CS 3505 Assignment 02

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Alex Clemmer

1 Design Purpose

The product we were meant to build was a spellchecker. There were several (artificial) design constraints in this assignment: we were required to use C++ implemented as per `g++ v4.*`, with all data structures (save a few notable exceptions, like `string`) to be completely hand-coded and managed. More notably, were also explicitly told to implement both a hash table and a BST, and to manage the memory properly.

2 Implementation

Basic timeline:

Our first group meeting happened on the first Wednesday of the assignment, and lasted for roughly 3 hours. In this time, we came up with the meat of the algorithm we were implementing, as well as the API for the entire application. We created the API specifically by generating `.h` files for every required file, as well as every file that we would need to implement the central algorithm.

Next came the one-time cost of developing the group's "system". In this phase, we implemented a secure repository for our version control, as well as our code review platform, forums, wikis, and issue trackers.

Our next group meeting was Saturday. At this point, we had the base working (both the hash table and the BST), which left the implementation of the algorithm. The details of what we did are noted below. We also began the implementation of our testing framework in order to start testing our core classes.

We then divided the project up into as many independent tasks as we could find, which allowed us to each concentrate on something individually, and reduced our over all communications overhead by at least 50%.

The next phase was the longest: the time was spent implementing everything. We spent at least 18 hours each doing this. We met both in pairs and as a group to complete the work, although some of it was done individually (depending on the task).

The last phase was testing, which we did extensively—although "last" is misleading, because we implemented the Google Tests C++ testing framework about 3 days into the project. A lot of this phase rolls up into the last phase (it comprised probably 50% or more of the implementation phase), but in addition to that, we spent probably 3 or 4 hours each (maybe even more) just doing pure testing.

NOTE that the details of our development strategy are under "Reflections". If you are looking for this information, please see our (extensive) notes there.

Our goals:

C++ is hard and introduces a lot of new things to learn. Our goals therefore mainly pertained to getting the project to work, rather than getting it to be the best spellchecker ever. (Consider that if we had to implement this in Java or Python or Ruby, the opposite would be the case.)

- Implement and test required files (`Dictionary`, `Word_Count`, `Hashtable`, `BST`, *et al*)
- Catch 100% of all errors as possible
- Make ∼30% correct spelling suggestions.
- Finish before that Monday to leave room for testing.

Readers may be wondering why we only want a 30% accuracy for corrections. This is because catching misspelled words is really easy, but suggesting them is really hard. Not only is the subject of ongoing research, even the experts tend to only get about 80% on a good day. Consider that most people will probably base their algorithms on a certain infamous researcher's spell correction algorithm, but even that only gets 67% correct on spelling suggestions for a reasonably good document.

Implementation:

2.0.1 The Problem:

Corrections are harder than one would be inclined to think. Consider if I misspell the word *cow* with an 'h' instead of a 'w' (*i.e.*, "coh"), what is a machine supposed to correct this to? Let's just list all possible corrections considering *only* substitutions of the last letter: cob, cod, cog, con, coo, cop, cot, coy. Note that this list does not even consider substituting other letters or accounting for letters that we missed when typing this word, or letters that were added erroneously.

A reasonably good spellchecking mechanism therefore cannot use minimum edit distance. Instead, we will have to use some probabilistic mechanism to infer which words are correct. This is actually pretty open-ended problem, but considering the problems we had last time, we decided to keep it simple: we're going to make this decision almost entirely based on how likely a correction is to appear in the English language.

2.0.2 The algorithm:

Almost all implementations will begin by building a probabilistic model of English. You can accomplish this in a number of ways, but we chose just to look through a large corpus and count the number of times each word appears.

The base of this implementation are our `File.cpp` and `Hashtable.cpp` files. The first parses words out of the corpus and hashes each of them in a `Hashtable`. If the word is already in the table, the value at its key is incremented; if not, it's set to 1. This gives us a count (sort of like a histogram for the English language) that tells us roughly how often a word occurs. We can use this as the basis of our probabilistic inference.

To spellcheck a document we again call `File.cpp` and parse the words in a file. Each word in turn is then subject to a combinatorial analysis. This was a point of contention but **note that under explicit permission from the instructor, we did not use a BST for this**. Why? Even though we implemented the BST itself, using it to find misspellings was critically flawed for several reasons:

First, as we have seen above in the "problems" section, minimum edit distance alone gets us nowhere. The other important thing to note is that it is also a really bad solution even in providing the words within a one-character edit distance, because although at each node you can branch off and try to spell a word using the "wrong" letters one letter at a time (*i.e.*, starting at the first letter of *cow* and walking down the tree to see if all possible permutations are correct, which would for example include starting with 'a' and seeing if *aow* and *bow* and *dow* and so on are all in the dictionary, and then repeating it for each letter in the word), one important thing that it's a *lot* harder to do is to account for if you missed a letter, or added one on top of the word.

So rather than implementing that inelegant and error-prone solution, we just decided to combinatorially figure out every possible word within a two-character edit distance that it could be and check to see if each is in the dictionary. This worked out pretty well.

Our suggestion is then the word that is "most probable" based on our histogram hash table described above.

The other thing we should probably mention is that we implemented `Word_Count` with a self-sorting vector, rather than a hash table. The reason was because sorting the words as they were added made it loads easier to find the top x results.

Another thing, for reference, is that we have included a multi-threaded `Dictionary`. We did this because our algorithm lends itself well to multithreading, but we do no use it as our core because our multithreading was so terrible that there was no advantage in speed. We could have fixed it, but we decided it wasn't worth it.

Where we were successful:

Clear win for our first goal: we did not just implement all the requirements and get them functionally working, we actually implemented the Google Tests (`gtests`) C++ testing framework, and thoroughly tested our classes. You can view our tests in the `tests/` and `check_file_tests/`. Our methodology is covered in the "testing" section below.

Goal two is also pretty close to a win. We do find almost all words that are misspellings. The one sticking point is words that appear very infrequently in the English language. How do you train to accept words you haven't seen, and may never see? We have some answers, but we didn't have time to implement them, and the point is that it should work in the common case.

Goal three is a bit harder to judge. Depending on the document we use, on the linguistic complexity, on the domain we're working in, and so on, our accuracy ranges from 20-60%. It is not obvious which metric to use, and thus it is not obvious this goal has been accomplished.

What is obvious is that our spellchecker (presumably like most of them) tends to do much better in common-path domains, or where words are used both common and consistent. This, of course, is expected.

These caveats in mind, we feel we were moderately successful at achieving goal three, although it could have been implemented with a lot more complexity.

Goal four was a clear win. We finished Monday night and spent most of the next few days either testing, relaxing, or thinking of ways to improve our application. See our bug reports a the bottom for proof of this.

Where we failed:

There were several features that were not explicitly in our goals that we wanted to implement, but didn't. One important deficiency in our process—and this is due to a failure of communication—was word parsing. Data indicates that a lot of our misspellings are missed because our parsing scheme was poor. Getting word parsing exactly right is *very* hard, but our implementation is beyond naive: we really just stop parsing words at punctuation, which means a word like "don't" would end up being "don".

Another place we failed was probabilistic inference. Again, it's not that our mechanism doesn't work, but there are several things we could have done in order to make huge improvements to our suggestion ability. For example, consider that we are basically estimating the probability that a user meant some word w_1 given that they typed a "bad" word, b: $P(w_1|b)$. Bayes' rule tells us that this is equivalent to $\frac{P(b|w_1)P(w_1)}{P(b)}$.

In other words, we can improve our suggestions by estimating the probability that we typed b when we meant $P(w_1)$. There are subtle ways to do this, but we know it can be done.

3 Project length

Our automated logs indicate that we spent about 55 hours on this project total. We probably spent slightly more than this. As noted before, for each person we estimate 5 hours for planning, 15-18 hours for implementation, and 4 hours for testing.

4 Testing:

Our testing battery uses Google's `gtest` framework. Our formal verification testing is pretty straightforward: we implemented a series of tests to make sure that our custom files behaved as we thought they should. In `Hashtable`, for instance, we tested adding lots of numbers to the table, then adding lots of unique numbers to the table, then adding all the same numbers to the table, and then to top it off, we tested how the size increases when we rehash.

We're relatively certain that the data structures are correct. What we're most uncertain about is the parsing. As we've noted before, parsing is a particularly difficult problem, and we don't expect to get it right, although we do expect to get it right enough.

We tested a lot on handwritten files designed to exploit possible sticking points. Those tests should be in `file_check_tests/`. We also tested over some larger documents, but mainly to make sure that the program didn't fail in any important way. For accuracy tests, we found that smaller tests are generally better (more effective, more portable, more controllable), and big tests are really best to verify what your small tests should be saying.

We actually ended up testing so well during implementation that our bugs in the formal testing phase tended to be bugs in our testing code, rather than with our core. Consider that we had 2 total bugs reported to the issue tracker for the master branch. If we had not been working in independent branches that could be merged at will, and we did not force code reviews, this would not have been the case; in fact, it's hard for us to think that this would have been possible at all committing to a central repository. This model of concurrent development and testing has worked out so well that we will be doing it for every project.

Memory Management

One thing we were explicitly careful about testing was memory management. To test this, we included a print statement that fired off every time something was deleted; then when we deleted (*e.g.*) the hash table, we could watch and make sure that all the things we needed to delete ended up being deleted. It's not the most repeatable test, but we understand that this is one of the harder problems for C++ programmers, so we're not that worried.

Our method for deletion was basically to delete everything allocated on the heap inside of a given data structure, and then to delete the data structure itself. We made sure to do this even in our hash table tests.

5 Reflections:

Our dev pipeline:

Arguably more impressive than anything we wrote was how well the development process went. We basically wanted to eliminate as much of the communications overhead as was humanly possible, and to shorten the feedback cycle to the nub. We accomplished this using a few crucial technologies, which collectively proved to be extremely valuble.

- **Version control** We knew that VCSs were useful, but they become a lot more useful when a lot of people are working on a project. We are prepared to grant our very rapid pace of development as a product largely of two things: the ability to branch and merge our version history trivially, and to commit locally.

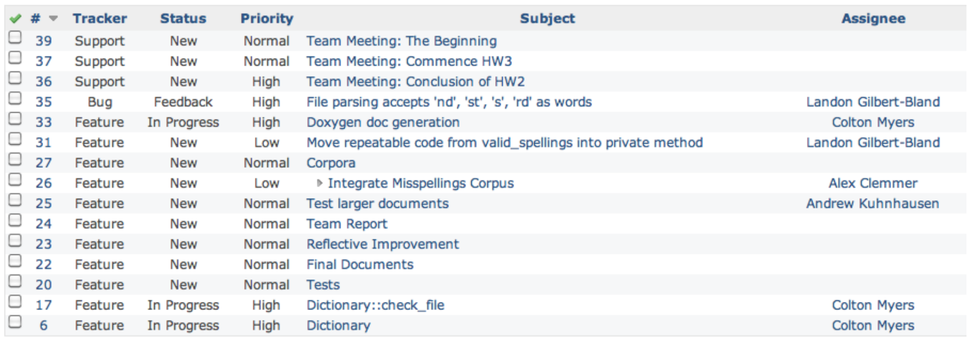
  In truth, these are the same thing: by being forced to commit to a local repository, rather than a central repository, our team members were able to experiment and checkin to their version control system freely without having to worry about breaking the build or introducing bugs for anyone else. And by being able to branch and merge trivially, our members were able to experiment with, and selectively discard changes they disliked. Using commands similar to `cherry-pick`, they were able to selectively put features into the central repository, which proved to be useful on several occasions.

  The ability to merge trivially meant that working on the same code was no longer a bottleneck, which meant greater code breathability and more familiarity with the codebase overall for all of our team members. All that's not to mention that we spent much more time developing software and much less time trying to get our VCS to merge, which we count as a huge win.

- **Issue and bug tracking** Every time we introduced a bug or ran into a wall and needed a new feature, we put it up on the issue tracker. In this way, anyone could pick an issue and address it at their convenience. The difference between having a formal issue tracker and a glob of emails asking people to do things is like the difference between getting emails as a TA and having the Moodle ticket system, where TAs get assigned problems to address.

  One major advantage is that everything gets documented, and you can see at a glance where there are bugs, what needs work, and roughly where the problems in dev are. Another advantage is that people who need something to do just need to pick something out of a library of issues. Yet another advantage is that you can (and should) actually assign issues to people, which means that they usually get done.

  Here's a picture of some issues in our issue tracker:



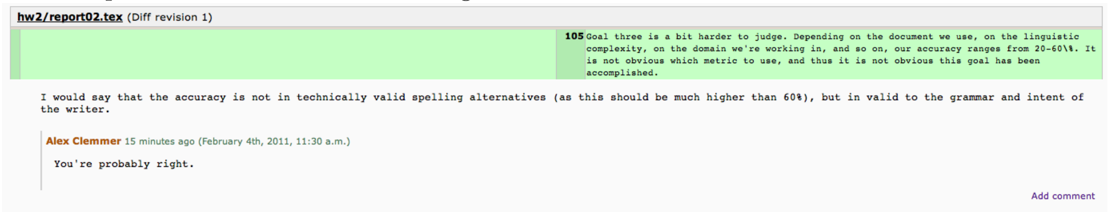
✓	#	Tracker	Status	Priority	Subject	Assignee
☐	39	Support	New	Normal	Team Meeting: The Beginning	
☐	37	Support	New	Normal	Team Meeting: Commence HW3	
☐	36	Support	New	High	Team Meeting: Conclusion of HW2	
☐	35	Bug	Feedback	High	File parsing accepts 'nd', 'st', 's', 'rd' as words	Landon Gilbert-Bland
☐	33	Feature	In Progress	High	Doxygen doc generation	Colton Myers
☐	31	Feature	New	Low	Move repeatable code from valid_spellings into private method	Landon Gilbert-Bland
☐	27	Feature	New	Normal	Corpora	
☐	26	Feature	New	Low	▸ Integrate Misspellings Corpus	Alex Clemmer
☐	25	Feature	New	Normal	Test larger documents	Andrew Kuhnhausen
☐	24	Feature	New	Normal	Team Report	
☐	23	Feature	New	Normal	Reflective Improvement	
☐	22	Feature	New	Normal	Final Documents	
☐	20	Feature	New	Normal	Tests	
☐	17	Feature	In Progress	High	Dictionary::check_file	Colton Myers
☐	6	Feature	In Progress	High	Dictionary	Colton Myers

- **Code review** Implementing code review meant that two people had to sign off on every line of code that you wrote. This kept the code a reasonably good quality, first, because you knew you were being watched, and second, because we were able to catch everyone's stupid mistakes. Posting to code review was a simple unix command: `post review --parent=master`. Doing this put up the diff online, at which point members could look at what changed, comment on a line-by-line basis, and approve or reject it.

  The difference between doing this and emailing tarballs around, or even pulling the branch and looking at the diff yourself is unequivocal, and we want to be emphatic about it: we will never not use this tool again; it is invaluable in terms of time saved in communication and pulling branches alone. And that's to say nothing of the fact that it forces us to be thorough: since the review doesn't go away until it's approved or rejected, you have to address it at some point.

  One issue we will have to address in the future is the consistency of reviews. Andrew and Landon tended to issue reviews pretty quickly, but were often left hanging when their code needed a second review. This did cause a minor hiccup in the process, but it is easily corrected.

  Here's a picture of someone commenting on a diff in review board:



hw2/report02.tex (Diff revision 1)

```
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complexity, on the domain we're working in, and so on, our accuracy ranges from 20-60\%. It
is not obvious which metric to use, and thus it is not obvious this goal has been
accomplished.
```

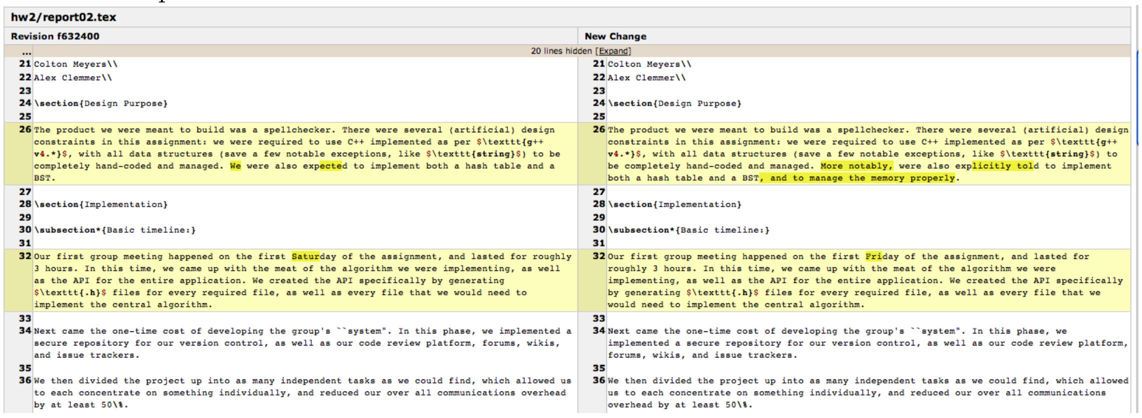
I would say that the accuracy is not in technically valid spelling alternatives (as this should be much higher than 60%), but in valid to the grammar and intent of the writer.

Alex Clemmer 15 minutes ago (February 4th, 2011, 11:30 a.m.)

You're probably right.

Add comment

  And here's a picture of a diff itself:



hw2/report02.tex

Revision f632400

```
...
Colton Meyers\\
Alex Clemmer\\

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constraints in this assignment: we were required to use C++ implemented as per $\texttt{g++
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completely hand-coded and managed. We were also expected to implement both a hash table and a
BST.

\section{Implementation}

\subsection*{Basic timeline:}

Our first group meeting happened on the first Saturday of the assignment, and lasted for roughly
3 hours. In this time, we came up with the meat of the algorithm we were implementing, as well
as the API for the entire application. We created the API specifically by generating
$\texttt{.h}$ files for every required file, as well as every file that we would need to
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Next came the one-time cost of developing the group's ``system". In this phase, we implemented a
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We then divided the project up into as many independent tasks as we could find, which allowed us
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```

New Change

20 lines hidden [Expand]

```
Colton Meyers\\
Alex Clemmer\\

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```
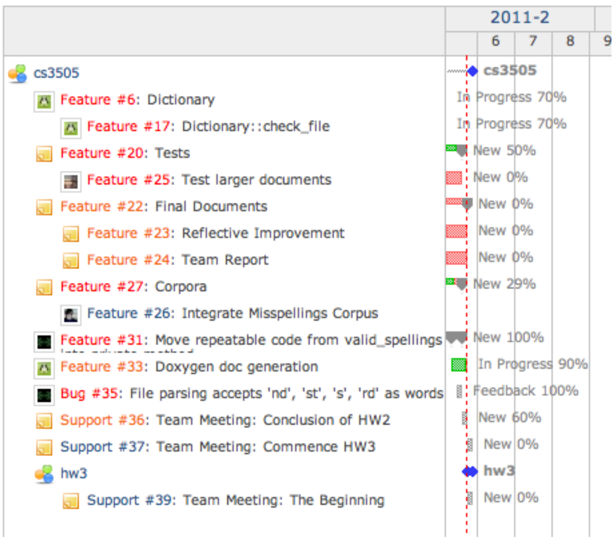

- **Auto-wikis, auto-stats, and forums** We found that wikis increased our ability to document not just the code, but the process, while auto-stat analysis gave us a good idea of how the project was progressing, as well as choke points. Forums are good for addressing design problems.

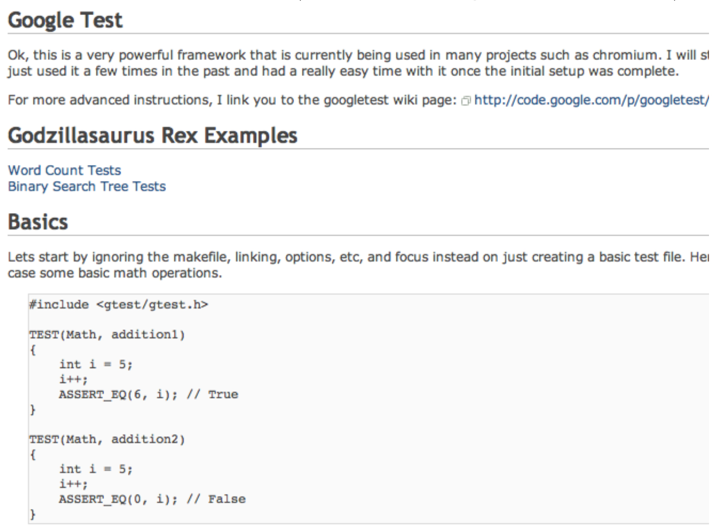
  More importantly, it's useful to have these tasks divided into compartments designed to address them. This system is infinitely superior to a series of emails, both because accessibility and organization is trivial in comparison to searching through piles of old mail, and because everyone sees the same thing, rather than what's in their inbox.

  Here's a picture of our update tracker:



```
                                                          2011-2
                                                       6   7   8   9
cs3505                                                cs3505
  Feature #6: Dictionary                              In Progress 70%
    Feature #17: Dictionary::check_file               In Progress 70%
  Feature #20: Tests                                  New 50%
    Feature #25: Test larger documents                New 0%
  Feature #22: Final Documents                        New 0%
    Feature #23: Reflective Improvement               New 0%
    Feature #24: Team Report                          New 0%
  Feature #27: Corpora                                New 29%
    Feature #26: Integrate Misspellings Corpus
  Feature #31: Move repeatable code from valid_spellings   New 100%
  Feature #33: Doxygen doc generation                 In Progress 90%
  Bug #35: File parsing accepts 'nd', 'st', 's', 'rd' as words   Feedback 100%
  Support #36: Team Meeting: Conclusion of HW2        New 60%
  Support #37: Team Meeting: Commence HW3             New 0%
  hw3                                                 hw3
    Support #39: Team Meeting: The Beginning          New 0%
```

Here's a shot of our wiki (talking about `gtest` integration):



Google Test

Ok, this is a very powerful framework that is currently being used in many projects such as chromium. I will s
just used it a few times in the past and had a really easy time with it once the initial setup was complete.

For more advanced instructions, I link you to the googletest wiki page: http://code.google.com/p/googletest/

Godzillasaurus Rex Examples

Word Count Tests
Binary Search Tree Tests

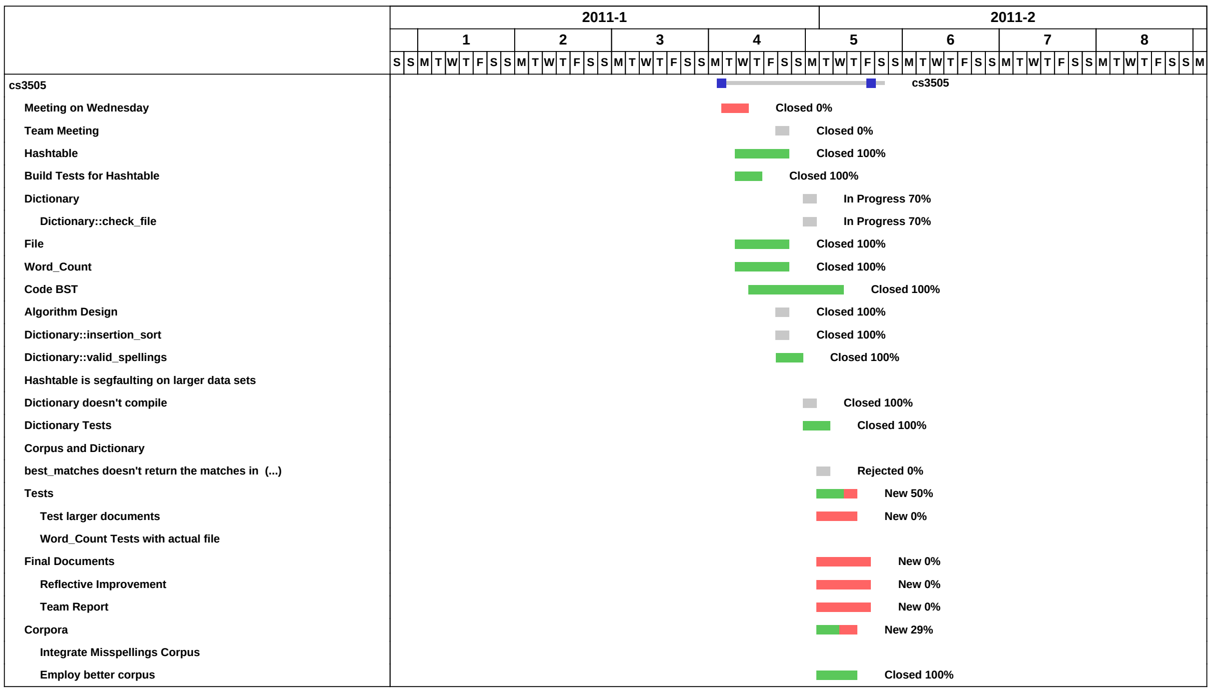
Basics

Lets start by ignoring the makefile, linking, options, etc, and focus instead on just creating a basic test file. He
case some basic math operations.

```
#include <gtest/gtest.h>

TEST(Math, addition1)
{
    int i = 5;
    i++;
    ASSERT_EQ(6, i); // True
}

TEST(Math, addition2)
{
    int i = 5;
    i++;
    ASSERT_EQ(0, i); // False
}
```

Here is a helpful summation of our bugs in total:

cs3505



cs3505	cs3505
Meeting on Wednesday	Closed 0%
Team Meeting	Closed 0%
Hashtable	Closed 100%
Build Tests for Hashtable	Closed 100%
Dictionary	In Progress 70%
Dictionary::check_file	In Progress 70%
File	Closed 100%
Word_Count	Closed 100%
Code BST	Closed 100%
Algorithm Design	Closed 100%
Dictionary::insertion_sort	Closed 100%
Dictionary::valid_spellings	Closed 100%
Hashtable is segfaulting on larger data sets	
Dictionary doesn't compile	Closed 100%
Dictionary Tests	Closed 100%
Corpus and Dictionary	
best_matches doesn't return the matches in (...)	Rejected 0%
Tests	New 50%
Test larger documents	New 0%
Word_Count Tests with actual file	
Final Documents	New 0%
Reflective Improvement	New 0%
Team Report	New 0%
Corpora	New 29%
Integrate Misspellings Corpus	
Employ better corpus	Closed 100%

2011-1
2011-2
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02/04/2011 *1/2*