C Programming Tools: Part 4

Building and Using your own Toolkit

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- The handout and tarballs are available on CATE and at: `http://www.doc.ic.ac.uk/~dcw/c-tools-2018/lecture4/`

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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 ‘123’).
  - Identifiers (eg ‘fact’).

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  - Numeric constants (eg '123').
  - Identifiers (eg 'fact').
- 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]+                  yylval.n=atoi(yytext); return NUMBER;
[a-z][a-z0-9]*          yylval.s=strdup(yytext);return IDENT;
.                       return TOKERR;
```

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

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- Our next task is to combine these tokens into THS programs via our grammar. However the grammar and (Datadec-generated) Abstract Syntax Trees intertwine, so let's start by looking at types.in - our 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     =  onerule( string fname, string param, expr e )
          or manyrules( string fname, string param, guardlist l );
flist     =  nil or cons( fdefn hd, flist tl );
program   =  pair( flist l, expr e );
```

- Now let's look at the Yacc input file parser.y, it starts with a long prelude of plain C code:

```
%{
// some includes

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

program ast  = NULL;
int yyerrors = 0;

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

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

- Note that among the prelude, we see:

```
program ast = NULL;
```

which is where the AST (the program) will be stored after a successful parse.

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

```
%union
{
        int       n;    char      *s;
        expr      e;    bexpr      b;
        guard     g;    guardlist gl;
        fdefn     f;    flist     fl;
}
```

In the generated C code, the union is turned into a type called YYSTYPE in parser.h. The Lex prelude includes parser.h, and Lex then defines the variable YYSTYPE yylval, which explains how yylval.n is an int, and yylval.s is a char *.

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- 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 TOKEOF
%token <n> NUMBER
%token <s> IDENT
```

  Yacc turns each token into an integer constant which the lexer uses (via including parser.h). The final two lines tell Yacc that a NUMBER token has an associated integer value (int n in the union), and that an IDENT token has an associated char *s (identifier name).

- Next, we do the same for those grammar rules with associated data: we associate a specific field in the union with particular rules:

```
%type <e> factor term expr              %type <b> bexpr
%type <g> guard                         %type <gl> guardrules
%type <f> fdefinition                   %type <fl> defns
```

- Next, we tell Yacc which rule to start parsing with:

```
%start program
%%
```

- Then we list the grammar rules and corresponding tree-building actions to take:

```
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 all the strange `$n` and `$$` syntax shortly.

- The grammar rules continue, defining guarded expressions (guard), boolean expressions (bexpr) and arithmetic expressions (rules expr, term and factor).
- Picking one rule out, we see:

```
guard          : GUARD bexpr IS expr { $$ = guard_pair( $2, $4 ); }
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  This means that one possible way of parsing a guarded expression is to find a GUARD token (the '|' symbol), followed immediately by an arbitrarily complicated boolean expression, followed by an IS token (the '=' symbol), followed by an expression.

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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 )`.
- Assigning that new guard to $$ sets the value associated with the whole guard rule, think of this as the return value.

- Note that recursive (list-handling) rules in Yacc, such as:

  ```
  guardrules : guardrules guard  { ACTION }
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- Turn parser.y into C code (parser.c and parser.h) via: yacc -vd -o parser.c parser.y.
- Putting it all together, using our macro tool from the previous lecture, and adding a main program that initializes the lexer, invokes the parser and (when parsing is successful) prints out the AST that was built, plus several other modules we haven't discussed, and a Makefile, compile and link by typing make.
- We end up with a THS parser and treebuilder ths1, in which we only write about 460 lines of code. Give it a try!

- 07.ths-codegen extends our treebuilder, adding semantic checking (eg. checking that we define every function we call) and then code generation - translating THS to C!
- How do we do semantic checks? A semantic checker either walks the AST, or builds and iterates over equivalent data structures.
- In fact, to reduce tree-walking, we enhanced parser.y to create a hash and a set as well: the funchash maps from a defined functionname to it's AST representation. The callset names all called functions.
- The Semantic checker then iterates through the callset checking that each called function is present in the funchash.
- How do we do code generation? A code generator is just another AST and funchash walker, one with suitable print statements!
- In fact, using datadec's print hints mechanism, 80% of the C code generation was done by making each AST type print itself in valid C form. The remaining 20% (approx 130 lines) was custom C code, mainly building and sorting an array of functions, then invoking datadec-generated print_TYPE() functions.

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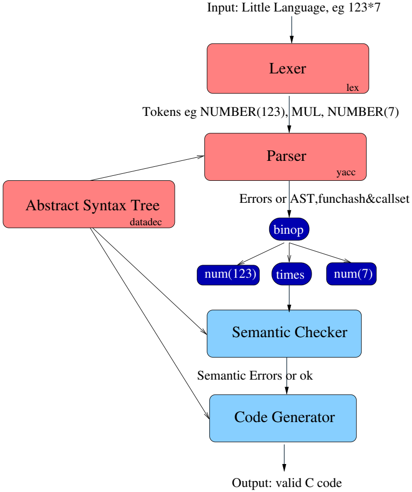

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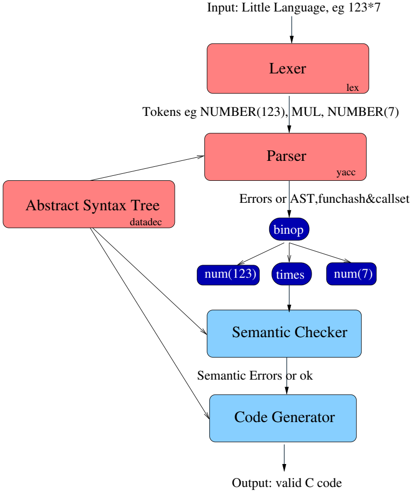

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- Our Parser (constructed for us by Yacc) checks whether the token stream matches the grammar,

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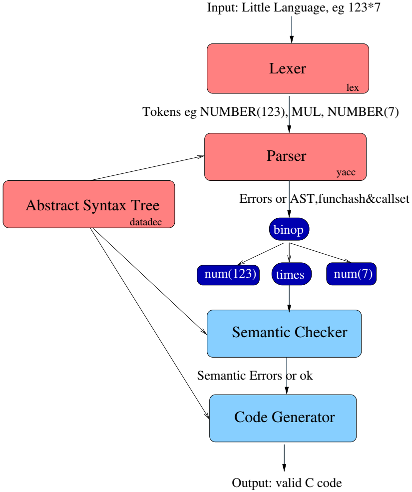

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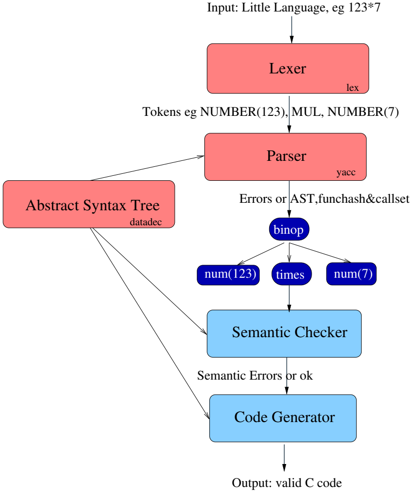

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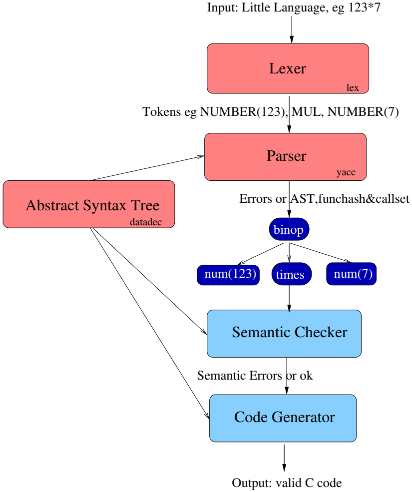

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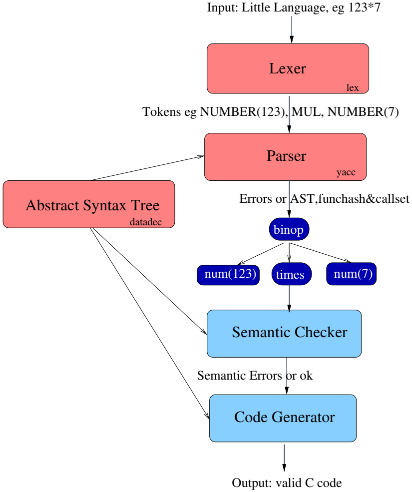

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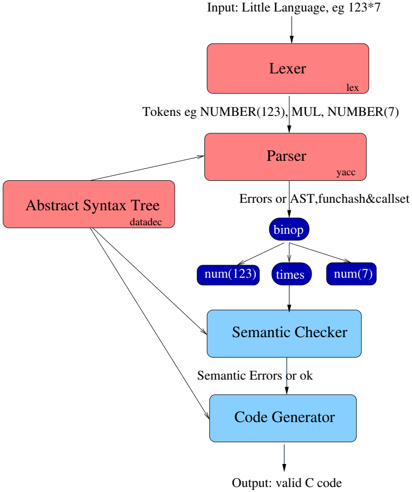

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- So, Yacc and Lex and Datadec are a scalable way of building translators for little languages, vital tools for your toolbox.
- In order to completely make sense of how they all fit together, with the `%union` and the `%type <f>` and `%token <f>` syntax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

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- But there's a lot of "do-nothing" work going on here.
- Is there any way of avoiding this?

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- In 08.cm-translator you'll find a Perl script called CM that grafts a simple "C with Modules" syntax onto the front of C. An example tiny.cm CM input file:

```
//  tiny "C+Module" example: a 100 element array type and one operation on it
#include <stdio.h>
#include <stdbool.h>
%pubconst MAXELEMENTS 100
%defn
{
        typedef int array[MAXELEMENTS];
}
%pubfunc bool ok = initialize( array x )
        initialize an array, did it work?
{
        for( int i=0; i<MAXELEMENTS; i++ )
        {
                x[i] = 0;
        }
        return true;
}
```

- CM turns this into a complete plain C module - tiny.c and tiny.h. See intstack.cm for a bigger example.

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