# Method for Determination of the Mountain Peaks

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## ABSTRACT

The key issue is to propose and develop the automated method for points of regional peaks detection applying spatial analysis on digital terrain model (DTM). Detection of the peaks bases on measurements of relative heights and distances between the peaks with support of potential surfaces fulfilling topographic (and some morphologic) criteria. The quality of the results has been proved visually, with the reference lists of peaks, and with triangulated spot heights. The advantage of the proposed automated approaches is higher comparability, objectivity and reliability of the results.

**Keywords:** peaks, DTM, spatial analysis, morphometry, GIS

## INTRODUCTION

There are a few important aims of this study starting with detecting of the points of peaks. The results are intended to generate automatically by spatial analysis on a high quality digital terrain model (DTM) and by utilizing reference data sets for a quality control. The paper is intending to show strength, reliability and robustness of the proposed automated method developed with considering some selected standardized definitions of peaks that have been used only in analogue way until now.

Three types of peaks are defined and introduced: local, regional and global. Regional and partly global peaks determination and analysis is focus of this study. Their determination is linked with a term mountain. The local peak definition is basically related to algorithms for local extremes detection that are included in commercial geographical information systems (GIS). This is the most elementary numerical (computer-based) approach for detection of the peaks from DTM as local relief features. The local peaks comprise every raising ground and are related with roughness of the relief depending on the DTM resolution, which may be assessed in a fractal sense. Regional peaks are more complex objects involved in common definitions of peaks that are found in basic dictionaries, described by International Mountaineering and Climbing Federation, or defined by people who live at the mountains. This term comprises and is defined by a broader range of topographical, morphological and other (mountaineering) properties in a regional scale. An example for numerical implementation is the algorithm for extracting of different number peaks based on morphological smoothing method (Sathyamoorthy, 2007). Global peaks or summits are just a few most prominent peaks in a certain mountain area, e.g. in entire Julian Alps. Such locations were a high interest of man several hundreds or thousands years ago. A number of studies have been trying to find these prominent locations using numerical algorithms. Their typical aim is to study specific cultural responses that influence to human behavior, including beliefs, taboos, rituals, etc. The prominent locations (peaks) are explored by analyzing their properties according to wider surroundings with exposure index, cumulative viewsheds, defining locations' hierarchy, etc. (Llobera, 2001; Christopherson, 2003).

We are going to discuss the definitions of the term peak (in connotation with regional one) and introduce its relation to the whole mountain. The conception of "peak" as a topographical and morphological extreme in geographical space has several other meanings in a semantic sense. Just the most significant peaks can be seen from long distances, while in the immediate neighborhood the peaks on the smaller rising ground are visible as well. Namely, the peaks look differently if seen from various distances, directions, and in different time or season. Furthermore, the peaks need to be defined on different way all around the world. For instance the characteristics of Alps, Carpathians, Himalaya or Pannonian Plain are immediately distinctive. These facts are depended on the physical and environmental properties like elevations above sea level, geological properties, shapes of peaks, illuminations, weather conditions, vegetation, and also on a particular perception of individual person. These findings may lead to various perceptions and consequently to different identifications, conceptions and classifications by the observer. In order to provide a proper description of the peaks, the certain surrounding with their properties has to be taken into consideration.

The case study area is Kamnik Alps located in the north part of Slovenia at the border with Austria, with dimensions of 30 km x 20 km. The selected data set for the modeling of the peaks are morphologically high quality DTMs of Slovenia with resolution of 12.5, 25 and 100 m, respectively (Podobnikar, 2005). The reference data are maps DTK 25, and geographical names REZI 25 (GURS, 2005). Additional reference data are two independent databases of 2000ers in Slovenia (SD, 2001; Kern and Cuderman, 2001).

## PROBLEM DEFINITION

The problem is definition of the peak and its feasibility for the automation process. The definition of a term peak is namely a complex task connected with definition of the whole mountain. Therefore the automation process should consider some possible ontological and geographical uncertainties.

The frame for technical description of the regional peak conception as the core of this study is the directive of the International Mountaineering and Climbing Federation (UIAA, 1994; 2008). The rules are formulated for the peaks higher than 4000 m in the Alps according to the following three groups of criteria:

- topographic
- morphologic
- mountaineering.

Topographic criterion defines the level of height difference between each peak and the highest adjacent pass or notch should be at least 30 m (calculated as an average of the peaks at the limit of acceptability). An additional criterion can be the horizontal distance between a peak and the base of another adjacent peak (UIAA, 1994). Suggested application of this rule is by geometric analysis on DTM: the main criterion is defining by relative height ($dH$) of the potential peak that should be split by the adjacent peaks with a certain gap (it should be basically for 30 m lower than the peak). An additional criterion is defined as minimum horizontal distance ($dL$) between the peaks. These values can define the dominance of the potential peak. The bigger the mentioned measures are, more extensive and significant the peak is.

The morphologic criterion takes into account the overall morphology and aspect of the peak applied especially for shoulders, secondary peaks, rock outcrops, etc. (UIAA, 1994). Suggested application focuses to various techniques of spatial analysis on different sizes of the immediate neighborhood (determination of mountain area $G_p$) of the peaks. The shape of the upper part of the mountain is therefore considered, which is much depended on geological characteristics.

The following mountaineering (or alpinistic) criterion takes into account the importance of the peak from the point of view of the mountaineers: qualities of the routes reaching the peak, historical significance, frequency of climbed, etc. (UIAA, 1994). This criterion is the weakest and difficult for standardization and numerical application. It considers inspection of terrain as subjective perception of humans. That may be changed during the evolution of alpinism. The mountaineering criteria are used just for interpretation of the results.

## PROCEDURE FOR PEAKS DETERMINATION

The procedure for detecting the points of (regional) peaks and analyzing surroundings to determine their shapes are developed. The proposed solution procedure applies the basic criteria in this field according to UIAA (1994). Topographic and some morphologic criteria are implemented to numerical algorithm, while some mountaineering criteria are used for their interpretation.

The following procedure for fulfilling of basic topographic and morphologic criterion for determination of the regional peaks is proposed:

- calculation of local peaks as a local maximum in elevation
- selection of peaks that are morphologically not on flat areas (peaks on plains are denoted as $G_p$)
- further selection considering a minimum horizontal distance ($dL$) between peaks
- further selection considering a relative height ($dH$) of peaks.

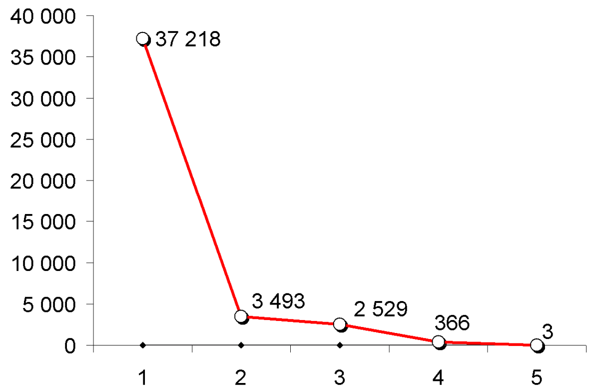


***Figure 1:*** Number of points of peaks for a study area of Kamnik Alps: from local (1) to regional peaks (4), (and to global peaks (5), calculated concerning topographic and some geomorphic criteria).

In each step of the procedure only the peaks are proceeded which satisfied all conditions in previous steps. The eventual result is graphically presented in Figure 1. The steps are in a higher detail described below.

Through the first step, the local peaks are calculated applying 3 x 3 local moving window (kernel), dedicated to raster-based spatial data analysis (e.g. Takahashi et al., 1995). This step bases on topographic criteria.

All of the local peaks on the flat areas ($G_p$) are eliminated setting criteria NOT $G_p$ in the second step. The removed local peaks are part of insignificantly convex areas. The classification to $G_p$ is part of regionalization process to plains, low hills, hills, and mountains. This process applied a combination of slope, curvature and elevation of terrain (Podobnikar, 2005). With an additional threshold the peaks lower than at a certain absolute elevation (e.g. < 600 m) can be eliminated. This step bases on morphologic criteria in order to significantly optimize the procedure.

The minimum horizontal distance *dL* is applied in the third step. Only those peaks are kept which are the highest within the circle of radius *dL*. The adjacent peaks are therefore arbitrary removed with *dL* > [150 m, 200 m]. This step bases on the topographic criteria.

The analysis of the relative height of the peaks (*dH*) serves as basic topographic criterion in the last, fourth step. The algorithm determinates the areas around individual peaks that are by up to the *dH* lower than the corresponding peaks. Then the entire area is examined and the other peaks are counted, which were found in the third step. If there is no peak found, the examined peak was adopted. Starting with the highest peak, the procedure is being repeated until the lowest peak has been processed. The peaks eliminated in the previous iterations of this procedure were not examined anymore. The removal condition is set to *dH* > [25 m, 30 m].

The procedure runs twice by applying two slightly different parameters in steps 3 and 4. In the first run the parameters are set to *dL* = 200 m and *dH* = 30 m, and in the second to *dL* = 150 m and *dH* = 25 m. These two calculations yield slightly different but complementary results. Acquiring of the regional (and global) peaks within the procedure is presented in the Figure 2.

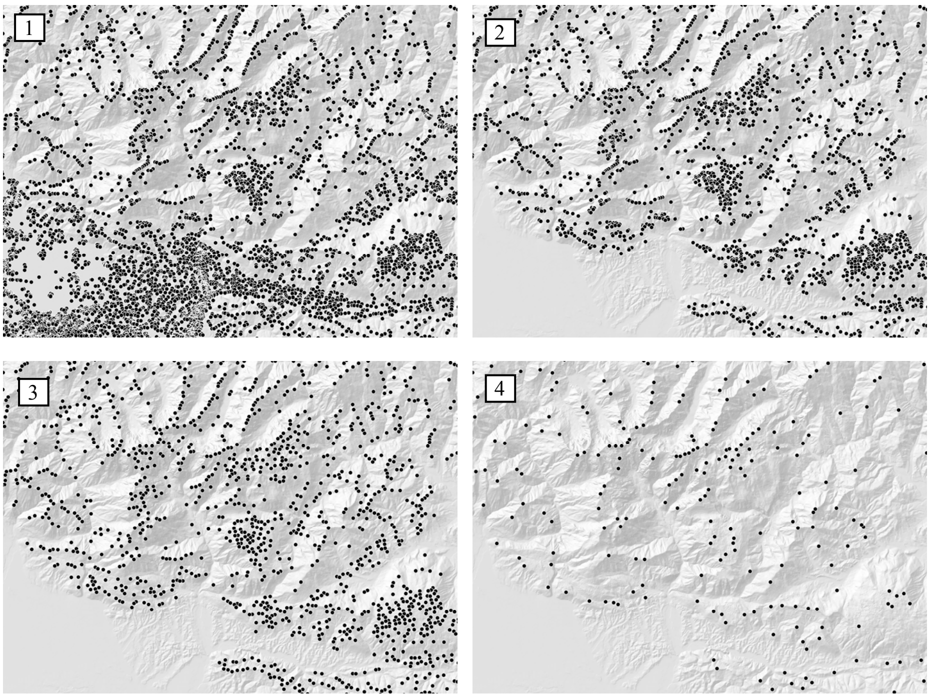


***Figure 2:*** Identification of the regional peaks (black dots) according to procedure steps considering topographic and some morphologic criteria in the area of Kamnik Alps.

## RESULTS AND INTERPRETATION

This interpretation of quality of the numerically determined peaks takes into account the reference lists of the peaks. The peaks above 2000 m are documented in the Slovenian Alps, in the whole Alps the peaks above 4000 m, and in the Himalaya the peaks higher then 8000 m. Number of peaks in Slovenia above 2000 m ranges between 179 and 349 according to different lists (SD, 2001; Kern and Cuderman, 2001). There are 128 peaks higher than 4000 m in the whole Alps, but only 82 when considered stricter criterions (UIAA, 1994; 2008). The number of peaks in Himalaya above 8000 m ranges between 14 and 21 (C4, 1990–2008; Peakware, 2002–2008). Manual process to define peaks was applied for all of the described data sets since the solutions with numerical methods were generally problematic.

The results of the proposed automated procedure (Figures 1 and 2) are determined peaks, starting with local (37,218), via immediate (3493, 2529), to regional (366), and to global (3). 42 (of 346) regional peaks higher than 2000 m were automatically selected (List No. 0). Two lists (List No. 1, List No. 2) of peaks above 2000 m were compared with our results (List No. 0) for the Kamnik Alps case study area. The List No. 1 includes 41 (SD, 2001) and the List 2 comprises 48 peaks (Kern and Cuderman, 2001). The comparison ascertains that 11 peaks (approx. 1/4) of List No. 1 do not exist in the List No. 0. Similarly, 12 peaks from List No. 1 are not presented in List No. 2. Considering the variability between the lists is possible to assess comparable accuracies of the automated approach (List No. 0) and the manual achievements (Lists No. 1 and No. 2). In the Table 1 is presented the List No. 1 and the differences to List No. 0 are assigned.

| | | | | | |
|---|---|---|---|---|---|
| Grintovec | 2558 | ***Mala Rinka*** | ***2289*** | Kogel | 2100 |
| Jezerska Kočna | 2540 | Brana | 2252 | Mrzli vrh | 2094 |
| Skuta | 2532 | Turska gora | 2251 | Krofička | 2083 |
| ***Na Křižu (Kokrska Kočna)*** | ***2484*** | Lučka Brana (Baba) | 2244 | Velika Raduha | 2062 |
| Kokrska Kočna | 2475 | Kalški Greben | 2224 | ***Krnička gora*** | ***2061*** |
| Dolgi hrbet | 2473 | Mrzla gora | 2203 | ***Velika Kalška gora*** | ***2058*** |
| Štruca | 2457 | ***Kljuka*** | ***2137*** | Ute | 2029 |
| Kranjska Rinka | 2453 | Storžič | 2132 | Mala Raduha | 2029 |
| ***Mali Grintovec*** | ***2447*** | Debeli špic | 2128 | Poljske device | 2028 |
| Koroška Rinka (Križ) | 2433 | Velika Baba | 2127 | Lučki Dedec | 2023 |
| Planjava | 2394 | ***Veliki kup*** | ***2126*** | ***Mala Kalška gora*** | ***2019*** |
| Planjava – vzhodni vrh | 2392 | Velika Zelenica | 2114 | ***Mala Baba*** | ***2018*** |
| Ojstrica | 2350 | Veliki vrh | 2110 | ***Mala Ojstrica*** | ***2017*** |
| ***Štajerska Rinka*** | ***2289*** | Ledinski vrh | 2108 | | |

***Table 1:*** List No.1 of 41 peaks above 2000 m form Kamnik Alps (SD, 2001). Peaks (described with names and heights [m]) written with bold italic letters were not automatically detected within the procedure (they are not in List No. 0).

### Quality of positions and heights of the peaks

Vectorised topographic map in scale 1:25,000 (DTK 25) was used for another quality control the results of automatic peak detection (Podobnikar, 2005; GURS, 2005). Triangulated spot heights of DTK 25 are commonly on the highest peaks and are the highest precision. As seen in the Figure 3, most heights of DTM 12.5 are usually a few meters lower than the spot heights (both in the same positions). The reason lies in generalization of the DTM where the values of the grid are just partially biased to the peaks. Quite different heights concerning DTM and spot heights were observed just at few peaks.

Quality of the determined peaks' positions is limited with the resolution of DTM 12.5 in the most cases. However, several peaks are dislocated by up to few 100 m. A problem of the described gross errors of heights and positions of the peaks was not investigated in a detail. The errors might have sources in both, DTM 12.5 or DTK 25.

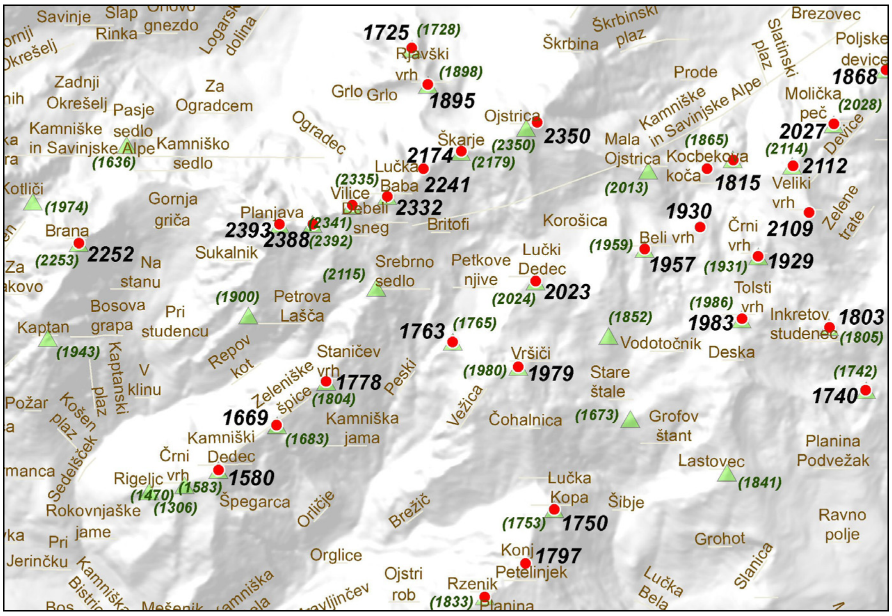


***Figure 3:*** Quality of the peaks generated by automated method (dots with altitude) in comparison with peaks from DTK 25 (triangles with altitude in brackets) and labeled with their geographical names from REZI 25 (zoom-in area presented with dimensions of 8 km x 6 km).

## CONCLUSION

The study demonstrates strength of the proposed automated numerical (quantitative) method to solve a relatively complex task: determination of the (regional) peaks of the mountains with analyzing and describing their shapes. The previous studies based on less objective manual approaches. Their applicability to numerical processing was studied. The peak detection was based on topographic, and some minor morphologic and mountaineering criteria of the International Mountaineering and Climbing Federation (UIAA, 1994). The peaks' shape analysis was based on morphologic criteria that were proposed and applied in this study.

The method was developed within GIS environment and tested with morphologically high quality DTM in the study area of the Kamnik Alps, Slovenia. The procedure for peaks detection based on topographic and some morphologic criteria, i.e. on measurements of relative heights and distances between the peaks with support of potential surfaces. High quality of the proposed algorithms was proved with comparison between official lists of the peaks over 2000 m (man-based, less objective) and our results. Variability amongst the official lists is similar to difference between the official lists and our result.

The results demonstrate ability for numerical application and improvement of the standards for the peaks determination. Advantages of the automated approaches are the standardized parameters, and more objective comparative results yielding a higher overall quality. However, the automated methods will never 100% satisfy the requirements that come from the complexity of the nature. Some details will have to be discovered and solved by a human being. This problem is similar to generalization in automatic cartography.

The subsequent work would compare results of the proposed approaches with the lists of all 2000ers in Slovenia and 4000ers in the Alps. This requires utilization of the morphologically high quality DTM of resolution around 10 m that is available in the main part of Alps. The additional methods of the peaks' shapes analysis can improve quality of the peaks determination. This more complex and interdisciplinary task includes various approaches in spatial modeling, geometry, geomorphology, or etymology – on geographically larger area. The lateral applicable outputs are numerous enhancements of: process of DTM production and quality control; cartographic presentation of the terrain; knowledge of planetary morphology, geology, tectonics; educational process; landscape architecture studies, and many others.

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