CS302 -- Lab 9 -- Letter Dice

- **CS302 -- Fundamental Algorithms**
- **Spring, 2022**
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- **This file: http://web.eecs.utk.edu/~jplank/plank/classes/cs302/Labs/Lab9**
- **Lab Directory: /home/jplank/cs302/Labs/Lab9**

What you are to submit

You are to submit the file **worddice.cpp**. This should be a standalone C++ file that the TA's will compile and test with the gradescripts.

Help

2017 TA Camille Crumpton has posted some youtube videos to help with this lab -- they are here.

Description

These will be specified by strings, one per die, that contain the letters on the die. We won't constrain dice to have six sides -- we'll assume that a die may have any number of sides, and that the length of the string defines the number of sides on a die.

For example, let's assume that the above dice only have three sides each -- the sides that you can see. Then, the file **Dice1.txt** defines the four dice pictured:

Now, you are also given a list of words, and your job is to spell the words on the dice so that each letter of the

word is on a different die. For example, "RAGE" may be spelled using 'R' from the "PRR" die, 'A' from the "SAA" die, 'G' from the "ENG" die and 'E' from the "EAE" die. Similarly, "SEEP" may be spelled with 'S' from the "SAA" die, 'E' from the "EAE" die, 'E' from the "ENG" die and 'P' from the "PRR" die. However, you cannot spell "PEEN", even though all the letters are there, because you would have to use the "ENG" die for both the 'E' and 'N'.

Your job is to write the program **worddice**, called as follows:

```
worddice dice-file word-list
```

The dice file is a list of dice as above. Each die may have any number of letters, and within a file, the dice may all have differing numbers of letters. The word list is a file that contains words. For each word in the word list file, your program should print out:

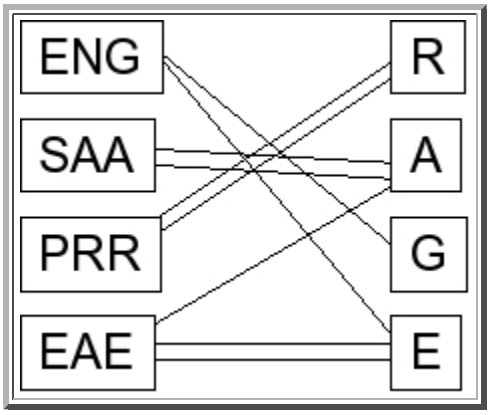
- If the word cannot be spelled: "Cannot spell *word*".
- If the word can be spelled: The order of the dice used to spell out the word, then the word. The dice are numbered starting with zero.

For example.

```
UNIX> cat Dice1.txt
ENG
SAA
PRR
EAE
UNIX> cat Words1.txt
RAGE
SEEP
ERR
PEEN
GASP
UNIX> worddice Dice1.txt Words1.txt
2,1,0,3: RAGE
1,0,3,2: SEEP
Cannot spell ERR
Cannot spell PEEN
0,3,1,2: GASP
UNIX>
```

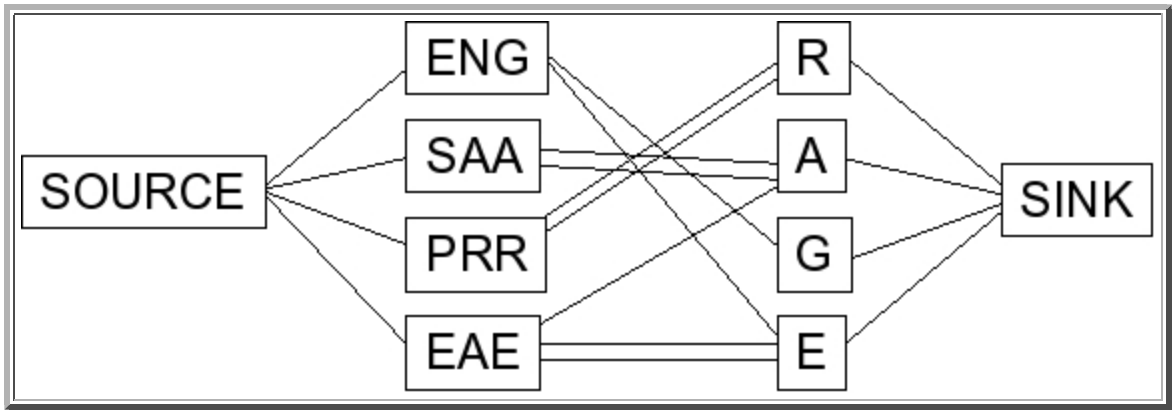
Organizing the program

This is an example of a bipartite matching. For each word, set up a graph that matches dice to letters of the words. For example, here are the above dice with the word "RAGE":

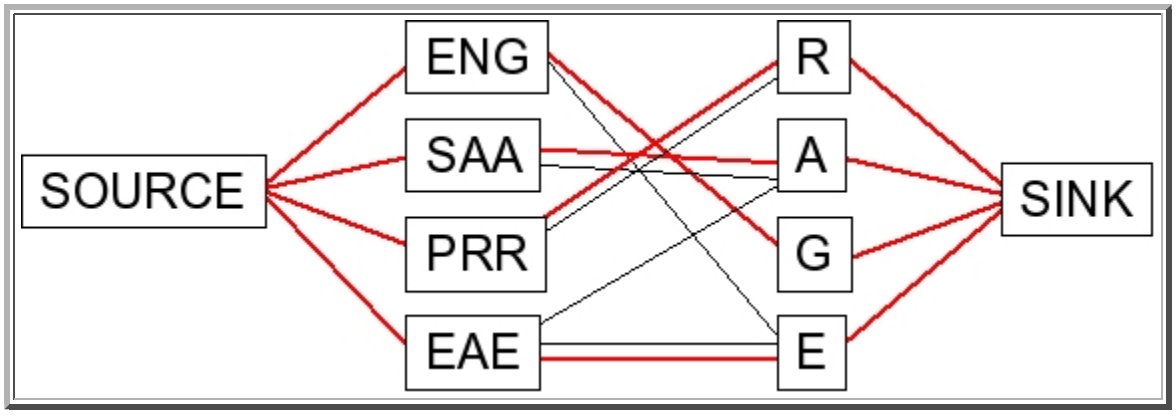


I've included double-edges for the duplicate letters. Your program can eliminate these if you want, since duplicate letters don't help you at all and just make your program run slower. My program does that. You want to find a *matching* of this graph that is composed of edges that connect two nodes, where no edge is incident to the same node.

To do this, you convert the graph into one in which network flow will solve the problem: a source node connected to each die, and a sink node connected to each letter of the word:



Finding the maximum flow will discover the matching if it exists. Here is the flow/matching in this example:



Your program should use the Edmonds-Karp algorithm to determine maximum flow. The fact that all edges have weight one makes this easier.

My program is slow for two reasons. First, I create and destroy the graph with each word. It would be faster if I never deleted the source and dice nodes/edges. Second, when I create the edges to each letter of the word, I use the **Find()** method on the dice strings. That is inefficient as I could instead have a 256-element array for

each die which has a 1 for each letter set in the die. That would speed things up. However, I'm not doing it for lack of time. Maybe next semester. That said, your program should not run more slowly than mine.

The first step -- reading the input and creating the graphs

The program **readorig** was my first step -- reading the input, creating the network flow graph, and printing it out. Note, my program does not have duplicate edges.

```
UNIX> readorig Dice1.txt Words1.txt
Node 0: SOURCE Edges to 1 2 3 4
Node 1: ENG Edges to 7 8
Node 2: SAA Edges to 6
Node 3: PRR Edges to 5
Node 4: EAE Edges to 6 8
Node 5: R Edges to 9
Node 6: A Edges to 9
Node 7: G Edges to 9
Node 8: E Edges to 9
Node 9: SINK Edges to

Node 0: SOURCE Edges to 1 2 3 4
Node 1: ENG Edges to 6 7
Node 2: SAA Edges to 5
Node 3: PRR Edges to 8
Node 4: EAE Edges to 6 7
Node 5: S Edges to 9
Node 6: E Edges to 9
Node 7: E Edges to 9
Node 8: P Edges to 9
Node 9: SINK Edges to

Node 0: SOURCE Edges to 1 2 3 4
Node 1: ENG Edges to 5
Node 2: SAA Edges to
Node 3: PRR Edges to 6 7
Node 4: EAE Edges to 5
Node 5: E Edges to 8
Node 6: R Edges to 8
Node 7: R Edges to 8
Node 8: SINK Edges to

Node 0: SOURCE Edges to 1 2 3 4
Node 1: ENG Edges to 6 7 8
Node 2: SAA Edges to
Node 3: PRR Edges to 5
Node 4: EAE Edges to 6 7
Node 5: P Edges to 9
Node 6: E Edges to 9
Node 7: E Edges to 9
Node 8: N Edges to 9
Node 9: SINK Edges to

Node 0: SOURCE Edges to 1 2 3 4
Node 1: ENG Edges to 5
Node 2: SAA Edges to 6 7
Node 3: PRR Edges to 8
Node 4: EAE Edges to 6
Node 5: G Edges to 9
Node 6: A Edges to 9
```

```
Node 7: S Edges to 9
Node 8: P Edges to 9
Node 9: SINK Edges to

UNIX>
```

Examples

I have a few example files besides the above:

Dice2.txt and **Words2.txt** are small files to test variable-sized dice:

```
UNIX> cat Dice2.txt
E
PITED
FOGCEF
UNIX> cat Words2.txt
DOG
PIG
CAT
DO
TEE
FEE
UNIX> worddice Dice2.txt Words2.txt
Cannot spell DOG
Cannot spell PIG
Cannot spell CAT
1,2: DO
1,0,2: TEE
2,0,1: FEE
UNIX>
```

Dice3.txt is a file with six randomly generated six-sided dice, and **Words3.txt** contains all words from the Unix dictionary that have six letters.

```
UNIX> cat Dice3.txt
IBTLCP
DUAQEM
DXLOTN
WMIVQA
NDCLOT
JKCEMR
UNIX> head Words3.txt
AARHUS
ABACUS
ABATER
ABBOTT
ABDUCT
ABJECT
ABLATE
ABLAZE
ABOARD
ABOUND
UNIX> worddice Dice3.txt Words3.txt | head
Cannot spell AARHUS
Cannot spell ABACUS
Cannot spell ABATER
Cannot spell ABBOTT
3,0,2,1,5,4: ABDUCT
```

```
3,0,5,1,4,2: ABJECT
1,0,2,3,4,5: ABLATE
Cannot spell ABLAZE
1,0,2,3,5,4: ABOARD
Cannot spell ABOUND
UNIX>
```

Dice4.txt is a file with eight randomly generated dice with between three and seven sides. Words4.txt contains all words from the Unix dictionary that have eight letters. As **worddice** shows, there are fewer successful spellings in this example:

```
UNIX> cat Dice4.txt
FJZ
BSYQ
WYUTI
SHTXVU
PRAFYBH
LWQCEI
ENLJB
BTJO
UNIX> head Words4.txt
ABDICATE
ABERDEEN
ABERRANT
ABERRATE
ABETTING
ABEYANCE
ABHORRED
ABLUTION
ABNORMAL
ABORNING
UNIX> worddice Dice4.txt Words4.txt | head
Cannot spell ABDICATE
Cannot spell ABERDEEN
Cannot spell ABERRANT
Cannot spell ABERRATE
Cannot spell ABETTING
Cannot spell ABEYANCE
Cannot spell ABHORRED
Cannot spell ABLUTION
Cannot spell ABNORMAL
Cannot spell ABORNING
UNIX> worddice Dice4.txt Words4.txt | grep ':' | head
7,6,4,2,3,5,0,1: BEAUTIFY
1,6,7,2,0,5,3,4: BLOWFISH
7,5,3,6,0,2,1,4: BLUEFISH
6,7,4,1,2,0,3,5: BOASTFUL
5,0,4,3,1,2,7,6: EFFUSION
0,4,6,2,5,7,3,1: FABULOUS
0,6,4,7,5,2,3,1: FEROCITY
0,5,1,7,2,3,4,6: FESTIVAL
0,2,6,4,7,3,5,1: FIBROSIS
0,6,4,2,3,5,1,7: FLAUTIST
UNIX>
```

Dice5.txt is a file with twenty randomly generated 5-sided dice and Words5.txt contains all words from the Unix dictionary:

```
UNIX> wc Dice5.txt
      20      20     120 Dice5.txt
UNIX> head -n 5 Dice5.txt
```

```
CWOZP
YFLBV
VNJGT
PUISB
MCGNQ
UNIX> wc Words5.txt
   24854   24853  205394 Words5.txt
UNIX> head -n 5 Words5.txt
AAA
AAAS
AARHUS
AARON
AAU
UNIX> time worddice Dice5.txt Words5.txt > /dev/null
20.827u 0.100s 0:21.07 99.2%    0+0k 0+0io 0pf+0w
UNIX>
```

It takes a little time, doesn't it? (*These timings are from 2008: This is on my MacBook Pro with a 2.16 Ghz processor. The Linux box in my office (much older) takes roughly twice as long. The cetus lab machines take 32 seconds*). Let's see if using compiler optimization helps:

```
UNIX> g++ -O -o worddice worddice.cpp
UNIX> time worddice Dice5.txt Words5.txt > /dev/null
2.736u 0.050s 0:02.80 99.2%     0+0k 0+1io 0pf+0w
UNIX>
```

Wow. The optimized version is in the lab directory and takes 2.85 seconds on the cetus machines.

We can use our mastery of Unix tools like **sed**, **awk** and **grep** to answer some questions. For example, how many words can be spelled, and how many cannot:

```
UNIX> worddice Dice5.txt Words5.txt | grep ':' | wc
   24400   48800  623204
UNIX> worddice Dice5.txt Words5.txt | grep Cannot | wc
     453    1359   10819
UNIX>
```

Quite a high success ratio -- 24400/24953 = 97.8 percent. What's the largest word that you can spell:

```
UNIX> worddice Dice5.txt Words5.txt | grep ':' | sed 's/,/ /g' | awk '{ print NF }' | sort -u
10
11
12
13
14
15
16
17
18
19
4
5
6
7
8
9
UNIX> worddice Dice5.txt Words5.txt | grep ':' | sed 's/,/ /g' | awk '{ if (NF == 19) print $NF }'
DIETHYLSTILBESTROL
ELECTROCARDIOGRAPH
UNIX>
```

What's the smallest word that you can't spell:

```
UNIX> worddice Dice5.txt Words5.txt | grep Cannot | awk '{ print $NF }' | sed 's/./x/g' | sort -u
xxx
xxxx
xxxxx
xxxxxx
xxxxxxx
xxxxxxxx
xxxxxxxxx
xxxxxxxxxx
xxxxxxxxxxx
xxxxxxxxxxxx
xxxxxxxxxxxxx
xxxxxxxxxxxxxx
xxxxxxxxxxxxxxx
xxxxxxxxxxxxxxxx
xxxxxxxxxxxxxxxxx
xxxxxxxxxxxxxxxxxx
xxxxxxxxxxxxxxxxxxx
xxxxxxxxxxxxxxxxxxxx
UNIX> worddice Dice5.txt Words5.txt | grep Cannot | awk '{ print $NF }' | grep '^...$'
AAA
UNIX>
```

The Gradescript

Your output format needs to match my exactly. However, as long as your output is correct, you don't have to match mine. There is a program called **grader** in the lab directory which is used to determine if your output is correct.