In this project, I developed and tested a Word Ladder Generator program that finds the shortest possible word ladder between two words of equal length. The program uses a breadth-first search algorithm to navigate through a dictionary of words, connecting words that differ by only one letter at each step. This reflection documents my experiences running the program with various inputs, including attempts to find longer word ladders and observations on how word length affects the ease of connecting words. Additionally, I explored the program's feature of selecting random words after multiple invalid inputs, using this to my advantage in testing.

# Observations from Testing

## 1. 3-Letter Word Ladders

### a. Direct Word Pair Test

- **Start Word:** hip
- **End Word:** toe

  **Shortest Word Ladder Found:**
  hip
  hie
  hoe
  toe

- **Ladder Height:** 4

**Observation:** The word ladder between hip and toe consisted of four words, indicating a relatively short path. This is expected with 3-letter words due to the limited number of possible combinations and the high density of neighboring words differing by one letter.

### b. Random Word Selection Test

- **Invalid Start Words Attempted:** hdb, bvj, ndn, hyg, ytf
- **Randomly Selected Start Word:** elf
- **Invalid End Words Attempted:** yuh, vjf, jfn, kdf, uyd
- **Randomly Selected End Word:** nit

  **Shortest Word Ladder Found:**
  elf
  eff
  aff
  aft
  ait
  nit

- **Ladder Height:** 6

**Observation:** By intentionally entering invalid words, the program's feature of selecting random words was activated. The resulting ladder between elf and nit had a height of six, slightly longer than the previous example, demonstrating that random word pairs can yield longer ladders even among 3-letter words.

## 2. 4-Letter Word Ladders

### a. Direct Word Pair Test

- **Start Word:** arch
- **End Word:** byte

  **Shortest Word Ladder Found:**
  arch
  arcs
  arts
  aits
  bits
  bite
  Byte

- **Ladder Height:** 7

**Observation:** The ladder between arch and byte had a height of seven, indicating a moderate increase in ladder length compared to the 3-letter words. This suggests that as word length increases, the number of steps required to connect two words can also increase.

### b. A test using antonyms

- **Start Word:** cold
- **End Word:** warm

  **Shortest Word Ladder Found:**

  cold
  cord
  card
  ward
  warm

- **Ladder Height:** 5

**Observation:** Despite cold and warm being antonyms with no shared letters, the program found a relatively short ladder of height five. This indicates that even with minimal letter overlap, certain word pairs can be connected efficiently due to the availability of intermediate words.

**c. Random Word Selection Test**

- **Invalid Start Words Attempted:** abbb, baaa, hgfd, nhfd, jhgf
- **Randomly Selected Start Word:** ands
- **Invalid End Words Attempted:** hgfd, jhgf, jhdf, jhfg, jhng
- **Randomly Selected End Word:** pike

  **Shortest Word Ladder Found:**
  ands
  aids
  aide
  bide
  bike
  pike

- **Ladder Height:** 6

**Observation:** Using the random word feature after entering invalid words resulted in a ladder of height six between ands and pike. This demonstrates that random word selection can produce ladders of varying lengths and provides an effective method for exploring different word pairings.

## 3. 5-Letter Word Ladders

**a. Direct Word Pair Test**

- **Start Word:** aback
- **End Word:** funny

  **Shortest Word Ladder Found:**
  aback
  alack
  plack
  plank
  plans
  peans
  peons
  peony
  penny
  fenny
  funny

- **Ladder Height:** 11

**Observation:** The ladder between aback and funny had a height of eleven, significantly longer than the ladders found for shorter words. This suggests that connecting 5-letter words often requires more intermediate steps due to fewer neighboring words and increased complexity.

**b. <u>Related Words Test</u>**

- **Start Word:** table
- **End Word:** chair

  **Shortest Word Ladder Found:**
  table
  cable
  carle
  carls
  carns
  cains
  chins
  chink
  chirk
  chark
  charr
  chair

- **Ladder Height:** 12

**Observation:** Despite both words being common household items, the ladder between table and chair consisted of twelve steps. This further illustrates that 5-letter words may require longer paths to connect, especially when the words have few letters in common.

**c. <u>Random Word Selection Test</u>**

- **Invalid Start Words Attempted:** fghhh, hgfhg, jhghg, kjhgh, jhgfg
- **Randomly Selected Start Word:** mulls
- **Invalid End Words Attempted:** ygfhg, ijhgy, hjghj, jhgvf, ijhgf
- **Randomly Selected End Word:** yokel

  **Shortest Word Ladder Found:**
  mulls
  molls
  moles
  mokes
  yokes
  yokel

- **Ladder Height:** 6

**Observation:** Activating the random word feature with invalid inputs yielded a ladder of height six between mulls and yokel. This shows that even with longer words, it's possible to find shorter ladders when the words are closely related or share common intermediate words.

# Reflection on Word Ladders and Word Length

- **3-Letter Words:** The longest ladder found was between elf and nit, with a height of six.
- **4-Letter Words:** The longest ladder found was between arch and byte, with a height of seven.
- **5-Letter Words:** The longest ladder found was between table and chair, with a height of twelve.

The ladder lengths increased with the word length, indicating that longer words generally require more steps to connect.

*I used the following approaches to find word pairs that yield relatively long ladders:*

- Choosing start and end words that have few or no common letters increases the number of steps required to transform one into the other. Examples include aback to funny and table to chair.
- Words with opposite meanings or no direct association often have different letter compositions, hence leading to longer ladders. The cold to warm pair is a case where antonyms resulted in a moderately long ladder.
- By entering invalid words intentionally, I activated the program's random word feature. This allowed me to test word pairs I might not have considered, sometimes resulting in longer ladders due to the randomness of the selection.

*Smaller words, such as 3-letter words, tend to have shorter word ladders because:*

- With fewer letters, each position change can yield a valid word, increasing the number of immediate neighbors. This abundance of neighboring words makes it easier to find short paths between words.
- The fewer possible combinations there are for shorter words, the more densely packed the dictionary is with words only one letter apart.

*Word length significantly affects the ease of connecting words with a word ladder:*

- As word length increases, the number of valid neighboring words decreases. This is because of the exponential increase in possible combinations of letters, most of which do not form valid words. Hence, it becomes quite difficult to find a sequence of intermediate connecting words between the start and the end words.
- I found that the random linking of words becomes significantly challenging from 5-letter words onwards. When 3-letter and 4-letter words tend to have chains linking them in several ways, 5-letter words can have very long searches and yield longer ladders or, in some instances, no ladder at all.

- When using random word selection for longer words, the likelihood of the program choosing words that can be connected decreases. This reflects the sparsity of valid transformations available for longer words in the dictionary.

The effect is based on combinatorial math. As the length of the word increases, the number of combinations increases exponentially, but the ratio of combinations that form valid words does not rise nearly as quickly. So the density of valid words in the space of combinations falls, and connecting paths become increasingly unlikely to find.

The Word Ladder Generator program shows how the length of a word and the composition of its letters affect the complexity of a ladder's path between two given words. From testing, I have found that words with a lesser length normally have shorter ladders, since the neighborhood density is high. On the other hand, longer words usually involve more steps to be connected and hence are difficult to find a valid path. I was able to easily create a variety of these ladders by using strategies such as choosing words with minimal overlap in letters, enhanced by the random word feature. The result was a tantalizing interplay between word structure and algorithmic pathfinding in this project.