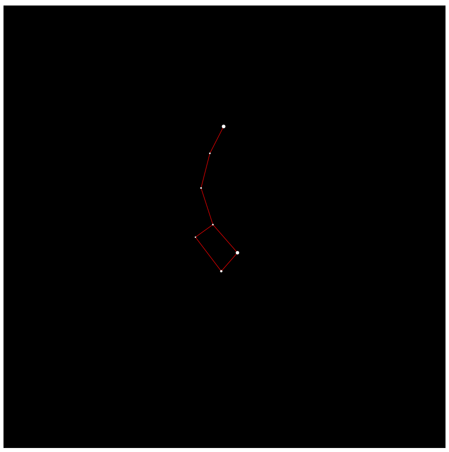
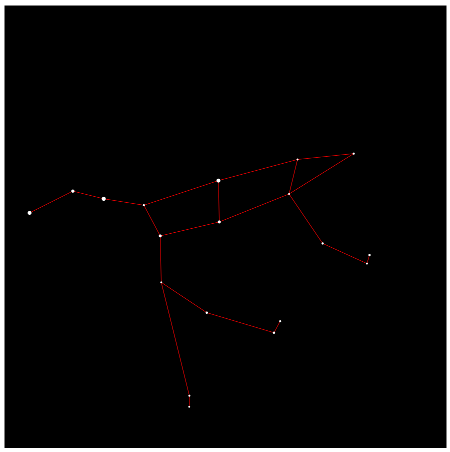
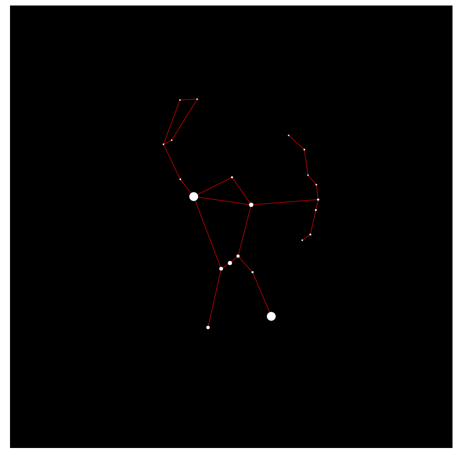
CSCI-1200 Data Structures — Fall 2021
Homework 9 — Constellation Hash Table

In this assignment we will search the stars of the night sky for known constellations. This is a challenging problem and you are welcome to use any data structures, algorithms, and techniques we have learned this semester. We hope that you experiment with using *hash tables* as one tool for this problem.

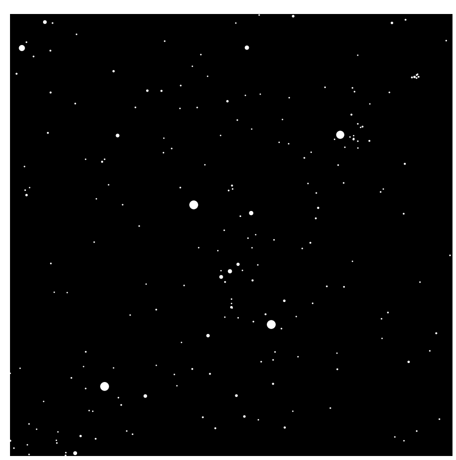
Below are three of the 88 modern constellations recognized by the International Astronomical Union (IAU). From left to right they are *Ursa Minor* (also known as the *Little Dipper*), *Ursa Major* (a subset of this constellation, an *asterism*, is also popularly known as the *Big Dipper*), and *Orion*. For clarity in these initial diagrams we only draw the brightest stars that are used to form the connect-the-dots constellation diagrams. But the night sky contains many, many more stars.

The stars are mapped to a sphere surrounding the Earth, and every star has a unique name and belongs to exactly one of these 88 constellations. *Not all stars in the constellation are used to connect-the-dots for the diagram. In a few cases, the diagram will use a star that technically belongs to another constellation.* Your task for this assignment is to write a program that will take a synthetic image of the night sky as input, along with a library of known constellations, and identify which portion of the night sky we are observing. Once identified, we can draw the constellation diagram on the image and label the visible stars by name.

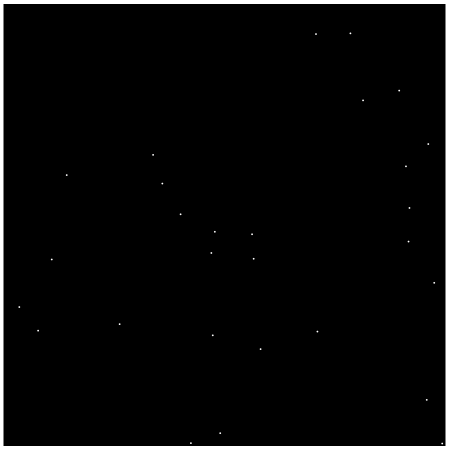
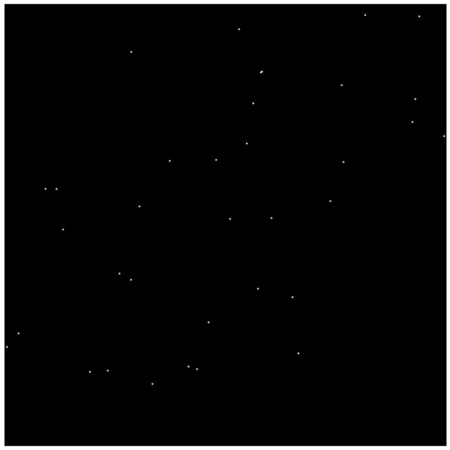
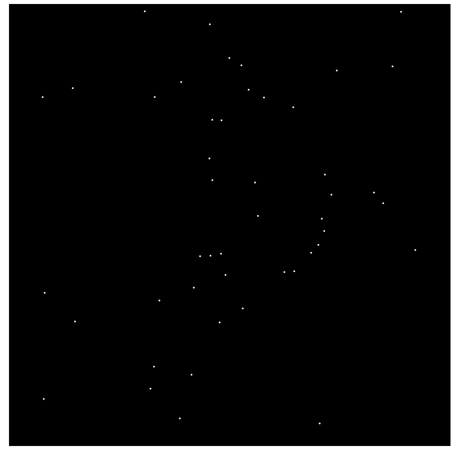
In the images below we visualize the same three constellations surrounded by many of their neighboring stars. Can you connect the dots to trace the same diagrams? Note that images of the night sky are challenging to visualize because of the high dynamic range from the inky black sky and the large range of dim and bright stars. We approximate this imagery by drawing the brighter stars as disks with larger radii.





Finding constellations can be especially challenging because the orientation (position & rotation) of the constellation changes with the observer's position on the Earth and the season. Furthermore, if we used actual photographs of the night sky, the stars might be over- or under- exposed causing us to miss some stars completely and making measurements of relative star brightness unreliable.

The images below show some of the brightest stars from the previous visualizations, but all of these stars are displayed with the same radius/brightness. Additionally, the images have been rotated. Can you still find the constellations in their rotated orientations and without relying on hints from the relative star brightness?

The three stars of Orion's belt are not as obvious when they are equal brightness to their neighbors! But we can still find them by matching distances and angles between neighboring stars.

Program Input and Output & Command Line Arguments

Your program will take in an input file with unidentified star data – an example is shown below on the left. Each row lists a star's *x,y* position within the synthetic image, the *apparent magnitude*, and the *constellation & star name*. The apparent magnitude is the star's brightness as observed from Earth – note that smaller numbers are brighter! In our input files, a value of -1 indicates that this data is unknown or unreliable. Star names beginning with `STAR_` are unidentified. Your task is to identify and label as many stars as you can in this file with the correct constellation and star name.

example_input.txt

```
star    784.74    66.13   -1.00  Unknown           STAR_00001
star     34.89   685.95   -1.00  Unknown           STAR_00002
star    813.38   217.91   -1.00  Unknown           STAR_00003
star    108.37   578.21   -1.00  Unknown           STAR_00004
star    957.61   896.12   -1.00  Unknown           STAR_00005
star    489.87   971.57   -1.00  Unknown           STAR_00006
star    895.22   195.74   -1.00  Unknown           STAR_00007
star    562.02   521.11   -1.00  Unknown           STAR_00008
star    142.30   387.11   -1.00  Unknown           STAR_00009
star    423.50   994.14   -1.00  Unknown           STAR_00010
star    961.07   316.81   -1.00  Unknown           STAR_00011
star    565.64   576.59   -1.00  Unknown           STAR_00012
star    992.62   995.02   -1.00  Unknown           STAR_00013
star    262.11   724.67   -1.00  Unknown           STAR_00014
star    910.54   367.30   -1.00  Unknown           STAR_00015
star    358.82   406.26   -1.00  Unknown           STAR_00016
star    918.46   461.54   -1.00  Unknown           STAR_00017
star    400.15   475.86   -1.00  Unknown           STAR_00018
star    473.01   749.98   -1.00  Unknown           STAR_00019
star    477.69   515.45   -1.00  Unknown           STAR_00020
star     77.51   739.39   -1.00  Unknown           STAR_00021
star    581.32   781.21   -1.00  Unknown           STAR_00022
star    974.54   631.06   -1.00  Unknown           STAR_00023
star    469.79   563.48   -1.00  Unknown           STAR_00024
star    710.01   741.47   -1.00  Unknown           STAR_00025
star    916.35   537.62   -1.00  Unknown           STAR_00026
star    706.76    67.74   -1.00  Unknown           STAR_00027
star    337.89   341.30   -1.00  Unknown           STAR_00028
```

Your program will also take as input a library of one or more known constellations; an example is shown below right. In addition to the star data, the file also contains the line segments between stars that make the classic constellation diagram. Note that the star names include extended ASCII characters from the Greek alphabet. The STL `string` library should handle this for you.

Ursa_Minor.txt

```
star    497.59   273.15    1.97  Ursa_Minor          Polaris
star    528.93   558.78    2.07  Ursa_Minor          β_UMi
star    492.26   600.57    3.04  Ursa_Minor          γ_UMi
star    446.47   412.32    4.21  Ursa_Minor          ε_UMi
star    473.30   495.15    4.29  Ursa_Minor          ζ_UMi
star    466.45   333.89    4.35  Ursa_Minor          δ_UMi
star    433.75   523.53    4.95  Ursa_Minor          η_UMi
line  Ursa_Minor          Polaris  δ_UMi
line  Ursa_Minor          β_UMi  γ_UMi
line  Ursa_Minor          β_UMi  ζ_UMi
line  Ursa_Minor          γ_UMi  η_UMi
line  Ursa_Minor          δ_UMi  ε_UMi
line  Ursa_Minor          ε_UMi  ζ_UMi
line  Ursa_Minor          ζ_UMi  η_UMi
```

Your program should search for potential matches between the input file and library of constellations. If you cannot find a match, your program should print "No matching constellation found" to `std::cout`. If you do identify a matching constellation, you should print the match to `std::cout` as shown below.

example_stdout.txt

```
FOUND CONSTELLATION Ursa_Minor
assigning  STAR_00008  β_UMi
assigning  STAR_00012  γ_UMi
assigning  STAR_00016  δ_UMi
assigning  STAR_00018  ε_UMi
assigning  STAR_00020  ζ_UMi
assigning  STAR_00024  η_UMi
assigning  STAR_00028  Polaris
```

Your program will also revise the input file to label each identified star with its constellation name and star name, update the apparent magnitudes, and add the line segment information. The updated file is saved to the specified output file name, which is shown on the right.

example_output.txt

```
star    784.74    66.13    -1.00  Unknown           STAR_00001
star     34.89   685.95    -1.00  Unknown           STAR_00002
star    813.38   217.91    -1.00  Unknown           STAR_00003
star    108.37   578.21    -1.00  Unknown           STAR_00004
star    957.61   896.12    -1.00  Unknown           STAR_00005
star    489.87   971.57    -1.00  Unknown           STAR_00006
star    895.22   195.74    -1.00  Unknown           STAR_00007
star    562.02   521.11     2.07  Ursa_Minor        β_UMi
star    142.30   387.11    -1.00  Unknown           STAR_00009
star    423.50   994.14    -1.00  Unknown           STAR_00010
star    961.07   316.81    -1.00  Unknown           STAR_00011
star    565.64   576.59     3.04  Ursa_Minor        γ_UMi
star    992.62   995.02    -1.00  Unknown           STAR_00013
star    262.11   724.67    -1.00  Unknown           STAR_00014
star    910.54   367.30    -1.00  Unknown           STAR_00015
star    358.82   406.26     4.35  Ursa_Minor        δ_UMi
star    918.46   461.54    -1.00  Unknown           STAR_00017
star    400.15   475.86     4.21  Ursa_Minor        ε_UMi
star    473.01   749.98    -1.00  Unknown           STAR_00019
star    477.69   515.45     4.29  Ursa_Minor        ζ_UMi
star     77.51   739.39    -1.00  Unknown           STAR_00021
star    581.32   781.21    -1.00  Unknown           STAR_00022
star    974.54   631.06    -1.00  Unknown           STAR_00023
star    469.79   563.48     4.95  Ursa_Minor        η_UMi
star    710.01   741.47    -1.00  Unknown           STAR_00025
star    916.35   537.62    -1.00  Unknown           STAR_00026
star    706.76    67.74    -1.00  Unknown           STAR_00027
star    337.89   341.30     1.97  Ursa_Minor        Polaris
line   Ursa_Minor          Polaris   δ_UMi
line   Ursa_Minor          β_UMi   γ_UMi
line   Ursa_Minor          β_UMi   ζ_UMi
line   Ursa_Minor          γ_UMi   η_UMi
line   Ursa_Minor          δ_UMi   ε_UMi
line   Ursa_Minor          ε_UMi   ζ_UMi
line   Ursa_Minor          ζ_UMi   η_UMi
```

We provide a simple stand-alone program, `plot_stars.cpp` *compiles to* `plot.out`, that will read the star positions and line segments from a file (the input file, the output file, or the library constellation file) and produce a Scalable Vector Graphics (SVG) visualization stored as an `.html` file. You can open this file locally in a standard web browser (e.g., Chrome, Firefox, etc.)

Here are sample command lines for the provided `plot.out` and the program you will write, `identify.out`:

```
./plot.out example_input.txt example_input.html
./plot.out --draw_diagram Ursa_Minor.txt Ursa_Minor.html
./identify.out -i example_input.txt -o example_output.txt -l Ursa_Minor.txt > example_stdout.txt
./plot.out --draw_diagram --label_constellation --label_stars example_output.txt example_output.html
./identify.out -i unknown_A.txt -o out.txt -l Ursa_Minor.txt -l Ursa_Major.txt -l Orion.txt
```

Getting Started

We suggest you start this homework by prototyping a brute-force search solution for some of the smaller example files. You may find that recursion is helpful! The idea is to start with a pair of stars in the input file, compute the distance between those points, and then see if you can find a matching pair of stars in one of the constellation library files that has the same distance. Note that when comparing floating point numbers (either distances or angles) you don't want to use exact equality because of coordinate rounding errors. You'll want to compare if the difference between the numbers is less than a small *epsilon* threshold value. Can you then expand that initial match to the whole constellation?

Once you have an initial version of the program working, evaluate what part of the search is most expensive. What data structures or algorithms can you use to improve this search? Can you use a hash table? What is the information you will be hashing? Should you consider using a spatial data structure to accelerate nearest neighbor queries? A grid is probably simpler than an octree or bounding volume hierarchy.

In addition to comparing distances, we can compare the angles formed between three neighboring stars. For extra credit extend your program to handle input images that might be scaled (a.k.a. zoomed), where the matched constellation is either smaller or larger than the example in the library.

Homework Submission

Use good coding style and detailed comments when you design and implement your program. You must do this assignment on your own, as described in the "Collaboration Policy & Academic Integrity" handout. If you did discuss this assignment, problem solving techniques, or error messages, etc. with anyone, please list their names in your `README.txt` file.