Section 2

CSCI E-22

Will Begin Shortly

Practice with Recursion

The following Java method should use recursion to remove all capital letters from a string. Some of the code has been omitted and we will need to fill it in:

```
public static String removeCapitals(String s) {
    if (s == null)
        throw new IllegalArgumentException();

    if (s.equals(""))
        return "";

    String removedFromRest = ____________________;

    ...



}
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    ...



}
```

```
removeCapitals("HeLLo")
```

```
return "eo"
```

Recall: Recursive Problem Solving

When solving problems using recursion, we break the problem down into smaller subproblems.

Once we have broken down the problem into the smallest subproblem (one that we can solve), we have reached a base case.

Then, we can progressively build up the solutions to the subproblems until we have a solution for the overall problem.

```
sum(n) =
```

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sum(n) = n + sum(n-1)
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sum(n) = n + sum(n-1)
```

```
public static int sum(int n) {
    if (n <= 0)
        return 0;

    int rest = sum(n - 1);
    return n + rest;
}
```

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}
```

```
sum(4) = 4 + sum(3)
  sum(3) = 3 + sum(2)
    sum(2) = 2 + sum(1)
      sum(1) = 1 + sum(0)
        sum(0) = 0
```

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  sum(3) = 3 + sum(2)
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      sum(1) = 1 + sum(0)
        sum(0) = 0
```

Recursive Problem Solving Approach

Before writing a recursive method, we can try to plan:

- What's the base case?
- What's the recursive subproblem?
- What work do we need to do before returning?

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Recursive Problem Solving Approach

Before writing a recursive method, we can try to plan:

- What's the base case?
  - When `s` is the empty string
- What's the recursive subproblem?
- What work do we need to do before returning?

Recursive Problem Solving Approach

Before writing a recursive method, we can try to plan:

- What's the base case?
  - When `s` is the empty string
- What's the recursive subproblem?
  - Removing the capitals from the rest of the string
- What work do we need to do before returning?

```
removeCapitals("HeLLo")
```

If we knew the solution to `removeCapitals("eLLo")`, we could solve `removeCapitals("HeLLo")`

Recursive Problem Solving Approach

Before writing a recursive method, we can try to plan:

- What's the base case?
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```
removeCapitals("HeLLo") = H + removeCapitals("eLLo")
                          ?
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If we knew the solution to `removeCapitals("eLLo")`, we could solve `removeCapitals("HeLLo")`

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`removeCapitals("HeLLo") = H` ? `+ removeCapitals("eLLo")` `"eo"`

If we knew the solution to `removeCapitals("eLLo")`, we could solve `removeCapitals("HeLLo")`

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- What's the base case?
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  - Test whether the first character in the string is a capital; if it is, it should not be included in the return value

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If we knew the solution to `removeCapitals("eLLo")`, we could solve `removeCapitals("HeLLo")`

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If we knew the solution to `removeCapitals("eLLo")`, we could solve `removeCapitals("HeLLo")`

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The following Java method should use recursion to remove all capital letters from a string. Some of the code has been omitted and we will need to fill it in:

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    char first = s.charAt(0);
    if (____________________)



}
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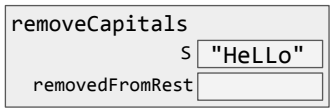

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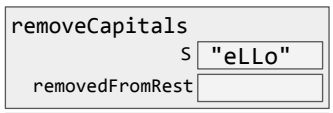

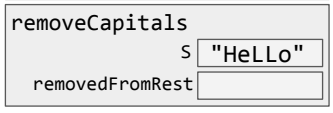

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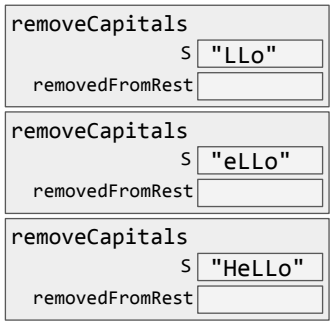

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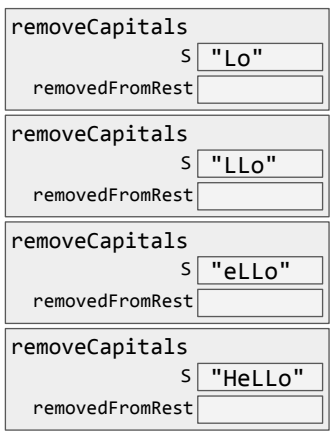

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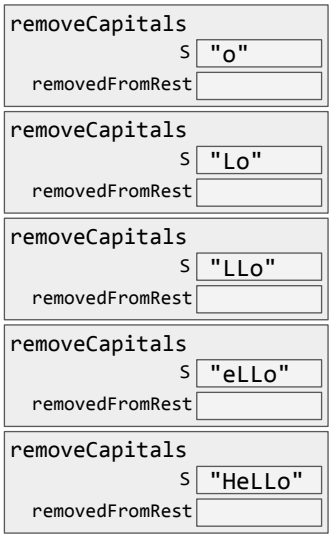

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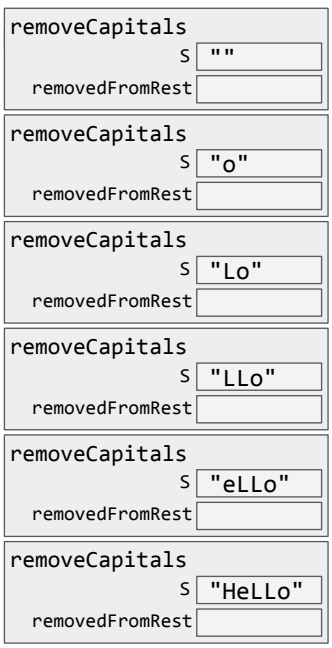

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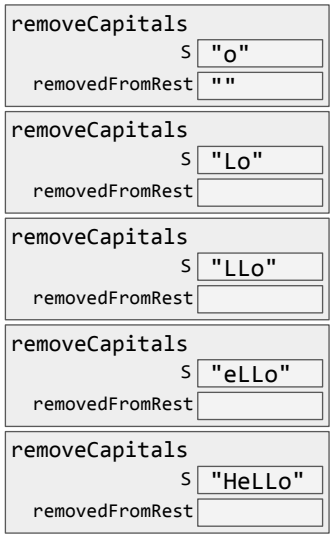

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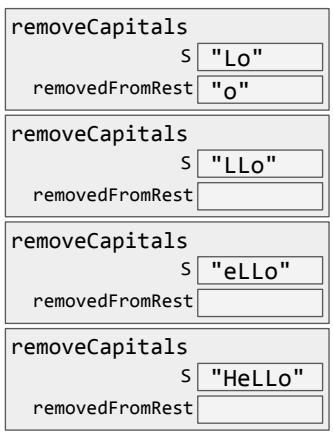

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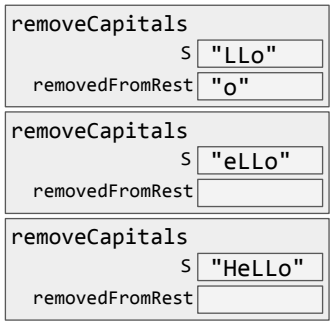

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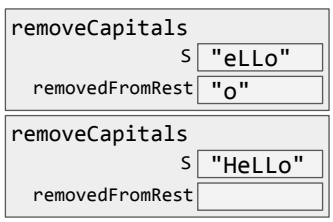

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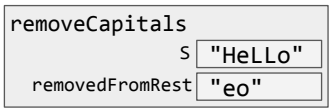

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How many calls of this method are needed when…

n is 0?

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n is 0? 1
n is 1? 2

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n is 0? 1
n is 1? 2
n is 2? 3
n is 3? 4

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How many calls of this method are needed when…

n is 0? 1
n is 1? 2
n is 2? 3
n is 3? 4

What is the general formula for the number of calls needed to process a string of length n?

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n + 1

Let's remember this while we complete the next exercise

The Fibonacci Sequence

The Fibonacci sequence is a well-known number series in which each number in the series is the sum of the two previous numbers.

We define the first two numbers as $F_0 = 0$ and $F_1 = 1$, and all successive numbers as:

$$F_n = F_{n-1} + F_{n-2}$$

Since the sequence is defined recursively, using recursion to calculate Fibonacci numbers is natural. Finish the code below to write an algorithm that calculates the *n*th Fibonacci number.

```
public static long fib(int n) {

    // base case
    if (_________________)




 }
```

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```
public static long fib(int n) {

    // base case
    if (n == 0 || n == 1)
        return _________;



}
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    // recursive case
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}
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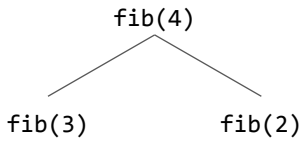
    // base case
    if (n == 0 || n == 1)
        return n;

    // recursive case
    return fib(n - 1) + fib(n - 2);

}
```

The Fibonacci Sequence

Draw a diagram that shows the number of times `fib()` is called with an initial value of 4. It has been started for you:



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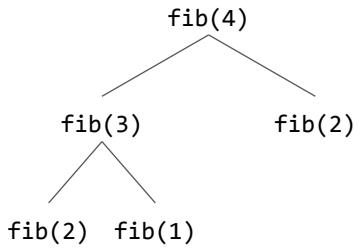

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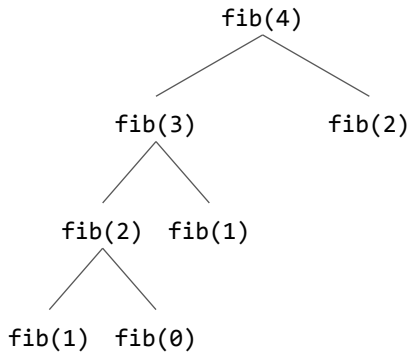

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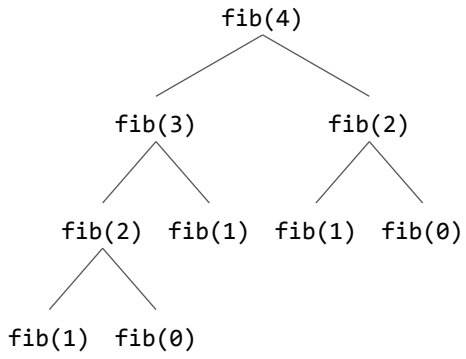
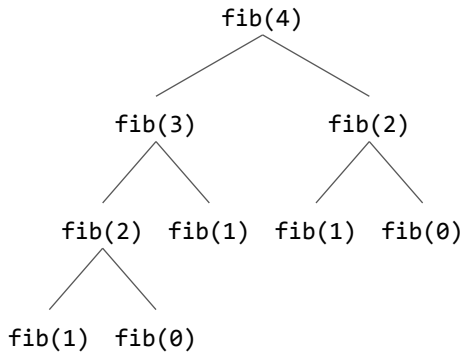


The Fibonacci Sequence

Draw a diagram that shows the number of times `fib()` is called with an initial value of 4. It has been started for you:

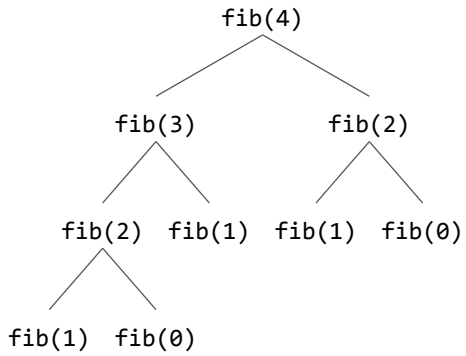
How many times did we call `fib()` to find the fourth Fibonacci number?



The Fibonacci Sequence

Draw a diagram that shows the number of times `fib()` is called with an initial value of 4. It has been started for you:

How many times did we call `fib()` to find the fourth Fibonacci number? 9



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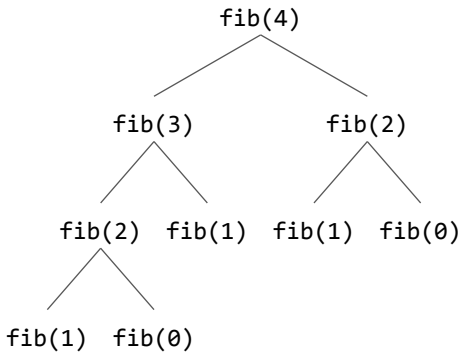
Do you see a problem with this? What if we tried larger numbers, like 50?



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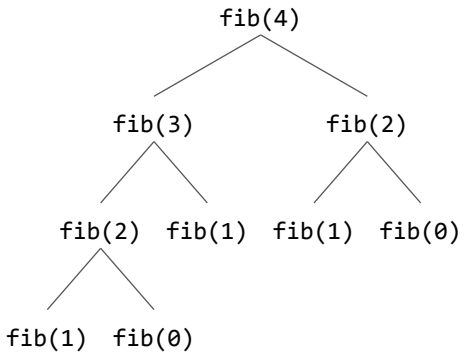
How many times did we call `fib()` to find the fourth Fibonacci number? 9

Do you see a problem with this? What if we tried larger numbers, like 50?

- The number of calls increases exponentially for the initial value of *n*. This means that we would have to make about 10 billion method calls to calculate `fib(50)`!



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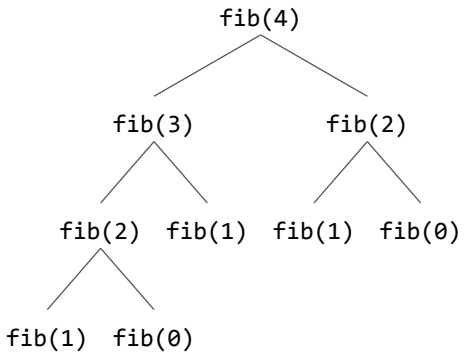
How would you rewrite `fib()` to be more efficient, either still as a recursive method or iteratively?



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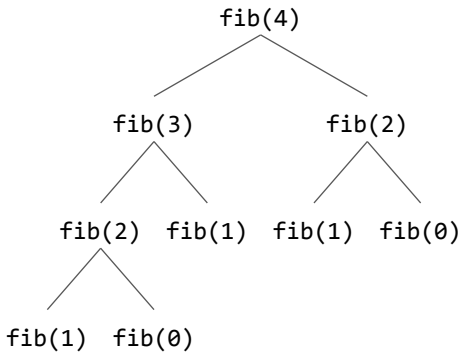

- You need to keep track of the previous two Fibonacci values while computing the next

The Fibonacci Sequence

Here is an example iterative solution:

```
public static long fib(int n) {

    if (n <= 0) {
        return 0;
    }


    long previous = 0;      // at the start, previous = F_0
    long current = 1;       // at the start, current = F_1


    for (int i = 2; i <= n; i++) {
        long tmp = previous + current;
        previous = current;
        current = tmp;
    }

    return current;
}
```

The Fibonacci Sequence

Here is an example recursive solution:

```
public static long fib(int n) {

    if (n == 0) {
        return 0;
    }

    return fibHelper(n, 1, 0);
}

public static long fibHelper(int n, long curr, long prev) {

    if (n == 1) {
        return curr;
    }

    return fibHelper(n - 1, curr + prev, curr);

}
```

Recursive Backtracking

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
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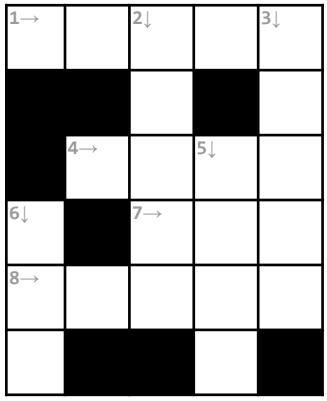

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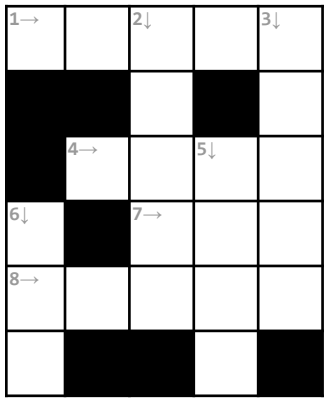


```
boolean findSolution(n, other params) {
    if (we found a solution) {
        displaySolution();
        return true;
    }

    for (val = first to last) {
        if (isValid(val)) {
            applyValue(val);
            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

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```

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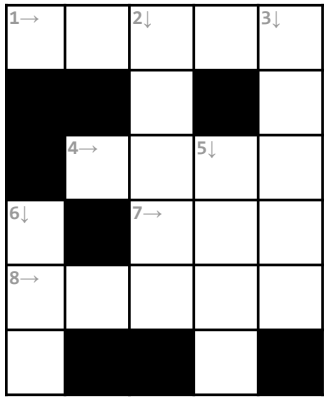


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}
```

This call to `findSolution()` is trying to place a value in position n

In this problem, n identifies the slot we're trying to put a word in, e.g. 5 down

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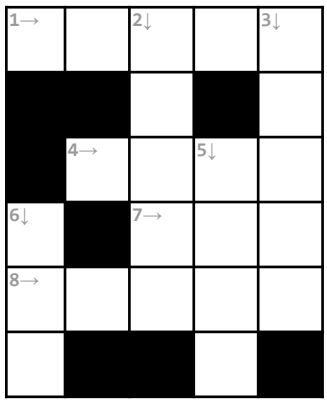


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```

The base case is when a solution is found

In this problem, a solution is found when all 8 slots are filled

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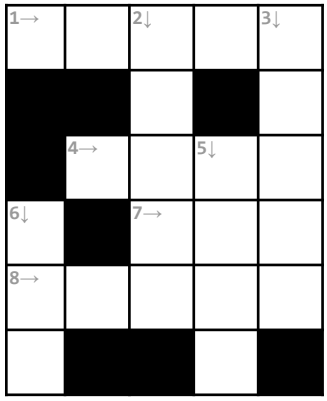


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```

For all possible values that can be put in positions

In this problem, the words from the word list are the values

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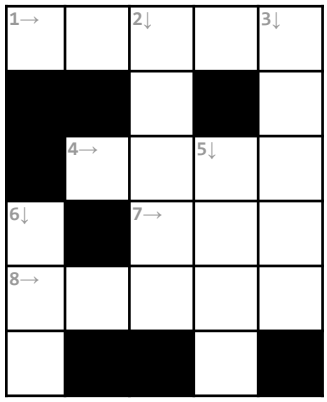


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```

`isValid()` checks whether the current potential value can be placed in the position

In this problem, what are the constraints for whether a word can be placed in a slot?

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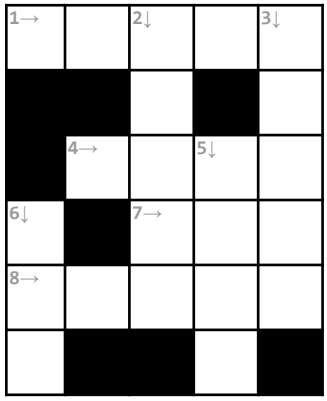


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`isValid()` checks whether the current potential value can be placed in the position

In this problem, what are the constraints for whether a word can be placed in a slot?

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

Recursive Backtracking

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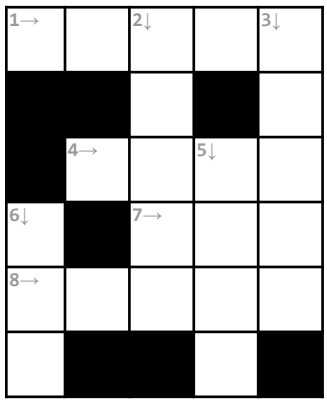


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    return false;
}
```

Add value to the board

Recursive Backtracking

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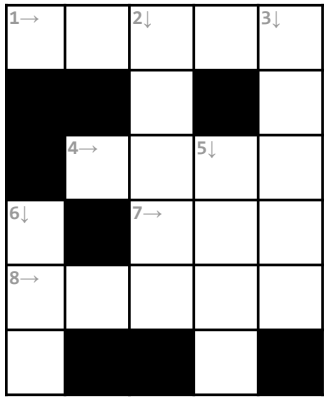


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        }
    }

    return false;
}
```

Make a recursive call to move on to next position (n+1) to try to continue to fill board

Recursive Backtracking

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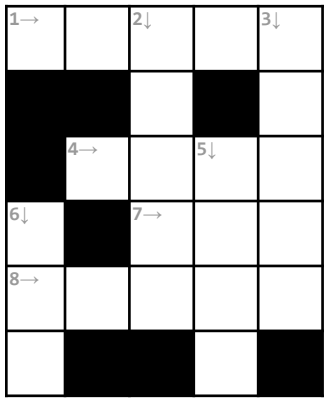


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Make a recursive call to move on to next position (n+1) to try to continue to fill board

There are two possibilities of what happens next

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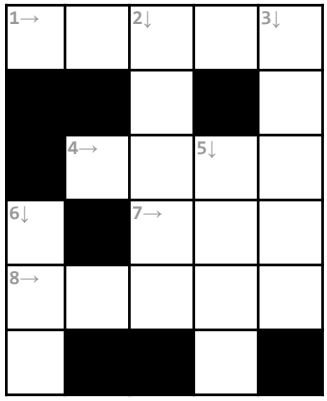


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        }
    }

    return false;
}
```

(1) If we continue to place values in positions until we find a solution, we return `true` in the base case and return `true` all the way back through the recursive call stack

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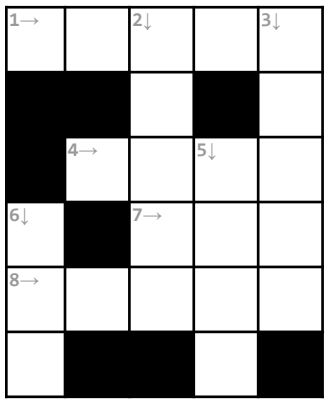


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        }
    }

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}
```

(2) If we reach a position `n` that we cannot fill -- because none of the values are valid for that position -- the `for` loop is exhausted

We then return `false`. We must backtrack!

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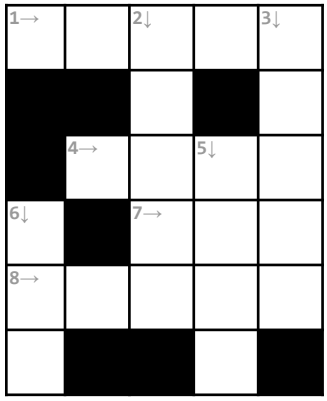


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}
```

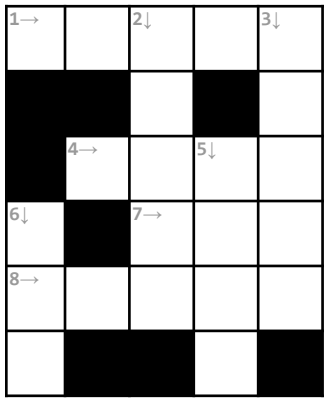
(2) When we backtrack, the recursive call returns false, indicating that placing that value on the board resulted in an unsolvable state

We must remove the value from the board and continue in the `for` loop to try to place other values

Recursive Backtracking

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
hoses
keel
laser
lee
line
sails
sheet
steer
tie




```
boolean findSolution(n, other params) {
    if (we found a solution) {
        displaySolution();
        return true;
    }

    for (val = first to last) {
        if (isValid(val)) {
            applyValue(val);
            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

Recursive Backtracking

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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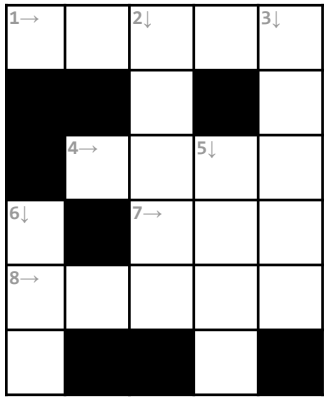


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            applyValue(val);
            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

Notice that, in order to do a sample run, we need to assign an arbitrary order in which to assign the spaces in the crossword puzzle.

We use the following order for this run: 1ACROSS, 2DOWN, 3DOWN, 4ACROSS, 7ACROSS, 5DOWN, 8ACROSS, 6DOWN.

Recursive Backtracking

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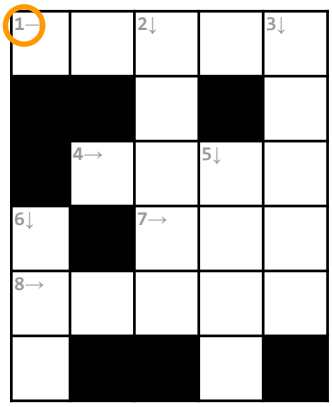


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            }
            removeValue(val);
        }
    }

    return false;
}
```


1 across

Recursive Backtracking

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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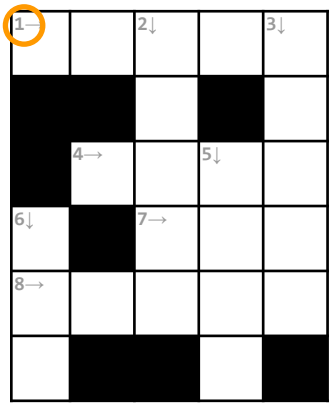


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        }
    }

    return false;
}
```

1 across

Recursive Backtracking

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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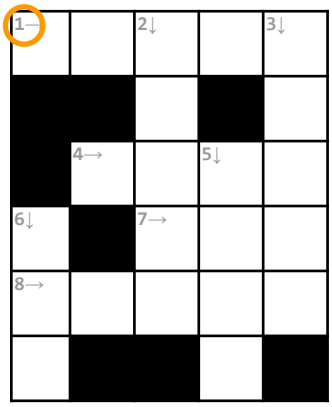


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        }
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    return false;
}
```

1 across

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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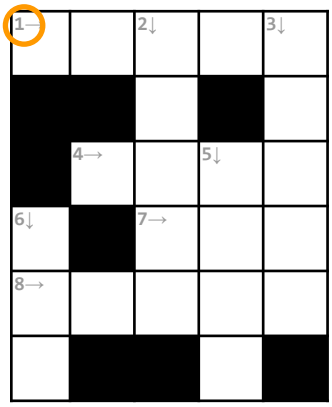


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            applyValue(val);
            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

`1 across  val "aft"`

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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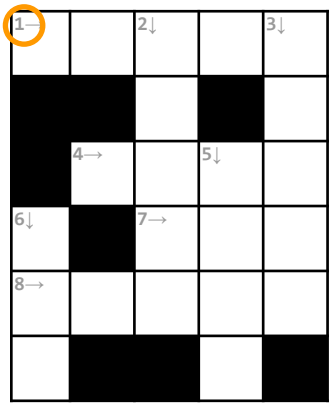


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            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

`1 across  val "ale"`

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which words used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
hoses
keel
laser
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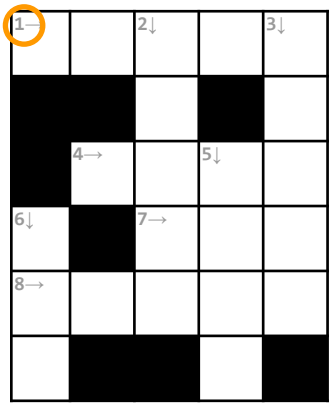
line
sails
sheet
steer
tie

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            applyValue(val);
            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

1 across val "eel"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which words used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
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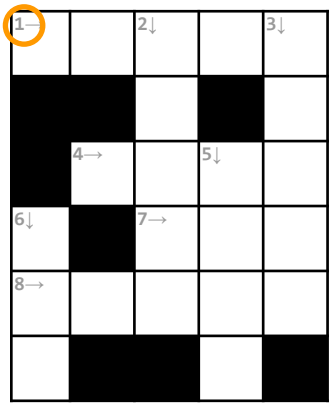


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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

1 across val "heel"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which words used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
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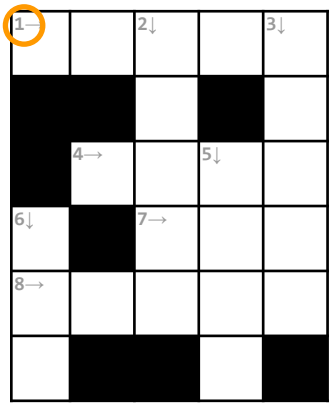


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            applyValue(val);
            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

`1 across  val "hike"`

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which words used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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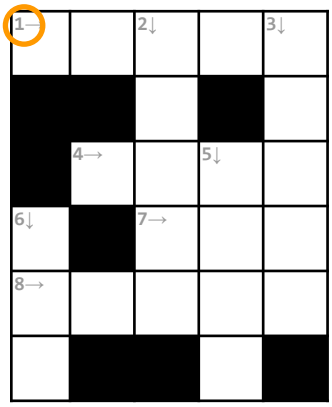


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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```


`1 across  val "hoses"`

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which ones are used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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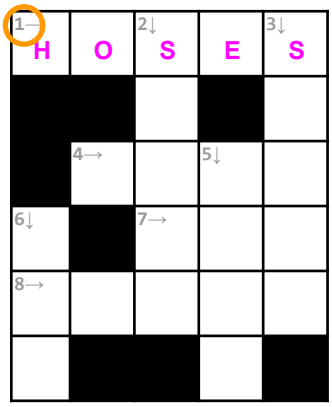


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            removeValue(val);
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    return false;
}
```

1 across val "hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which ones are used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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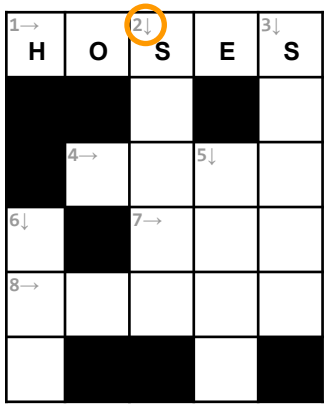


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            applyValue(val);
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                return true;
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            removeValue(val);
        }
    }

    return false;
}
```


2 down

1 across val "hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which words used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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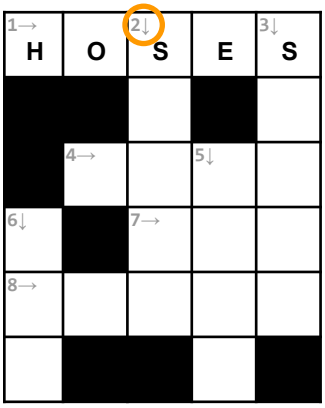


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            removeValue(val);
        }
    }

    return false;
}
```

2 down		
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which words used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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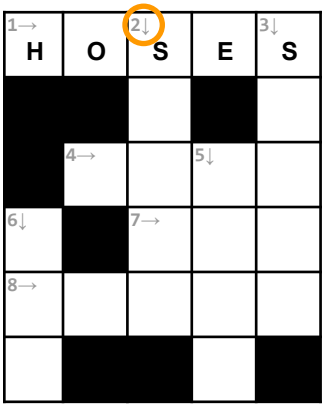


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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

2 down	val	"aft"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Words not reused

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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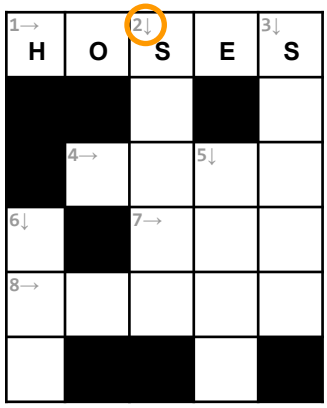


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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

2 down	val	"ale"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Words not reused

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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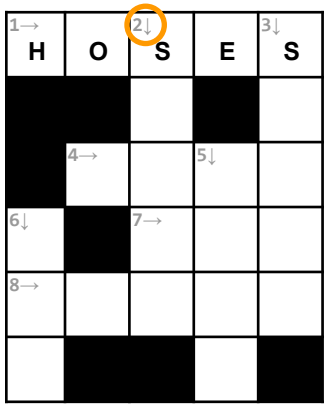


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            applyValue(val);
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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```


2 down	val	"eel"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which one is unused

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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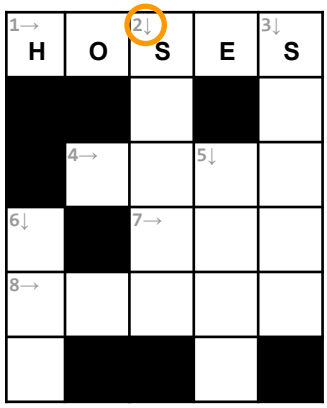


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            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which one is unused

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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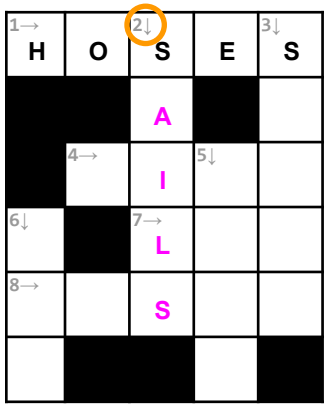


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            applyValue(val);
            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which one is used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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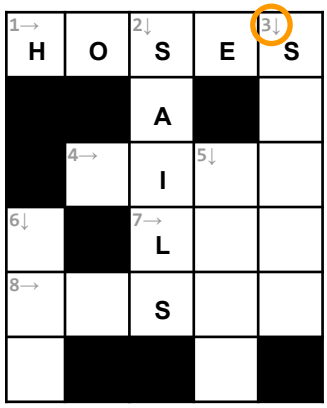


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            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

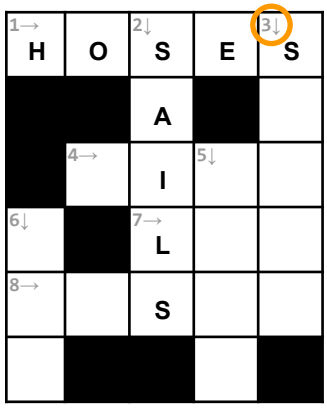
3 down		
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which one is used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
hoses
keel
laser
lee
line
sails
sheet
steer
tie

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    if (we found a solution) {
        displaySolution();
        return true;
    }

    for (val = first to last) {
        if (isValid(val)) {
            applyValue(val);
            if (findSolution(n + 1, other params)) {
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

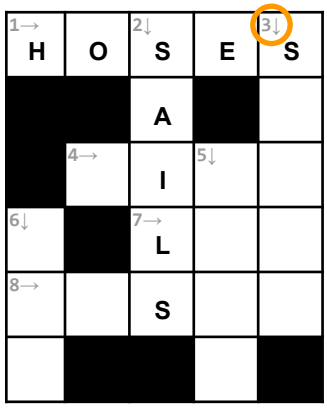

3 down	val	"aft"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
hoses
keel
laser
lee
line
sails
sheet
steer
tie

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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

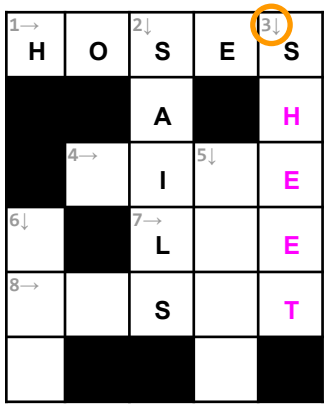
3 down	val	"ale"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
hoses
keel
laser
lee
line
sails
sheet
steer
tie

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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```


3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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hike
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keel
laser
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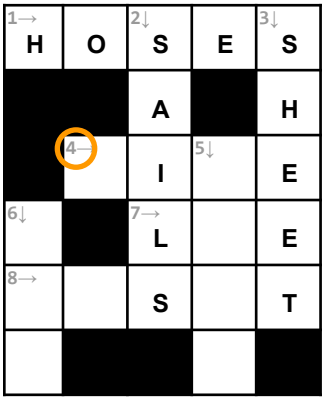
line
sails
sheet
steer
tie

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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

4 across		
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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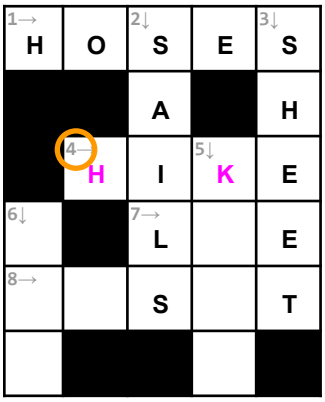
sails
sheet
steer
tie

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            }
            removeValue(val);
        }
    }

    return false;
}
```

4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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keel
laser
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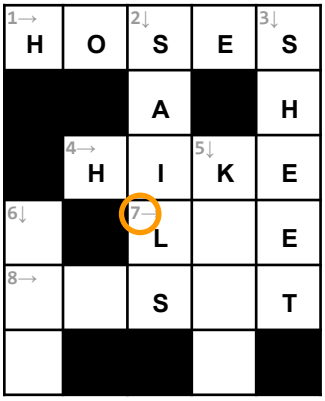


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                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

7 across		
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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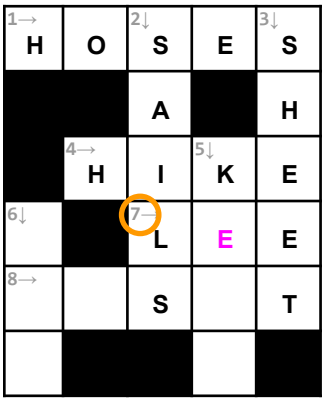
tie

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                return true;
            }
            removeValue(val);
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    }

    return false;
}
```

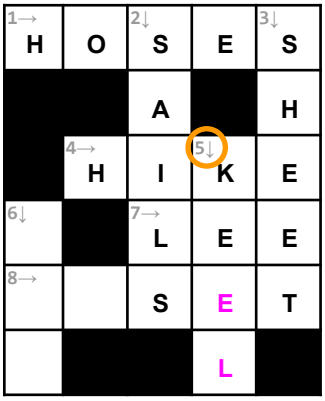
7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Words can be used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
hoses
keel
laser
lee
line
sails
sheet
steer
tie

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            if (findSolution(n + 1, ot
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

5 down	val	"keel"
7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Words can be used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
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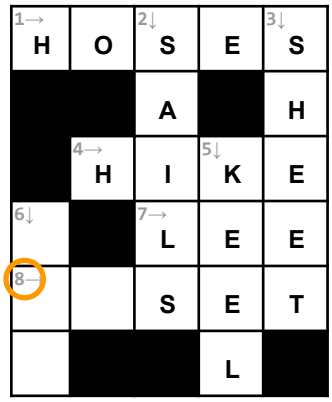
tie

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            if (findSolution(n + 1, ot
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

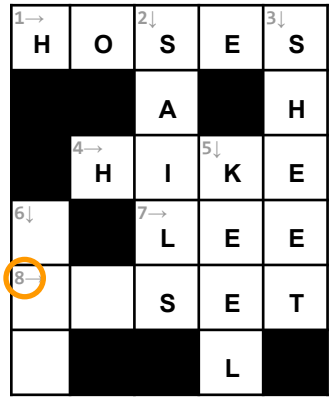

8 across		
5 down	val	"keel"
7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
hoses
keel
laser
lee
line
sails
sheet
steer
tie



No words are valid! Must backtrack

```
boolean findSolution(n, other params) {
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        }
    }

    return false;
}
```

8 across		
5 down	val	"keel"
7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
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keel

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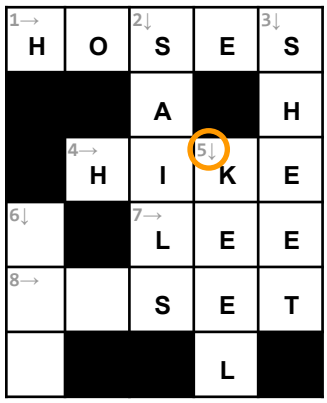


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    return false;
}
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5 down	val	"keel"
7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which words used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
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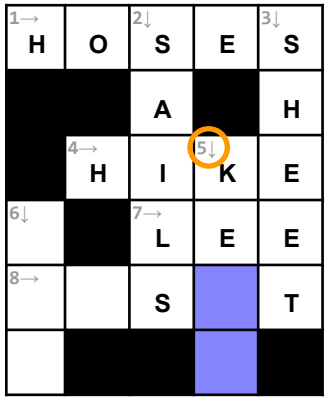
line
sails
sheet
steer
tie

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    return false;
}
```

5 down		
7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Which words used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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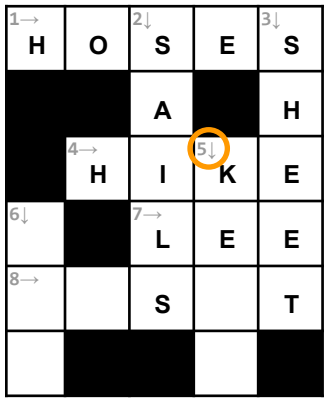


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    return false;
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```

5 down		
7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not reused

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
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sheet
steer
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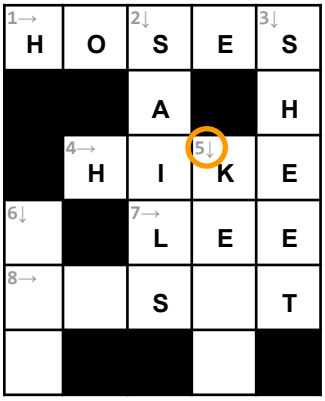

No words are valid! Must backtrack

```
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            }
            removeValue(val);
        }
    }

    return false;
}
```

5 down		
7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not reused

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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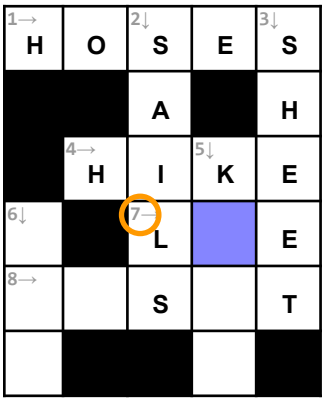


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    return false;
}
```


7 across	val	"lee"
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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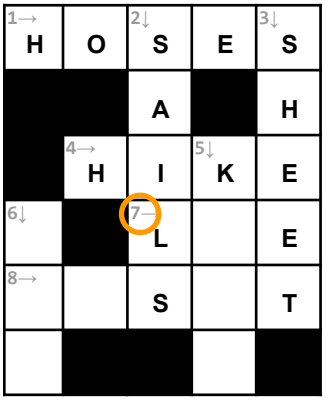

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}
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7 across		
4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
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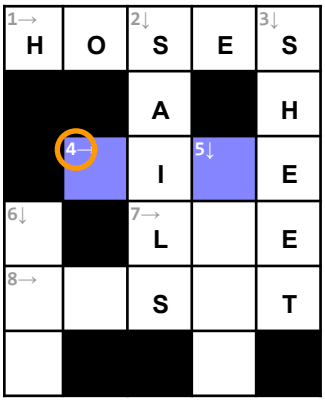


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    }

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}
```

4 across	val	"hike"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
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We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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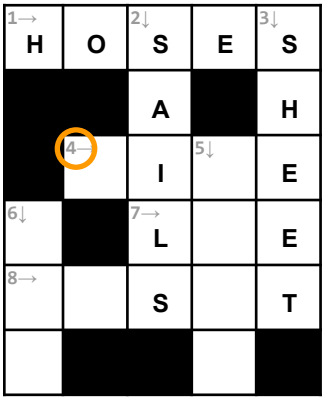


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            }
            removeValue(val);
        }
    }

    return false;
}
```

4 across		
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

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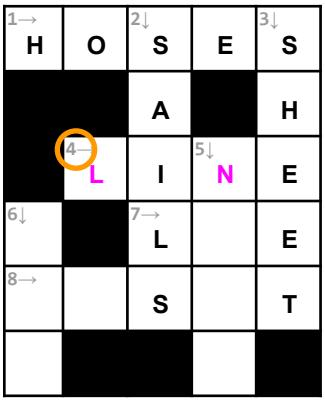


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            }
            removeValue(val);
        }
    }

    return false;
}
```

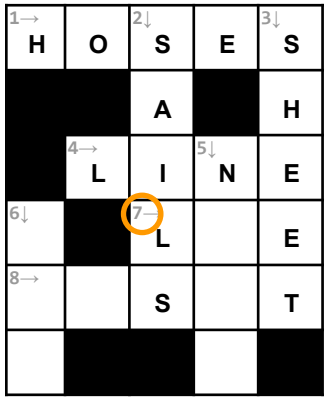

4 across	val	"line"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

Recursive Backtracking

1. Intersecting letters match
2. Must fit in slot (length)
3. Word not yet used

We consider another problem that can be solved with recursive backtracking. Given a list of words that are to be filled into a crossword puzzle, how do we find a solution that satisfies the rules of the conventional crossword?

aft
ale
eel
heel
hike
hoses
keel
laser
lee
line
sails
sheet
steer
tie

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boolean findSolution(n, other params) {
    if (we found a solution) {
        displaySolution();
        return true;
    }

    for (val = first to last) {
        if (isValid(val)) {
            applyValue(val);
            if (findSolution(n + 1, ot
                return true;
            }
            removeValue(val);
        }
    }

    return false;
}
```

7 across		
4 across	val	"line"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"

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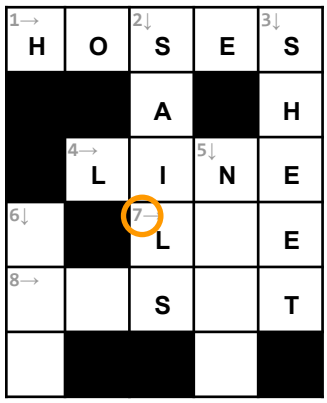


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Notice that, since this is a fresh stack frame for n == 7, we start the loop over from the beginning again!

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3 down	val	"sheet"
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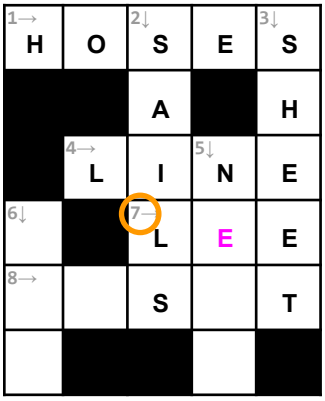


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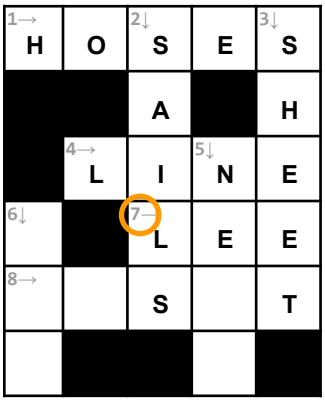


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    }

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```


And so on...

7 across	val	"lee"
4 across	val	"line"
3 down	val	"sheet"
2 down	val	"sails"
1 across	val	"hoses"