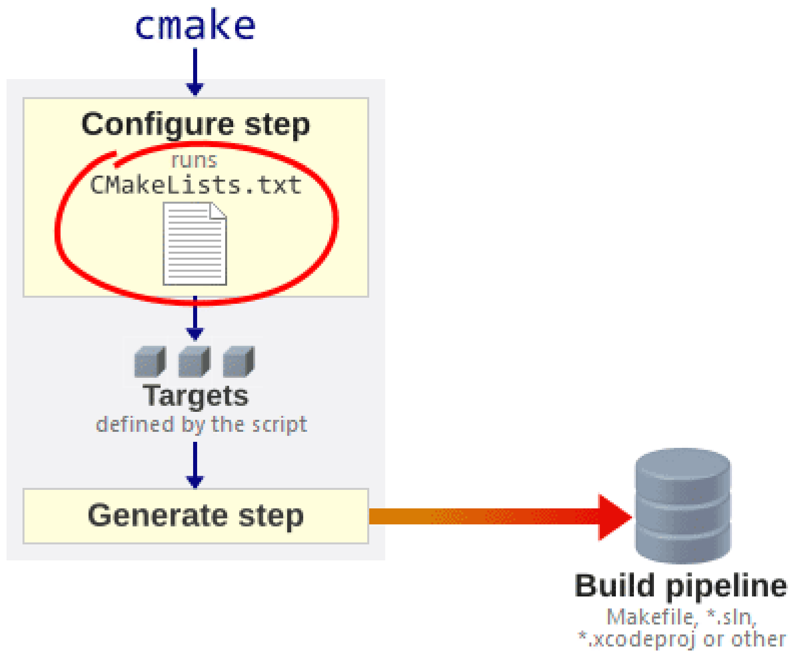
May 22, 2017

Learn CMake's Scripting Language in 15 Minutes

As explained in my previous post, every CMake-based project must contain a script named `CMakeLists.txt`. This script defines **targets**, but it can also do a lot of other things, such as finding third-party libraries or generating C++ header files. CMake scripts have a lot of flexibility.



Every time you integrate an external library, and often when adding support for another platform, you'll need to edit the script. I spent a long time editing CMake scripts without *really* understanding the language, as the documentation is quite scattered, but eventually, things clicked. The goal of this post is to get you to the same point as quickly as possible.

This post won't cover all of CMake's built-in commands, as there are hundreds, but it is a fairly complete guide to the **syntax** and **programming model** of the language.

Hello World

If you create a file named `hello.txt` with the following contents:

```
message("Hello world!")         # A message to print
```

…you can run it from the command line using `cmake -P hello.txt`. (The `-P` option runs the given script, but doesn't generate a build pipeline.) As expected, it prints "Hello world!".

```
$ cmake -P hello.txt
Hello world!
```

All Variables Are Strings

In CMake, every variable is a string. You can substitute a variable inside a string literal by surrounding it with `${}`. This is called a **variable reference**. Modify `hello.txt` as follows:

```
message("Hello ${NAME}!")       # Substitute a variable into the message
```

Now, if we define `NAME` on the `cmake` command line using the `-D` option, the script will use it:

```
$ cmake -DNAME=Newman -P hello.txt
Hello Newman!
```

When a variable is undefined, it defaults to an empty string:

```
$ cmake -P hello.txt
Hello !
```

To define a variable inside a script, use the `set` command. The first argument is the name of the variable to assign, and the second argument is its value:

```
set(THING "funk")
message("We want the ${THING}!")
```

Quotes around arguments are optional, as long as there are no **spaces** or **variable references** in the argument. For example, I could have written `set("THING" funk)` in the first line above – it would have been equivalent. For most CMake commands (except `if` and `while`, described below), the choice of whether to quote such arguments is simply a matter of style. When the argument is the name of a variable, I tend not to use quotes.

You Can Simulate a Data Structure using Prefixes

CMake does not have classes, but you can simulate a data structure by defining a group of variables with names that begin with the same prefix. You can then look up variables in that group using nested `${}` variable references. For example, the following script will print "John Smith lives at 123 Fake St.":

```
set(JOHN_NAME "John Smith")
set(JOHN_ADDRESS "123 Fake St")
set(PERSON "JOHN")
message("${${PERSON}_NAME} lives at ${${PERSON}_ADDRESS}.")
```

You can even use variable references in the name of the variable to set. For example, if the value of `PERSON` is still "JOHN", the following will set the variable `JOHN_NAME` to "John Goodman":

```
set(${PERSON}_NAME "John Goodman")
```

Every Statement is a Command

In CMake, every statement is a command that takes a list of **string arguments** and has **no return value**. Arguments are separated by (unquoted) spaces. As we've already seen, the `set` command defines a variable at file scope.

As another example, CMake has a `math` command that performs arithmetic. The first argument must be `EXPR`, the second argument is the name of the variable to assign, and the third argument is the expression to evaluate – all strings. Note that on the third line below, CMake substitutes the *string* value of `MY_SUM` into the enclosing argument before passing the argument to `math`.

```
math(EXPR MY_SUM "1 + 1")                   # Evaluate 1 + 1; store result in MY_SUM
message("The sum is ${MY_SUM}.")
math(EXPR DOUBLE_SUM "${MY_SUM} * 2")       # Multiply by 2; store result in DOUBLE_SUM
message("Double that is ${DOUBLE_SUM}.")
```

There's a CMake command for just about anything you'll need to do. The `string` command lets you perform advanced string manipulation, including regular expression replacement. The `file` command can read or write files, or manipulate filesystem paths.

Flow Control Commands

Even flow control statements are commands. The `if`/`endif` commands execute the enclosed commands conditionally. Whitespace doesn't matter, but it's common to indent the enclosed commands for readablity. The following checks whether CMake's built-in variable `WIN32` is set:

```
if(WIN32)
    message("You're running CMake on Windows.")
endif()
```

CMake also has `while`/`endwhile` commands which, as you might expect, repeat the enclosed commands as long as the condition is true. Here's a loop that prints all the Fibonacci numbers up to one million:

```
set(A "1")
set(B "1")
while(A LESS "1000000")
    message("${A}")                 # Print A
    math(EXPR T "${A} + ${B}")      # Add the numeric values of A and B; store result in T
    set(A "${B}")                   # Assign the value of B to A
    set(B "${T}")                   # Assign the value of T to B
endwhile()
```

CMake's `if` and `while` conditions aren't written the same way as in other languages. For example, to perform a numeric comparison, you must specify `LESS` as a string argument, as shown above. The documentation explains how to write a valid condition.

`if` and `while` are different from other CMake commands in that if the name of a variable is specified without quotes, the command will use the variable's value. In the above code, I took advantage of that behavior by writing `while(A LESS "1000000")` instead of `while("${A}" LESS "1000000")` – both forms are equivalent. Other CMake commands don't do that.

Lists are Just Semicolon-Delimited Strings

CMake has a special substitution rule for **unquoted** arguments. If the entire argument is a variable reference without quotes, and the variable's value contains **semicolons**, CMake will split the value at the semicolons and pass **multiple arguments** to the enclosing command. For example, the following passes three arguments to `math`:

```
set(ARGS "EXPR;T;1 + 1")
math(${ARGS})                                 # Equivalent to calling math(EXPR T "1 + 1")
```

On the other hand, **quoted** arguments are never split into multiple arguments, even after substitution. CMake always passes a quoted string as a single argument, leaving semicolons intact:

```
set(ARGS "EXPR;T;1 + 1")
message("${ARGS}")                            # Prints: EXPR;T;1 + 1
```

If more than two arguments are passed to the `set` command, they are joined by semicolons, then assigned to the specified variable. This effectively creates a list from the arguments:

```
set(MY_LIST These are separate arguments)
message("${MY_LIST}")                            # Prints: These;are;separate;arguments
```

You can manipulate such lists using the `list` command:

```
set(MY_LIST These are separate arguments)
list(REMOVE_ITEM MY_LIST "separate")             # Removes "separate" from the list
message("${MY_LIST}")                            # Prints: These;are;arguments
```

The `foreach`/`endforeach` command accepts multiple arguments. It iterates over all arguments except the first, assigning each one to the named variable:

```
foreach(ARG These are separate arguments)
    message("${ARG}")                            # Prints each word on a separate line
endforeach()
```

You can iterate over a list by passing an unquoted variable reference to `foreach`. As with any other command, CMake will split the variable's value and pass multiple arguments to the command:

```
foreach(ARG ${MY_LIST})                          # Splits the list; passes items as arguments
    message("${ARG}")                            # Prints each item on a separate line
endforeach()
```

Functions Run In Their Own Scope; Macros Don't

In CMake, you can use a pair of `function`/`endfunction` commands to define a function. Here's one that doubles the numeric value of its argument, then prints the result:

```
function(doubleIt VALUE)
    math(EXPR RESULT "${VALUE} * 2")
    message("${RESULT}")
endfunction()

doubleIt("4")                            # Prints: 8
```

Functions run in their own scope. None of the variables defined in a function pollute the caller's scope. If you want to return a value, you can pass the name of a variable to your function, then call the `set` command with the special argument `PARENT_SCOPE`:

```
function(doubleIt VARNAME VALUE)
    math(EXPR RESULT "${VALUE} * 2")
    set(${VARNAME} "${RESULT}" PARENT_SCOPE)     # Set the named variable in caller's scope
endfunction()

doubleIt(RESULT "4")                     # Tell the function to set the variable named RESULT
message("${RESULT}")                     # Prints: 8
```

Similarly, a pair of `macro`/`endmacro` commands defines a macro. Unlike functions, macros run in the same scope as their caller. Therefore, all variables defined inside a macro are set in the caller's scope. We can replace the previous function with the following:

```
macro(doubleIt VARNAME VALUE)
    math(EXPR ${VARNAME} "${VALUE} * 2")         # Set the named variable in caller's scope
endmacro()

doubleIt(RESULT "4")                     # Tell the macro to set the variable named RESULT
message("${RESULT}")                     # Prints: 8
```

Both functions and macros accept an arbitrary number of arguments. Unnamed arguments are exposed to the function as a list, though a special variable named `ARGN`. Here's a function that doubles every argument it receives, printing each one on a separate line:

```
function(doubleEach)
    foreach(ARG ${ARGN})                # Iterate over each argument
        math(EXPR N "${ARG} * 2")       # Double ARG's numeric value; store result in N
        message("${N}")                 # Print N
    endforeach()
endfunction()

doubleEach(5 6 7 8)                     # Prints 10, 12, 14, 16 on separate lines
```

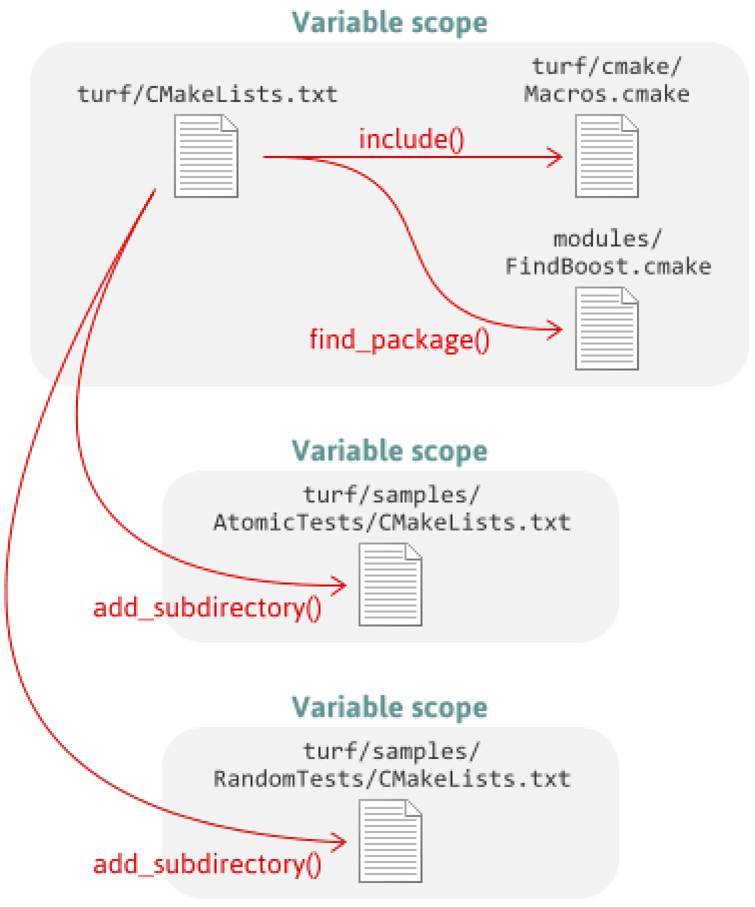
Including Other Scripts

CMake variables are defined at file scope. The `include` command executes another CMake script in the **same scope** as the calling script. It's a lot like the `#include` directive in C/C++. It's typically used to define a common set of functions or macros in the calling script. It uses the variable `CMAKE_MODULE_PATH` as a search path.

The `find_package` command looks for scripts of the form `Find*.cmake` and also runs them in the same scope. Such scripts are often used to help find external libraries. For example, if there is a file named `FindSDL2.cmake` in the search path, `find_package(SDL2)` is equivalent to `include(FindSDL2.cmake)`. (Note that there are several ways to use the `find_package` command – this is just one of them.)

CMake's `add_subdirectory` command, on the other hand, creates a **new scope**, then executes the script named `CMakeLists.txt` from the specified directory in that new scope. You typically use it to add another CMake-based subproject, such as a library or executable, to the calling project. The targets defined by the subproject are added to the build pipeline unless otherwise specified. None of the variables defined in the subproject's script will pollute the parent's scope unless the `set` command's `PARENT_SCOPE` option is used.

As an example, here are some of the scripts involved when you run CMake on the Turf project:



Getting and Setting Properties

A CMake script defines **targets** using the `add_executable`, `add_library` or `add_custom_target` commands. Once a target is created, it has **properties** that you can manipulate using the `get_property` and `set_property` commands. Unlike variables, targets are visible in every scope, even if they were defined in a subdirectory. All target properties are strings.

```
add_executable(MyApp "main.cpp")        # Create a target named MyApp

# Get the target's SOURCES property and assign it to MYAPP_SOURCES
get_property(MYAPP_SOURCES TARGET MyApp PROPERTY SOURCES)

message("${MYAPP_SOURCES}")             # Prints: main.cpp
```

Other target properties include `LINK_LIBRARIES`, `INCLUDE_DIRECTORIES` and `COMPILE_DEFINITIONS`. Those properties are modified, indirectly, by the `target_link_libraries`, `target_include_directories` and `target_compile_definitions` commands. At the end of the script, CMake uses those target properties to generate the build pipeline.

There are properties for other CMake entities, too. There is a set of directory properties at every file scope. There is a set of global properties that is accessible from all scripts. And there is a set of source file properties for every C/C++ source file.

Congratulations! You now know the CMake scripting language – or at least, it should be easier to understand large scripts using CMake's command reference. Otherwise, the only thing missing from this guide, that I can think of, is generator expressions. Let me know if I forgot anything else!

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Andrew · *19 weeks ago*

Thank you this is exactly what I have been looking for!

Reply

Cristian · *19 weeks ago*

Regarding CMake documentation, one could also give https://devdocs.io/cmake~3.8/ a try.

Reply

Andreas Weis · *19 weeks ago*

Excellent overview, this is really useful for people writing their CMake on their own for the first time. Thanks for that!

Minor nitpick: There are actually cases where it does matter whether you explicitly dereference variables in an if() or while() condition. See this StackOverflow answer for details: https://stackoverflow.com/a/25809646/577603

My personal advice would be to never dereference variables explicitly here, as it can lead to surprising results which are almost never the intended behavior.

Reply **1 reply** · *active 19 weeks ago*

Jeff Preshing · *19 weeks ago*

That's good advice. Stick with the variable name itself, unquoted, when writing conditions.

Reply

Dave Ryan · *19 weeks ago*

Thank you so much for this article. I've been wanting a smoother introduction to CMake scripting. I bought the book but it appears to be several versions old; do you know if they will be updating the book. I didn't like the books bindings; the pages appeared to fall out to easily. Thanks again.

Dave Ryan

Reply [1 reply](#) · *active 19 weeks ago*

[Jeff Preshing](#) · *19 weeks ago*

Sorry your book is falling apart! I hope this post filled in some of the blanks for you.

Reply

Anton · *18 weeks ago*

Cool and really 15min long introduction! Another interesting thing (and different from general purpose languages) to cover would be cached variables.

Reply

Spencer · *10 weeks ago*

This was great. Thanks.

Reply

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