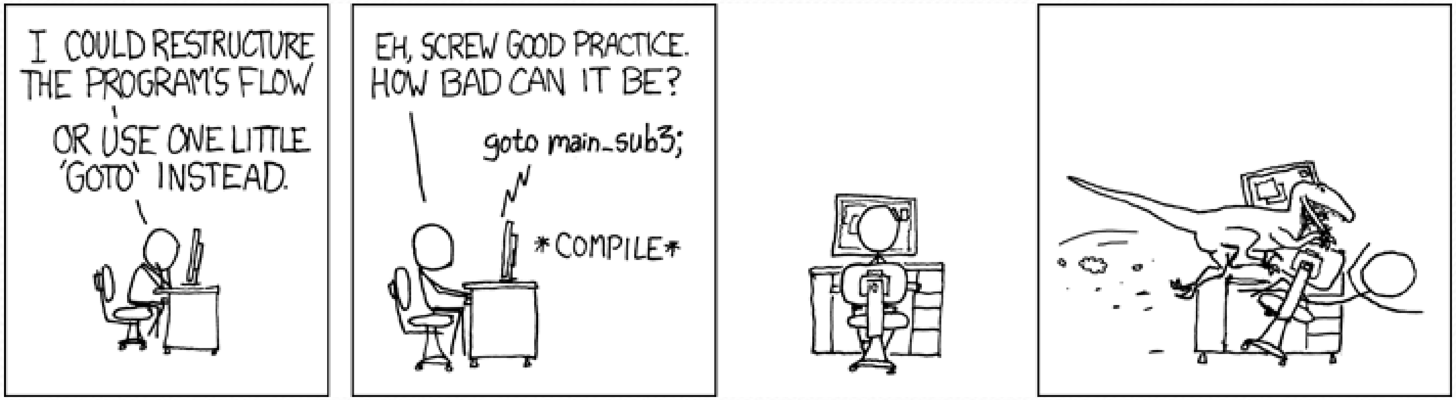
CSE 143

Recursive backtracking



Exercise: Dice rolls

- Write a method `diceRoll` that accepts an integer parameter representing a number of 6-sided dice to roll, and output all possible arrangements of values that could appear on the dice.

```
diceRoll(2);
```

```
[1, 1]    [3, 1]    [5, 1]
[1, 2]    [3, 2]    [5, 2]
[1, 3]    [3, 3]    [5, 3]
[1, 4]    [3, 4]    [5, 4]
[1, 5]    [3, 5]    [5, 5]
[1, 6]    [3, 6]    [5, 6]
[2, 1]    [4, 1]    [6, 1]
[2, 2]    [4, 2]    [6, 2]
[2, 3]    [4, 3]    [6, 3]
[2, 4]    [4, 4]    [6, 4]
[2, 5]    [4, 5]    [6, 5]
[2, 6]    [4, 6]    [6, 6]
```

```
diceRoll(3);
```

```
[1, 1, 1]
[1, 1, 2]
[1, 1, 3]
[1, 1, 4]
[1, 1, 5]
[1, 1, 6]
[1, 2, 1]
[1, 2, 2]
   ...
[6, 6, 4]
[6, 6, 5]
[6, 6, 6]
```

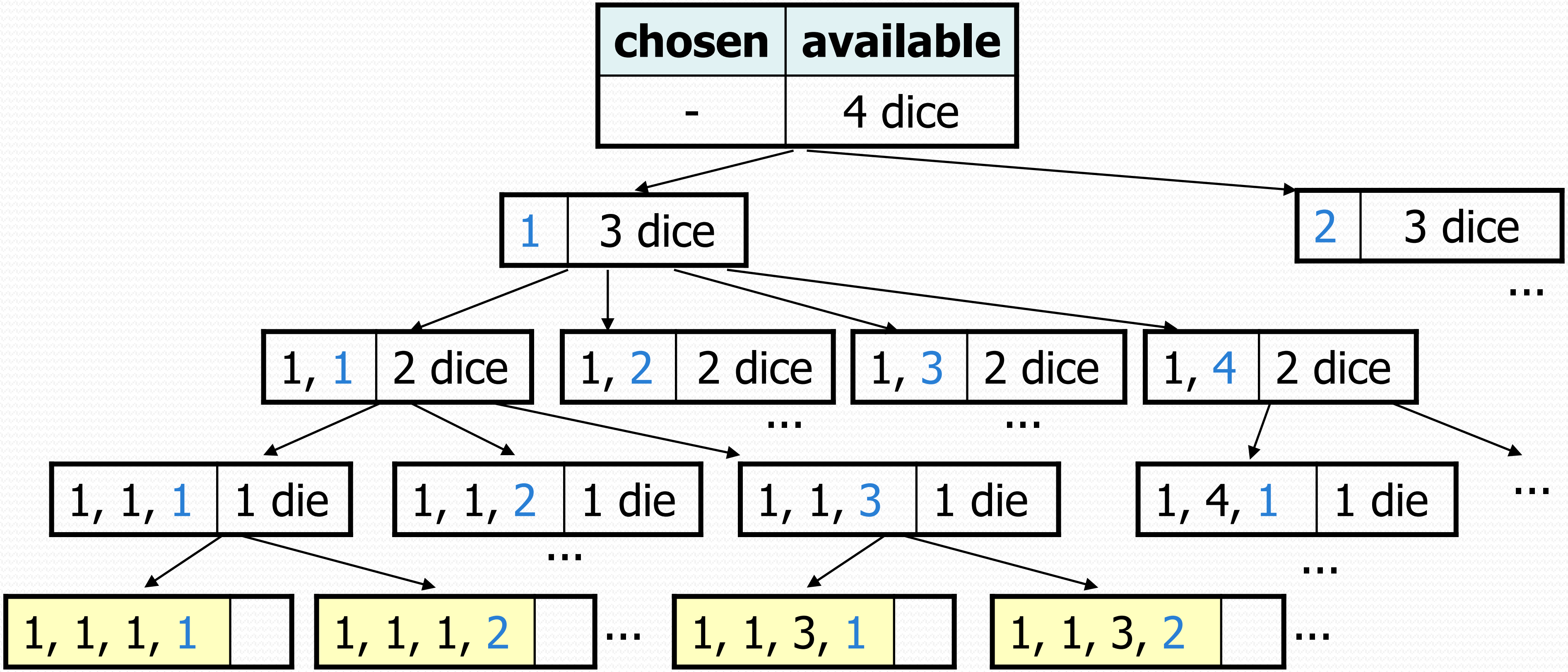
Examining the problem

- We want to generate all possible sequences of values.

```
for (each possible first die value):
    for (each possible second die value):
        for (each possible third die value):
            ...
                print!
```

  - This is called a **depth-first search**
  - How can we completely explore such a large search space?

A decision tree



Exercise: Dice roll sum

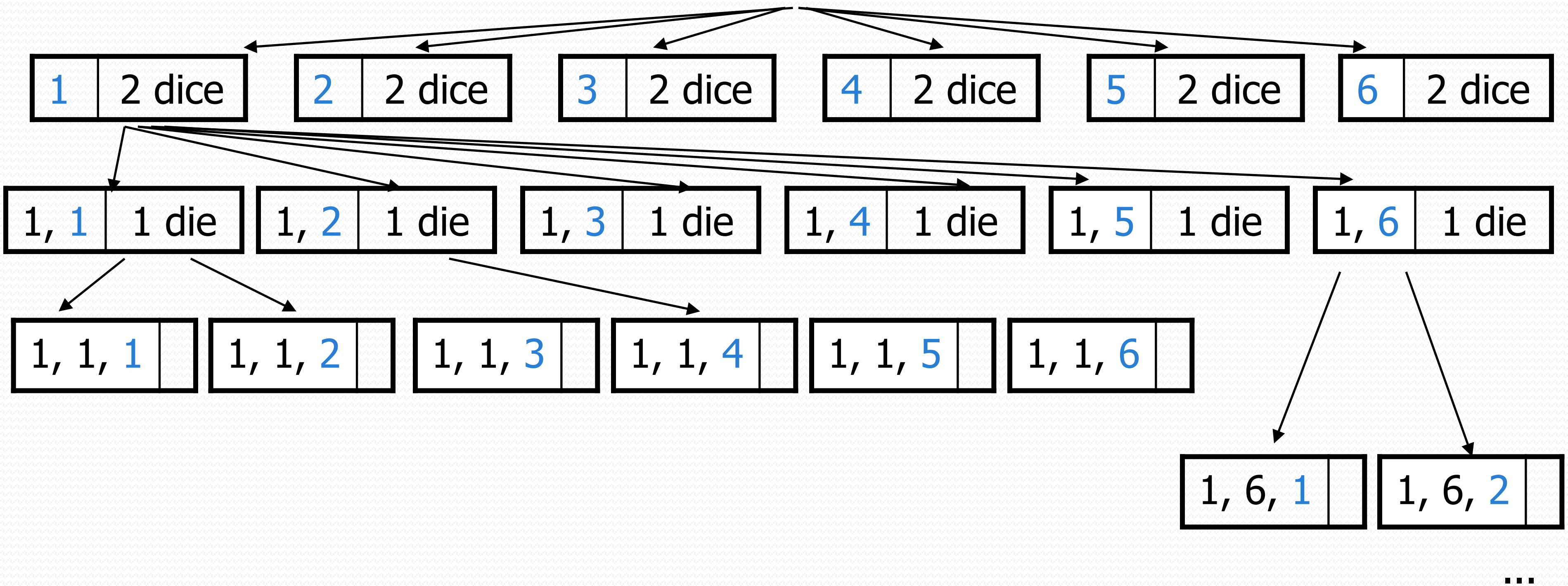
- Write a method `diceSum` similar to `diceRoll`, but it also accepts a desired sum and prints only arrangements that add up to exactly that sum.

```
diceSum(2, 7);

[1, 6]
[2, 5]
[3, 4]
[4, 3]
[5, 2]
[6, 1]
```

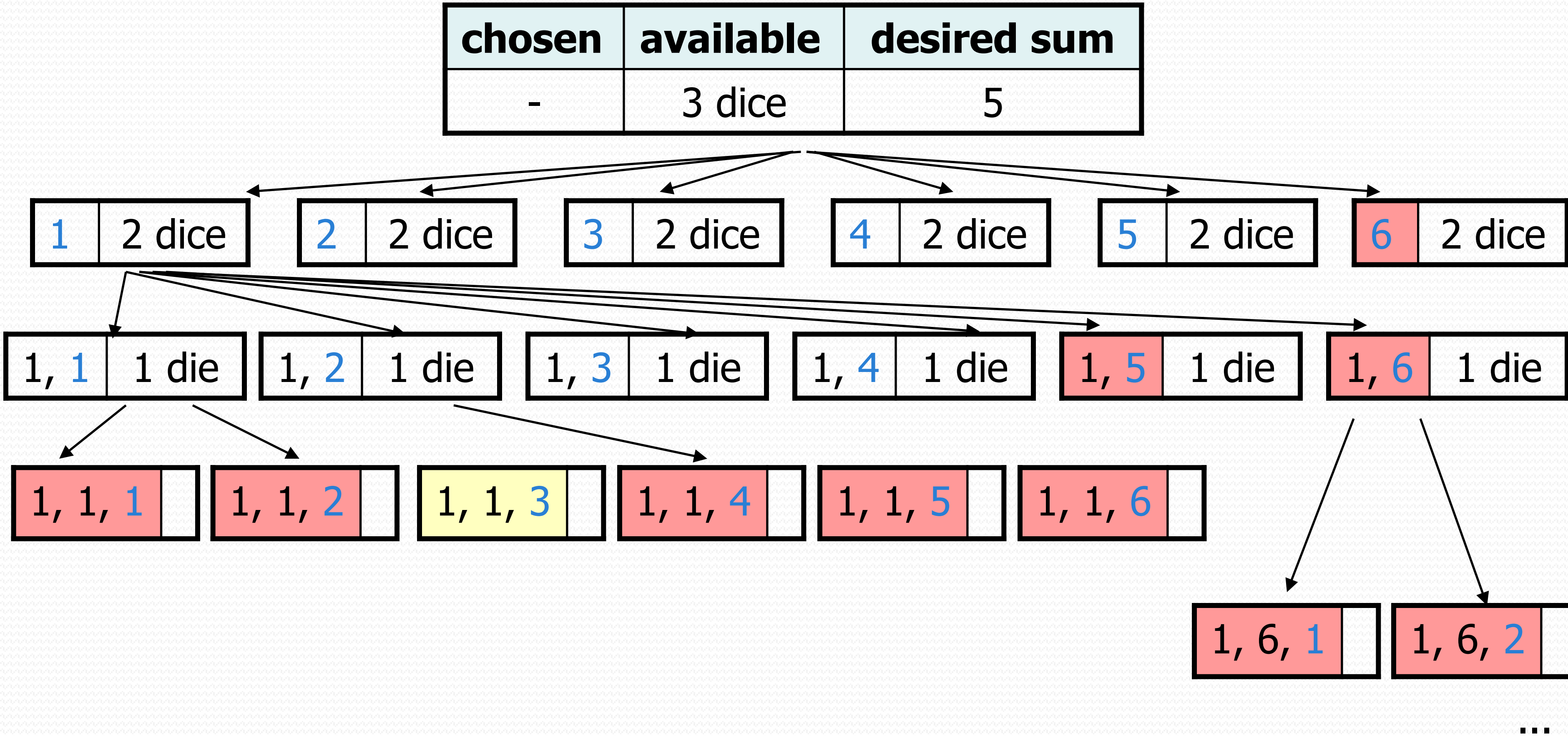
```
diceSum(3, 7);

[1, 1, 5]
[1, 2, 4]
[1, 3, 3]
[1, 4, 2]
[1, 5, 1]
[2, 1, 4]
[2, 2, 3]
[2, 3, 2]
[2, 4, 1]
[3, 1, 3]
[3, 2, 2]
[3, 3, 1]
[4, 1, 2]
[4, 2, 1]
[5, 1, 1]
```

Consider all paths?

chosen	available	desired sum
-	3 dice	5



New decision tree



Backtracking

- **backtracking**: Finding solution(s) by trying partial solutions and then abandoning them if they are not suitable.
  - a "brute force" algorithmic technique (tries all paths)
  - often implemented recursively

  Applications:
  - producing all permutations of a set of values
  - parsing languages
  - games: anagrams, crosswords, word jumbles, 8 queens
  - combinatorics and logic programming

Backtracking algorithms

A general pseudo-code algorithm for backtracking problems:

Explore(**choices**):

- if there are no more **choices** to make: stop.
- else:
  - Make a single choice **C**.
  - Explore the remaining **choices**.
  - Un-make choice **C**, if necessary. (backtrack!)

Backtracking strategies

- When solving a backtracking problem, ask these questions:
  - What are the "choices" in this problem?
    - What is the "base case"? (How do I know when I'm out of choices?)
  - How do I "make" a choice?
    - Do I need to create additional variables to remember my choices?
    - Do I need to modify the values of existing variables?
  - How do I explore the rest of the choices?
    - Do I need to remove the made choice from the list of choices?
  - Once I'm done exploring, what should I do?
  - How do I "un-make" a choice?

Exercise: Combinations

- Write a method `combinations` that accepts a string *s* and an integer *k* as parameters and outputs all possible *k* -letter words that can be formed from unique letters in that string. The arrangements may be output in any order.
  - Example:
    `combinations("GOOGLE", 3)`
    outputs the sequence of lines at right.
  - To simplify the problem, you may assume that the string *s* contains at least *k* unique characters.

EGL	LEG
EGO	LEO
ELG	LGE
ELO	LGO
EOG	LOE
EOL	LOG
GEL	OEG
GEO	OEL
GLE	OGE
GLO	OGL
GOE	OLE
GOL	OLG

Initial attempt

```
public static void combinations(String s, int length) {
    combinations(s, "", length);
}

private static void combinations(String s, String chosen, int length) {
    if (length == 0) {
        System.out.println(chosen);     // base case: no choices left
    } else {
        for (int i = 0; i < s.length(); i++) {
            String ch = s.substring(i, i + 1);
            if (!chosen.contains(ch)) {
                String rest = s.substring(0, i) + s.substring(i + 1);
                combinations(rest, chosen + ch, length - 1);
            }
        }
    }
}
```

- Problem: Prints same string multiple times.

Exercise solution

```
public static void combinations(String s, int length) {
    Set<String> all = new TreeSet<String>();
    combinations(s, "", all, length);
    for (String comb : all) {
        System.out.println(comb);
    }
}

private static void combinations(String s, String chosen,
                                 Set<String> all, int length) {
    if (length == 0) {
        all.add(chosen);           // base case: no choices left
    } else {
        for (int i = 0; i < s.length(); i++) {
            String ch = s.substring(i, i + 1);
            if (!chosen.contains(ch)) {
                String rest = s.substring(0, i) + s.substring(i + 1);
                combinations(rest, chosen + ch, all, length - 1);
            }
        }
    }
}
```