C Programming Tools: Part 4

Building and Using your own Toolkit

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- Specifically, by using Parser and Lexer Generator tools: Yacc and Lex.
- As always, there's a tarball of examples associated with this lecture. The handout and tarballs are available on CATE and at:
  `http://www.doc.ic.ac.uk/~dcw/c-tools-2017/lecture4/`

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- With Lex, specify the tokens as regular expression/action pairs:

```
[0-9]+                  return NUMBER;
\+                      return PLUS;
-                       return MINUS;
\*                      return MUL;
\/                      return DIV;
mod                     return MOD;
\(                      return OPEN;
\)                      return CLOSE;
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.                       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 C code via: lex -o lexer.c lexer.l.

- These tokens can be combined to form expressions using the following BNF-style grammar rules (in Yacc-format):

```
%token PLUS MINUS MUL DIV MOD OPEN CLOSE TOKERR
%token NUMBER

%start here
%%
here          : expr
              ;
expr          : expr PLUS term
              | expr MINUS term
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- You can now compile and link parser.c and lexer.c to form expr1, just type make. See the Makefile for details. expr1 is a recognizer: it will say whether or not the expression (on standard input) is valid.

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- Add actions to grammar rules taking the calculated value from each sub-part and computing the result, plus a top level action which sets expr_result. Here's a sample:

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here         : expr              { expr_result = $1; }
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expr         : expr PLUS term    { $$ = $1 + $3; }
             | expr MINUS term   { $$ = $1 - $3; }
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- After make we have expr2, an expression calculator. Play with it.

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- Ok, what Haskell subset? Specifically, we'll allow:
  - Zero-or-more function definitions, with optional type definitions,
  - Followed by a compulsory integer expression (often a call to one of those functions).
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- For example:

```
f x = 1

abs x | x>0  = x
      | x==0 = 0
      | 0>x  = 0-x

f(20) + abs(10) * 30
```

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  - Each function takes and returns a single integer value,
  - Each function implemented either by a single expression, or
  - A sequence of guarded expressions involving simple boolean expressions, eg. `x==0`,
- For example:

```
f x = 1

abs x | x>0  = x
      | x==0 = 0
      | 0>x  = 0-x

f(20) + abs(10) * 30
```

- In a break with strict Haskell-syntax, we'll decide that brackets on function calls like `abs(10)` are compulsory.

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[0-9]+              yylval.n=atoi(yytext); return NUMBER;
mod                 return MOD;
Int                 return INTTYPE;
True                return TRUEV;
[a-z][a-z0-9]*      yylval.s=strdup(yytext);return IDENT;
::                  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;
[ \t\n]+            /* ignore whitespace */;
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- Note that we are being extremely minimal with our tokens, including (for example) True but not False. These can trivially be added.

- As usual, our grammar and (Datadec-generated) AST intertwine, 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 );
```

- In parser.y, here's our `%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;
}
```

- Here are some of the declarations that associate tokens and grammar rules with specific members of the union:

```
%token <n> NUMBER
%token <s> IDENT
%type <e> factor term expr
%type <b> bexpr
%type <g> guard;
...
```

- Let's look at a few grammar rules to give a flavour:

```
program      :  defns expr      { prog_result = program_pair( $1, $2 ); }
             ;
defns        :  /* empty */     { $$ = flist_nil(); }
             | defns ftypedefn   { $$ = $1; /* ignore type defns */ }
             | defns fdefinition { $$ = flist_cons( $2, $1 ); }
             ;
ftypedefn    : IDENT COLONCOLON type IMPLIES type { free_string( $1 ); }
             ;
type         : INTTYPE
             ;
fdefinition  : IDENT IDENT IS expr { $$ = fdefn_onerule( $1, $2, $4 ); }
             | IDENT IDENT guardrules
               {
                         guardlist rightorder = reverse_guardlist($3);
                         $$ = fdefn_manyrules( $1, $2, rightorder );
                         free_guardlist_without_guard( $3 );
               }
             ;
guardrules   : guard             { $$ = guardlist_cons($1, guardlist_nil()); }
             | guardrules guard { $$ = guardlist_cons( $2, $1 ); }
             ;
...
```

- Note that recursive rules in Yacc, such as:

```
guardrules   : guardrules guard
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- I've attempted to free() everything I malloc(), checking with valgrind. The reversing exposes a shared pointers subtlety: we build a new guardlist with the same heads (guards) as the original list. We must only free each guard once!
- To fix this, we had to add free_guardlist_without_guard() to the prelude, and call it from the above Yacc action to free the original guardlist.
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- free_guardlist_without_guard() is a copy of the automatically generated free_guardlist() function, with the free_guard(head) call commented out.
- Putting it altogether, adding named constants (via the hash module), using datadec and our macro tool from the previous lecture, we end up with a THS (Tiny Haskell subset) parser and treebuilder, of 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 involves walking the AST and building convenient data structures. We create a hash and a set: the hash maps from functionname to AST function definition (for every defined function); the set names all called functions. Then we check that every called function is defined, exactly once.
- How do we do code generation? A code generator is just another ASTwalker, 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% was custom C code, mainly printing boilerplate and then invoking datadec-generated print_TYPE() functions.

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- That's all folks!