Using Abstractions: Breadth-First Search
How can we use the unique properties of different abstractions to solve problems?
Examples of interesting problems to solve using ADTs

- Simulate potential impacts of flooding on a topographical landscape (how does water flow outwards from a source and settle into the surrounding areas)
- Generate simulated text in the style of a certain author. Similarly, do textual analysis to determine who the author of a provided piece of text was.
- Spell check and autocomplete for a word document editor
- Manage information about the natural landmarks and state parks in California to help tourists plan their trip to the state
- Develop a ticketing management system for Stanford Stadium
- Aggregate and analyze reviews for an online shopping website
- Solve fun puzzles
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- **Solve fun puzzles**
Word Ladders
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Word Ladders

- A word ladder is a type of puzzle based on a start word and a target word. To solve the puzzle, you must generate a sequence of intermediate words (which must be valid English words) where each word is one letter different from the previous one, thus forming a path from the start word to the target word.
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How can we come up with an algorithm to generate these word ladders?
Word Ladder Generation First Attempt

- Given a start word and a target word, a natural place to start would be to model how a human might attempt to solve this problem
Word Ladder Generation First Attempt

- Given a start word and a target word, a natural place to start would be to model how a human might attempt to solve this problem
  - Start at the start word
  - Make an educated guess about what letter to change first
  - Modify that letter to get to a new English word
  - From there, make another educated guess about which letter to change and modify that letter
  - Keep repeating this process until you reach the target word (unlikely) or hit a dead end (likely)
  - If you hit a dead end, start over again, taking a different first step
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- What are the issues with this approach?
  - Requires intuition – does a computer have intuition?
  - Unorganized – no organized strategy for the exploration
  - No guarantee that you'll ever find a solution!
Breadth-First Search
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- We need a structured way to explore words that are "adjacent" to one another (one letter difference between the two of them)
Breadth-First Search

● We need a structured way to explore words that are "adjacent" to one another (one letter difference between the two of them)
● What's the simplest possible word ladder we could find?
  ○ If the words are only one letter different from one another (pig and fig), then finding the word ladder is relatively easy – we look at all words that are one letter away from the current word
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- What's the simplest possible word ladder we could find?
  - If the words are only one letter different from one another (pig and fig), then finding the word ladder is relatively easy – we look at all words that are one letter away from the current word
- What's the next simplest possible word ladder we could find?
  - If the word ladder requires two steps, then we can break down the problem into the problem of exploring one step away from all the words that are one step away from the starting word
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- We need a structured way to explore words that are "adjacent" to one another (one letter difference between the two of them).
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- What's the next simplest possible word ladder we could find?
  - If the word ladder requires two steps, then we can break down the problem into the problem of exploring one step away from all the words that are one step away from the starting word.
- **Important observation:** In order to keep our search organized, we first explore all word ladders of "length" 1 before we explore any word ladders of "length" 2, and so on.
BFS Example
Breadth-First Search Example

- Let's try to apply this approach to find a word ladder starting at the word "map" and ending at the word "way"
Breadth-First Search Example

start: map
destination: way
Breadth-First Search Example

start: map
destination: way

0 steps away
Breadth-First Search Example

map

start: map
destination: way

0 steps away
1 step away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
Breadth-First Search Example

start: map
destination: way

Note: For the sake of brevity/demonstration, we will not enumerate all possible words that are 1 step away

0 steps away
1 step away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
Breadth-First Search Example

0 steps away
1 step away
2 steps away

start: map
destination: way

map
rap
man
mop
nap
may
Breadth-First Search Example

start: map
destination: way

Observation: 2 steps away from "map" is really just 1 step away from any of its neighbors

0 steps away
1 step away
2 steps away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
2 steps away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
2 steps away
Visiting a word we've already been at before is basically like going backwards in our search. We want to avoid this at all costs!
Breadth-First Search Example

Idea: Keep track of a collection of visited words, and don't double visit.

start: map
destination: way

0 steps away
1 step away
2 steps away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
2 steps away
Breadth-First Search Example

0 steps away
1 step away
2 steps away

start: map
destination: way
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
2 steps away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
2 steps away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
2 steps away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
2 steps away
Breadth-First Search Example

start: map
destination: way

0 steps away
1 step away
2 steps away
Breadth-First Search Example

Start: map, Destination: way

Success! We have found a valid word ladder:
map -> may -> way
Formalizing BFS
Breadth-First Search Data Structures

We need...

- A data structure to represent (partial word) ladders
  - Desired characteristics: We should be able to easily access the most recent word added to the word ladder
Breadth-First Search Data Structures

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- A data structure to store all the partial word ladders that we have generated so far and have yet to explore
  - Desired characteristics: We want to maintain an ordering of ladders such that all ladders of a certain length get explored before ladders of longer length get explored
Breadth-First Search Data Structures

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- A data structure to store all the partial word ladders that we have generated so far and have yet to explore
  - Desired characteristics: We want to maintain an ordering of ladders such that all ladders of a certain length get explored before ladders of longer length get explored
- A data structure to keep track of all the words that we've explored so far, so that we avoid getting stuck in loops
  - Desired characteristics: We want to be able to quickly decide whether or not a word has been seen before.
Breadth-First Search Data Structures

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Breadth-First Search Data Structures

We need...

- A data structure to represent (partial word) ladders
  - Stack<string>
- A data structure to store all the partial word ladders that we have generated so far and have yet to explore
  - Desired characteristics: We want to maintain an ordering of ladders such that all ladders of a certain length get explored before ladders of longer length get explored
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Breadth-First Search Data Structures

We need...

- A data structure to represent (partial word) ladders
  - `Stack<string>`
- A data structure to store all the partial word ladders that we have generated so far and have yet to explore
  - `Queue<Stack<string>>`
- A data structure to keep track of all the words that we've explored so far, so that we avoid getting stuck in loops
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Breadth-First Search Data Structures

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  - `Queue<Stack<string>>`
- A data structure to keep track of all the words that we've explored so far, so that we avoid getting stuck in loops
  - `Set<string>`
Breadth-First Search Pseudocode
Breadth-First Search Pseudocode

Create an empty queue and an empty set of visited locations
Create an initial word ladder containing the starting word and add it to the queue
Breadth-First Search Pseudocode

Create an empty queue and an empty set of visited locations
Create an initial word ladder containing the starting word and add it to the queue
While the queue is not empty
Breadth-First Search Pseudocode

Create an empty queue and an empty set of visited locations
Create an initial word ladder containing the starting word and add it to the queue
While the queue is not empty
    Remove the next partial ladder from the queue
    Set the current search word to be the word at the top of the ladder
    If the current word is the destination, then return the current ladder
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Create an initial word ladder containing the starting word and add it to the queue
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  Remove the next partial ladder from the queue
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  Generate all "neighboring" words that are valid English words and one letter away from the current word
  Loop over all neighbor words
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    Loop over all neighbor words
        If the neighbor hasn't yet been visited
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Create an initial word ladder containing the starting word and add it to the queue
While the queue is not empty
    Remove the next partial ladder from the queue
    Set the current search word to be the word at the top of the ladder
    If the current word is the destination, then return the current ladder
    Generate all "neighboring" words that are valid English words and one letter away from the current word
    Loop over all neighbor words
        If the neighbor hasn't yet been visited
            Create a copy of the current ladder
            Add the neighbor to the top of the new ladder and mark it visited
            Add the new ladder to the back of the queue of partial ladders
Live Coding:
Implementing BFS

[Qt Creator]
We hope that you find this to be a helpful resource when working on Assignment 2. However, we do not encourage trying to copy the code as a starting point. The problems are distinctly different, and you will benefit from explicitly developing your own problem-specific pseudocode first.