C Programming Tools: Part 3

Building your own Tools

Duncan C. White
d.white@imperial.ac.uk

Dept of Computing,
Imperial College London

The handout and tarballs are available on materials.doc.ic.ac.uk and at:

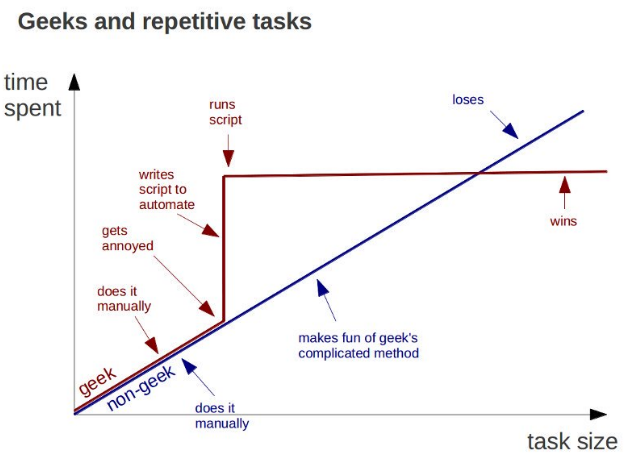
http://www.doc.ic.ac.uk/~dcw/c-tools-2021/lecture3/

- So far, most tools we've covered have already existed (not all though).
- But I said at the beginning: When necessary: don't be afraid to build your own tools!
- And I meant it!

Today, we're going to cover building tools at a range of scales:

- Tiny: Building shortlived tools on the fly.
- Medium: Generating prototypes automatically: proto.
- Large: Reusable ADT modules: hashes, sets, lists, trees etc.
- Large: Generating ADT modules automatically.

- The Pragmatic Programmers exhort us to: Learn a Text Manipulation Language (tip 28) - such as Perl - and Write Code that Writes Code (tip 29).
- Let's see an example of those tips together, remembering..



- Suppose we find ourselves writing hundreds of repetitive "pattern instances" like this:

```
int plus( int a, int b ) { return (a+b); }
int minus( int a, int b ) { return (a-b); }
int times( int a, int b ) { return (a*b); }
...
```

- If we need to write 10 of them - do it in your favourite programmer's editor using clone-and-alter.
- What if we need to write 50 of them? Or 100 of them? Or 100 int functions and another 100 double functions?
- Are we bored yet? Is clone-and-alter too error-prone? Then why not..
- Generate such function instances automatically using a shortlived tool, scaffolding that you build on demand, use a few times, then discard:
- Clearly, all that varies from instance to instance is (funcname,operator), eg. (plus,+).
- Let's assume the input format is an F,Op pair. In C terms, the corresponding output would be produced by:

```
printf( "int %s( int a, int b ) { return (a%sb); }\n", F, Op )
```

- Simple job for a scripting language like Perl.
- Here's a Perl oneliner I composed in a minute or two:

```
perl -nle '($f,$op)=split(/,/); printf "int %s( int a, int b ) { return (a%sb); }\n", $f, $op' < input
```

- The basic structure:

```
perl -nle 'PERL CODE' < input
```

  means execute that chunk of Perl code for every line of the input.
- The Perl code:

```
($f,$op)=split(/,/)
```

  means split the current line on "," into two strings, storing the part before the comma into the variable $f, and the part after the comma into $op.
- The Perl code:

```
printf "int %s( int a, int b ) { return (a%sb); }\n", $f, $op
```

  should be understandable to any C programmer (as Perl takes printf from C).
- Don't want to do it in Perl? (weirdo). Then use a different tool! (Ruby, Python, Awk, Bash).
- I wrote it in C in 15 minutes using standard library function strtok() to split on comma: See 01.tiny-tool/genfuncs1.c.

- Note that our tool doesn't have to be perfect; just good enough to save us time.
- Once you have a tiny tool, don't be afraid to modify it:
- Left-justify the function names in a field of some suitable width:

```
perl -nle '($f,$op)=split(/,/); printf "int %-15s( int a, int b ) { return (a%sb); }\n", $f, $op' < input
```

- Or, prefix the typename onto function names, eg. `int_plus`:

```
perl -nle '($f,$op)=split(/,/); printf "int %-15s( int a, int b ) { return (a%sb); }\n", "int_".$f, $op' < i
```

- Why not let the user change the type at any point in the input:

```
TYPE,int
plus,+
minus,-
TYPE,double
plus,+
minus,-
```

  generates:

```
int    int_plus      ( int a, int b ) { return (a+b); }
int    int_minus     ( int a, int b ) { return (a-b); }
double double_plus   ( double a, double b ) { return (a+b); }
double double_minus  ( double a, double b ) { return (a-b); }
```


- To implement this, we'll need to treat lines where `$f eq "TYPE"` specially:

```
perl -nle '($f,$op)=split(/,/); if( $f eq "TYPE" ) { $t=$op; next; }
           printf "%s %-15s( %s a, %s b ) { return (a%sb); }\n", $t, $t."_".$f, $t, $t, $op' < input
```

- See 01.tiny-tool/genfuncs3.c for a C implementation.
- Final thought, instead of hardcoding the output format in the printf, we could replace TYPEs with TEMPLATEs in the input, for example:

```
TEMPLATE,int int_<0>( int a, int b ) { return (a<1>b); }
plus,+
minus,-
TEMPLATE,double double_<0>( double a, double b ) { return (a<1>b); }
plus,+
minus,-
```

- Here, the marker <0> means "replace this marker with the current value of the first field". Our Perl one-liner becomes more powerful but shorter:

```
perl -nle '@f=split(/,/,$_,2); if( $f[0] eq "TEMPLATE" ) { $t=$f[1]; next; }
          $_=$t; s/<(\d+)>/$f[$1]/g; print' < input
```

- This is now a simple template processor. See `01.tiny-tool/README` for further extensions, allowing any number of marker fields, and how to turn our one-liner into a proper command with a man page (install it via `make install`).

- Let's move on to an example medium scale tool I built.
- While developing C code, you may find certain things irritate you.
- The Pragmatic Programmers describe such things as broken windows, and tell us - in tip 4 - Don't live with broken windows. Find a way to fix the problem!
- One particular thing irritated me some years ago: keeping the prototype declarations in .h files in sync with the function definitions in the paired .c files that form modules.
- Whenever you add a public function to intlist.c you need to remember to add the corresponding prototype to intlist.h.
- Even adding or removing parameters to existing functions means you need to make a corresponding change in the prototype too. What a pain!
- The problem here is that there's a lot of repetition between the .c file and the .h file. This violates the single most important Pragmatic Programmers tip:
  DRY - Don't Repeat Yourself (tip 11).

- So let's generate the prototypes from the function definitions. Does a tool exist to do this? Couldn't find one at the time. So: write a tool to solve this problem, then integrate it into our editor for convenience!
- So I wrote proto to do this: It reads a C file looking for function definitions, and produces a prototype for each function.
- But this sounds pretty hard. Don't we need a complete C parser?
- I found an easier way. I imposed LIMITATIONS on my layout approach to make the tool easier to construct: I decided that the whole function heading must be placed on one line, and also that the function heading could only use simple type declarations eg. `typename [**..] paramname` (use typedef for complex declarations). New this year: `const` is supported as a simple prefix on parameter declarations.
- Then I wrote a vi macro bound to an unused key that piped the next paragraph into proto % (current filename). Let's see **proto** in action!
- See `http://www.doc.ic.ac.uk/~dcw/PSD/article4/` for an

- Most problems are made a lot easier by having a library of trusted reusable ADT modules:
  - indefinite length dynamic strings
  - indefinite length dynamic arrays
  - linked lists (single or double linked)
  - stacks (can just use lists)
  - queues and priority queues
  - binary trees
  - hashes (aka maps/dictionaries/associative arrays).
  - sets of strings - several possible implementations.
  - bags - frequency hashes, mapping strings to integers.
- Unlike C++, the C standard library fails to provide any of the above. So, either find a collection of such modules that others have written, or build them yourself as and when you need them, and reuse them at every opportunity.
- Note: Reuse can be done without OO or generics, *Make it Easy to Reuse* (PP Tip 12) - in C, use `void *` for generic pointers, and use pointers to functions for callbacks.

- To get you started, **tarball 03.adts** includes a group of half a dozen ADTs (plus unit test programs) that I've written over the years, plus a Makefile to package them as the libADTs.a library.
- You will recognise a couple: our running example intlist.[ch] and our old friend hash.[ch], after Lecture 2's memory-leak fixes and profiling-led optimizations.
- Investigate them all at your own leisure - but make install them now so they're installed in your TOOLDIR (`~/c-tools`) directory.
- Next, **tarball 04.hash-set.eg** contains an example application that uses some of those ADTs, specifically:
  - Hashes and Sets of strings,
  - Then combines them to represent family information, i.e. a mapping from a named parent to set of named children.
  - It's left for you to examine and play with.
- C+hashes+sets makes it easy to pretend that you're programming in Perl:-)
- Note also **tarball 05.utils** contains a couple of reusable utility

include a .ini file parser too; but I've never needed one:-) Do

- Principle: It's often an excellent idea to import cool features from other languages.
- Many years ago, I realised that one of the best features of functional programming languages such as Haskell is the ability to define inductive data types, as in:

  `intlist = nil or cons( int head, intlist tail );`
- I'd dearly love to have that ability in C.
- If only there was a tool that reads such type definitions and automatically writes a C module that implements them..
- I looked around, *but I couldn't find one*. Noone seemed to have ever suggested that such a tool could be useful!
- Decision time: do I abandon my brilliant idea, or build the tool?
- Cost/benefit analysis: a serious tool, a mini-compiler (with parser, lexical analyser, data structures, tree walking code generator): at least a week's work! Think hard!

- I built the tool! After a fortnight's work, the result was datadec - in the 06.datadec directory (also installed throughout DoC labs). After installing it, use as follows:
- In 07.datadec-eg you'll find an input file types.in containing:

```
TYPE {
        intlist =  nil or cons( int head, intlist tail );
        tree    =  leaf( string name )
                   or node( tree left, tree right );
}
```

- To generate a C module called datatypes from types.in, invoke:

```
datadec datatypes types.in
```

- This creates datatypes.c and datatypes.h, two normal looking C files, you can read them, write test programs against the interface, use them in production code with no license restrictions. But don't modify these files - if you do then you can't...
- ... change types.in later - suppose you realise that a tree node also needs to store a name (just as the leaves do). Change the type defn, rerun datadec. The `tree_node()` constructor now takes 3 arguments!

- Let's look inside datatypes.h, to find what tree functions datadec generates, and how to use them.
- There are two constructor functions, one for each *shape of tree*:

```
extern tree tree_leaf( string name );
extern tree tree_node( tree l, tree r );
```

- So, this allows us to build trees as in:

```
tree t1 = tree_leaf( "absolutely" );
tree t2 = tree_leaf( "fabulous" );
tree t = tree_node( t1, t2 );
```

- Then a function telling you which shape a tree is: is it a leaf or a node?

```
typedef enum { tree_is_leaf, tree_is_node } kind_of_tree;
extern kind_of_tree tree_kind( tree t );
```

- Then two deconstructor functions which, given a tree of the appropriate shape, breaks it into it's constituent pieces:

```
extern void get_tree_leaf( tree t, string *namep );
extern void get_tree_node( tree t, tree *lp, tree *rp );
```


- These allow you to write tree-walking code like this leaf-counter:

```
int nleaves( tree t )
{
    if( tree_kind(t) == tree_is_leaf )
    {
        string name; get_tree_leaf( t, &name );
        return 1;             // leaf( name ): contains 1 leaf.
    } else
    {
        tree l, r; get_tree_node( t, &l, &r );
        // node( l, r ): process l and r trees.
        return nleaves(l) + nleaves(r);
    }
}
```

- In Haskell, this'd be:

```
nleaves(leaf(name)) = 1
nleaves(node(l,r))  = nleaves(l) + nleaves(r)
```


- The final function prints a tree to a writable file handle, in human readable format:

```
extern void print_tree( FILE *out, tree t );
```

- To see all the above in use, see `mintesttree.c`.
- By default, datadec does not generate free functions. Why? Hard to do right due to shallow vs deep considerations.
- You can now run datadec -f.. to get experimental free_TYPE() functions, although you still have to be careful using these - see the README file for details.
- Looking back, I now view the fortnight I spent building datadec (and, more recently, the day or two adding free_TYPE() support) as the single best investment of programming time in my career. I have saved hundreds of days programming time using it - and so can you!
- You can read a 3-part article I wrote about how I designed datadec here:

  `http://www.doc.ic.ac.uk/~dcw/PSD/article8/`

Remember:

(and learn Perl, it's great!)