

EECS 281 – Spring 2018

Programming Project 1

Letterman Reboot

(Path Finding)



Due Tuesday, May 8 11:59 PM

Overview

The evil Spell Binder is loose, and it's up to [Letterman](#) to save us! Letterman hasn't been very active lately, and his power of changing one word into another by changing only one letter needs upgrading. Yes, in the old days he could change "[tickle](#)" into "[pickle](#)", but can this new Letterman 2.0 change "evil" into "good"? Only you can say!

Program Input

You must help Letterman navigate through the Spell Binder's word traps. You will be given a starting and ending word, and a dictionary to search. The starting and ending words, and any other necessary flags, will be given on the command line when the program is run.

Input file format (The Dictionary)

The program gets its dictionary from a file that will be read from standard input (`cin`). There are two different types of dictionaries that the program needs to be compatible with: complex (`C`) and simple (`S`).

For both dictionaries, the first line will be a single character specifying the dictionary type '`C`' or '`S`'. **Unlike the output mode, which is given on the command line (see below), this is part of the file.** The second line will be a single positive integer `N` indicating the number of lines in the dictionary not counting the first line and lines that are comments (i.e. for simple dictionaries, the number of words, and for complex dictionaries, the number of word-generating lines).

We do not place a limit on the magnitude of `N` and neither should your code.

Comments may also be included in any input file. Comment lines begin with "`//`" (without quotes) in column 1, and are allowed anywhere in the file after the second line. When

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developing your test files, it is good practice to place a comment on line 3 describing the nature of the dictionary in the test file. Any dictionaries with noteworthy characteristics for testing purposes should also be commented. *You should discard all existing comments from the input file; do not save them in memory as part of your data structures.*

Additionally, there may be extra blank/empty lines at the end of any input file: your program should ignore them. If you see a blank line in the file, you may assume that you have hit the end.

Simple Dictionary

The first type of dictionary that your program needs to handle is the simple dictionary. This is a simple text file specifying the words in the dictionary, one word per line. Each “word” will be a sequence of alphabetic characters.

Each word in the dictionary is unique; there will never be two copies of the same word.

Here is a valid input file:

```
S
10
// Just a short example dictionary.  Although these words
// are in alphabetical order, that is not required.
chip
chop
junk
leet
let
shin
ship
shop
shot
stop
```

Complex Dictionary

The second type of dictionary that your program needs to handle is a complex dictionary. Like the simple dictionary, there will be one string per line. However, in this dictionary, each line could be a simple alphabetic string, like the simple dictionary, or it could contain special characters. If a line contains special characters, then it will be used to generate alphabetic words that are a part of the dictionary. **Each line will contain at most one special character** (except in the case of insert-each, where a pair of square brackets counts as one special character).

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Here are the special characters that may be included:

- **Reversal (&):** If an ampersand appears at the end of the word, then both the word and the reversal of the word are generated, in that order. An ampersand will not appear in the middle of a word.
 - Example: “desserts&” - both “desserts” and “stressed” are generated
- **Insert-each ([]):** If a set of characters appears inside square brackets, each character is inserted into the word, generating N words in the order of the letters, where N is the number of characters within the square brackets. There will not be square brackets without letters within them and there will not be duplicate letters.
 - Example: “tre[an]d” - “tread” and “trend” are generated, in that order
 - Example: “c[auo]t” - “cat”, “cut”, and “cot” are generated, in that order
- **Swap (!):** If an exclamation point appears after two characters, then the original string and the string with the two previous characters swapped are generated, in that order. An exclamation point will only occur if at least two characters precede it.
 - Example: “bar!d” - “bard” and “brad” are generated
- **Double (?):** If a question mark appears after one character, then the original string and the string with the one previous character doubled are generated, in that order. A question mark will only occur if at least one character precedes it.
 - Example: “le?t” - “let” and “leet” are generated

Here is an example complex dictionary, with words similar to the previous simple dictionary:

```
C
7
//This generates the dictionary:
//chip, chop, junk, star, tsar, ship, shop,
//shot, stop, pots, let, leet
ch[io]p
junk
st!ar
sh[io]p
shot
stop&
le?t
```

Morph Modes

There are a few ways that Letterman can convert words to other words.

- **Change:** Letterman can change a single letter of a word
 - Example: he can turn “pun” into “fun”
- **Swap:** Letterman can swap any single pair of adjacent letters

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- Example: he can turn "brad" into "bard"
- **Insert:** Letterman can add a letter
 - Example: he can turn "stun" into "stunt"
- **Delete:** Letterman can remove a letter
 - Example: he can turn "boar" into "bar"

The modifications that Letterman is allowed to make will be determined by arguments on the command line.

Command line arguments

Your program should take the following case-sensitive command line options (when we say a switch is "set", it means that it appears on the command line when you call the program):

- **--stack, -s:** If this switch is set, use the stack-based routing scheme.
- **--queue, -q:** If this switch is set, use the queue-based routing scheme.
- **--change, -c:** If this switch is set, Letterman is allowed to change one letter into another.
- **--swap, -p:** If this switch is set, Letterman is allowed to swap any two adjacent characters.
- **--length, -l:** If this switch is set, Letterman is allowed to modify the length of a word, by inserting or deleting a single letter.
- **--output (W|M), -o (W|M):** Indicates the output file format by following the flag with a `W` (word format) or `M` (modification format). If the `--output` option is not specified, default to word output format (`W`). If `--output` is specified on the command line, the argument (either `W` or `M`) to it is required. See the examples below regarding use.
- **--begin <word>, -b <word>:** This specifies the word that Letterman starts with. This flag must be specified on the command line, and when it is specified a word must follow it.
- **--end <word>, -e <word>:** This specifies the word that Letterman must reach. This flag must be specified on the command line, and when it is specified a word must follow it.
- **--help, -h:** If this switch is set, the program should print a brief help message which describes what the program does and what each of the flags are. The program should then `exit(0)` or `return 0` from `main()`.

When we say `--stack`, or `-s`, we mean that calling the program with `--stack` does the same thing as calling the program with `-s`. See `getopt_long()` for how to do this.

Legal command line arguments must include exactly one of `--stack` or `--queue` (or their respective short forms `-s` or `-q`). If none are specified or more than one is specified, the program should print an informative message to standard error (`cerr`) and call `exit(1)`. A legal command line must specify at least one of `--change`, `--length`, and `--swap` or their respective short forms.

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Examples of legal command lines:

- `./letter --stack -b ship -e shot -l < infile`
 - This will run the program using a the stack algorithm and word output mode. The only modifications allowed on words are inserting/deleting letters, NOT changing one letter into another.
- `./letter -b ship -e shot -c --queue --output W < infile | more`
 - This will run the program using the queue algorithm, word output mode, and letters can only be changed into other letters.
 - Output is sent to the `more` program; press the spacebar after each page.
- `./letter --stack --output M -b ship -e shot --length --change < infile > outfile`
 - This will run the program using the stack algorithm, modification output mode, and letters can be changed, inserted, or deleted.

Examples of illegal command lines:

- `./letter --queue -s -b ship -e shot -c < infile > outfile`
 - Contradictory choice of routing
- `./letter -b ship -e shot -c < infile | more`
 - You must specify either stack or queue
- `./letter -s -b ship -e shot < infile > outfile`
 - You must specify at least one of change, length, and swap.

Routing schemes

You are to develop two routing schemes to help Letterman get from the starting word to the ending word:

- A queue-based routing scheme
- A stack-based routing scheme

In the routing scheme use a data structure (queue or stack) of words to check. First, initialize the algorithm by adding the starting word into the data structure. Then loop through the following steps:

1. Remove the next word from the data structure.
2. Add all words that are sufficiently similar to (as defined by the command line) the word you just removed that are available (not already considered). **Add any such words in the following order: beginning of dictionary to the end. Do not add words that have been added to the data structure before.**
3. As you add these words to the data structure, check to see if any of them is the ending word; if so, stop; else go back to step 1.

If the data structure becomes empty before you reach the ending word, the search has failed and there is no series of words to foil the Spell Binder's evil plan.

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Output file format

The program will write its output to standard output (`cout`), and there are two possible output formats. The output format will be specified through a command line option '`--output`', or '`-o`', which will be followed by an argument of `W` or `M` (`W` for word output and `M` for modification output). See the section on command line arguments below for more details.

For both output formats, you will show the path of words you took from start to finish. In both cases you should first print the number of words in the morph, and include the start word (see examples below).

Word output mode (W):

For this output mode, you should print each word. Beginning at the starting word, print the words in the morph until you reach the ending word.

For both the simple and complex dictionary sample inputs specified earlier, using the queue-based routing scheme and word (`W`) style output and trying to change “chip” into “stop”, you should produce the following output:

```
Words in morph: 4
chip
chop
shop
stop
```

Using the same input file but with the stack-based routing scheme, you should produce the following output:

```
Words in morph: 4
chip
ship
shop
stop
```

Modification output mode (M):

For this output mode, instead of printing each word, each line of output should be how to change from one word to the next. The start word should always be displayed. The

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modification lines which follow the start word have one of the following forms:

- `c,<position>,<letter>`
- `i,<position>,<letter>`
- `d,<position>`
- `s,<position>`

These four forms correspond to a letter changing (c), a letter being inserted (i), a letter being deleted (d), or two letters being swapped (s). The `<position>` always indicates the index of the modification (for swaps, the index of the first letter swapped), and the `<letter>` is the new letter (either changed to or inserted).

The following are examples of correct output format in (M) modification mode that reflect the same solution as the word output format above.

For the queue solution:

```
Words in morph: 4
chip
c,2,o
c,0,s
c,1,t
```

In the above output, it is saying to start with the word “chip”, change the letter at index 2 into o (producing chop), then change the letter at index 0 into s (producing shop), then change the letter at index 1 into t (producing stop).

For the stack solution:

```
Words in morph: 4
chip
c,0,s
c,2,o
c,1,t
```

There is only one acceptable solution per routing scheme for each dictionary and start/end word pair. If no valid morphing exists (such as trying to change “ship” into “junk”), the program should simply display “No solution, X words checked.” (without quotes) on a line by itself, instead of the “Words in morph” line. The X represents the number of words in the dictionary that were part of the search. A word has been “checked” if it was ever added to the stack or

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queue. For example, if you were trying to change “ship” into “junk”, simple dictionary with change mode on, the output would read “No solution, 7 words checked.”. This output will be the same for either word or morph output mode, and for either stack or queue mode.

Errors you must check for

A small portion of your grade will be based on error checking. You must check for the following errors:

- More or less than one `--stack/-s` or `--queue/-q` on the command line.
- No `--change/-c`, `--length/-l`, or `--swap/-p` on the command line.
- The `--output/-o` flag is followed by an invalid character.
- Either the start or end word is not specified, or does not exist in the dictionary.
- The `--change/-c` and/or `--swap/-p` flags are specified, but `--length/-l` is not, and the start/end words do not match in length (creating an impossible situation).

In all of these cases, print an informative error message to standard error (`cerr`) and call `exit(1)`. The autograder will not look at the actual text of the error message itself, but these error messages may help you while you’re debugging your program. Anyone on staff can look at your submission and tell you what error you displayed before the `exit(1)`. So if your program does an `exit(1)` but the autograder informs you it was a valid test case, come to office hours.

You do not need to check for any other errors.

Assumptions you may make

- The first line of the dictionary will contain either a capital letter `C` or `S` and that letter will correctly reflect the dictionary type.
- The second line of the dictionary will contain a number, and the number of words in the file will match that number (the file will contain that many words/word generating lines).
- Comments will begin with `//` as the first two characters on a line, and can have any number of words on that line. No comment will appear before the number of words on line 2.
- The number of words on line 2 does NOT include comment lines.
- A dictionary will not contain any duplicate words.
- Other than comment lines, the dictionary will have one word per line (thus words will never contain blank spaces).
- For complex dictionaries, special characters will not appear incorrectly (for example, the reversal symbol will not appear in the middle of a word).
- You do not have to consider upper- and lower-case versions of words to be the same (for example “a” and “A” are different words).

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Test Files

It is **extremely frustrating** to turn in code that you are "certain" is functional and then receive half credit. We will be grading for correctness primarily by running your program on a number of test cases. If you have a single bug that causes many of the test cases to fail, you might get a very low score on the project *even though you completed 95% of the work*. Most of your grade will come from correctness testing. Therefore, it is imperative that you test your code thoroughly. To help you do this we will require that you write and submit a suite of test files that thoroughly test this project.

Your test files will be used to test a set of buggy solutions to the project. Part of your grade will be based on how many of the bugs are exposed by your test files. We say a bug is *exposed* by a test file if the test file causes *our* buggy solution to produce different output from our correct solution.

Each test file should be a dictionary input file. Each test file should be named *test-n-start-end-flags.txt*, where $0 < n \leq 15$ for each test file. The *start* and *end* indicate the start/end words, and the *flags* portion should include a combination of letters which correspond to command line arguments. Valid letters in the *flags* portion of the filename are:

- s: Run stack mode
- q: Run queue mode
- c: Run in change mode
- l: Run in length mode
- p: Run in swap mode
- w: Produce word output
- m: Produce modification output

The *flags* that you specify as part of your test filename should allow us to produce a valid command line. For instance, don't include both s and q, but include one of them; include at least one of c, l and p; include at most one of w or m, but if you leave it off, we'll run in word output mode. For example, a valid test file might be named `test-1-ship-shot-scw.txt` (change from ship to shot, stack mode, change mode, word output). Given this test file name, we would run your program with a command line similar to the following (we might use long or short options, such as `--change` instead of `-c`):

```
./letter --begin ship -e shot --stack -c -o W < test-1-ship-shot-scw.txt > test-1-out.txt
```

Each dictionary may have no more than 20 words. You may submit up to 15 test files (though it is possible to get full credit with fewer test files). The dictionaries the autograder runs with your solution are **NOT** limited to 20 words; your solution should not impose any size limits (as long as

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sufficient system memory is available). Your complex dictionary might start with 20 words but produce more; that is still a valid dictionary.

Input and Output Redirection

We are using input and output redirection in some of the above examples. While we are reading our input from a file and sending our output to another file in this case, we are **NOT** using file streams! The `<` *redirects* the file specified by the next command line argument to be the standard input (`stdin/cin`) for the program. This is much easier than retyping the dictionary every time you run the program! The `>` *redirects* the output (to `stdout/cout`) of the program to be printed to the file specified by the next command line argument. The `|` *pipes* the output of your program to the input of the command that follows, such as `more` (which displays with page breaks). The operating system makes calls to `cin` to read the input file and it makes calls to `cout` to write to the output file. Come to office hours if this is confusing!

Runtime

The program must run to completion within 35 seconds of total CPU time (user + system). This is more time than you should need. See the `time` manpage for more information (this can be done in Unix by entering “man time” to the command line). We may test your program on very large dictionaries (up to several hundred thousand words). Be sure you are able to navigate to the end word in large dictionaries within 35 seconds. Smaller dictionaries should run MUCH faster.

Libraries and Restrictions

Unless otherwise stated, you are allowed and encouraged to use all parts of the C++ STL and the other standard header files for this project. You are **not** allowed to use other libraries (eg: boost, pthread, etc). You are **not** allowed to use the C++ smart pointers (shared or unique), or the C++11 regular expressions library (it is not fully implemented in the version of gcc used by the autograder) or the thread/atomics libraries (it spoils runtime measurements).

Submission to the Autograder

Do all of your work (with all needed files, as well as test files) in some directory other than your home directory. This will be your "submit directory". Before you turn in your code, be sure that:

- You have deleted all `.o` files and your executable(s). Typing `'make clean'` shall accomplish this. If `make clean` does not remove all of these files, you will lose points.
- Your makefile is called `Makefile`. Typing `'make -R -r'` builds your code without errors and generates an executable file called `letter`. The command line options `-R` and `-r`

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disable automatic build rules (which will not work on the autograder).

- Your Makefile specifies that you are compiling with the gcc optimization option -O3. This is extremely important for getting all of the performance points, as -O3 can often speed up code by an order of magnitude. You should also ensure that you are not submitting a Makefile to the autograder that compiles with the debug flag, -g, as this will slow your code down considerably. If your code “works” when you don’t compile with -O3 and breaks when you do, it means you have a bug in your code!
- Your test files are named test-n-start-end-flags.txt and no other project file names begin with test. Up to 15 tests may be submitted.
- The total size of your program and test files does not exceed 2MB.
- You don’t have any unnecessary files or other junk in your submit directory and your submit directory has no subdirectories.
- Your code compiles and runs correctly using version 6.2.0 of the g++ compiler. This is available on the CAEN Linux systems (that you can access via login.engin.umich.edu). Even if everything seems to work on another operating system or with different versions of GCC, the course staff will not support anything other than GCC 6.2.0 running on CAEN Linux. In order to compile with g++ version 6.2.0 on CAEN you must put the following at the top of your Makefile:

```
PATH := /usr/um/gcc-6.2.0/bin:$(PATH)
LD_LIBRARY_PATH := /usr/um/gcc-6.2.0/lib64
LD_RUN_PATH := /usr/um/gcc-6.2.0/lib64
```

- To run the generated executable, you need to run `module load gcc/6.2.0` once per session. You can add this line to your `~/ .bashrc` file if you don’t want to run it on every login.
- Note that `valgrind` may report “still reachable” memory when compiling with GCC 6.2.0. This is not a concern on the autograder; you need only worry about “definitely lost” memory.

Turn in all of the following files:

- All your .h and .cc or .cpp files for the project
- Your Makefile
- Your test files

You must prepare a compressed tar archive (.tar.gz file) of all of your files to submit to the autograder. One way to do this is to have all of your files for submission (and nothing else) in one directory. Go into this directory and run this command:

`dos2unix -U *; tar czvf ./submit.tar.gz *.cpp *.h *.cc *.c Makefile test*.txt`

This will prepare a suitable file in your working directory. If you’re using our `Makefile`, instead just type

`make fullsubmit`

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Submit your project files directly to either of the two autograders at: <https://g281-1.eecs.umich.edu/> or <https://g281-2.eecs.umich.edu/>. You should load-balance yourselves: if you see that there are 10 people in the queue on autograder 1 and none for autograder 2, submit your project to autograder 2. Do not submit to both autograders at once! You can safely ignore and override any warnings about an invalid security certificate. **When the autograders are turned on and accepting submissions, there will be an announcement.** The autograders are identical and your daily submission limit will be shared (and kept track of) between them. You may submit up to three times per calendar day with autograder feedback (double that during Spring semester). For this purpose, days begin and end at midnight (Ann Arbor local time). **We will count only your best submission for your grade.** If you would instead like us to use your LAST submission, see the autograder FAQ page, or [use this form](#). We strongly recommend that you use some form of revision control (ie: SVN, GIT, etc) and that you 'commit' your files every time you upload to the autograder so that you can always retrieve an older version of the code as needed. **If you use an online revision control system, make sure that your projects and files are PRIVATE; many sites make them public by default! If someone searches and finds your code and uses it, this could trigger Honor Code proceedings for you.**

Please make sure that you read all messages shown at the top section of your autograder results! These messages will help explain some of the issues you are having (such as losing points for having a bad Makefile).

Grading

80 points -- Your grade will be primarily based on the correctness of your algorithms. Your program must have correct and working stack and queue algorithms and support both types of output modes. **Additionally:** Part of your grade will be derived from the runtime performance of your algorithms. Fast running algorithms will receive all possible performance points. Slower running algorithms may receive only a portion of the performance points. The same applies for use of system memory: programs using less memory will receive full points, solutions that use too much will lose points. The autograder machines keep track of the fastest run times ("click on View scoreboard" from the autograder project page). You may track your progress relative to other students and instructors there.

10 points -- Not leaking memory. You can ensure that your program does not leak memory by running it with valgrind.

10 points -- Test file coverage (effectiveness at exposing buggy solutions).

We reserve the right to deduct up to 5 points for poor style (1000 line main, 20 single-letter

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variables, etc.). Readability is generally defined as follows:

- Clean organization and consistency throughout your overall program
- Proper partitioning of code into header and cpp files
- Descriptive variable names and proper use of C++ idioms
- Omitting globals, unnecessary literals, or unused libraries
- Effective use of comments
- Reasonable formatting - e.g. an 80 column display
- Code reuse/no excessive copy-pasted code blocks

Hints and advice

- It is **extremely helpful** to compile your code with the gcc options: `-Wall -Wextra -pedantic -Wconversion -Werror`, and the default Makefile will turn on these flags. This will help you catch bugs in your code early by having the compiler point out when you write code that is either of poor style or might result in behavior that you did not intend.
- Design your data structures and work through algorithms on paper first. Draw pictures. Consider different possibilities *before* you start coding. If you're having problems at the design stage, come to office hours. After you have done some design and have a general understanding of the assignment, re-read this document. Consult it often during your solution's development to ensure that all of your code is in compliance with the specification.
- Always think through your data structures and algorithms before you code them. It is important that you use efficient algorithms in this project and in this course, and coding before thinking often results in inefficient algorithms.
 - If you are considering linked lists, be sure to review the lecture slides or measure their performance against vector first (theoretical complexities and actual runtime can tell different stories).
- Only print the specified output to standard output. You may print whatever any diagnostic information you wish to standard error (`cerr`). However, make sure it does not scale with the size of input, or your program may not complete within the time limit for large test cases.
- Don't try to write the entire program at once.
 - Start with a single input mode (start with simple dictionary).
 - Start with a single morphing mode (we suggest change mode).
 - Start with a single output mode (word mode, rather than morph mode).
- Maybe start by finding if a solution is possible or not.
 - Print correct output if no solution is possible.
 - Then work on correct output if a solution is possible.
- Add other morphing modes, dictionary type, output mode after the basics are working.
- *This is not an easy project. **Start reading, thinking and planning immediately!***

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Have fun coding!

Appendix A -- Larger Example

This example uses a slightly larger dictionary, and allows letter changes and insertions/deletions. The dictionary is on this page, followed by queue output and stack output. You can easily create a complex dictionary containing the same words, and we leave that to you. Note that a complex dictionary might give slightly different output, since the words in the in-memory dictionary might appear in a different order (i.e. `so[au]p` and `so[iu]l` produce `soap soup soil soul`).

Dictionary:

```
S
20
// Used for Appendix A example
rain
ruin
run
sail
she
shy
ski
skip
sky
slap
slip
soap
soil
soul
soup
sue
sun
tail
trail
train
```

Let's use the simple dictionary given above to change sky into sun (I wanted to change snow into sun, but snow wasn't in the dictionary).

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Word Output (Queue):

Words in morph: 5

sky

shy

she

sue

sun

Modification Output (Queue):

Words in morph: 5

sky

c,1,h

c,2,e

c,1,u

c,2,n

Changing sky into sun again, but with stack mode.

Word Output (Stack):

Words in morph: 17

sky

ski

skip

slip

slap

soap

soup

soul

soil

sail

tail

trail

train

rain

ruin

run

sun

Version 04-30-18

Current version by: David Paoletti

Previous versions by: David Paoletti, David Snider, Laura Wendlandt, Luum Habtemariam, Jiaxi Wu

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Modification Output (Stack):

Words in morph: 17

sky
c,2,i
i,3,p
c,1,l
c,2,a
c,1,o
c,2,u
c,3,l
c,2,i
c,1,a
c,0,t
i,1,r
c,4,n
d,0
c,1,u
d,2
c,0,s

Appendix B -- Autograder Information

You'll notice that the test cases on the autograder have a somewhat intricate naming pattern. In general that pattern follows the following scheme:

- First letter indicates whether the dictionary is simple (S) or complex (C)
- Second letter indicates the size of the dictionary - small (S, approximately 20 words), medium (M, about 4k words), large (L, about 45k words), or huge (H, about 350k words).
- Number of the test, completely arbitrary.
- Next letters indicate what changes are allowed to the words: changing one letter into another (C), modifying the length of a word (L), or swapping letters (P)
- Last letter indicates whether output is word format (W) or modification format (M)

For complex dictionaries, the test case name is followed by an underscore and a series of letters. These letters indicate which special characters are included in the dictionary - reverse (R), insert-each (I), double (D), and swap (S).

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For example, a test case named “CL7QCLW_RIDS” is a complex dictionary, of large size, test number 7, queue mode, change and length modes, word output, and the complex dictionary was produced using all 4 modifications (R, I, D, S).

Some test cases don't follow this naming scheme. Any test case starting with "INV" means that your solution should exit 1 because of some sort of INValid input. The test cases starting with "Spec" use the first example dictionary in the spec (page 2), the test cases starting with "SpecComp" use the complex dictionary in the spec (page 3), and the test cases starting with "AppA" use the dictionary from Appendix A.

The test files that you submit are run against our correct solution, your solution, and our “buggy” solutions. If the output of your solution differs from our “correct” solution, we will display both your output and our output for the first such test file encountered. There are 19 different bugs; you will start earning points at the 7th bug found, and will earn full points for finding 16 bugs. The points scale linearly between 7 and 16 bugs found.

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