Analysing the pyramid representation in one arc-second SRTM model

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***Abstract*—The pyramid representation is an important and popular method in the storage of image data. The lower resolution index images are very useful in displaying the image and several spatial analysis. This paper studies these properties of the pyramid images in the one second resolution SRTM elevation model. In addition to the usual mean-based pyramid representation, I studied the minimum and maximum pyramids.**

***Index Terms*—pyramid representation, DEM, SRTM**

I. Introduction

The pyramid images are a well-known method in the digital image processing. [1], [2] Lower resolution images are created from these original image data, and this images are used in some cases. For example, when an image must be showed in the screen, the program use the pyramid image, which resolution is the nearest to the map resolution in the screen.

The resolution of an image of the pyramid index is the half of the next level of the index. These are $1/2$, $1/4$, $1/8$, ... $1/2^n$ resolution of the original image. The size of the images is $1/4$, $1/16$, $1/64$, ... $1/2^{2n}$ part of the size of the original image. The total size of this pyramid images is the $1/3$ part of the original image.

The pyramid images like index can be used with digital elevation models (DEM) [11], the different resolution DEM grids are used in different cases. The DEM grids are similar to the digital images. Both of these datasets are a two dimensional array of the numbers.

The pyramid index has more kinds depending on the method, that calculates the values of the cells of the derived lower resolution images. The Gaussian pyramid uses Gaussian average, the steerable pyramid uses steerable filter. The Laplacian pyramid is similar to the Gaussian pyramid, but it does not store different images in different levels. These method represented in this article is suitable to compress the image data, instead of the data growth.

II. Pyramid representation with DEM data

The raster (image) data and the DEM grid data are similar in the data storage, because both of them are a two dimensional array, but the georeference of these arrays are different. The raster data contain rectangles, and the DEM data contain nodes of a grid.

The pyramid data even contain rectangles, if the original data contain the nodes of a grid. The rectangles of the first level of the pyramid is based on the 3×3 nodes of the grid (see on the Figure 1.).

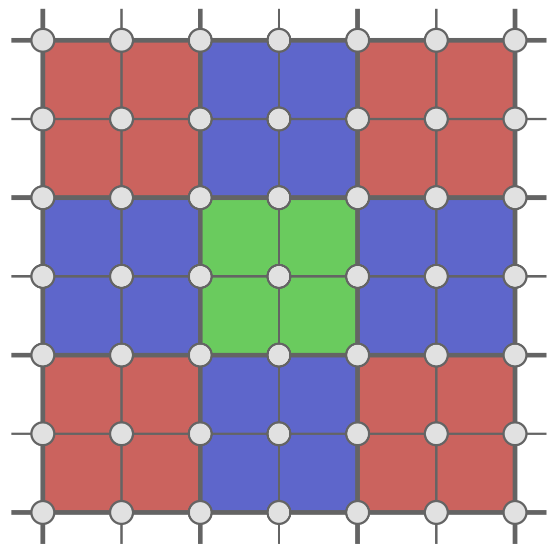

Figure 1. The first level of pyramid, based on a GRID.

The values of the first level pyramid can be calculated with the weights of the Figure 2. The result of this calculation is the average elevation of the area of this 2×2 rectangle (raster) of the grid, which will be one element of the first level pyramid. The other levels of the pyramid will be calculated by simple arithmetic mean. (With 0.25 weight in each raster of the last pyramid.)

The mean of the values of the pyramid rasters are same: the average elevation of the area of the raster. These pyramids are useful to calculate the volume under the elevation surface. This volume under a raster of a pyramid can be calculated by the multiplication the average elevation (the value of the raster) and the area of the raster (the square of the raster resolution, that constant in a pyramid level).

III. Minimum and maximum pyramids

The values of the pyramid rasters can be the minimum or maximum values instead of the average value. The values of this pyramid rasters provides the lower and higher elevation of the area of the raster. These data with the position of the raster assign a bounding box of a part of the elevation surface.

Logically, this inequalities are true:

$$MIN_{UP} \leqq MIN \leqq ELEV \leqq MAX \leqq MAX_{UP}$$

where MIN and MAX are the minimum and maximum values of a raster of the pyramid, the $ELEV$ is the elevation

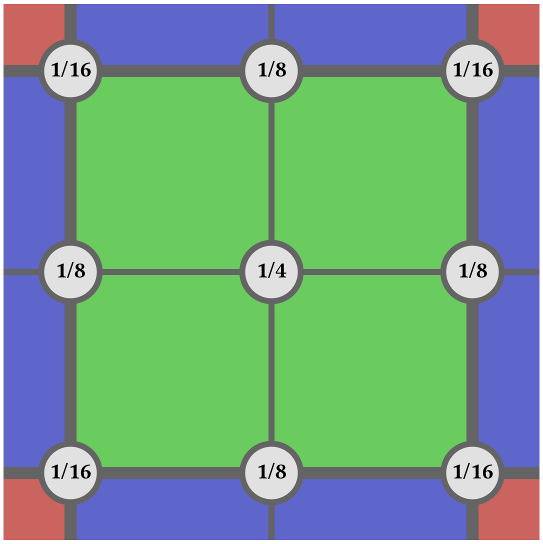

Figure 2. The weights of the first level of the pyramid.

of any point of the DEM surface in the area of the raster, and the MIN_{UP} and MAX_{UP} are the minimum and maximum values of the related raster in the upper level of the pyramid.

The first level of the minimum and maximum pyramids contains the minimum and maximum values of the nine related nodes (see in the Figure 2.) of the grid. The next levels of the pyramid contain the maximum and minimum values of the four related raster of the upper level of the pyramid.

IV. Application of minimum and maximum pyramid data

The minimum and maximum pyramids can be used in viewshed analysis [5], [4], [3], [10]. The classical method of the viewshed analysis checks each elements of the elevation model along the line that joins the viewpoint and the examined point. The number of the steps of this process is proportional to the length of this line, because the number of the examined elements of the elevation model is proportional to the length of the line.

The viewshed analysis can be faster, if the minimum and maximum pyramids are used. One element of a pyramid dataset can decide that a (3 dimensional) line crosses or does not cross the surface of the elevation model in the area of the element. If it can not decide, the process can continue in the lower level of the pyramid recursively.

A line crosses a part of a surface, if any endpoint of the line segment is under the bounding box of the surface's part. (The red lines in the Figure 3.) The line segment is the part of the line, that crosses the horizontal projection of the bounding box. If both of the endpoints of the line segment are over the bounding box, the line does not cross the surface. (The green line in the Figure 3.) The other cases need the test of the bounding boxes of the lower level of the pyramid recursively. (The blue lines in the Figure 3.)

When the program tests recursively the bounding boxes of the lower level pyramid, it does not need check all of the four bounding boxes. The Figure 4. presents some typical layout of the line segments and bounding boxes of the lower level.

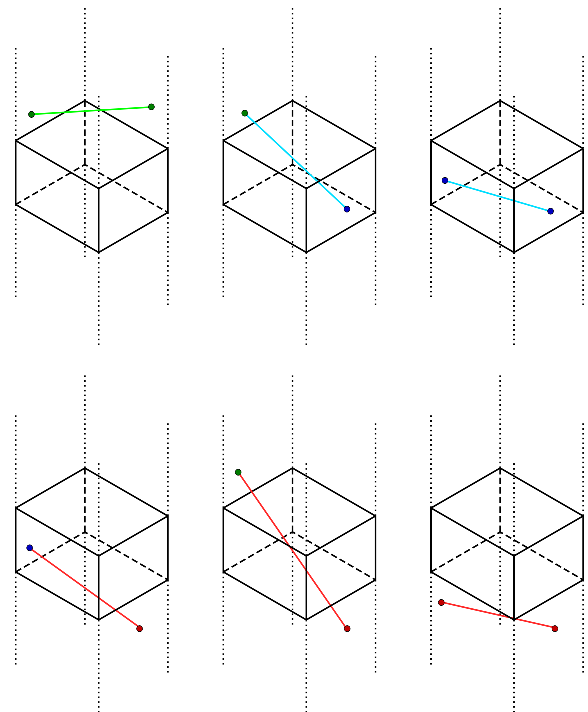

Figure 3. Intersection of a line segment and a bounding box.

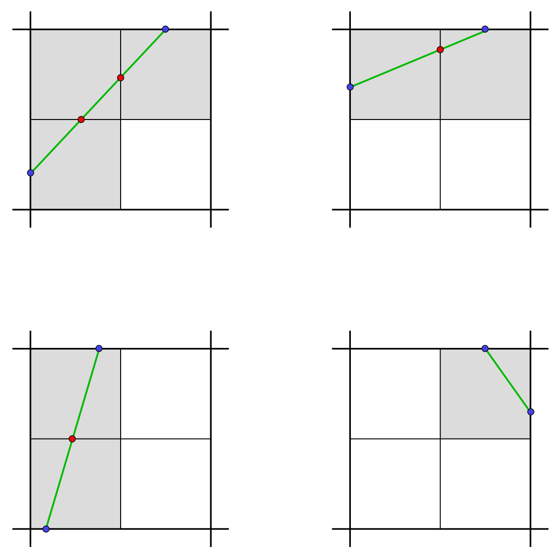

Figure 4. Intersection of a line and the pyramid cells.

V. Study of the one arc-second SRTM dataset

I studied the pyramid data structures with the one arc-second SRTM [6], [7], [9] dataset. This is a global elevation model with around 30 meters (one arc-second) resolution. This dataset was ideal for my research, because it is free and available from different places of the world. I could try the following tests in several type of territories.

I wrote an Python [8] application that reads the SRTM data, and calculate the pyramid data. Another Python applications analyze this pyramid data.

I studied the distribution of the difference between the minimum and the maximum values in different pyramid levels.

I made this analysis in different areas. The areas are in the Table I. My program create the bounding boxes from the pyramid data, and calculate some statistical values of the heights of this bounding boxes (the difference between the minimum and the maximum values). The data from the analysis are in from Table II. to Table VIII.

VI. Conclusion

The pyramid images can be a useful tools in digital elevation models in several spatial analysis. The classical mean-based index is capable of calculate the volume under the surface of the elevation models.

The minimum and maximum pyramids can be used in viewshed analyzes. The recommended method provides the result of a viewshed analysis faster than the program check all elements of the elevation model.

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Table I
THE LOCATIONS OF THE STUDY AREAS

short name	min. lon.	min. lat.	max. lon	max. lat.	size
AREA1	18-10-00	47-13-51	18-44-09	47-48-00	2049×2049
AREA2	19-12-00	46-13-51	19-46-09	46-48-00	2049×2049
AREA3	20-10-30	46-15-21	20-44-39	46-49-30	2049×2049
AREA4	18-01-30	46-28-25	18-18-35	46-45-30	1025×1025
AREA5	17-35-30	47-03-25	17-52-35	47-20-30	1025×1025
AREA6	24-02-30	46-13-21	24-36-39	46-47-30	2049×2049
AREA7	15-05-30	47-19-21	15-39-39	47-53-30	2049×2049

Table II
THE DIFFERENCES BETWEEN MINIMUM AND MAXIMUM LEVELS IN AREA1

raster size	2×2	4×4	8×8	16×16	32×32	64×64	128×128
raster count	1049K	262K	65536	16384	4096	1024	256
average	5.11	9.65	17.53	30.46	50.63	82.04	127.74
std. dev	4.87	8.87	15.47	25.53	39.99	60.46	81.92
median	3.0	7.0	12.0	22.0	39.0	65.0	106.5
minimum	0.0	0.0	0.0	0.0	4.0	8.0	12.0
maximum	78.0	110.0	157.0	208.0	305.0	371.0	443.0

Table III
THE DIFFERENCES BETWEEN MINIMUM AND MAXIMUM LEVELS IN AREA2

raster size	2×2	4×4	8×8	16×16	32×32	64×64	128×128
raster count	1049K	262K	65536	16384	4096	1024	256
average	2.41	4.07	6.23	8.9	12.28	16.61	22.31
std. dev	1.41	1.96	2.55	3.18	3.78	4.31	4.53
median	2.0	4.0	6.0	8.0	12.0	16.0	22.0
minimum	0.0	0.0	0.0	0.0	0.0	6.0	12.0
maximum	25.0	28.0	28.0	28.0	28.0	32.0	40.0

Table IV
THE DIFFERENCES BETWEEN MINIMUM AND MAXIMUM LEVELS IN AREA3

raster size	2×2	4×4	8×8	16×16	32×32	64×64	128×128
raster count	1049K	262K	65536	16384	4096	1024	256
average	1.73	2.85	4.21	5.85	7.91	10.65	14.85
std. dev	1.04	1.40	1.82	2.44	3.42	4.67	6.40
median	2.0	3.0	4.0	5.0	7.0	9.0	13.0
minimum	0.0	0.0	0.0	2.0	4.0	5.0	7.0
maximum	27.0	36.0	43.0	46.0	46.0	46.0	46.0

Table V
THE DIFFERENCES BETWEEN MINIMUM AND MAXIMUM LEVELS IN AREA4

raster size	2×2	4×4	8×8	16×16	32×32	64×64	128×128
raster count	262K	65536	16384	4096	1024	256	64
average	3.06	5.58	9.66	16.01	25.66	39.49	59.5
std. dev	2.95	5.17	8.52	13.08	18.84	25.29	35.56
median	2.0	4.0	6.0	11.0	20.0	33.5	50.0
minimum	0.0	0.0	1.0	3.0	6.0	10.0	18.0
maximum	68.0	97.0	103.0	116.0	143.0	143.0	217.0

Table VI
THE DIFFERENCES BETWEEN MINIMUM AND MAXIMUM LEVELS IN AREA5

raster size	2×2	4×4	8×8	16×16	32×32	64×64	128×128
raster count	262K	65536	16384	4096	1024	256	64
average	7.31	13.94	25.56	44.53	73.98	118.77	184.84
std. dev	5.77	10.35	17.65	28.11	41.56	59.98	81.92
median	6.0	11.0	21.0	38.0	66.0	109.0	165.5
minimum	0.0	1.0	2.0	4.0	11.0	24.0	43.0
maximum	57.0	91.0	142.0	196.0	238.0	279.0	394.0

Table VII
THE DIFFERENCES BETWEEN MINIMUM AND MAXIMUM LEVELS IN AREA6

raster size	2×2	4×4	8×8	16×16	32×32	64×64	128×128
raster count	1049K	262K	65536	16384	4096	1024	256
average	8.53	16.50	30.93	54.67	87.93	127.17	167.6
std. dev	5.65	10.34	17.97	28.26	38.56	43.57	38.9
median	8.0	16.0	30.0	55.0	92.0	133.0	168.5
minimum	0.0	0.0	0.0	3.0	5.0	10.0	36.0
maximum	58.0	89.0	130.0	176.0	252.0	265.0	311.0

Table VIII
THE DIFFERENCES BETWEEN MINIMUM AND MAXIMUM LEVELS IN AREA7

raster size	2×2	4×4	8×8	16×16	32×32	64×64	128×128
raster count	1049K	262K	65536	16384	4096	1024	256
average	28.08	54.77	103.51	186.07	311.94	484.55	692.21
std. dev	14.76	26.77	47.12	78.22	120.12	158.34	187.0
median	27.0	53.0	100.0	179.0	300.5	469.0	656.5
minimum	0.0	0.0	0.0	6.0	14.0	78.0	306.0
maximum	263.0	330.0	459.0	650.0	1046.0	1266.0	1483.0