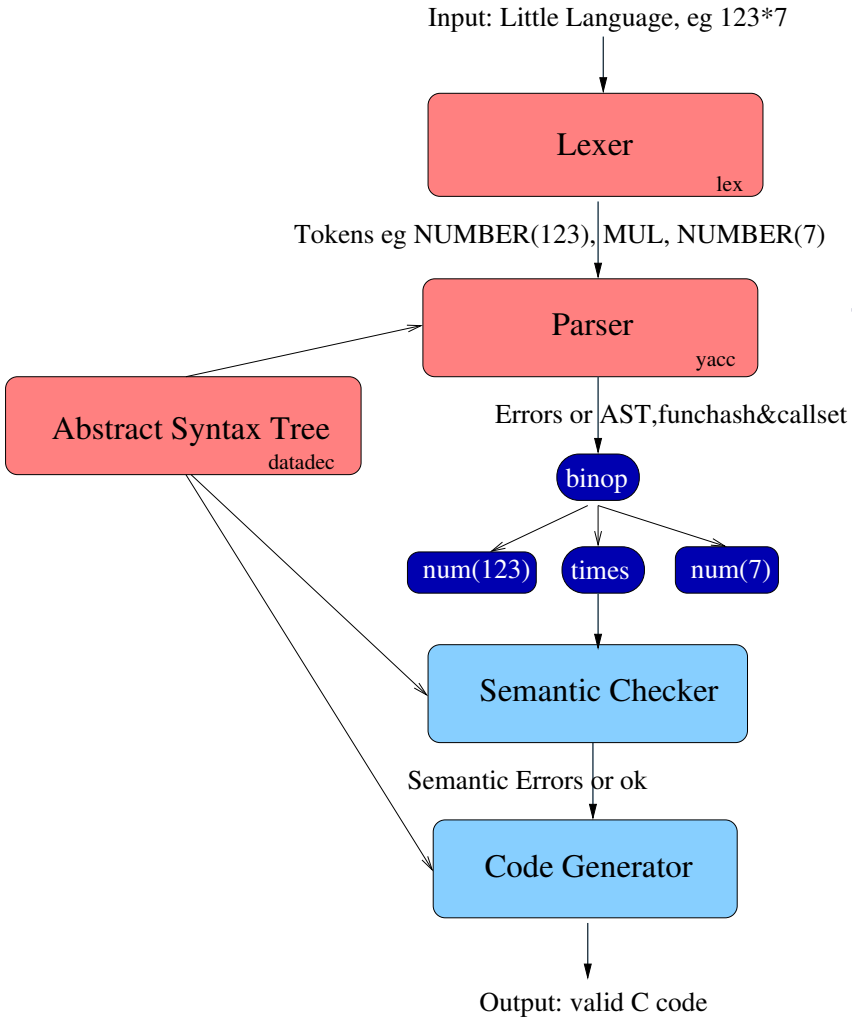

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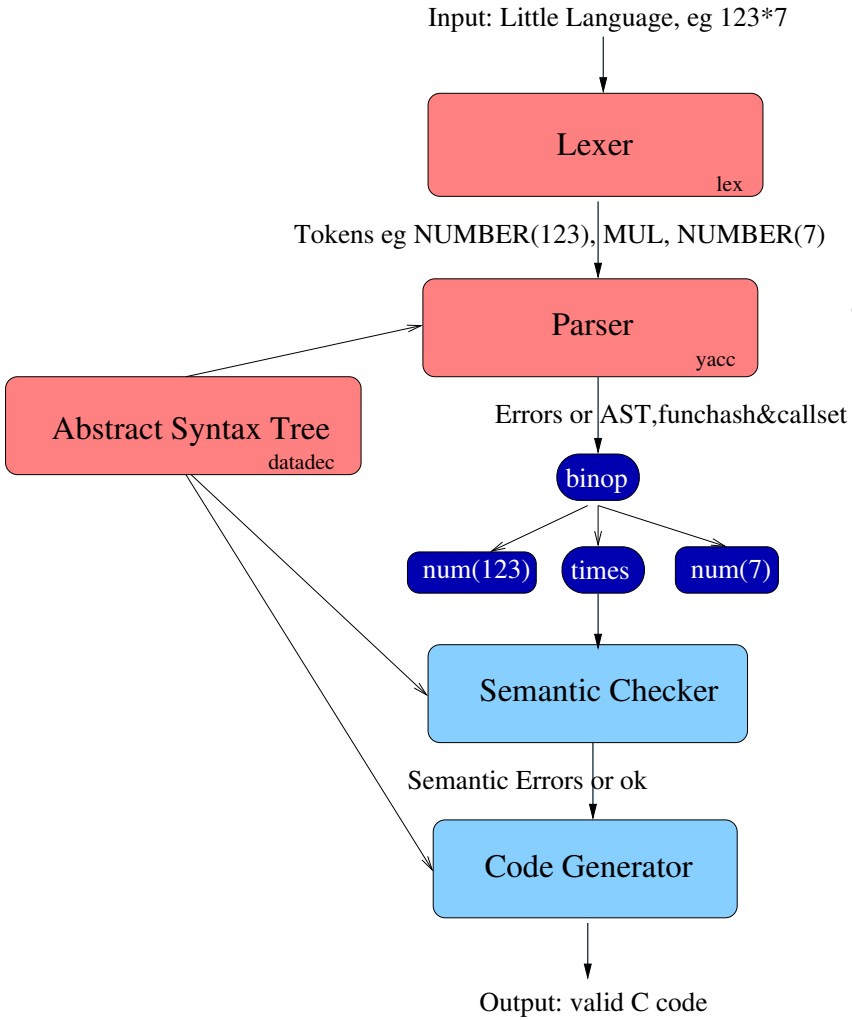

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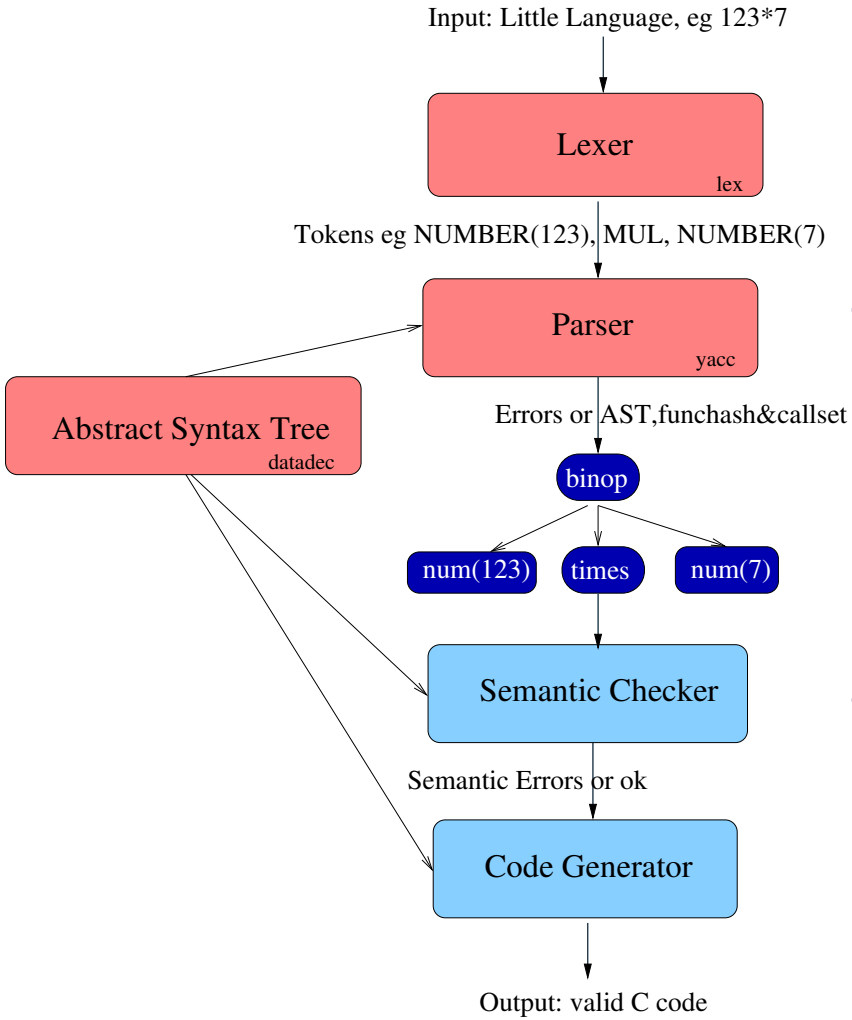

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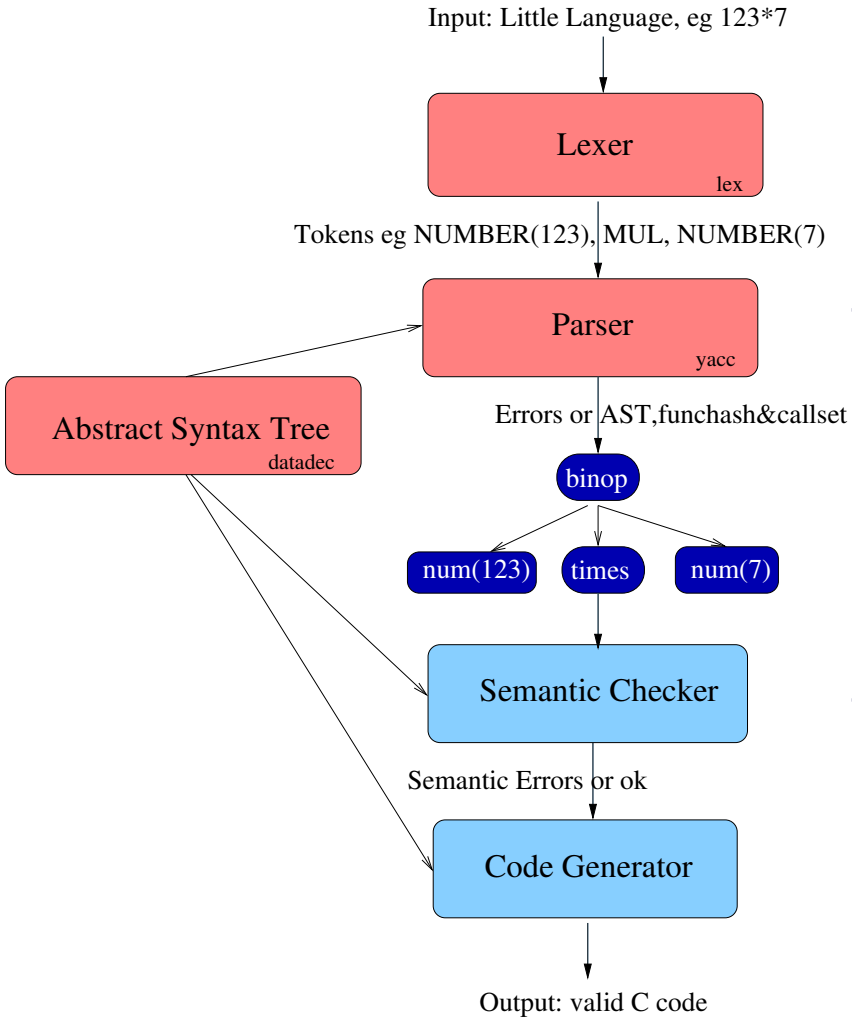

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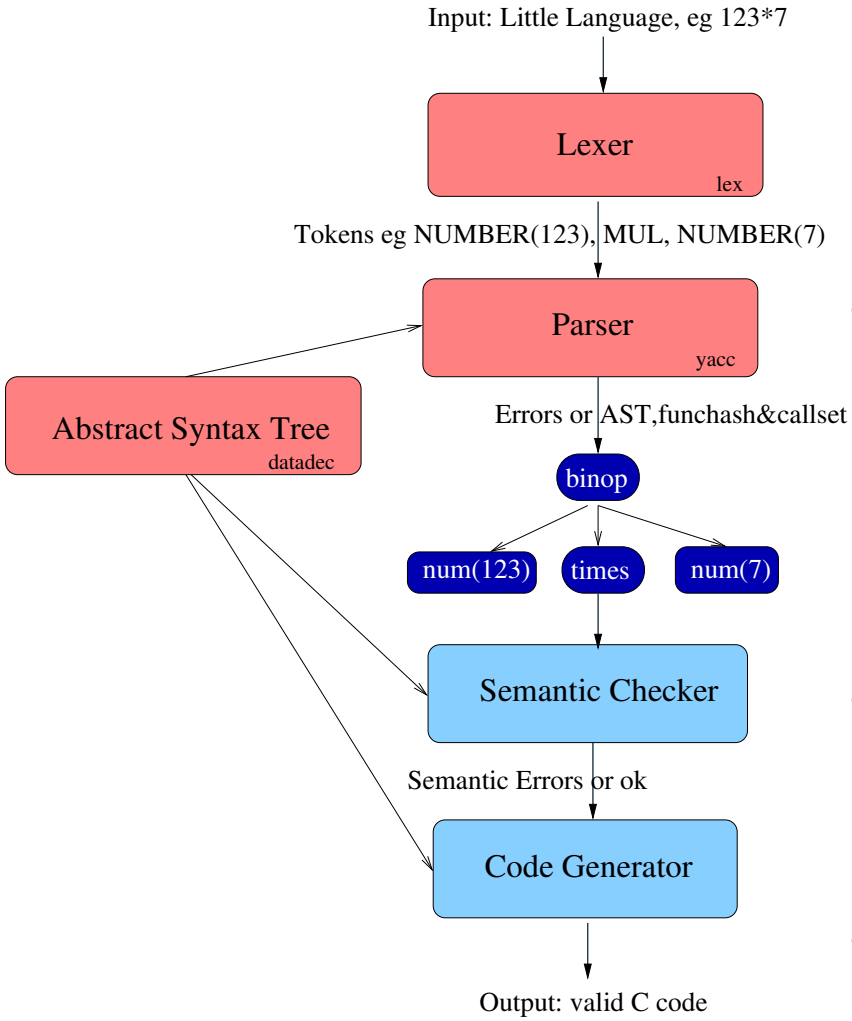

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- So, Yacc and Lex and Datadec are a scalable way of building translators for little languages, vital tools for your toolbox.
- In order to make sense of how they all fit together, with the `%union` and the `%type <f>` and `%token <f>` syntax and all the `$n` notation, please work slowly through the tarball examples.

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- Having defined the syntax of the new feature, we define it's semantics via a precise description of how to translate it back to standard C.

- The first whenshape example turns into the plain C code:

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- But that sounds like hard work! We'd have to work out what assembly code (or intermediate code such as Register Transfer Code) to emit for our new features.

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- Graft our new feature into C by writing a simple line-by-line pre-processor that copies most lines through unchanged (assuming, or hoping, that they contain valid C), but locates specially marked extension directives, turning each into a corresponding chunk of plain C.

- Another way would be to build (or find) a *C to C translator* which can be extended. Perhaps someone has already built one that we could extend?
- If not, you could build one by finding a complete Yacc grammar spec, Lex lexer spec and AST module for C and extend them - adding our new tokens to the lexer spec, new rules to the grammar spec to recognise our new forms of syntax, and new actions to build AST fragments representing the plain C equivalents for each new construct.
- This also sounds like a lot of work!
- Isn't there a less... scary way to do this? Yes there is!
- Graft our new feature into C by writing a simple line-by-line pre-processor that copies most lines through unchanged (assuming, or hoping, that they contain valid C), but locates specially marked extension directives, turning each into a corresponding chunk of plain C.
- Thus, C with directives comes in, standard C goes out.

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- In the tree-eg subdirectory, you'll find nleaves.cpm that implements a close approximation to what we wanted to write:

```
int nleaves( tree t )
{
        %when tree t is leaf(name)
        {
                return 1;
        }
        %when tree t is node( l, r )
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- There are several other pattern matching directives as well.
- See interprete.cpm (found in the `interprete-eg` subdir) for a bigger example - the THS interpreter rewritten using the lovely new syntax.
- BTW, cpm reads information about types, shapes, and their parameters from datadec in a particularly sneaky fashion, which I'm very proud of.

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- Read The Pragmatic Programmer. Then read it again!
- Most importantly: enjoy your C programming! Build your toolkit - and let me know if you build any particularly cool tools!