Development of Three-dimensional Model of Bunch of Grapes

A dissertation submitted to The University of Manchester for the degree of Masters in Advanced Computer Science in the Faculty of Science and Engineering.

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Abstract

Grapes is a kind of fruit that people often see in their daily lives, and grapes are also loved by different age groups. Because grapes have obvious differences in terms of maturity, quality, and shape in different regions, it is necessary to develop an automated tool to model the grapes in digital phantoms. The research team is currently developing a classifier that can determine the current maturity of the grape on the basis of the image of the grape information detected in order to detect the right time to harvest. The classifier needs a great amount of data to do testing. However, there is an urgent problem to be solved, which the image of a bunch of grapes is rare on IT industry nowadays. The focus of this project is to collect all the information about the grapes firstly, such as the thickness of the grape skin, the thickness of the stalks, the number of grapes and the number of layers of grapes. With all the data collected from the Internet, a useful mathematical model of a bunch of grapes is introduced. Through the detailed implementation of the mathematical model, a similar bunch of grapes will appear on digital pictures. These various pictures will be applied to the current research team to train their classifiers and also help the researchers testifying the correctness and evaluating the tool.

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Acknowledgement

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Finally, I would like to give a big thank you to my family and friends for their continuous support throughout the duration of my degree.

1.Introduction

Grape (scientific name: Vitis vinifera L.) is a woody vine of the genus Vitis,[3] with small branches, longitudinal ribs, glabrous or sparsely pubescent, leaves ovoid, panicle dense or absent, base branches developed. The fruit is spherical or elliptical, flowering from April to May, and fruiting from August to September.

Grapes are one of the oldest fruit tree species in the world. The plant fossils of the grapes are found in the Tertiary strata, indicating that they were already found in Europe, Asia, and Greenland. Grapes are native to western Asia and are cultivated all over the world. About 95% of the grapes around the world are concentrated in the northern hemisphere.

Human cultivation of grapes, winemaking and the creation of grape culture have a long history, and China is one of the earliest cultivated regions of the world. The ancient Chinese cultivated grapes are foreign material civilizations, and their native land is in the Black Sea and the eastern Mediterranean coast and in the Central Asian region. About five or six thousand years ago, in Egypt, Syria, Iraq, the South Caucasus and Central Asia, cultivation of grapes and wine production began. Later, it was introduced to Western Europe, such as Italy and France, and spread eastward to East Asia.

After 2 to 3 years of grape planting, the production period can reach 20 years. [1] The root system is developed, and the roots are concentrated in the 20-60 cm soil layer. The roots of European grape begin to move at a soil temperature of 7 to 9 ° C, and new roots occur at 12 to 14 ° C. Winter buds generally sprout new shoots after the temperature reaches 10 °C in spring. The summer buds in the leaves are germinated into the secondary shoots. The growth period requires warm, sunny, long-term dryness in summer. The most suitable temperature is 25 to 30 °C. [1][2] The temperature is high, the temperature difference between day and night is large, the nutrient accumulation is high, the fruit is well colored, and the sugar content is high. The grape has strong adaptability to the soil. The groundwater level is less than 1 meter. Most of the soil can be planted, and most of the calcium is most suitable. Grapes are mainly propagated by cuttings and strips.

The growth of grape fruit can be divided into two periods with the turning point as the turning point. [4] Before the color change period is the fruit formation period, mainly the accumulation of acid, the fruit contains a lot of malic acid and tannin; after the color change period is the ripening period of the fruit, mainly accumulated sugar.

The main focus of this project is to generate different grape image models according to the materials found. There are many different varieties of grapes in the world. Most of the berries are circular or elliptical, with gold green, purple-blue, purple-gray, etc., with pollen.

There are about 70 species of a grape genus. There are about 8,000 grape varieties, of which about 100-200 cultivars. [5] according to the actual function of the grapes, the grapes can be divided into two categories: the first is the grapes that can be used for eating (table grape); the second is used to make wine (wine grape). The varieties of wine have high sweetness but poor taste. The seeds are thick and have less flesh and this type of wines are not suitable for consumption directly. Relatively speaking, the table grapes are also not suitable for winemaking because of their low sweetness and thin skin. For most grapes on the market, their shape can be roughly divided into oval or spherical.

1.1 Aims

Due to the large variety of grapes and the fact that there are no tools for image generation on the market, it is a difficult problem to test the proper picking period of the grapes. The composition and growth environment of each grape is different, so it is necessary to achieve an effective grape mathematical model according to the position, size, shape and skin thickness of the grapes, and then produce different images of grapes on the PGM image platform according to this model. These PGM images generated by the software will be used as resources for the classifier. They will help scientists test whether the classifiers they implemented can effectively classify different ripeness for different types of grape.

Since many of the classifiers are currently in an immature stage, using real grapes to test data can be a waste. Therefore, a valid PGM image file is highly desirable. With so many image files about different grapes, of course, the accuracy of the classifier will be better improved. Therefore, the goal of this project is to create different forms of grapes according to the needs of users, so that the classifier can be used.

1.2 Objectives

In order to be able to complete the project reasonably and effectively, the project was divided into the following small projects, these include:

- Make an investigation report based on the size, shape, skin thickness, grape position and stem thickness of the grape.
- Understand the structure of the portable graymap format-PGM files.
- Create different mathematical models for different grapes.
- Develop an effective algorithm then implement a software to produce some available grape digital pictures.
- Test the running efficiency of the algorithm and optimize the algorithm deficiencies according to relevant reports.
- implement a command line program that allows users to generate images based on their needs, such as the number of layers of grapes, the number of layers, the radius of the stem, and the shape of the grapes.

1.3 Report Outline

This paper will be composed of the following chapters:

Chapter2-Background: The differences between grape varieties are described in detail, such as the shape, size, growth cycle and ultimate functional use of different grape varieties. At the same time, the picking period for judging the grape is also discussed.

Chapter3-PGM File: Detailed information about PGM files, such as usage and presentation.

Chapter4-Implementation: All implementation details of the project will be presented in this section. All important information about the project will be elaborated in pictures and text, which includes all mathematical formulas used to express grapes.

Chapter5-Evaluation: This section describes the relevant evaluation criteria. In particular, comparing the image of the software-generated grape bunch with other real grape bunch images also examined the effectiveness of the tool to generate the image. Further, the operating efficiency of the software is also an important measure in terms of memory usage and runtime.

Chapter6-Conclusion: Summarize the objectives of the project and the reasons for the unfinished part. Also, point out where the project can be improved in the future

2. Background

Section 2.1 describes the internal structure of a single grape, even a single grape, which contains a relatively complex structure. So this chapter will introduce the components of the grape one by one. Section 2.1.1 describes the composition of the grape skin and details of the three different levels of the grape skin. Section 2.1.2 focuses on understanding the knowledge of grape flesh, including the nutrients contained in the grape flesh, as well as some other important chemical components such as tannins. Section 2.1.3 describes the chemical composition of the stems of the grapes. Section 2.1.4 describes the composition and use of grape seeds. The next section introduces the specific functions of the grapes, such as the table grape and the wine grapes. It also introduces the differences in the composition and taste of the wine grapes and table grapes. Finally, in section 2.3, it briefly introduced four criteria for judging whether the grapes are mature enough.

2.1 Structure of a Single Grape

It is necessary to have a detailed understanding of the composition of the grapes before starting the 3D modeling of the bunches. It is important to know that the different composition of the grapes may have different effects on the display of the grapes on the electronic pictures.

The composition of the grape is relatively complex and can be divided into many parts. The grape ear is composed of the fruit stem(pedicels) and the fruit, and the fruit is composed of the peel, the core, and the flesh(pulp).

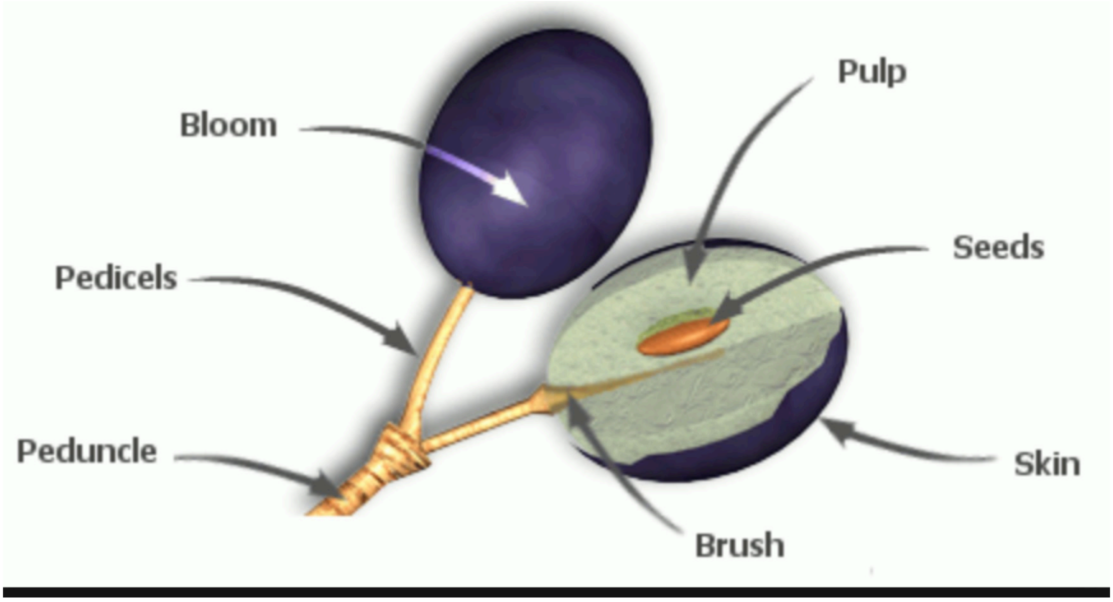


Figure2.1 Simple internal structure of a single grape

2.1.1 Grape Skin

Grape skin contains more resveratrol than grape meat and grape seed. This is a polyhydric phenolic compound. It has a strong anti-cancer ability in addition to preventing cardiovascular and cerebrovascular diseases.

1) Exocarp

The exocarp is developed from the outer epidermis of the ovary wall (equivalent to the epidermis of the leaf) and can be composed of one layer of cells or several layers of cells. If the outer pericarp has several layers of cells, in addition to the outer epidermal cell layer, there are one to several layers of thick-angled tissue cells, such as peaches, apricots, etc., which may also be thick-walled tissue cells (such as kidney beans, soybeans, etc.). Generally, there are stomata, horny and waxy stalks on the outer pericarp, and some have hair, wings, hooks and other appendages. They have the functions of protecting fruits and contributing to the spread of fruits and are also one of the bases for identifying species.

2) Mesocarp

The mesocarp is developed from the middle layer of the ovary wall (corresponding to the mesophyll and veins of the leaves) and consists of multiple layers of cells. The mesocarp varies greatly in structure. Some mesocarpes have many nutrient-rich parenchyma cells that become fleshy edible parts of the fruit (such as peach, apricot, plum, etc.); some have a thin-walled tissue of the mesocarp. It also contains thick-walled tissue; some of the fruit peels become dry and shrink into membranous, leathery, or loose fibrous, and the vascular tissue is developed, such as the citrus "orange".

3) Endocarp

The endocarp is developed from the inner epidermis of the ovary wall (equivalent to the upper epidermis of the leaf) and is mostly composed of a layer of cells. But it can also be composed of multiple layers of cells, such as tomatoes, peaches, apricots and the like. In fruits such as tomatoes, the endocarp is composed of multiple layers of parenchyma cells; in fruits such as peaches and apricots, the multi-layered cells of the endocarp are usually thickened and stoned to form a hardcore. In fruits such as citrus and grape fruit, many cells of the endocarp become large and succulent juice sacs; in fruits such as grapes, endocarp cells are separated into a slurry during fruit ripening; in gramineous plants Because the endocarp and seed coat of the fruit are very thin, during the ripening process of the fruit, usually the two heal and are not easy to separate, forming a unique type of caryopsis.

4) Placenta

The placenta is a structure formed by the healing of the edge of the carpel, a place where the ovule is bred, and a nutrient supply base during the development of the seed. During the ripening of the fruit, the placenta in the fruits of most plants gradually dry and shrink; however, some of the placentae are more developed, and part of the flesh is formed, such as the fruits of plants such as tomatoes and kiwi; The developing seeds, in addition to providing the nutrients needed for seed development, further develop thick, succulent arils, such as plants such as lychee and longan (Limocrpus longan Lour).

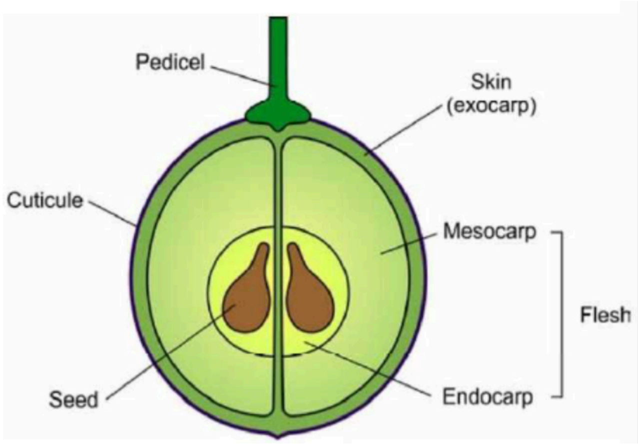


Figure2.2 In a single grape, the position of each skin layer

2.1.2 Grape Flesh

The flesh of the grapes is rich in nutrients: water 68%-80%, reducing sugar 15%-30%, organic acid 5%-6%, pectin 5%-6%, other ingredients 5%-6%, and the grapes are not only delicious but also have high nutritional value. In mature berries, the sugar content of the grapes is as high as 10% to 30%, mainly glucose. A variety of fruit acids in the grapes help digestion, eat more grapes, and can be healthy and stomach. Grapes contain minerals such as calcium, potassium, phosphorus, iron, and vitamins B1, vitamin B2, vitamin B6, vitamin C and vitamin P. They also contain a variety of amino acids required by the body. Grapes are often weakened and fatigued [6].

Before the fertilization is completed to form the fruit until the color change period, the fruit mainly accumulates some substances used to protect the grape fruit from the birds or mammals. The main reason is that during this period, the seeds are also constantly developing because before the seeds are mature and not fully viable, the following substances play a variety of strange characters to keep the birds away:

- Malic Acid: it is the most acidic organic acid in grapes (tartaric acid & citric acid). For birds, sour or fresh and refreshing acids are equally unpleasant. In terms of taste, they will not be too picky. But malic acid can cause gastrointestinal discomfort, indigestion, and even diarrhea. This kind of experience can make the birds sick and not touch the same fruit twice.
- Tannin: The importance of tannins to wine is not to be overstated, it is the pillar of the rich taste and skeleton of the wine. [7] It is known that the fruit

contains tannins, which are mainly found in grape skins and grape seeds. And this is just a little cleverness that the grape was forced out during the natural selection process. The main use of tannins is to inhibit digestion. In short, it is to let people eat for a long time and not digest. If someone eat grapes before the seeds are ripe, it is necessary to use a few stomach and digestion tablets to ease the effort.

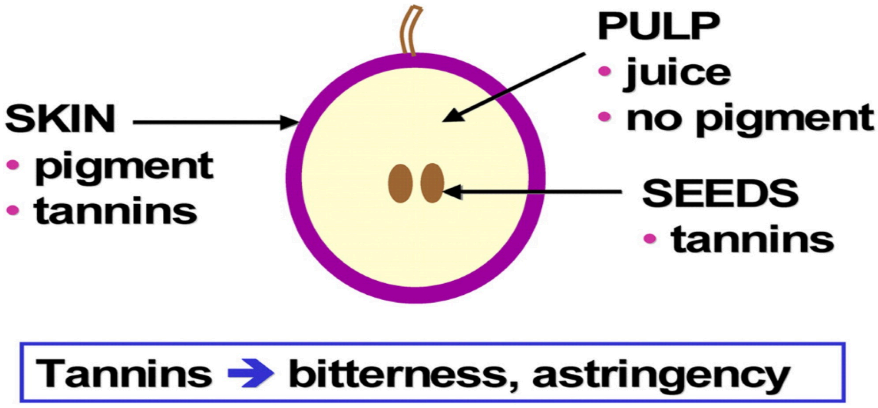


Figure2.3The part of the grape that produces tannin and the effect of tannin on the taste

2.1.3 Berry Stem

The chemical composition of the berry stem is: water 70%-80%, cellulose 6%-7%, tannin 1%-3%, resin 1%-2%, inorganic salt (mainly calcium salt) 1.5%-2.5 %, organic acid 0.3% - 1.2%, sugar 0.3% -0.5%. Because the fruit stem is rich in tannins, bitter resin, and other substances, it often causes the wine to produce excessive astringency. [6] The presence of fruit stalks also increases the moisture content of the juice by 3%-4%. No matter which kind of wine, there is no stalk fermentation.

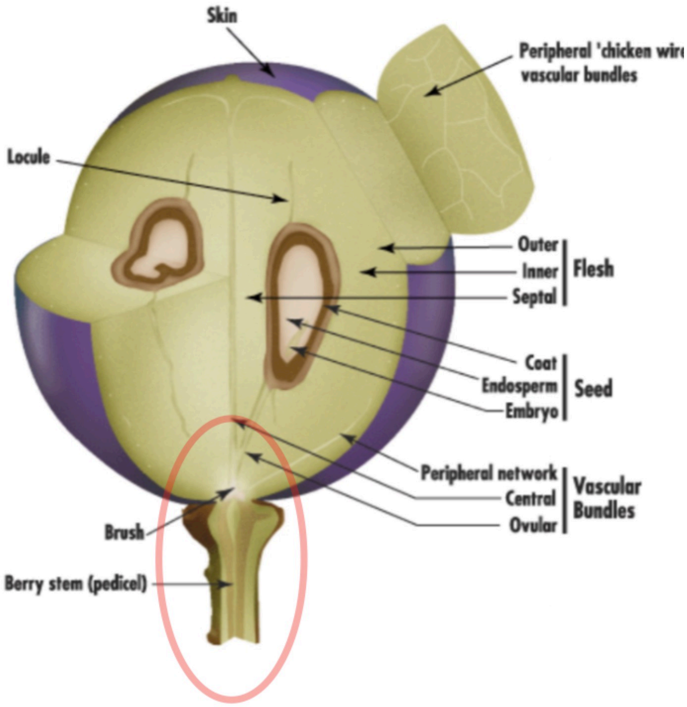


Figure2.4 The red circle in the figure indicates the position of the stem of the grape

2.1.4 Grape Seed

Grape seeds contain polyphenols, mainly catechins, and proanthocyanidins. The catechins, including catechins, epicatechins and their gallic acid esters, are the major monomeric components in grape seed and the constituent units of proanthocyanidin oligomers and multimers. Grape seed is rich in oil, accounting for about 12% to 15% of its weight [3], the oil contains a large amount of unsaturated fatty acids, of which the content of linoleic acid is between 58% and 78%. Grape seeds also contain a small number of volatile components, most of which are alcohols, phenols, and terpenoids, all of which have high biological activity. [1]

In addition to the above-mentioned various substances, grape seeds also contain crude protein, amino acids and vitamins A, E, D, K, P and various trace elements such as calcium, zinc, iron, magnesium, copper, potassium, sodium and manganese, cobalt, etc.

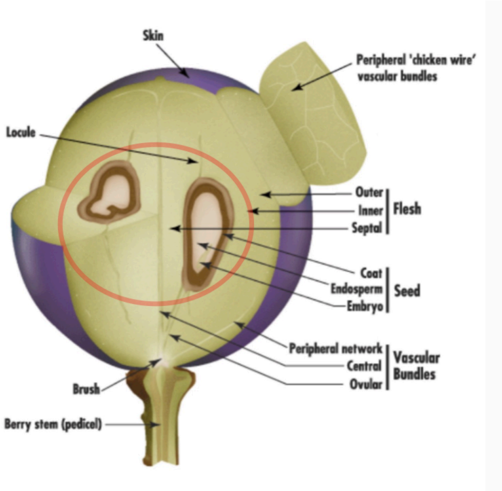


Figure2.5 The red circle in the figure indicates the position of the seed of the grape.

2.2 Main Types of grapes

There are many types of grapes in the world, some of which are only suitable for making wine, called wine grapes. Some of the grapes that are suitable for eating are called table grapes. The table grapes and wine grapes are quite different in many respects, and the differences will be elaborated in the following sections:

Figure2.6 In terms of size, wine grapes are smaller than table grapes

2.2.1 Table Grapes

Table grapes are generally grown in subtropical and temperate zones, with one to three harvests a year. It is rich in natural meat and fat, and the skin is thin and small. The taste is chewing. Its physiological state is far from the wine grape. Fresh vines generally live for about 10-30 years. They need to be watered frequently. [8] The roots of the grapes will develop horizontally, absorb more water, and absorb less. Fresh grape wine produces an unacceptable special smell. Compared to wine grapes, the grapes have larger fruits and thicker flesh, thin skin and small seeds. Of course, table grapes have less acidity and more beautiful, stronger grapes than wine grapes. This grape is smaller and has larger seeds than the grape. It has a thicker peel and a low sugar content.

The acidity of table grapes is usually lower than that of wines, only about 3-5g/L. Fresh grapes are usually bagged during cultivation, which prevents photosynthesis of grapes and reduces tannins and polyphenols. The generation. The sugar content of table grapes is usually around 100g/L, which is lower than that of wine grapes.

1) Shasla (French: Chasselas) is a grape variety produced in Switzerland. Shasla has a certain reputation in white grapes and is grown in many European vineyards, mainly for table grapes, as well as for wine, with a yellowish color and bubbles. In the high-quality vineyards of western Switzerland, the wines made with Chasselas are of superior quality and have a high concentration and a long-lasting taste. They are well known in the area.
2) Miller-Tuco (or Muller-Turco) is a wine grape that is mostly used to make white wine. In 1882, the Swiss botanist Hermann Muller cultivated the grapes in a combination of Riesling and Royal Madeleine. At that time, he wanted to develop a grape variety that combines the high quality of Riesling and the stable performance and precocious characteristics of Sivanni, but the actual use is a kind of fresh called Royal Madeleine. Grapes. Miller-Tuco is the most widely planted artificially-matched grape in the world. The main growing areas of Miller-Tuco are in Germany, Austria, Switzerland and northern Italy, New Zealand. [9] It is the most important white grape variety in Germany, and its planting area is second only to Riesling. The grape skin of this variety is blue-yellow, and the fruit contains a slight musk and is very early. Grapes of this variety need to be planted in deep soil with good water retention function. They are easily attacked by downy mildew, powdery fungus, pseudomonas fungi and Phomopsis spp and fruits and stems are also prone to decay. More plant protection measures are needed

compared to other grape varieties.

2.2.2 Wine Grape

The fruit is very small, the same weight of table grapes and wine grapes, wine grape skin is more, because the wine needs a lot of flavors (phenols, tannins, etc.), the flavor substances are mostly from the grape skin, Therefore, there are many small skins and it is helpful for the quality of the wine [10]. High-sugar wine is almost 17-18g / L of sugar corresponding to a degree of alcohol, the general wine requires 13-15% volume, so the sugar is not enough, it is necessary to add sucrose artificially, adding sugar, acid, tannin, etc. is almost impossible avoided, but the less added it is, the better the quality of the wine. This is also why domestic wineries are generally located in Hebei, Xinjiang's sandy areas, because the sunshine is relatively sufficient, the temperature difference between day and night is also relatively large for the grape to accumulate sugar. High in acidity, without acid and tannins, the wine has no skeleton, and it is ugly to say that it is hard to hear. The yield is low, because the yield is high, and the flavor of the wine can be given less. This is also why farmers choose to plant grapes in the sand, the water is small, the wine should be deeply rooted and can absorb more minerals.

The vines used for winemaking are generally around 60 years old. In the first 9 years in Europe, it is impossible to make wine, 10-20 years is infancy, 20-30 years is adolescence, 30-40 years is a prosperous period, 40-50 years later into the aging period, 50 years later generally is no longer winemaking. [4] The grapes that can be used for making wine are not less than 170 grams per liter of sugar. The wine-growing vines are generally not watered, and the grape roots will enter the soil for 15-20 centimeters to find water so that the grapes are rich in nutrients. The ripening period of wine grapes is generally after September, the ripening period of wine grapes is longer, and the content of tannins and polyphenols accumulated in fruits is higher. The sugar content of wine grapes is usually about 205g/L, and some are late or the sugar content of the noble rot grapes can even reach 400g/L.

The types of wine grapes are:

1) Cabernet Sauvignon is a red grape mainly used for making wine and is the most widely used in the world with Chardonnay. Cultivated grape varieties [1]. The

young leaves of Cabernet Sauvignon are reddish-brown. The color of the leaves is deep, the leaves are medium and small, and the leaves are deep and U-shaped. The lobes overlap adjacent to the lobes. The back fluff has a lower density. The fruit is small and round, the skin is thick, the weight of the fruit is 1.3-1.4g, and the weight of the stem is about 100g.

2) Riesling (German: Riesling), a grape variety, is considered to be one of the most important and best white wines for white wines. Riesling grapes are suitable for growing in cooler areas, making them the main varieties in Germany and other cooler areas. Riesling grapes have historically originated in Germany, and German Riesling wines are well known throughout the world, so many of Germany's best grape fields are occupied by Riesling grapes, the most important of which is the Moselle Valley and the Middle of the North. Grape fields on steep slopes on either side of the Rhine Valley. Riesling grapes prefer a cool climate. Riesling's maturity is slow in Germany's growing areas under the influence of continental climate. Generally, harvesting begins between mid-October and the end of November. It is because of the long maturity that the Riesling grape has an outstanding performance in terms of fragrance.

2.2.3 Seedless Grape

Seedless, there are two cases. Seed is the seed of the plant. The first is to use auxin treatment, but the premise is to emasculate or kill the stamens by some means, auxin will promote the development of its ovary, forming fruit, but there will be no seeds without stamens. [11] The second is the use of its association disorder to form fertile plants, which are treated with colchicine at the seedling stage to double the chromosomes, and then the doubling plants are mated to normal plants, after which the seeds are formed. Plants cannot be properly fed because their chromosomes are odd and cannot form seeds.

Figure2.7 An example of seedless grapes

Seedless grapes cannot be propagated (falling) like ordinary grapes. The growers have to intercept the branches and plant them in the land after rooting. Seedless grapes are derived from natural mutations; seeds do not develop hard seed coats. Although its exact source is unknown, it may have been nurtured by people from Iran or Afghanistan thousands of years ago. Today, 90% of raisins are made from Thompson seedless grapes.

2.3 Criteria for judging grape maturity

1) Sugar accumulation [12]: When the branches of the vine grow completely, the ripening process of the grapes begins. At this time, the vines use the metabolic process to gradually transfer the sugar to the plant's energy storage organs - fruit bunches and shoots, while the malic acid in the plant begins to transform into trace amounts of sugar. As the maturity stage progresses, glucose and fructose in the grape fruit gradually accumulate, and the young greenish fruit mainly contains fructose, and the glucose concentration in the fruit increases after the Veraison period, in some grape varieties. Medium glucose concentration may even exceed fructose
2) Reduced acidity: During the growth of the grape plants, the organic acids accumulated in the leaves and cyan young fruits are gradually released, which makes the grape fruit acidity higher. Especially when the summer comes, the ambient temperature rises, the respiration of the plant weakens, and the various acids in the plant increase and the more organic acids are released, eventually

forming malic acid and tartaric acid. By the fruit ripening stage, malic acid can be converted into sugar, which reduces the acidity of the grape to some extent, while the amount of tartaric acid in the grape fruit is small and the effect is small. In addition, the moisture content of the fruit can also dilute the acidity and lower the acidity.

3) Formation of phenolic substances: phenolic play an important role in the color, taste, and flavor of wines, and are therefore one of the indicators for determining the maturity of grapes. Phenolic substances are present in various parts of the grape fruit. As the grapes mature, various phenolic substances gradually form.

4) Aromatic compound formation [12]: The aroma of the wine is generally the smell of aromatic compounds. The aromatic compounds are mainly derived from vines, and their types are determined by the variety and brewing process. When concerned about the maturity of wine grapes, the formation of aromatic compounds in grape fruit is also one of the factors that should be concerned.

3.PGM File

Section 3.1 simply explains what a PGM file is. section 3.2 describes in detail the composition of the PGM file, and what the meaning and role of each region are. Finally, a sample file is used to deepen the understanding of the composition of the PGM file.

3.1 What PGM file is

The full name of the PGM name is called "Portable Gray Map". [17] In many grayscale image formats, the PGM format standard is the simplest. Second, there are two image formats that are most similar to it, called PBM and PPM. These two image formats correspond to black and white images and color images. [18]
For the JPG image format, the data content will be compressed, and the data content stored in the PGM file will not be compressed. So from the size of the image, the size of the generated PGM file will be larger than the JPG. As mentioned above, since the data in the PGM is not compressed, one can open the PGM file with a very common editing tool such as Notepad.

3.2 The Structure of PGM File

All PGM files consist of two parts demonstrated in figure3.1: the file header and the file content, the header part contains multiple pieces of information; The first line of data indicates whether the format of the PGM file is P2 type or P5 type [19]; the second line indicates that the comment of the picture given by the developer ;the third line indicates the width value of the picture; the fourth line indicates the height value of the image; the fifth line may be the maximum value of the gray value of the image, which can be determined by the user. The information of these four parts is stored in the form of ASCII code in the file header, [20] so the user can directly open the PGM file in P2 or P5 format in Notepad to understand the specific information of the image.

Regarding the body content part of the PGM file, each pixel value can only be filled with a value of a decimal number, and the decimal number cannot exceed the maximum value defined in the file. The data content of the PGM file is generally read from left to right, top to bottom. According to the structure of PGM file mentioned(figure3.2), due to the head information of the file, the sample file is a P2 format image format, in which the height and width of the image is 128*120 and the maximum gray value of the sample file set by the user cannot exceed 146, so in the content area of the sample file, the value of each pixel is less than 146 and the width and length do not exceed the size of 128*120.

PGM file type	P2 or P5
Comment area	#example
The height and width of the image (X-axis and Y-axis)	5 5
Maximum value of grey value	10
File content	Value of each pixel from 0 to 10

Figure3.1. The structure of PGM file (left column) with actual content (right column)

```
saavik_left_angry_open.pgm
P2
128 120
146
2 10 5 3 0 0 0 1 14 10 9 15 26 13 9 13
16 6 4 1 2 5 8 17 17 12 12 23 23 17 11 9
10 11 9 7 9 11 10 12 15 16 16 15 15 14 15 15
20 12 7 9 14 9 7 8 10 16 19 21 22 28 30 30
30 30 28 28 28 23 24 25 25 20 21 21 20 16 15 15
15 16 13 13 17 23 24 28 28 27 27 28 27 26 26 25
24 23 22 21 21 20 20 20 19 21 22 21 21 22 21 21
22 21 19 16 15 14 14 13 13 13 13 13 14 14 14 14
8 4 0 0 0 0 0 0 2 14 20 26 23 26 15 5
0 0 1 3 1 0 0 8 19 33 26 20 12 13 13 12
7 1 1 2 3 4 10 14 16 14 13 9 13 13 15 14
18 22 15 6 0 3 6 7 3 2 13 23 27 21 23 24
24 24 26 28 29 28 25 22 23 24 24 23 25 26 20 15
10 13 16 19 18 18 17 18 19 21 21 19 19 18 17 16
15 15 14 14 13 13 13 12 12 13 15 16 15 15 14 14
12 10 9 9 9 9 8 8 8 8 8 9 9 10 10 10
0 0 0 0 0 0 0 5 27 25 28 29 18 0 0 0
0 0 0 0 0 2 24 34 31 17 15 14 14 14 13 3
0 1 4 5 4 5 4 7 5 3 1 4 7 7 9 24
```

Figure3.2 Contents of an example PGM file with value from 0 to 146(maximum grey scale value)

Although this is not an existing PGM file for grape bunches, the example of Figure3.3 can still be used to show people the specific effects of PGM files. [21] In this figure3.3, the maximum gray value allowed by PGM is 15 pixels. Each of the different color values can represent different items depending on the needs of the user. For example, in a CT picture of the brain, different color values may represent different organ tissues in the brain.

Figure3.3 A PGM file with different pixels' values. Although the figure is not the shape of the human brain, the pixel values of each color may represent different organs in the human brain.

3.3 Related Work

A research study on 3D fruit shape on basis of PGM image modeling was conducted, but the results show that most of the PGM image modeling now focuses on the direction of medical images, such as the modeling of human brain organs or the brain, modeling of tumors, although these images are more realistic, they have limited help for the 3D modeling method of this project. There is a lack of image processing information on fruits such as grapes or strawberries.

4 Design and Implementation

In section 4.1, some basic information about grape bunches is going to be introduced. Then introducing some parameter information about generating a bunch of grapes which satisfy the user's requirement. In the next section 4.2, information about mathematical modeling and four guidelines for mathematical modeling are presented in detail. The definitions and related formulas for spherical and ellipsoidal models are described in detail in the following sections. Finally, this section will give the reader a detailed look at how individual ellipsoidal grapes and individual spherical grapes are created in three dimensions.

4.1 Grapes Summary

According to the data of various grapes; in terms of appearance, the grapes are roughly divided into two different shapes; the first is a grape with a circular shape, the other is similar to an oval but not Perfect oval grapes. At the same time, functionally, the size of wine grapes is relatively small compared to table grapes. In many cases, the shape of wine grapes is mostly smaller and spherical, on the other hand, as for a bunch of table grapes, for table grapes, they are slightly larger than wine grapes and, in most cases, are similar to football shapes.

So the following factors can be manipulated due to user's preferences:

- Number of layer on a bunch of grapes
- The radius of stem size on each layer
- Number of grape on each layer
- Type of grape (spherical or football shape)

4.2 Design of Grape Berry Model

4.2.1 Introduction to mathematical models

When a mathematical structure is interpreted as a formal language (that is, a set of symbols including common symbols, function symbols, predicate symbols, etc.), this mathematical structure is called a mathematical model. That is to say, the mathematical model can be described as: for a specific object of the real world, for a specific purpose, according to the unique internal laws, make certain necessary assumptions, and then use a mathematical model obtained by appropriate mathematical tools. [13] In this way, a mathematical structure, that is, a mathematical model, obtained on the basis of certain abstraction and simplification can help people to have a deeper understanding of the object under study. For example, the physics we study, especially the physics applied to engineering, such as circuits, theoretical mechanics, and material mechanics, is a good and straightforward example of mathematical modeling, the connection between the mathematical model and the realistic model can be seen in the figure4.1 below.

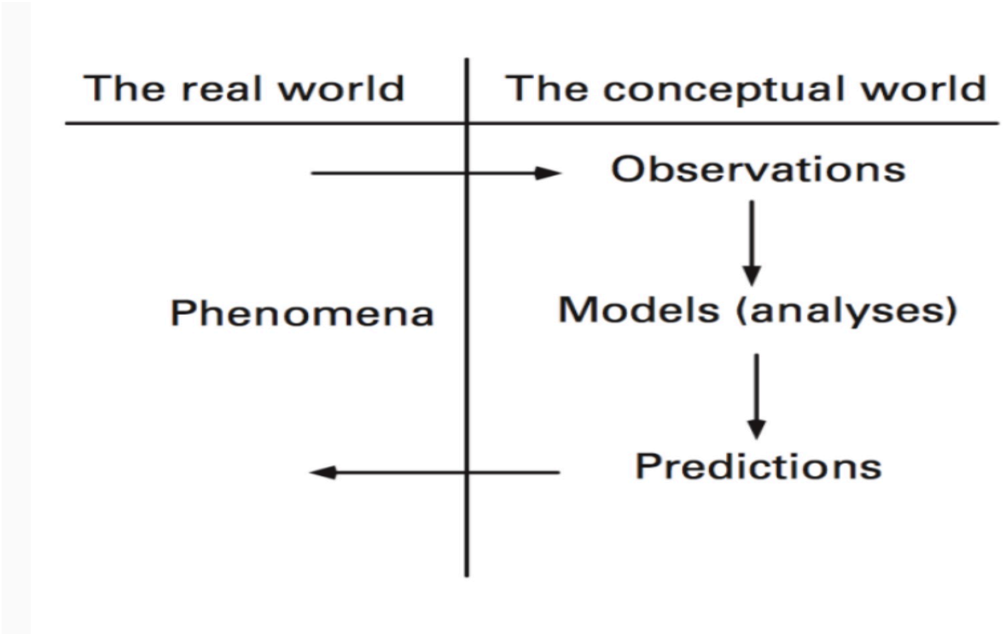


Figure4.1[29] Depiction of the scientific mathematical model

Basic principles of mathematical models [14]:

- Simplification principle: The prototypes of the real world are multi-factor, multi-variable, multi-level and relatively complex systems. The simplification of the prototype is to grasp the main contradiction. The mathematical model should be simplified than the prototype. The mathematical model itself should be the "simplest".

- “Can be derived” principle: Some research results can be derived from the study of mathematical models. If the established mathematical model is mathematically indefinable, and the results that can be applied to the prototype are not obtained, this mathematical model is meaningless.

- The principle of reflection: A mathematical model is actually a form of reflection of the human being on the real world. Therefore, the mathematical model and the prototype of the real world should have a certain "similarity". Grasping a mathematical expression or mathematical theory similar to the prototype is the key skill to establish a mathematical model.

The mathematical model can quantitatively describe the process of the movement of living matter. A complex biological problem can be transformed into a mathematical problem by means of mathematical models [16]. Through the logical reasoning, solving and computing of mathematical models, the relevant conclusions of objective things can be obtained. The purpose of researching the phenomenon of life. By using such a mathematical model, it is possible to create an effective 3d grape bunch for different shapes of grapes with different numbers and different layers.

4.2.2 Sphere Model

As found in background studies, for the shape of most table grapes, table grapes can be modeled by spheres. The spatial geometry of a semicircle that rotates around the diameter of a circle is called a sphere. Referring to the sphere, the radius of the semicircle is the radius of the sphere. A sphere is a solid figure with one and only one continuous surface. This continuous surface is called a spherical surface.

Here are some basic concepts about spheres. The semicircle has its diameter as the axis of rotation, and the curved surface is called a spherical surface. The geometry enclosed by the sphere is called a sphere, referred to as a sphere. [15] The center of the semicircle is called the center of the ball. The line connecting the center of the sphere to any point on the sphere is called the radius of the ball. The line connecting the two points on the sphere and passing through the center of the sphere is called the diameter of the ball.

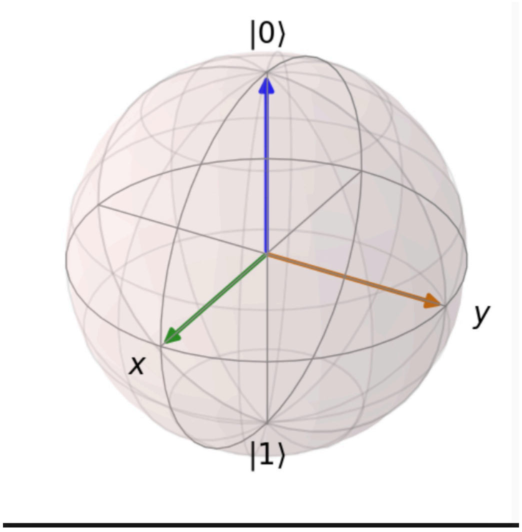


Figure4.2 Math model of sphere

To better describe how to find all the coordinates that satisfy the pixel points inside the sphere, Spherical Formula 2 can be used to model and operate:

$$(x - x_{center})^2 + (y - y_{center})^2 + (z - z_{center})^2 \leq r^2 \qquad (2)\ [29]$$

In this formula, the variable r represents the radius distance of the sphere in space. In other words, r represents the distance to the X-axis, the Y-axis and the Z-axis in three-dimensional space, because of it is a sphere. Therefore, the distance from the variable r to the three axes should be the same.

Further to explain the usage of the equation (2), if the position of the center coordinate of the sphere in the three-dimensional space and the space radius of the sphere are known, then the three-dimensional coordinates of a point are now (x, y, z). Then, when the coordinate value of this point is put into equation (2), if the result calculated by the left formula is less than or equal to the space radius of the sphere, then it can be inferred that the coordinate point should fall within the sphere or boundary of the sphere. It can also be obtained that if the result is greater than the variable r, then this point is not within the scope of the sphere.

4.2.3 Ellipsoid Model

A cylinder means that there are a fixed line and a moving line in the same plane. When this plane rotates around this fixed line, the surface formed by this moving line is called the rotating surface. This straight line is called the rotating surface. The axis, this moving line is called the bus bar of the rotating surface. If the cylindrical surface is cut by two planes perpendicular to the axis, the geometry enclosed by the two sections and the cylindrical surface is called a straight cylinder, which is called a cylinder. The two bottom faces of the cylinder are exactly the same two circular faces. The distance between the two bottom faces is the height of the cylinder.

According to previous research reports, most of the grapes appear in a spherical shape. But in addition, there is a class of grapes that can not be ignored, that is, many grape varieties are shaped like ovals, or they can be compared to a "capsule shape". As the name suggests, it is like an ellipsoid. However, it is not a perfect ellipsoid shape, instead, it is a shape like a capsule.

Figure4.3 Capsule shaped grape

By observing picture 4.3, the middle part of the grape can be represented by a cylinder model. For both ends of the grape, two semi-spherical balls can be used to complete the overall modeling of the entire elliptical grape. In general, there are two mathematical models that will be considered for the modeling of this type of grape.

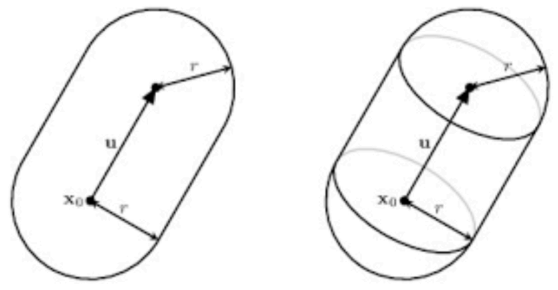


Figure4.4 Mathematical model of ellipsoid (or Capsule shaped) model

Now there is a point (x, y, z), just put the value of this coordinate point into Equation 2 and find that its final result is less than or equal to the radius r. Since the middle of the grape is a cylinder interconnected with the hemisphere, it can be known that if the Z value of the point is smaller than the height h of the cylinder, then the point will also be located in the cylinder. It can be known from the same reason that the bottom hemisphere of the elliptical grape is also the same as above.

4.2.4 Spherical grape model

A spherical mathematical model will be used to represent most of the spherical grapes, as explained in detail in Section 4.2.2. This spherical mathematical model will be transformed into a viable algorithm to represent how the grapes appear on the PGM file. Next figure4.5 shows an example of a sphere on PGM file.

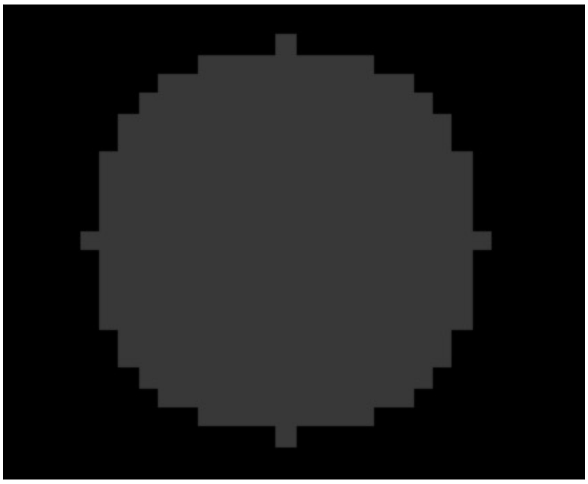


Figure4.5 An example of a sphere from a slice of the 3d model

a) Single grape generation algorithm

The basic requirement of a single grape generation algorithm is to successfully generate a single spherical mathematical model, as described in equation (2) provided in section 4.2.2; a reasonable coordinate point (x, y, z) before generating an effective spherical model in 3d space must be determined first, so that the center point of the sphere is known. Next, the effective radius of the circle must also be provided for calculation. The above two valid variable values are supplied to the equation (2), and then the program traverses all the pixel points in the 3-dimensional space, and changes the value of the coordinate point that meets the condition in equation (2), for example, if the value of the point is changed to 2, The color of the point will be distinguished from the color of the other coordinate points. When all the pixels in the 3-dimensional space have been traversed, a visible spherical model that conforms to the spherical definition will be presented.

Of course, the center point of the spherical model can be set by the user through the parameter transferred to the method or can be determined by generating three integers with the random generation function. If the user intends to use a random function to determine the center point, then in the Python library, a class called random can be introduced; the random class provides a very powerful random number generated function called random (), this function provides a floating-point value that ranges from greater than 0 to less than 1. However, because one of the properties of the PGM file is that it cannot allow decimal points, that is, the existence of floating-point data, the floating-point type data generated by the random () function has no effect on the file. Then another function called uniform () will be used. The function receives two parameters. The first parameter specifies the minimum value for generating a random number, and the second parameter defines the maximum value for generating a random number. The final result will be an integer in the interval [a, b].

b) Single grape with skin generation algorithm

Equation (2) in section 4.2.2 is very important, and the multi-layered spherical model must also rely on it to implement. According to the method of the Single grape generation algorithm provided in the previous section, before the spherical model is specifically implemented, the center of the ball (x, y, z) and the radius of the ball must be known and it is necessary to put these variables into the equation (2). Then the program uses the loop statement to traverse all the pixels (or coordinate points) in the space to find all the pixel coordinates that satisfy the value of the left side in equation (2) and the pixel points that satisfy the condition will be set to the appropriate color as required. At this point, the image of the outer skin of a grape is drawn; because the spacing between the grape skin and the flesh is very subtle, in order to better display the delamination between the skin and the flesh on the PGM file, it will be just a spherical model of smaller size that is embedded in the spherical model to represent the pulp layer of the grape. The algorithm is implemented in the circulation process of the outer skin; the coordinates of the center of the circle are not changed, and the value of the radius r is further subtracted by two pixels, and the new radius value and the center coordinate are put into the equation (2), so when the entire loop statement ends, two spherical models of different sizes and nested are completed.

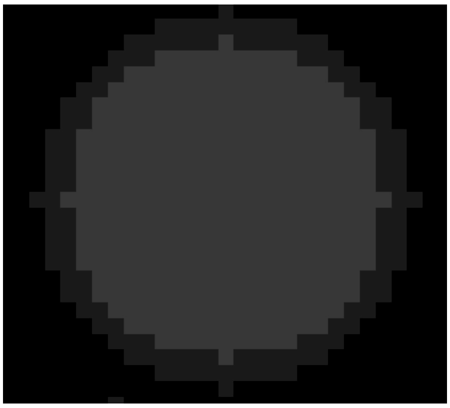


Figure4.6 A sphere with two layers (grape flesh and skin)

4.2.5 Ellipsoid grape model

As described in section 4.2.4, certain grape varieties resembling ellipsoid shapes can be represented by a combination of two different mathematical models. These two mathematical models are spherical mathematical model and cylindrical mathematical model. As can be seen from the figure 4.3, the difference between the ellipsoidal grape and the spherical grape is somewhat large. Therefore, a new modeling method will be described in detail in this chapter.

a) Single ellipsoid grape algorithm

First of all, the parameters that the algorithm needs to receive are basically the same as those required in the single spherical grape algorithm mentioned in the previous section, although the number and type of parameters required by the two methods are the same, but because of the ellipses. The model used by the sphere grape model algorithm is different from the model used in the spherical grape model algorithm, so the specific operation of the ellipsoid grape algorithm will be different.

Initially, the user can decide where the center (X, Y, Z) point of the model is based on user's input value, or randomly generate it using the random class provided in the Python library mentioned in the previous section. Three integer values generated should be assured that the range of values of X and Y in these three numbers cannot exceed the width and length set in the current PGM file. Then the user can enter the width r of the model he wants to generate. After the user completes all the parameter input, the algorithm will start from the lowest level in the 3-dimensional space, that is, the coordinate value is (X, Y, 0). In the beginning, the operation is started. First, the three points in (X, Y, 0) are put into the coordinates in equation (2), the value of r0 is put into the right side of equation (2), and then each PGM is traversed in order to find all pixel coordinates and points in the image for all compound conditions. It is worth noting that in the case where Z is 0 at the beginning, the range of r0 should not be greater than 1, so the circle generated in this case should be a small black dot; then the program will make the value r0 gradually increased by one until the value of r0 is equal to the value of the user inputting initially for r. Until now A hemispherical model is completed and the program automatically performs the calculation of the next model. At this point, for example, if Z has increased from the most 0 to 15, then the program will start to generate a cylindrical model, that is, keep the center coordinates of the model X and Y and the radius r0 unchanged, find the current plane in accordance with the equation (2) All pixel point coordinate values, then the value of Z changes from the current value to the height h, and the value of h is equal to r. At this point, a hemispherical model at the bottom and a complete cylindrical model have been completed, and the hemispherical model at the top can be continued as described in the method described at the beginning.

b) Single ellipsoid grape with skin algorithm

The implementation of the Single ellipsoid grape with skin algorithm is very similar to the implementation of the Single sphere grape with skin algorithm, which emphasizes the central point, that is, the (X, Y, Z) coordinates and the importance of the radius r.

In the case where the coordinates of the center point of the circle (X, Y, Z) and the radius r are known, in the case of creating each sub model in the outer ellipsoid model, such as a hemispherical model and a cylindrical model; according to the data that the gap between the peel and the flesh is very small, the program will add a set of loop statements in the case of generating an external model, that is, the peel, and the loop statement still uses equation (2) as the calculation formula. The only difference is that the program will subtract 1 to 2 pixels from the resulting r value, and set all the pixels that satisfy the cycle to a value different from the outer skin to distinguish the inner and outer structures. In other words, if the width of the shape of the ellipsoid grape produced by the end of the external loop in the algorithm is r, then it can be seen that the radius r0 of the ellipsoid model completed by the simultaneous internal loop is r-1 pixel or r-2 pixel

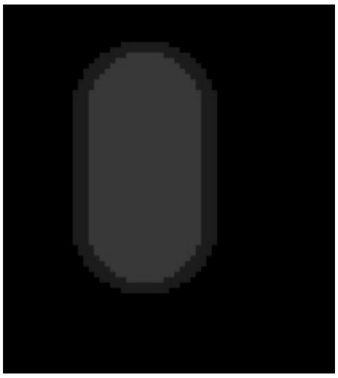


Figure4.7 An ellipsoid grape with skin

4.2.6 Stem model

According to the introduction of the grape stem in the background section, the point of the stem on the main stem and the growth point on the head of the grape is not in a horizontal plane, that is, the z values between the two points are not the same. So the ordinary two-point equation is not suitable in this case. The three-point line formula in space based on the two-point equation will now be introduced. However, in equation (3), the coordinate values of points in some spaces are relatively special, and it is easy to cause the error that the denominator is zero. So considering this situation, the equation (3) must be changed. So a set of equations (4) was discovered.

$$\frac{x^2-x^1}{x-x^1} = \frac{y^2-y^1}{y-y^1} = \frac{z^2-z^1}{z-z^1} = t \quad (3)$$

$$\begin{aligned} \mathrm{x} &= (x_2 - x_1)\mathrm{t} + x_1 \\ \mathrm{y} &= (y_2 - y_1)\mathrm{t} + y_1 \\ \mathrm{z} &= (z_2 - z_1)\mathrm{t} + z_1 \end{aligned} \quad (4)$$

The main usage of the equation (4) is as follows: First, the coordinates (x1, y1, z1) and (x2, y2, z2) of the two points in space must be found first, because it is necessary to know the z1 and z2 on two different planes according to the situation of the grape stems in reality. The connected line(stem) must have a certain slope. Substituting the two values z1 and z2 into equation (4) to obtain the slope value under the current plane, then calculating the coordinates of the pixel points that should be drawn on the current plane according to the corresponding slope value t of each layer and drawing a two-dimensional circular image with a radius of 2 pixels centering on the coordinates of the point. When all the above steps are completed, the user can see that all the grape heads and the main stem are connected by a stalk with a certain thickness when viewing the side view of the model. This is the model of the grape stem.

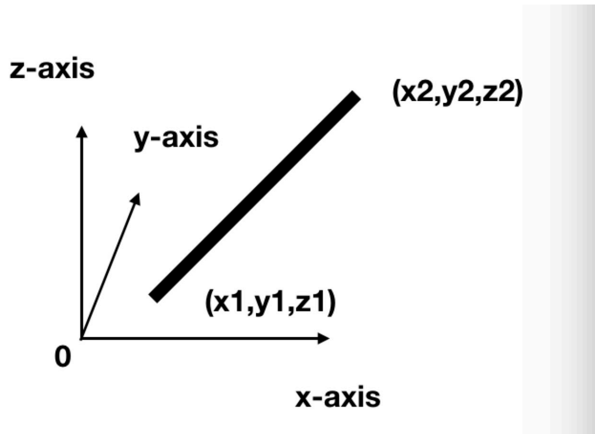


Figure4.8 an artificial stem displaying in the 3-dimensional space.

4.3 Implementation of a Bunch of Grapes Model

4.3.1 Language

Python is a very powerful and efficient programming language, and it is also a general-purpose language and object-oriented interpreted computer programming language[24][23]; the grammar of Python language is very brief and easy to understand, its main feature is to abandon the tradition which the semicolon is used to end the statement, but it is mandatory to use whitespace as the indentation of the statement; Python's application restrictions are very few, and Python can be seen in almost every field[22], whether in website development, game development, robotics development or some high-end aviation industry, people can see the emergence of Python code. The Python language also provides interfaces to different traditional mainstream databases, such as PostgreSQL, SQLite, MySQL, and Oracle.

Python is an open source and free language. People who use it can read its source code freely, and users can change the source code according to their own needs to achieve customized goals. While using the Python language, users don't need to think about how to manage the underlying problems of memory used by the program. There are many IDEs that support Python, the most famous of which is the commercial software Pychram. It is a powerful IDE that helps users improve their productivity when developing in Python, such as program debugging, syntax highlighting, project management, code jump, unit test and other functions.

Like many other programming languages, Python has its own powerful library functions and many third-party libraries available on the market [24]. By calling these rich library functions, users can easily complete their own programming tasks, such as the use of argparse library in Python, allowing users to write an efficient Python program that can run in the terminal environment, and the argparse function can also simplify the setting and inputting of parameters on the command, so it also improves the interactivity between the program and the user.

Numpy is an open source Python scientific computing library [25]. It is the base library for the Python scientific computing library. Many other well-known scientific computing libraries such as Pandas and Scikit-learn use some of the functions of the Numpy library. The multidimensional array in Numpy is called ndarray, which is the most common array object in Numpy [26]. A ndarray object usually consists of two parts: the ndarray data itself describes the metadata of the data. The advantage of the Numpy array is that the Numpy array is usually composed of the same kind of elements, that is, the types of data items in the array are the same. This has the advantage of knowing the size of the array elements, so the user can quickly determine the amount of space needed to store the data. Numpy arrays can use vectorization to process entire arrays at a faster rate. Python lists usually require looping statements to traverse the list, which is relatively inefficient. Numpy uses an optimized C API that is faster [27].

4.3.2 Plane generation

The focus of this project is to draw a complete and multi-layered 3d bunch of grapes in a number of blank PGM files (all pixels have a value of 0). It should be noted that the length and width of all PGM file images in this project should not exceed 300 pixels. In other words, the size of the image is 300 (x-axis) * 300 (Y-axis).

When a complete 3D grape bunch model is drawn, then the pile of PGM files can be treated as a complete three-dimensional array. Then the next series of operations can be implemented on this three-dimensional array, such as switching to another perspective for observation. But as the previous chapters describe, each PGM image is a 2d plane containing only the X and Y axes, and its Z axis is at a fixed value. The blue 2d plane (b) in Figure 4.11, its Z-axis value remains the same, only the pixels within the X-axis and Y-axis can be manipulated. Such a plane can be stored in a 3D array and array[0][X][Y] can be used for representation. Therefore, it can be seen that each 2d PGM file can be regarded as a cut surface of a three-dimensional model, which is composed of such two-dimensional slices.
In Figure 4.11, there is a variable Z-axis in the three-dimensional space (a). In other words, the maximum value of the Z-axis in this project can be regarded as the maximum height of the bunch of grape.

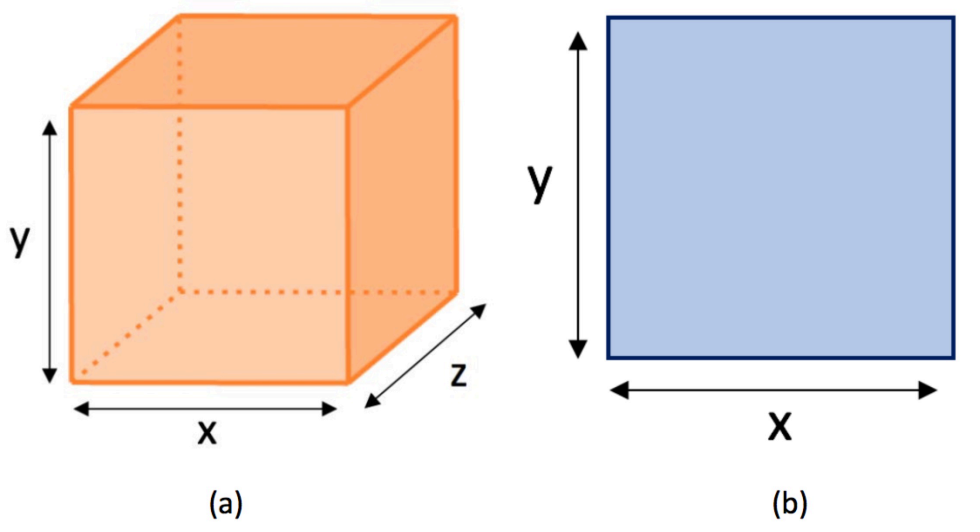


Figure 4.11[29] 3d cube model(a) and 2d plane mode(b)

In order to observe the bunch of grapes model from different angles, it is necessary to generate cutaway images from different directions. In order to achieve such an effect, firstly, all the drawn 2dPGMs should be based on a certain view, such as a top view or a side view. The file data is saved into a three-dimensional array one by one; then the contents of the three-dimensional array are manipulated according to the requirements to produce the correct two-dimensional slice.

From the perspective of the top view, all grape shapes, whether it is ellipsoidal or spherical, should be the round shape on a two-dimensional PGM file. As shown in Figure 4.12, there is a PGM picture of a grape slice in the top view angle. In the perspective of the top view, the Z index value of the picture is set to a constant value of 1 in the three-dimensional array, because the grape image on the picture is a small black dot, so it is known that this is the bottom of a grape. This two-dimensional slice of a grape can be represented by the 3-dimensional array [1][x][y] in the programming language.

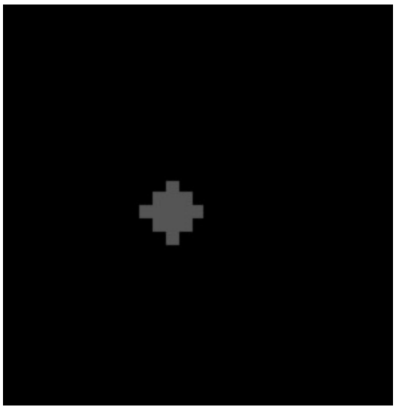


Figure4.12 A slice of a single spherical grape on 2d plane from top view (z-value is fixed)

From a side view perspective, Figure 4.13 shows how the specific 2d grape cutaway is different when the value of x is set to a fixed value (x is set to 210). Of course, under this vision, the detailed data in the 2d plane slice can be saved by the three-dimensional array [210][y][z]. Since Figure 4.13 shows a side view of a spherical grape, also the radius of the spherical shape is the same length in three dimensions, the side view of the spherical grape presents the same shape as the top view. If it is a side view of an ellipsoidal grape, the results will be different.

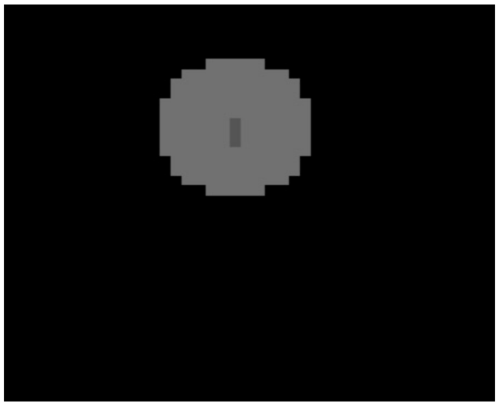


Figure4.13 A slice of a spherical grape on 2d plane from side view (x-value is fixed)

4.3.3 Initialization of a Three-dimensional Array

Because the details of PGM files are mentioned in the previous chapters, it is well known that each PGM file can only be considered as a two-dimensional array. The PGM map for each grape slice is treated as a two-dimensional array, so after each grape model is completed, the program will generate a large number of 2D PGM files, in other words, a large number of 2D arrays. Next, a three-dimensional array will be created, and the program will save all the previously generated large array of 2D PGM files into a 3D array. Figure 4.14 will describe in detail how to convert all the data in a PGM file from a one-dimensional array to a two-dimensional array and how to save all the two-dimensional arrays generated before with a three-dimensional array.

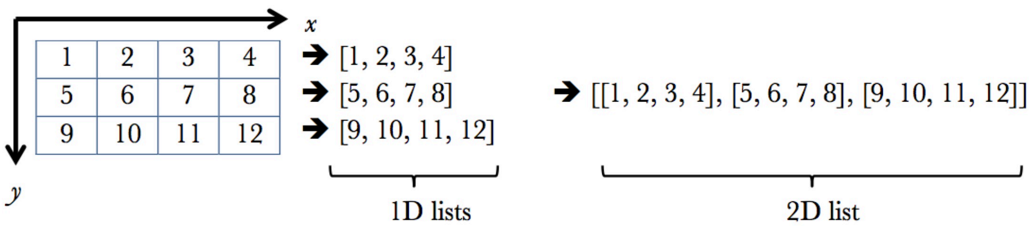


Figure4.14[28] An Example of manipulating different arrays

The representation of the data in a PGM file on the plane coordinates can be represented by the leftmost example in Figure 4.14. Since in Python, the representation of an array is generally composed of a List structure, the example in the middle of Figure 4.14 is to read a row of data in a PGM file into a one-dimensional array. When the data in each row of the PGM file is successfully succeeded. When in the process of reading, the program will store all the one-bit arrays into another new List() array, so that a new two-dimensional array is generated, which also represents a complete PGM file.

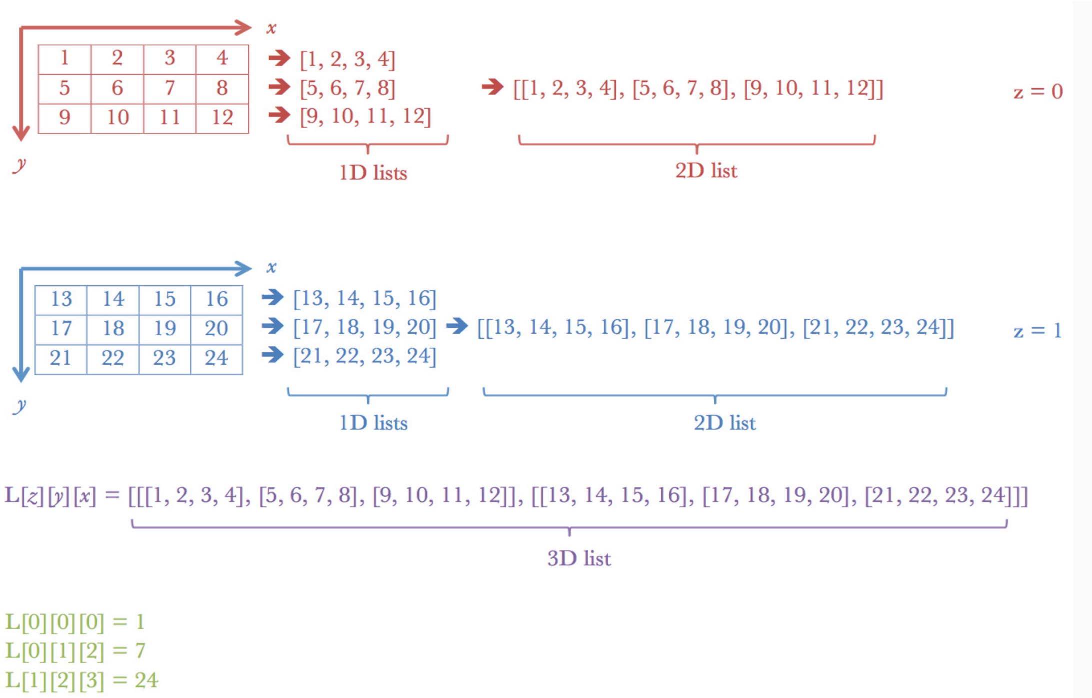


Figure4.15[28] An Example of Merging Two-dimensional Arrays into a Three-dimensional Array

As seen in Figure 4.15; essentially the size of the z-axis in three-dimensional space determines how many two-dimensional arrays representing PGM files in the project. Similarly, in Figure 4.15, whenever the value of z is transformed, it represents the data in different PGM files. When all two-dimensional arrays (numbers with different m values) are stored in another new List array, a new three-dimensional array containing all PGM file data can be further used by the program in the future. For example, when the user wants to select the data of the first row and the first column in the first slice of the three-dimensional array L, L [0][0][0] can be used to obtain detailed data. Python provides such a multi-dimensional array operation based on the List structure, which is convenient for the user to quickly switch between different slices and operate on a specific value in the actual position.

4.3.4 Algorithm for Generating a Bunch of Grapes Model

Because the focus of the project is on creating the size and shape of a bunch of grapes, without having to consider other environmental factors or inherent chemical factors. So only grapes of different shapes need to be generated on the PGM picture. When all the grapes have been generated, the three-dimensional array is finally saved after the grape bunch is scanned. There are several factors that must be considered when modeling a grape bunch on a PGM file; since the project only focuses on shape, size, and the maximum number of pixels allowed for a pixel in the PGM file is 9. In the project, the following grape tissue and pixel values will be associated:

- 0 – Air
- 1 – Grape skin
- 2 – Grape Flesh
- 3 – Berry stem

The specific steps for modeling a bunch of grapes are as follows:

Step 1) Creating empty PGM file

First, according to the width and length information of each PGM file set in the project, there is a PGM file initialization function called initial_pgm_array() in the project. The function of this method is to initialize one before each modeling operation, which it contains a two-dimensional array of integers 0 (all air) and returns them to other functions for use. The specific process is to use the two ‘for’ loop statements (ranging from 0 to the width and length of the PGM file) inside the initial_pgm_array() function to set each pixel value in the newly generated two-dimensional array list to 0 (Air), and use the array() method in Numpy (Python's third-party library) mentioned in the previous section to turn the entire list into a real multidimensional array, and finally return this real two-dimensional array to the main function.

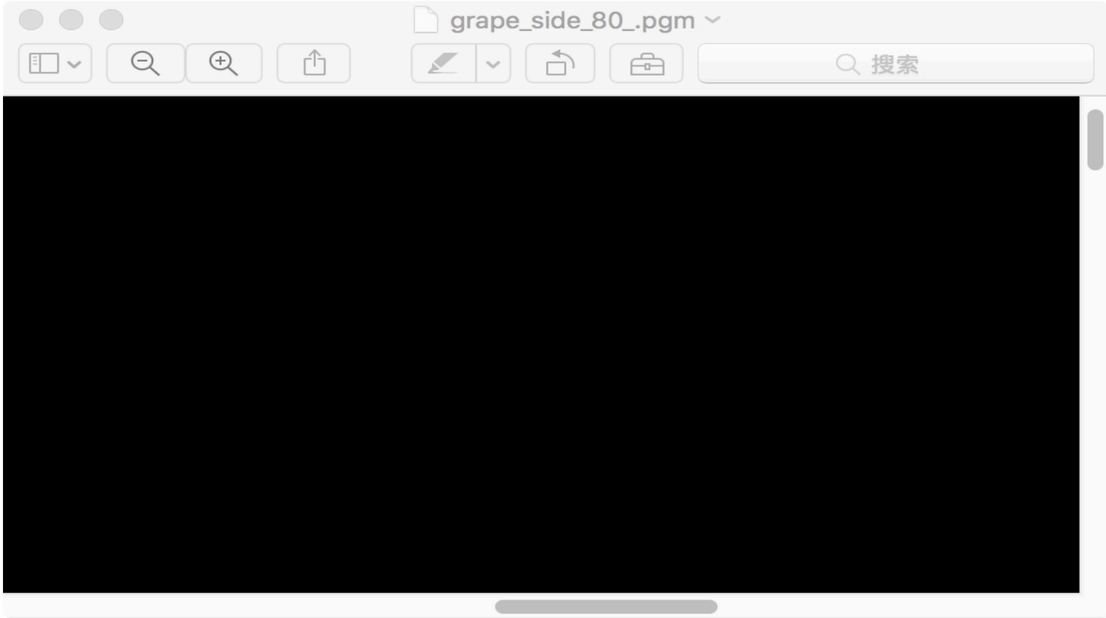


Figure4.16 An Empty PGM File Generated by the Function with all pixels set by 0 pixels.

Step 2) Algorithm of Finding the center of the grape for one layer or multiple layers

- **<u>For one layer</u>**: According to the previous chapters on the spherical model and the ellipsoidal model, the center point and radius of the circle are two very important and indispensable values for the generation of the model. First, the length and width values of all generated PGM files in the project are set to 300 pixels that it could change according to user's requirements. Then there is no doubt that the coordinates of the center point of the PGM picture are (150, 150). Since the program will also ask the user to enter the value of the berry stem size and the number of grapes generated, then the value of the parameter r is equal to the berry stem size. value. There is a function called find_vertical_pictures_points(numbers_on_the_layer,radius,centerX, centerY) that must receive the three parameters mentioned above. Next, based on the size of the berry stem size entered by the user and the coordinates of the center point of the known PGM file, and the number of grapes the user wants to generate, the find_vertical_pictures_points() method calculates the coordinates of the center point of each grape based on these parameters. The corresponding formula for calculating the center point of a single grape is shown in Figure 4.17.

```
Xn = X + r * cos(-degree * PI / 180));
Yn = Y + r * sin(-degree * PI / 180));
```

Figure 4.17 Formula of Locating coordinate points

For example, if the user wants to generate 12 grapes on the first layer of the grape bunch and set the value of the berry stem size to 50, then the function will automatically calculate the specific degree of each grape in a circle. For example, if there are 12 grapes, then each grape has 30 degrees (360/12 = 30). So the value calculated in Figure 4.17 will be 0°, 30°, 60° to 360°. As can be seen from Figure 4.17, each time the two formulas are running, an X value and an Y value are generated, and these two values represent the center coordinates of a grape in the PGM. The two-dimensional coordinate array that has been created in advance in the program will save the X and Y values in pairs. When the function body finishes running, there should be twelve pairs of similar coordinate values in the two-dimensional coordinate array. These twelve pairs of coordinate values are the central points to be modeled for each grape. This array of coordinates containing twelve pairs of coordinate values will be returned to the main function body after the end of the function body for other functions to continue to use.

- **For multiple layers**: Just like the algorithm of finding all coordinate points on one layer, the multi-layered grape means the find_vertical_pictures_points() function which will be called multiple times by the main function to find the center coordinates of all the grapes in each level. For example, whenever the user wants to generate two layers of a bunch of grapes, the user will enter the value of the number of grapes that will be generated on each layer, and the program will store the two values in a list of variables called value_list; whenever the find_vertical_pictures_points() runs, the first value in the value_list will be passed to the body of the function and the result will be evaluated; next, the second value in the value_list will also be passed to find_vertical_pictures_points() for calculation. Until all the values in the value_list have been used, the coordinates of the center point (x, y) of all the grapes in the two layers will be all found.

Step 3) Radius calculation

The specific value of the radius is a very meaningful and important variable in the modeling of grapes. It should be very careful when calculating the specific size of the radius, because the value of the radius may eventually affect the distance between each grape and also the size of the grapes itself. In the field of geometry, there are three kinds of positional relationship between circle M and circle N, the following figure4.18 is a great illustration: the first is the sum of the distances between the two centers is greater than the sum of radius of the two circles, in this case, the circle M is separate from the circle N(a); The two are the sum of the distances between the two centers equal to the sum of the radius of the two circles, in which case the circle M is tangent to the circle N(b); the third is the sum of the distances between the two centers less than the sum of radius of the two circles, in this case the circle M is intersected with the circle N(c).

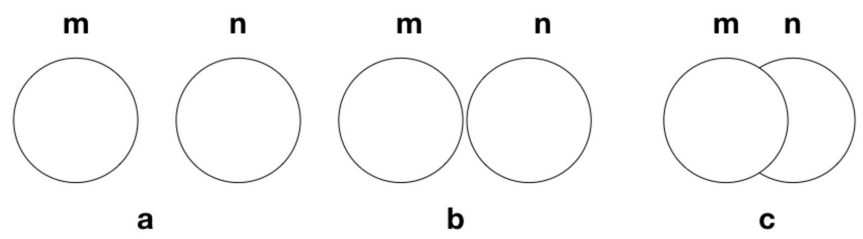


Figure4.18 The positional relationship between two circles M and N

Although the positional relationship between the two circles has the three cases mentioned above, as seen in Figure 4.19, the distance between the true grapes should be tangent. Therefore, in this project, the value of the radius r is not allowed to be set by the user at will, because the number of grapes on a layer is already set by user, it is possible that the value of radius given by the user may not be able to make the grapes tangent but it is possible to make the grapes in an intersection case or a separate case, which is unrealistic in real situation.

Figure4.19 A picture of real grapes touching closely with each other

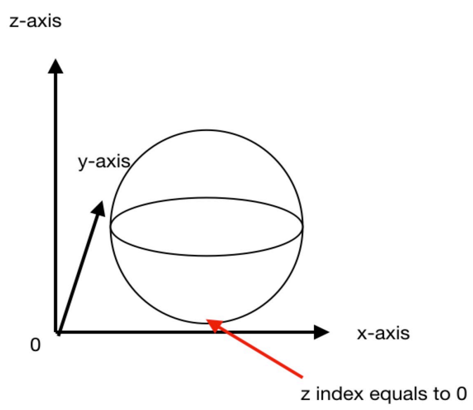
In order to find the correct value of the radius which could make each grape in a tangential situation, the distance formula between two points will be introduced, the equation (5) is going to be used in the future.

$$AB = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (5)$$

Before calculating the exact radius value that makes the circle tangent, the center points (x1, y1) and (x2, y2) of the adjacent two circles (grapes) must also be taken out first. Then the coordinates of the two center points are substituted into the formula in equation (5) to obtain the distance d between the two center points. Because of the tangent nature of the two circles, the final value of the radius r is equal to half of the distance value d. This radius value r will play an extremely important role in modeling a bunch of grapes.

Step 4) Building a bunch of grapes

- **<u>A bunch of sphere grapes</u>**: Because it is required to create a bunch of 3d spherical grapes, the best way is to determine all the center points of each layer of grapes firstly, and then gradually build up from the bottom of each grape, which means the z index ranges from 0 to a certain number on Z-axis values. Whenever the user enters the number of grapes that need to be generated for each layer, such as 10 grapes, the main function will call the method mentioned in the previous section to confirm the different center coordinates of the 10 grapes. Of course, because it is a three-dimensional model and the model is also built from the bottom, the current plane can be represented by the three-dimensional array[0][x][y], where the maximum values of x and y are the width and length of the PGM file. Now the model of all the grapes on the first layer will be created in the perspective of the top view. When the coordinates of the center point of each grape are found, these coordinate values (x, y) will be substituted into the equation (2) together with the radius value r. For the equation (2) mentioned in section 2.2, it should be noted that the radius value at this time should be calculated from 0 or 1, because the slice is the first from the bottom of the grape, that is, the z index is equal to 0 on the Z axis. As shown in Figure 4.20, in the bottom section, all grapes are a black dot.



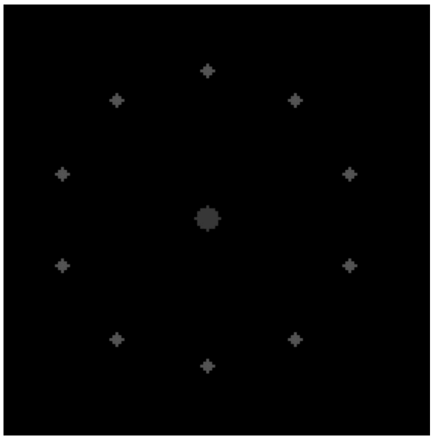


Figure4.20 An example of a single 3d grape when it comes to the slice from the bottom, which radius is only 1 pixels (picture on the right).

When the center coordinate (x, y) of each grape remains the same, and the value of z increases from 0 to the same size as the radius, for example, 15 pixels, the three-dimensional array expression is array[15][x][y], at this time the cross-sectional area of the grapes is maximized, and each grape is in a tangential position, that is, half of the three-dimensional grapes have been completed, as shown in Figure 4.20. When the radius reaches a maximum of 15, the next step is to generate the remaining half of the grapes, so the program will keep the coordinates of the center point of the circle unchanged and the value of the variable r slowly decrease to 1 pixels. A complete grape model has been successfully implemented to a height of 30 pixels, which is twice the radius. Because there are now ten different center coordinates representing ten different grapes on the same layer, the first layer of the three-dimensional grape string has been modeled when ten grapes are completed in the same way.

When it comes to multi-layered grapes, as described in the previous section, the modeling method is probably the same, except in the three-dimensional array[z][x][y], the height of the grapes will vary greatly. That is, the z value is increased on the z-axis, or the number of sheets of the PGM picture is increased. Because value_list will save the number of each layer of the grape string, if there are two layers, when the program completes the modeling of the first layer of the grape bunch according to the method discussed above, in the array[z][x][y] The z value is increased to m. When the program uses the next value in the value_list and completes the modeling of the second grape bunch, the z value will increase from m pixels to n pixels, so it can be seen that the height of the whole grape bunch will reach m. +n pixels (see figure4.21-1), which means that the number of PGM files will reach m+n. This method is still effective for bunches with more than two layers.

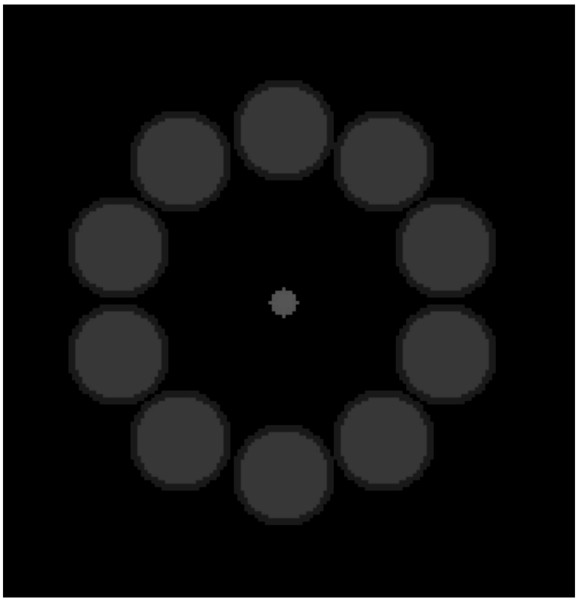


Figure4.21 a slice of the middle part of the grape from top view

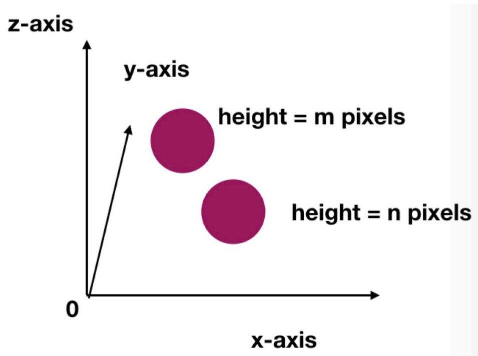


Figure4.21-1 The height of each grape in the first layer is m pixel value, and height of the second layer grape is n pixel value, so the overall height of the two layers of grapes is m+n pixel values.

- **A bunch of ellipsoid grapes:** For ellipsoidal grape bunches, the center point and radius of the different grapes in each layer have been determined according to the previously mentioned method; as with the spherical grape modeling method, the ellipsoidal grape is also modeled from the bottom, which means the first panel can be represented as array[0][x][y] in three-dimensional space. There is a method called draw_3d_vertical_oval_pictures() that takes different coordinate points and radius values and then models it according to the method mentioned for modeling a single ellipsoidal grape in section 4.2.3. When the function ends, all the grape models in the first layer in the 3D grape bunch will be successfully created. It is worth noting that, unlike the spherical grapes mentioned above, the heights of the two grapes will differ, that is, the maximum value of the z value on the z-axis will be different. For the height of the ellipsoidal grape, it should be the radius of the two hemispheres plus the height of the middle cylinder, that is, the height h = 3r. The specific difference can be observed in Figure 4.22.

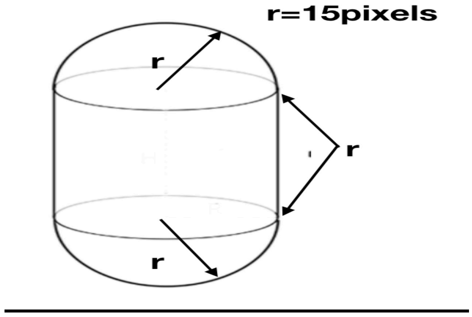


Figure4.22 An example of the height of an ellipsoid grape

In the case of the need to generate multiple layers of grapes, such as two layers, the method used is the same as the method mentioned in the previous section; the main function will read the values stored by the user in the value_list one by one. (that is, the number of grapes per layer). When all the ellipsoidal grapes of the first layer are successfully created, the function draw_3d_vertical_oval_pictures () will be called again and receive the second value in the value_list, continuing to generate all the ellipsoid grape models in the second layer. At the end, all PGM file data or two-dimensional arrays will be saved in a three-dimensional array, and the value of z will continue to increase by n pixels from the height m pixels of the first layer (the second layer of grapes) Height), so the z value at this time should be equal to m pixels + n pixels. The figure4.23 illustrates this situation.

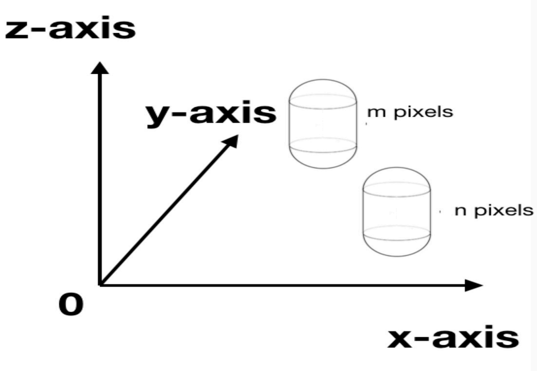


Figure4.23 In the side view, the representation of the height of the two layers of grapes.

Step5) Generating the stalk

Grape stems are an important part of the connection between grape stalks and grapes.

According to the association between grape tissue and color, as previously defined in section 4.3.4, the color of all grape stems will be represented by a 3-pixel value. However, the premise of generating stems must be that a complete three-dimensional grape bunch must have been successfully created and stored in the three-dimensional array[z][x][y]. That is, the program can operate through different three-dimensional arrays in different grape slices.

One thing to note here is that, in the perspective of the side view, the real situation is that all the stems of the grapes should grow in the head of the grapes rather than in the middle of the grapes as shown in Figure 4.24. According to figure 4.24, the main stem of the grape is generally grown in the center of the bunch. Since the width and length of the PGM are known to be 300 pixels, the positive center position of the picture is (150, 150). And because a complete three-dimensional grape bunch has been generated at this time, and the overall height value of the grape bunch is also known, the main function will traverse the two-dimensional array representing each PGM file, that is, the z value in array[z][x][y] is increased from 0 to the overall height of the grape bunch, and the center point of each picture and the self-set stem radius value are substituted into the previously mentioned equation (2) for calculation, then a three-dimensional cylinder is created, and the cylinder also represents the main stem of the bunch.

Figure4.24 An example of the position of the grape stem

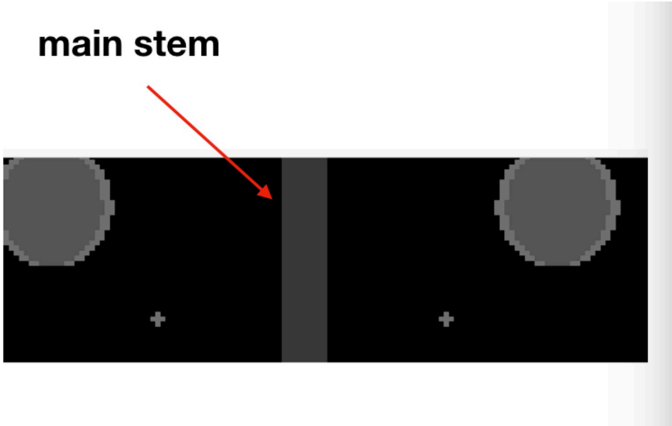


Figure4.25 Main stem of a bunch of grape

The next step is to create stalks that connect the grapes to the main stem. According to the actual situation of the grapes in the real world, the stems of the grapes generally grow on the top of the grapes. So every time a grape is gradually formed to the top, the model of the stem is also ready to start. However, in order to generate some effective grape stems, the three-dimensional line formula in mathematics shown in equation (4) will be applied to the project.

The specific grape stems are implemented as follows: For the first layer of grapes, when each grape begins to generate its own top image, the formula of the line equation in equation (4) will be called to generate a specific three-dimensional grape stem. For example, the first layer of a bunch of grapes has 10 grapes and the diameter of each grape is 30 pixels. At this time, the z1 value which belongs to the value of main stem (x1, y1, z1) and the z1 value in the three-dimensional array is 2 pixels at first and there are ten different pairs of coordinate points. The coordinate values of ten grapes are stored in a two-dimensional array called coordinate_value. For each grape, its stem must be connected to the main stem located in the middle of a bunch of grape. In the range of z1 to z2 on the z-axis, the point of the center of each grape (x2, y2, z2) and the coordinate point of the main stalk, that is, the center point of the entire PGM picture (x1, y1, z1) will be substituted into equation (4) for calculation to draw a line connecting two points in a three-dimensional space, that is, the stem connecting the main stem and the grape. the result is shown in the figure4.26-1.

For multi-layered grape bunches, the specific implementation of the grape stems of each layer is the same as that achieved by the single-layered grape stems mentioned above. It is worth noting that the z-value changes on the z-axis, because the stem is created at the top of the grape, so the change of z-value must be discontinuous. For example, in the first layer of grapes, the program will start the creation of the grape stems on the cut surface with the z value equal to 90 pixels and 70 pixels. However, in the second layer of the grape bunch, the slice with the z value equal to 60 pixels and 40 pixels and then the creation of the grape stem will begin. According to the previous definition of the relationship between the grape organ and the color, all the colors about the stem will be set to 3 pixels.

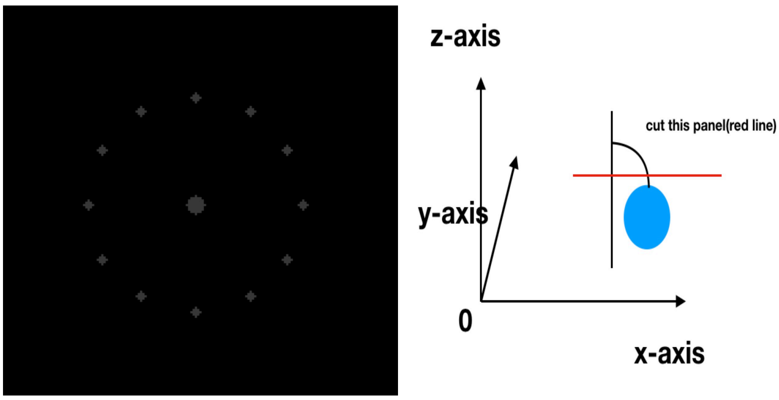


Figure4.26 grape_1.pgm the slice of the three-dimensional stem when z=40 in array[z][x][y] from top view.

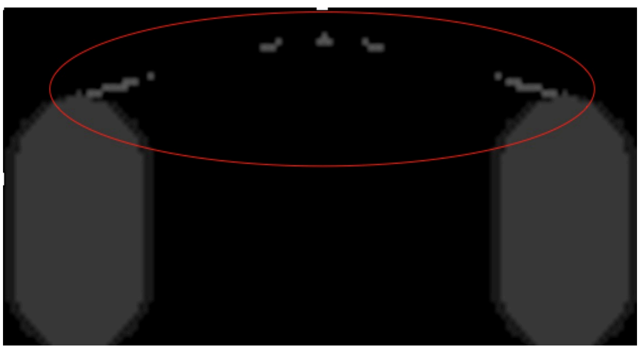


Figure4.26-1 grape_side_148.pgm, a slice of the three-dimensional stem from the side view when z=148.

Step 6) Generating side view files

After completing the creation of PGM files of a bunch of grapes from top view perspective, based on this three-dimensional array containing all PGM file information, the side view can also be generated quickly. The Python third-party library Numpy provides a very convenient and efficient transpose function called transpose (); transpose() method can reset the array and return a view of the source data. For high-dimensional arrays, transpose requires a tuple of axis numbers to be transposed. For multidimensional arrays, the number of indexes needed to determine the position of the bottom element of a basic element is the dimension. For example, a three-dimensional array, then number the dimensions, that is, 0, 1, 2. After the transposition of the three-dimensional array containing the three-dimensional grape cluster top view information by this function, the dimensional position of the three-dimensional array is changed. This allows the user to view the bunch of grapes from another angle, so the user will look at it from a side view. In the main function, all the top view data is stored in the three-dimensional array of plist, and then a new three-dimensional array called plist_side is used to store the new data of the plist array after the function transpose(). Finally, the top view data of the three-dimensional grape bunch is stored in the plist and the side view of the three-dimensional grape bunch is stored in the plist_side array.

```
[[[ 0  1  2]     [[[ 0  1  2]
  [ 3  4  5]]      [ 6  7  8]]

 [[ 6  7  8]      [[ 3  4  5]
  [ 9 10 11]]]      [ 9 10 11]]]
```

Figure4.27 The first array is transposed and becomes a new array. So, after transposing the array of 3D models, a new view (second array on the right) will be produced.

Step 7) Writing files into disks

After all the side view files and the top view files have been successfully created, and since the PGM raw data stored in the three-dimensional array is in a two-dimensional format, all PGM data will be written one by one into local disk by using a function called write_info(), the function receives a three-dimensional array as a parameter, The function first writes the PGM header information, including the picture type (p2), the width and length, and the maximum gray value allowed, and then writes each two-dimensional array in the three-dimensional array line by line into the local disk in a certain order. All top and side view files are saved in the same folder and numbered with different numbers (that is, the value of z on the z-axis).

4.4 Implementation of Terminal Interaction

Command line-based interaction allows users to generate a three-dimensional bunch of grapes according to their needs, such as the size of the stem ring, the shape of the grapes, and the number of layers of grape bunches. Because the user cannot view all the picture information currently generated on the command line, the user can wait until the end of the generation process to go to the current folder to view all the top view and side view files that have just been generated.

4.4.1 Detailed usage of the program

First of all, the project is based on Python 3.6.3. Users must confirm that the current computer running environment can support this version perfectly before using it. Besides that, the third-party library “Numpy” is also required to be installed.

The first step is to open the terminal and type the “cd” command to find the file path where the project is stored. In the current project path, what the user needs to do is to enter the complete python command and the commands provided in the project. A complete usage of the software is shown in Figure 4.28. Here are a few different numbers before character ‘-c’, the different numbers here represent the number of grapes in each layer in this three-dimensional bunch of grape, for example, the first number ‘12’ means that the first layer of the bunch has 12 grapes and the following numbers also mean the same thing. There are 4 different numbers here, and it also means that the bunch of grape that the user wants to generate has four layers, that is, how many layers the user wants to generate, the user is also required to input several numbers which match the number of layers.

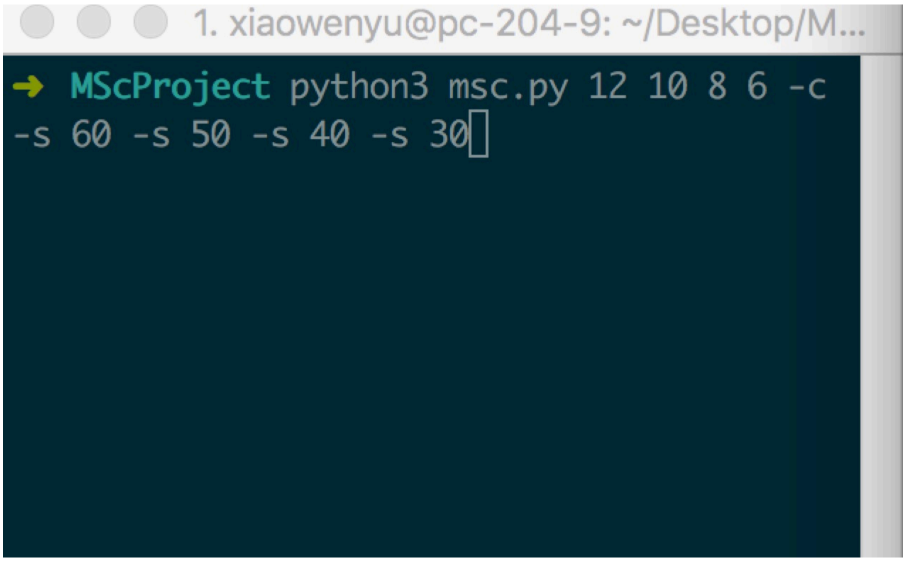


Figure4.28 An Example of how to use the software with combination of different commands at the same time.

In Figure 4.28, there is a character called ‘-c’. This is a parameter on the command line and is also an abbreviation of English word (circle). When the user enters the character ‘-c’, it means that the user wants to generate a bunch of grapes with all the grapes in a spherical shape. At the same time, the software also supports the creation of another grape model by entering the character ‘-o’ on the same position, in this case, all the grapes on the bunch of grapes are in an ellipsoid shape.

Next, another command parameter provided by the project is called '-s', and the full name is called ‘-size’. This command represents the size of the berry stem, which is the size of the ring currently composed of the grapes. The specific effect can be seen in the picture 4.29. As can be observed from the figure, the ‘-s’ in the command here means that the radius of the generated berry stem is 50 pixels, so the diameter of the whole berry stem is 100 pixels.

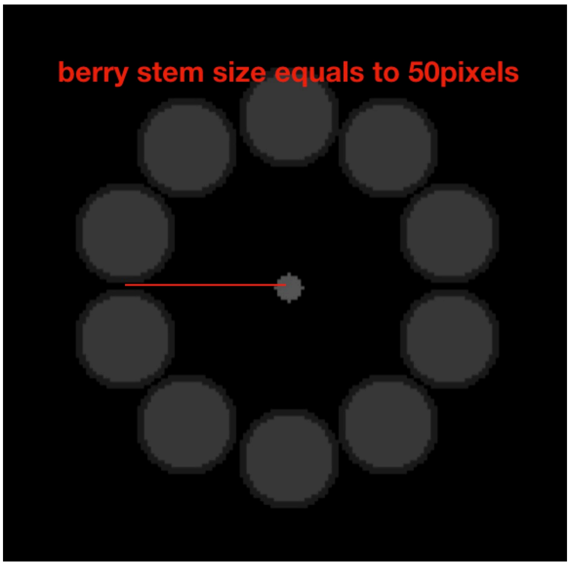


Figure4.29 Showing the size of the berry stem with 50 pixels

It should be noted that when all the parameter numbers are input, the number of layers of the grape bunch, that is, the number before the character '-c' or '-o', must match the number of the command '-s'. For example, if the user enters 10, 8 two numbers, then the user must enter two '-s' commands. On the other hand, each '-s' argument can only be followed by a single digit and not a string of numbers. If the user wants to enter multiple berry stem values, the user must enter the '-s' argument multiple times.

The software also comes with an explanation document. When the user does not understand the meaning of various parameters, the user can type the software name in the terminal and add the '-h' command to see all the commands with detailed explanation. Figure 4.30 shows a concrete example of ‘-h’ command.

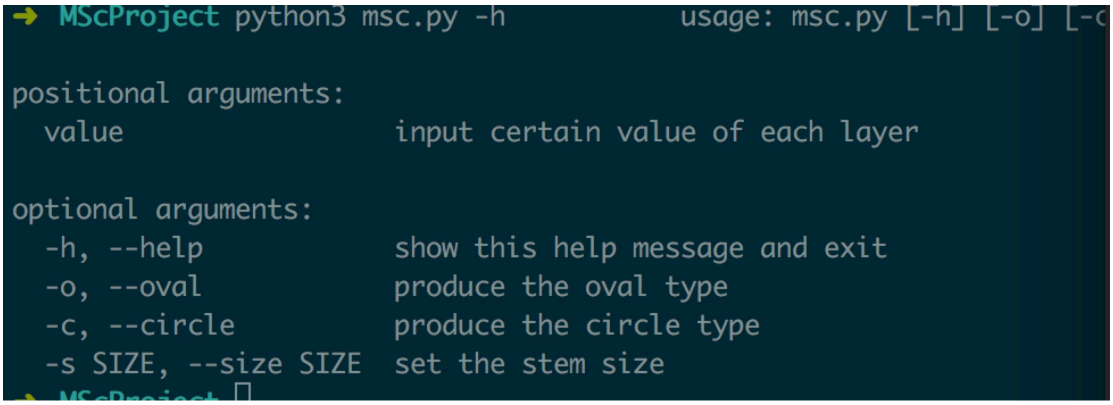


Figure4.30 Message given by the software after entering ‘-h’ command

4.4.2 Error Message

In order to improve the efficiency of human-computer interaction, the software also provides a mechanism for handling errors. For example, whenever the parameter name or number entered by the user is incorrect, the software will throw a corresponding error according to the specific input situation in order to give users a clearer understanding of the cause of the error.

1) **Number does not match**: When the user only enters the number of grapes per layer without inputting the value of berry size, or when the number of grapes per layer and the number of berry sizes are not equal, the system will throw an error message of mismatch between the parameters. The software will then be re-run and the user can enter the parameters again.

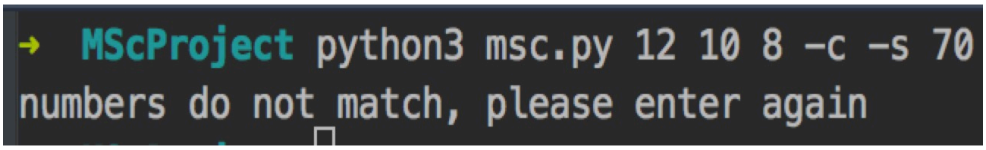


Figure4.31When the number of layers' input by the user does not match the number of specific sizes of each layer, because there is only one '-s' command. It should have three '-s'.

2) **Too many layers**: According to the detailed information about the grapes mentioned in the background section, the height of the grapes is limited. In real life, there is a situation where the number of layers of the grape can reach more than ten layers, although the software can generate an infinite number of layers, although in reality there is no such bunch of grapes and an infinite number of layers is generated. A very resource-intensive thing. The software will impose certain restrictions on the number of layers of grapes that can be generated. Therefore, according to the background investigation, the average number of layers of grape bunches is generally between 7-12 layers. So when the user enters the number of grapes per layer more than 12 times, the system will throw an error message called "Too many layers".

Figure4.32 When user enters many layers for a bunch of grapes.

3) **<u>Invalid command</u>**: At present, the software only supports modeling of two models, namely a spherical model and an ellipsoidal model. The arguments corresponding to these two models are '-c' and '-o'. If the user enters an argument '-q' that is not supported by the system, the software will throw an error called invalid argument. Figure4.33 shows an example of invalid command error.

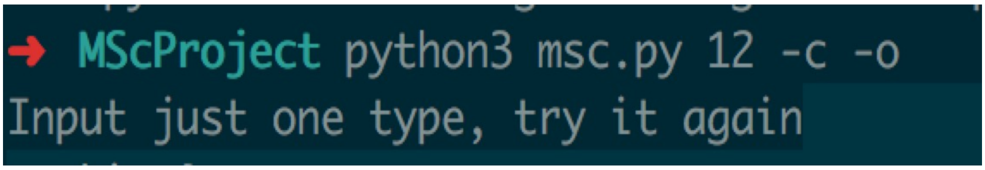


Figure4.33 When the user inputs two types of model at same time, the error message will be thrown.

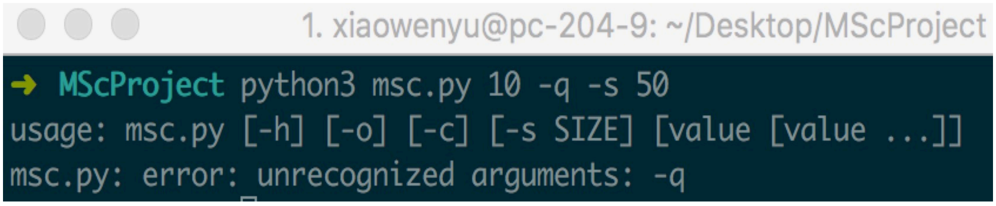


Figure4.34 When the user inputs a unrecognized argument, a error message will be thrown

5 Evaluation

Once all the work of the project is completed, it is an indispensable part of evaluating the project. This will give the maximum information to the project whether it meets the standards and objectives set before the job. In the process of evaluation, the accuracy and efficiency of the project will be investigated intensively.

1. **The Accuracy of the software**: The PGM file of the grape bunch generated by the software will be compared with the grapes in real life. By detailed comparison, the specific similarities and differences between the grapes generated by the software and the grapes in the real world can be found. This is an effective way to judge the accuracy of the software.
2. **Software efficiency**: The software's operational efficiency and resource utilization efficiency is a very important indicator, because for a software if its running time is too long and the resources consumed exceed a certain range, the efficiency of the software is relatively low. When the software starts running, some memory-based analysis commands and timing commands will be applied to the software. These commands will give a detailed operational report at the end, which it is a clear way to tell whether the efficiency of the software is acceptable or not.

5.1 Accuracy

In this chapter, some different shapes of grape bunches will be compared with the generated electronic pictures, and the accuracy index of the different types of grape generated by the software will be judged by such comparison.

5.1.1 Sphere Grape

Figure 5.1, Figure 5.2 shows the specific appearance of the top view of the grapes in real life. From the left side of Picture 5.1, the real grape bunch is also a few grapes that form a ring with the main stem in the middle, on the right side of the figure 5.1, most of the grapes are also close together and form a circle.

Figure5.1 Top view of a bunch of grapes(left) and a digital bunch of grapes for one layer(right)

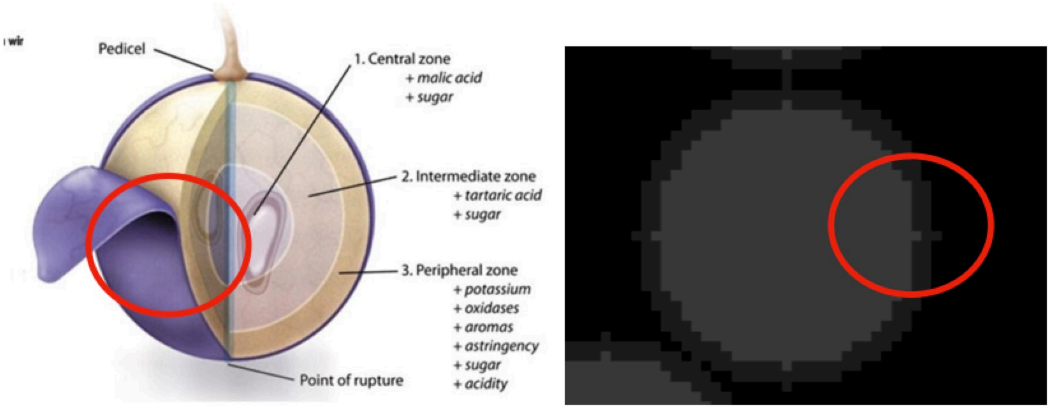


Figure5.1-1 Comparison between a single real grape and a single grape produced by the software. The grape includes skin (inner layer) and flesh (outer layer)

Shown on the left side of Figure 5.2 is a side view of the real bunch of grapes. Presumably all the grapes are divided into layers. However, the right side of Figure 5.2 shows a slice of a three-dimensional grape. Similarly, it can be seen from the figure that the grapes are also divided into layers.

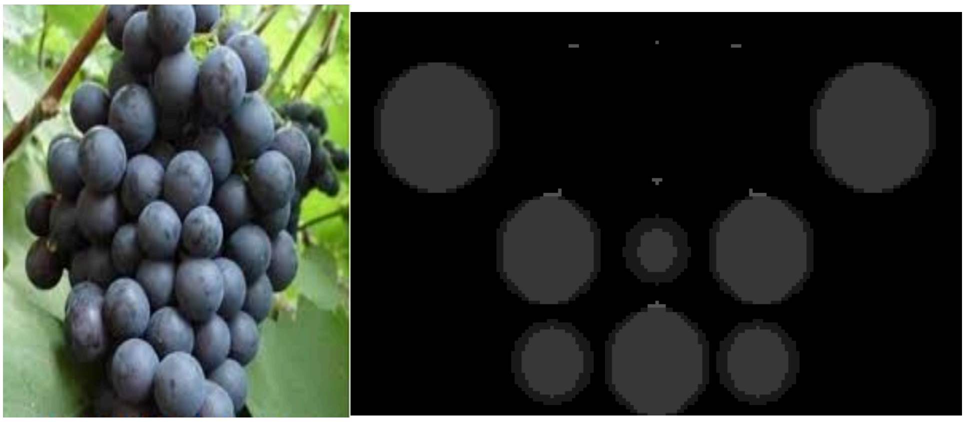


Figure5.2 Side view of a bunch of grapes(left) and a digital bunch of grapes for 3 layers(right)

5.1.2 Ellipsoidal grape

A common feature of ellipsoidal grapes and spherical grapes is that when viewed from a top view, the shapes formed by the two are circular in the picture. So in this section, the side view files of the ellipsoidal grapes are compared.

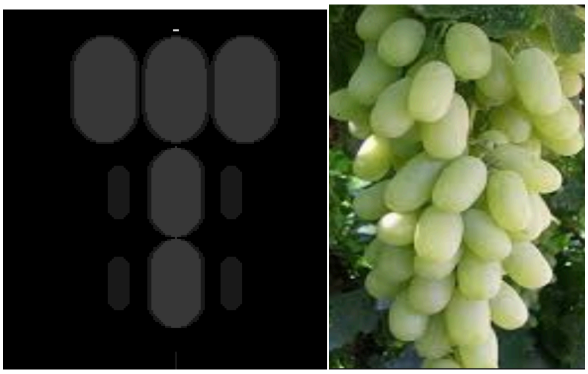


Figure5.3 A digital bunch of ellipsoidal grapes on the left(a slice from side view), the grey point in the middle is the stem and the real bunch of grapes on the right.

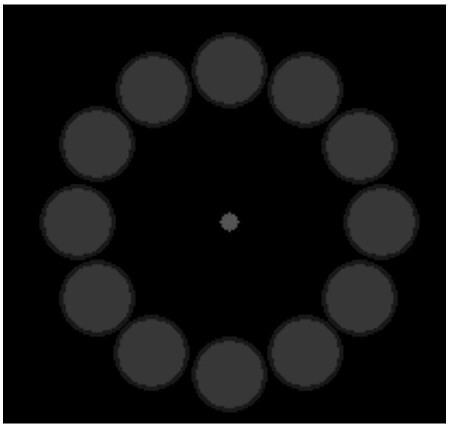


Figure5.3-1 In the perspective of the top view, all the images of the ellipsoidal grapes are still circle

5.1.3 Stem

In real grapes, the growth angle of the stem is oblique rather than parallel. In the figure5.4, all stems are also grown at an angle

Figure5.4 A real stem(left) and a artificial stem(a certain slice of stem) generated by the software(right)

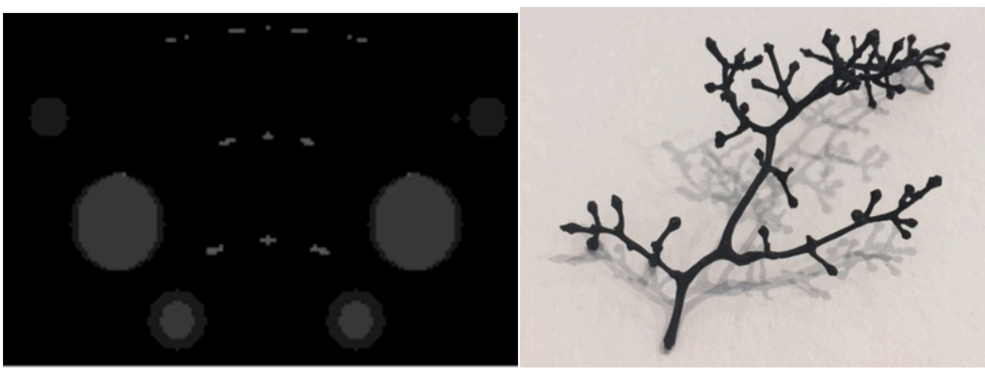


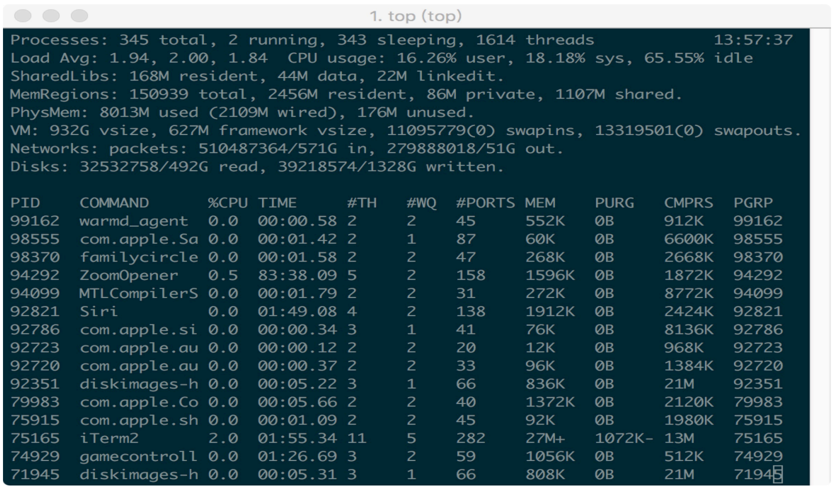
Figure5.5 A slice of stem from side view for spherical grapes, grape_side_188_.pgm compared with a real grape stem.

5.2 Efficiency

Efficiency is a very important part of software engineering theory. The efficiency of a software determines whether it can be widely promoted, if a software is running very inefficient, such as taking up too much memory and long running time. then the scope of use of this software will become restricted.

5.2.1 Memory Usage

Similar to the tool-task manager under Windows operating system. The top command is a command that can be dynamically displayed, which means that the user can constantly refresh the current system state by using the keyboard. If the command is running in the foreground, it will occupy the foreground alone until the user chooses to terminate the program. In the system, all tasks that are sensitive to the CPU are displayed on the monitor. At the same time, users can also sort all tasks in the system according to CPU usage, memory usage and execution time. This command also has the characteristics of human-computer interaction.



```
1. top (top)
Processes: 345 total, 2 running, 343 sleeping, 1614 threads          13:57:37
Load Avg: 1.94, 2.00, 1.84  CPU usage: 16.26% user, 18.18% sys, 65.55% idle
SharedLibs: 168M resident, 44M data, 22M linkedit.
MemRegions: 150939 total, 2456M resident, 86M private, 1107M shared.
PhysMem: 8013M used (2109M wired), 176M unused.
VM: 932G vsize, 627M framework vsize, 11095779(0) swapins, 13319501(0) swapouts.
Networks: packets: 510487364/571G in, 279888018/51G out.
Disks: 32532758/492G read, 39218574/1328G written.

PID    COMMAND      %CPU TIME     #TH   #WQ  #PORTS MEM    PURG   CMPRS  PGRP
99162  warmd_agent  0.0  00:00.58 2     2    45     552K   0B     912K   99162
98555  com.apple.Sa 0.0  00:01.42 2     1    87     60K    0B     6600K  98555
98370  familycircle 0.0  00:01.58 2     2    47     268K   0B     2668K  98370
94292  ZoomOpener   0.5  83:38.09 5     2    158    1596K  0B     1872K  94292
94099  MTLCompilerS 0.0  00:01.79 2     2    31     272K   0B     8772K  94099
92821  Siri         0.0  01:49.08 4     2    138    1912K  0B     2424K  92821
92786  com.apple.si 0.0  00:00.34 3     1    41     76K    0B     8136K  92786
92723  com.apple.au 0.0  00:00.12 2     2    20     12K    0B     968K   92723
92720  com.apple.au 0.0  00:00.37 2     2    33     96K    0B     1384K  92720
92351  diskimages-h 0.0  00:05.22 3     1    66     836K   0B     21M    92351
79983  com.apple.Co 0.0  00:05.66 2     2    40     1372K  0B     2120K  79983
75915  com.apple.sh 0.0  00:01.09 2     2    45     92K    0B     1980K  75915
75165  iTerm2       2.0  01:55.34 11    5    282    27M+   1072K- 13M    75165
74929  gamecontroll 0.0  01:26.69 3     2    59     1056K  0B     512K   74929
71945  diskimages-h 0.0  00:05.31 3     1    66     808K   0B     21M    71945
```

Figure5.5 Detailed information of all tasks after using 'top' command

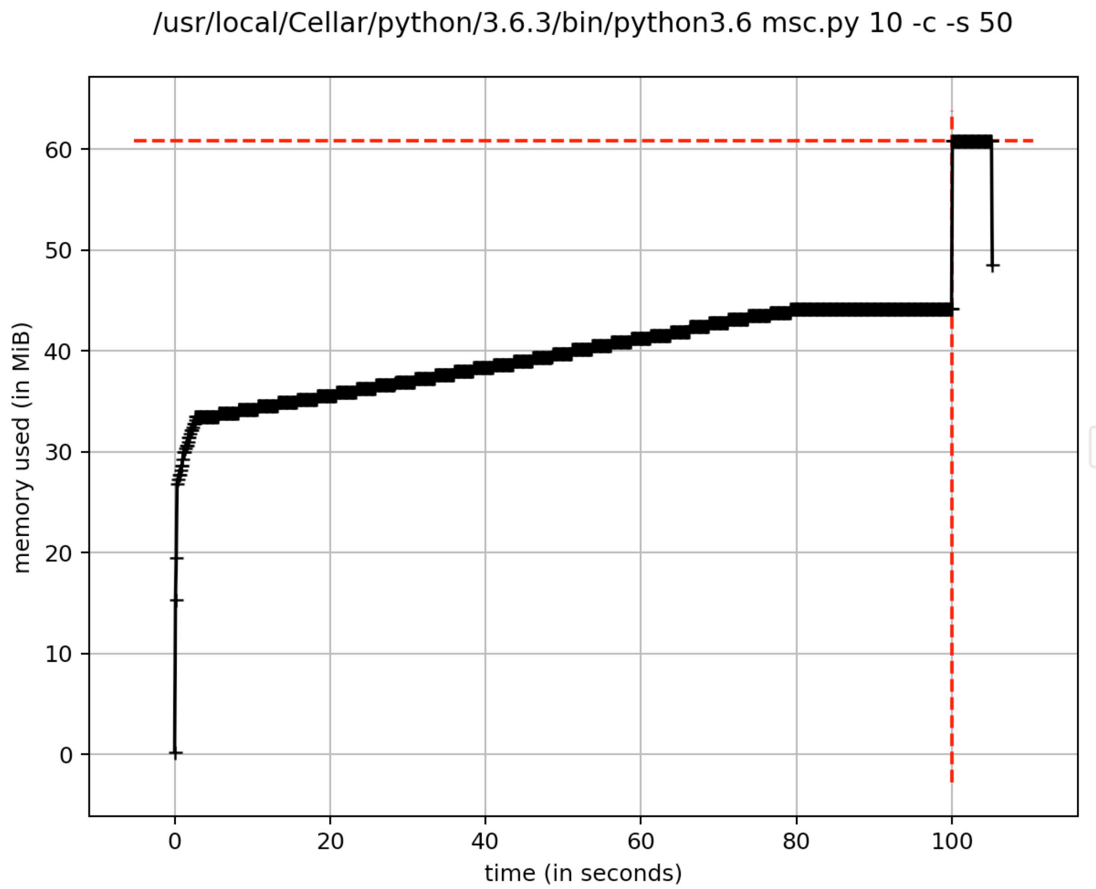


Figure5.6 The maximum memory used in this case is around 60 MB where only one layer was created.

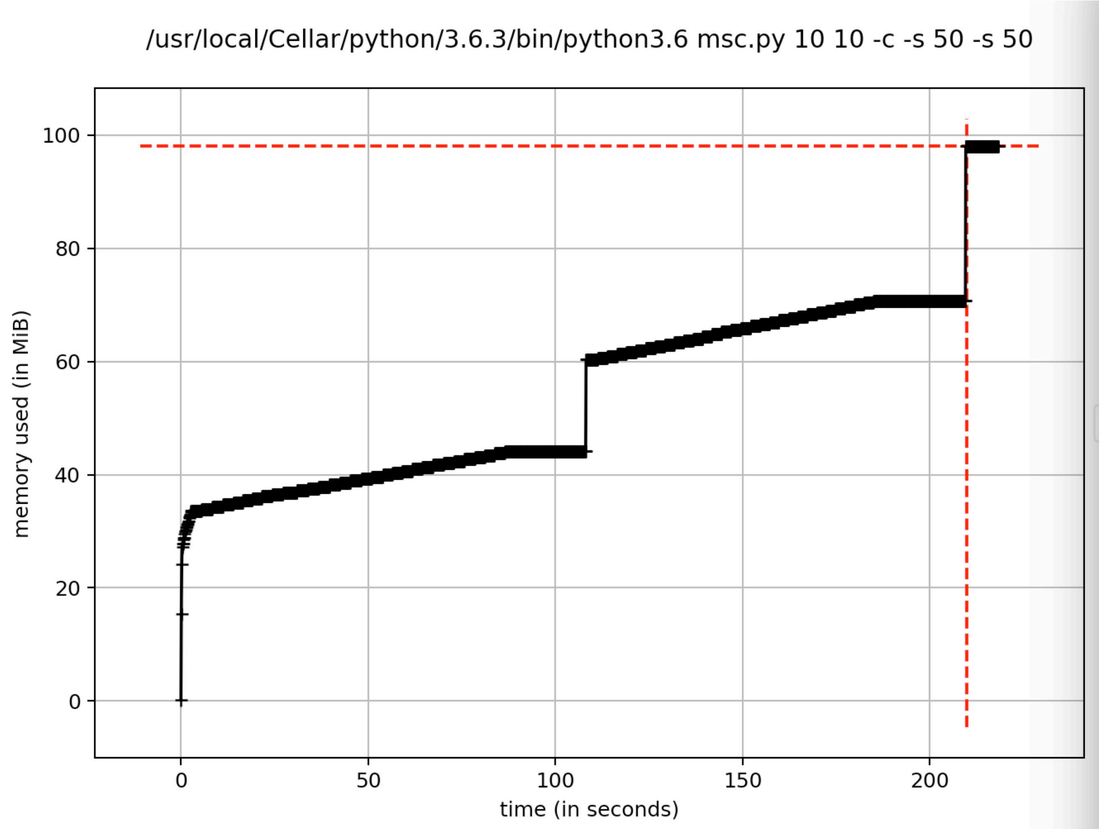


Figure5.6 The maximum memory used in this case is around 98 MB where only two layers was created, it is clear memory usage is divided into two phases because of two layers created.

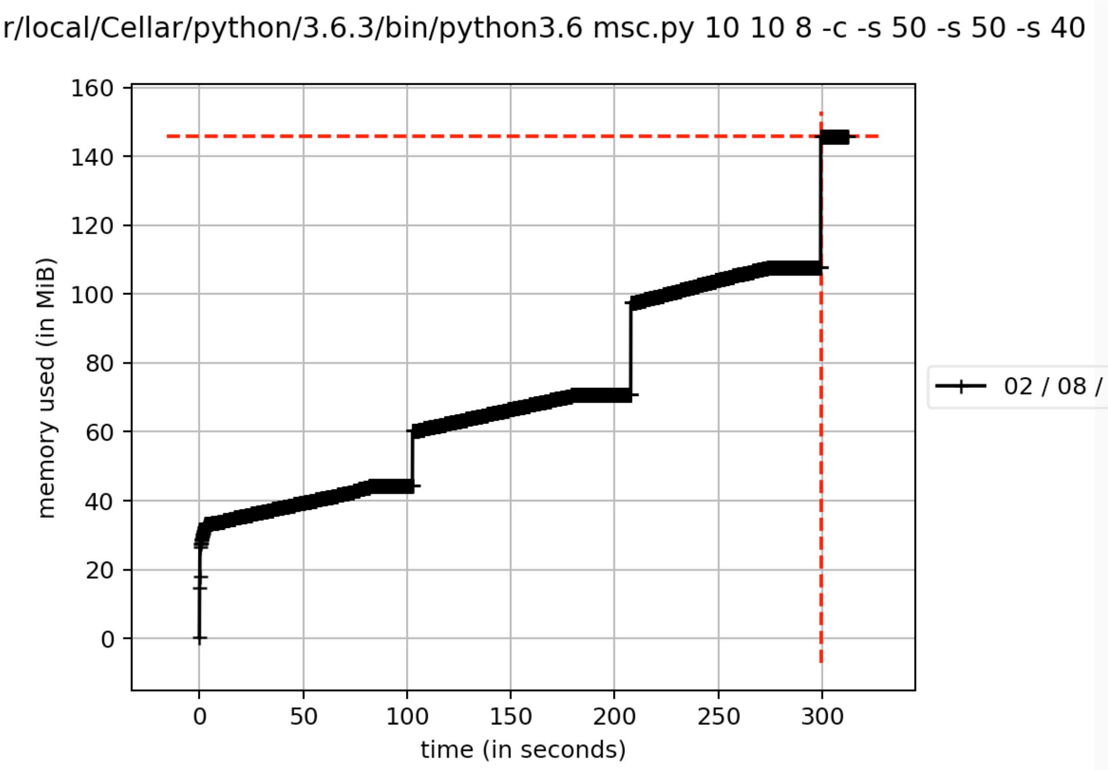


Figure5.7 The maximum memory used in this case is around 142 MB where only three layers was created, it is clear memory usage is divided into three phases because of three layers created.

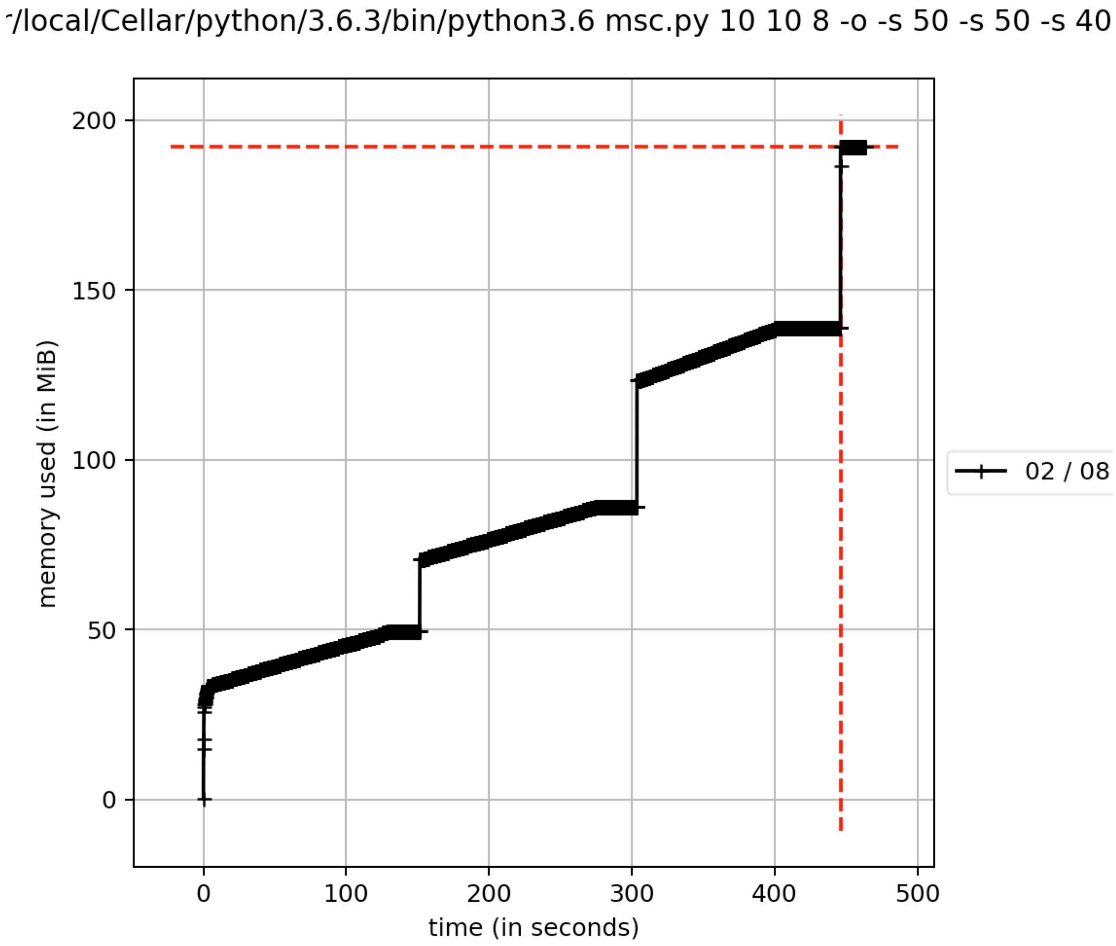


Figure5.8 The maximum memory used in this case is around 180 MB where only three layers was created, it is clear memory usage is divided into three phases because of three layers created.

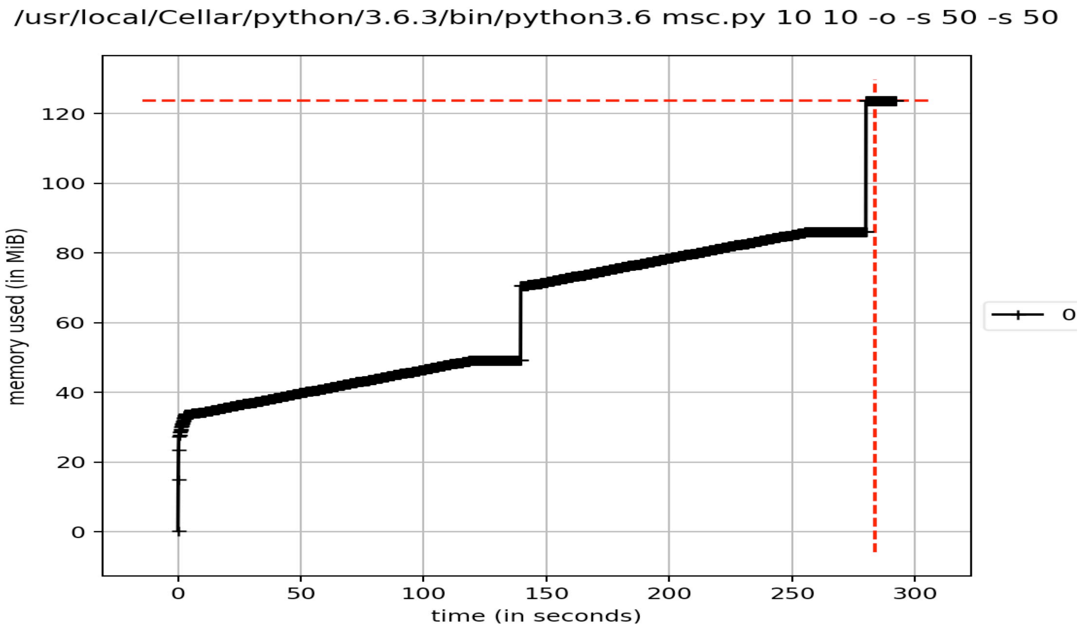


Figure5.9 The maximum memory used in this case is around 122 MB where only two layers was created, it is clear memory usage is divided into two phases because of two layers created.

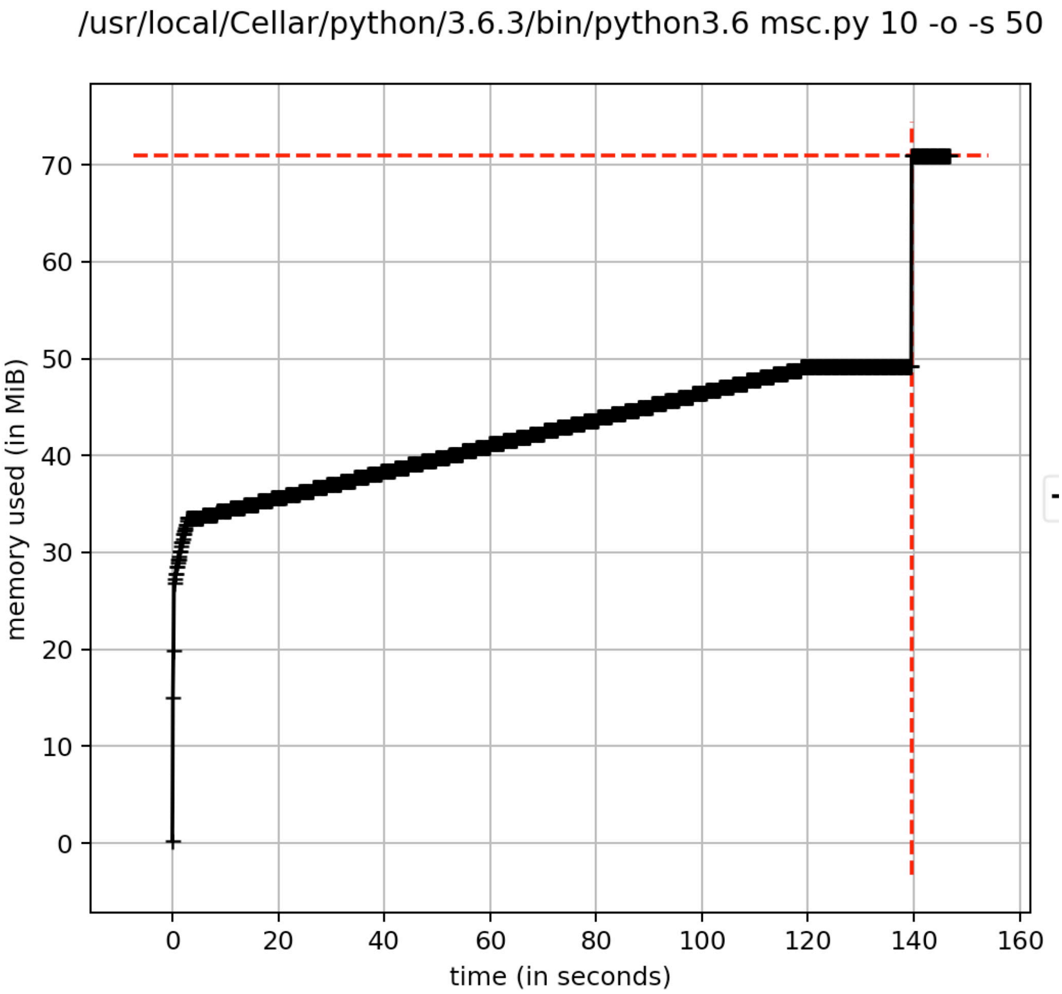


Figure5.10 The maximum memory used in this case is around 72 MB where only one layer was created

All of the above experiments are based on a 300-by-300-size PGM image. If the PGM image size is enlarged, then the memory used will increase significantly. From the figure 5.6 to the figure 5.7, the memory usage of generating the spherical bunch of grapes has been increasing, but the growth rate is not too large. In detail, the memory usage has been maintained at a relatively stable stage during the generation of each layer of grapes. For example, in Figure 5.6, the memory usage of a layer of grapes has been maintained at around 40MiB. Figure 5.8 to Figure 5.10 show the amount of memory used to generate ellipsoidal bunch of grapes. It is obvious in the picture that the amount of memory required for ellipsoidal grape production is slightly larger than that of spherical grapes, because the calculation of the ellipsoidal grape design is more complex than spherical grapes.

5.2.2 Time Consuming

Under the Linux system, there is a built-in time command to calculate the time required for the program to complete. The specific usage of the command is to add the time command before running the program, and then it will print three times real, user after the program ends. , sys is on the monitor. Real is the time elapsed from the start of the program until the end of the program execution, including the sum of the CPU's time and all the factors that delay the execution of the program. Then user and sys can be included in the CPU time, user time indicates the program itself, and the time used by the subroutine in the library it calls. Sys is the time when a system call is called directly or indirectly by a program.

From now on, the system will detect the specific running time of the software for different layers and different shapes of grapes. From the data in table 5.1, it is obvious that for spherical grapes, when the number of layers of grape bunches increases, the running time of the software will inevitably increase, but the growth rate is not too large. According to the data from background , in life, the number of layers of grape bunches is generally around 8 or 9 . Therefore, according to the results in the table, when the number of layers reaches 10 layers based on the current picture size, the running time will not exceed half an hour or more. So the running time is acceptable. However, the experimental time results will vary on different machines

Layer(s)	User time(s)	System time(s)	Total(mins)
1	111.75	0.84	1:53.83
2	207.55	1.89	3:32.53
3	295.10	2.09	5:01.59
4	374	1.50	6:17.08
5	462.40	2.62	7:49.29
6	551.58	3.24	9:19.57

Table5.1 The time consumed on creating different layers for spherical grapes

Layer(s)	User time(s)	System time(s)	Total(mins)
1	193.61	0.92	3:09.83
2	312	2.06	8:12.09
3	461.19	2.09	11:11.32
4	534	2.12	17:22.05
5	663.61	2.36	24:30.36
6	799.85	2.74	29:02.20

Table5.2 The time consumed on creating different number of layers for ellipsoid grapes

5.2.3 Summary of accuracy and efficiency

From the comparison of the above groups of results, the modeling algorithm used in the project can more accurately reflect the shape and size and position of the grapes in real life, although the details of the grapes are not exactly the same. The grape pictures produced by the software according to user's requirements conform to the basic definition of grape. From the perspective of memory usage, as the number of layers increases, more memory will be used. However, because the number of layers of grape bunches is limited, the memory usage does not increase indefinitely. Moreover, according to the previous figures, the running time of the six-layer grape bunch will not exceed one hour, so the efficiency and running time of the software is acceptable on the basis of the current size.

6 Conclusion

In section 6.1, a comprehensive summary of the entire project will be made. In section 6.2, future work will be discussed, such as some problems that can be solved in the future, and some effective ways of how to improve the accuracy of the project.

6.1 Conclusion

Grapes are one of the fruits that people like around the world. In addition to their edible functions, grapes are also made into wines of different tastes. Then the maturity of the grapes is a very important factor for the taste of the grapes and the taste of the wine. If the period of picking grapes is not selected properly, the quality of the picked grapes will be greatly affected. However, the reality is that there is currently no effective software that can determine the proper picking period of grapes.

The project spends most of the time in modeling the bunch of grapes and two types of grape are the main focus of the project, the first is an bunch of ellipsoidal grape, and the second is a bunch ofspherical grape. Before modeling two different shapes of grape bunches, a large amount of grape data was summarized, mainly to better understand the structure of the grapes, the position between the grapes and the grapes, and the height or number of layers of the bunches. After learning the information about the grapes themselves, some detailed information about the PGM file, such as the head information and different pixel values, and how to operate the PGM, was also studied beforehand in order to better display the grape model properly.

The most critical factor in the grape modeling problem is how to pick the right mathematical model, and then apply these appropriate mathematical models to the Python code to generate the final desired grape model. In addition, in order to better enhance the experience of human-computer interaction, a command-line-based interaction is also implemented, and the user can operate according to the user documentation provided by the software, such as the shape of grapes, the number of generated grapes and layers. In the end, all the grape models generated by the software were compared and tested with the real grapes, and the software runtime and memory usage were also recorded in detail, which will be part of the assessment.

6.2 Future Work

Although the software can generate different layers and different shapes of grape bunches according to the user's needs. But due to the limitation of time and techniques, there are some gaps in the details of the real grape. These can be used as future plans to better improve the accuracy of the model.

Future work involves making the position between the grapes on each layer slightly messy rather than neatly rounded into a perfect circle. In addition, since only the skin and fruit of the grapes are currently considered, the details of the grapes are not perfect, for example, there are other varieties of seeded grapes in the world. In addition to ellipsoidal grapes and spherical grapes, there are some varieties of grapes that exhibit this irregular shape. In addition, problems related to the software itself can also be improved. For example, the algorithm contains more for loop statements. If the for loop statement can be reduced while ensuring accuracy, the time efficiency of the software is also Will be greatly improved.

In the project, the main stem of each bunch of grapes is formed in the center of the bunch, so the main stems of each layer are in the same position. In the following work, in order to be more realistic, the center point position of each main stem can be randomly generated. When the center point of the main stem of each layer of grapes is different, the main stem of the whole bunch will no longer be a straight line, so when the main stems of each layer are joined together, the main stem will become more distorted.

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Fig2.1 Grape structure. url:grain-en.gif

Fig2.2 grape skin. url:Structure-of-a-ripe-grape-berry-depicting-the-three-primary-tissues-skin-flesh.png

Fig2.3 Tannings.url:F1.large.jpg

Fig2.4 grape stem.url:berry-structure.gif

Fig2.5 grape seed.url:berry-structure.gif

Fig2.6 table and wine grape.url:wine-grapes-vs-table-grapes-vitis-vinifera.jpg

Fig2.7seedless grape. url:iStock_98992499_LARGE-1024x835.jpg

Fig4.3 capsule shaped grape.url:images

Fig4.19 real grapes.url:20150921082925838.jpg

Fig5.1 grapes from topview .url:https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcSZij13Jp2uIVMWhft5otSS1tD1EFmU_HFtwiUDdv14MrF7tfsuIQ

Fig5.1-1 grape structure.url:9ecd19cbf5c5b25b1c47e42a2348ee9b.jpg

Fig5.2 side view of real grapes.url:https://encrypted-tbn0.gstatic.com/images?q=tbn:ANd9GcTjtamGkSkOSq1o26OSTmjz0YJlBmDth3gvTujsbjnzxOuzpE1HsA

AppendixA:

```
Def
find_vertical_pictures_points(numbers_on_the_layer,number_layers,radius,centerX,c
enterY):
    # float x = (float) (centerX + radius * Math.cos(-degree * Math.PI / 180));
    # float y = (float) (centerY + radius * Math.sin(-degree * Math.PI / 180));
    circle_degree = 360
    each_degree = int(circle_degree/numbers_on_the_layer)
    initial_degree = 0
    coordinate = list()
    # finding all meaningful points
    for i in range(0,numbers_on_the_layer):
        temp = list()
        x = int(centerX + radius * math.cos(initial_degree * math.pi / 180))
        y = int(centerY + radius * math.sin(initial_degree * math.pi / 180))
        temp.append(x)
        temp.append(y)
        coordinate.append(temp)
        initial_degree += each_degree
    return coordinate

    def
draw_vertical_pictures(radius,coordinate_value,stem_size,center_X,center_Y):

        pgm_value = initial_pgm_array()
        w = 4
        w *= 0.5
        # switch = flag
        # draw berry stem
        for i in range(0, width):
            for j in range(0, length):
                if pow(i - center_X, 2) + pow(j - center_Y, 2) <= pow(4, 2):
                    pgm_value[i][j] = '3'
        # draw grape pictures
```

```
    for k in coordinate_value:
        for i in range(0, width):
            for j in range(0, length):
                if pow(i - k[0], 2) + pow(j - k[1], 2) <= pow(radius, 2):
                    pgm_value[i][j] = '1'
    for k in coordinate_value:
        for i in range(0, width):
            for j in range(0, length):
                if pow(i - k[0], 2) + pow(j - k[1], 2) <= pow(radius-2, 2):
                    pgm_value[i][j] = '2'

    return pgm_value

def draw_line_stem(plist,x1,y1,z1,x2,y2,z2):
    for z in range(z1, z2):
        t = (z - z1) / (z2 - z1)
        y = y1 + (y2 - y1) * t
        y = int(get_round(y))
        x = x1 + (x2 - x1) * t
        x = int(get_round(x))
        plist[z][y][x] = '3'

        for yy in range(0,length):
            for xx in range(0,width):
                if pow((xx-x),2) + pow((yy-y),2) <= pow((2),2):
                    plist[z][yy][xx] = '3'
```

AppendixB:

Introduction of different varieties of grapes：

1.Variety name: Honey red

Source: Approved by ZTE University in Japan in the early 1980s, it is a mixture of Golden muscat and Kuroshio.

Fruit shape: The fruit is large, the peel is bright red, with thick fruit powder. The meat is soft and juicy than the giant grape. The fruit is about 10-13 grams, the maximum is more than 15 grams, and the weight is about 300-450 grams. 17-20 Brix, acidity 0.4%-0.7%; easy to soften at maturity, easy to crack fruit when raining and not resistant to storage and transportation.

2. Variety name: Italia IP65

Source: Mixed in Bicane+MuscatHamburg in Italy in 1911, this variety is pure vinifera variety.

Fruit-shaped: round or kidney-shaped, fruit-shaped oblong, fruity yellow-green, thin, smooth with fruit powder, fleshy transparent, fleshy sweet and crisp, not easy to thresh, resistant to transport and refrigeration, fruit 7-12 grams, sugar content about 15 -18 Brix, with an acidity of about 0.7%, has an elegant rose scent when fully mature, suitable for European and American tastes.

3. Variety name: Himrod seedless

Source: A hybrid of Europe and America, cultivated by the New York Agricultural Testing Center with Ontario + Sultana (Thompson seedless). It is a very early seedless variety.

Fruit shape: oval, yellowish white peel, soft and juicy flesh, with special aroma, fruit close to round, fruit 2-3 g, sugar content about 17-19 Brix, acidity about 0.4%-0.7%, fruit easy to soften , threshing, not resistant to storage and transportation.

4. Variety name: Golden muscat

Source: 1915 is a breed of Muscat Hamburg (European species) + Diamond (American species) for the New York State Agricultural Test Site. It is suitable for fresh or wine-making, some aromatic, soft and juicy, mature and easy to rain. Severe cracking and threshing, less resistant to storage and transportation.

Fruit shape: oval or round, peel yellow-green, smooth with fruit powder, fleshy, fleshy and juicy, fruit about 5-7 grams, average sugar summer fruit about 13-18 Brix; winter fruit about 13-24 Brix, with a fruit weight of about 400-600 grams, is suitable for winemaking.