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Transferability of a Tree-Crown Delineation Approach Using Region-specific Segmentation

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Abstract. In this paper we present experiences of a transferability study on single tree delineation by region-specific segmentation of air-borne laser scanning (ALS) data with varying point density. Encouraged by promising results of preceding studies on high-density ALS data (Tiede et al., 2006, Tiede & Hoffmann, 2006) we assessed the transferability to an area, in which (1) lower density ALS data is available obtained by a different flight campaign; (2) the generation of a normalised crown model (nCM) is quite influenced by rough terrain; and (3) optical data (FCIR aerial photographs) differs from ALS data in terms of resolution and time of acquisition. Region-specific segmentation means utilising a-priori knowledge of the respective scale domain of the envisaged target features, while finally representing the scene content in a spatially contiguous one-level-representation (OLR). In total 2,344 single trees taller than 5 m were detected, for almost all of which a tree crown was delineated, even in dense pole forest. That means an average overestimation of 23 % as compared to visual interpretation, mainly due to shady conditions of the aerial photographs. A comparison based on 100 m x 100 m raster cells of manually and automatically extracted tree tops shows high congruence (correlation coefficient: 0.95).

Key words: object-based image analysis, ALS data, laser scanning, GIS, forest monitoring, remote sensing.

1. Introduction

Multifaceted, interrelated dimensions of forests, comprising climatic, ecological, social and economic aspects, require new technologies for assessing and monitoring the state and development of forests. Forest structure, though an ambiguous concept and difficult to operationalise, is widely considered a crucial indicator of forest integrity. Measuring forest structure is essential to assessing protection functions of forests (Maier et al., 2006) in hazard-prone areas exposed to rock-fall, avalanches, mudflows, landslides, and similar events. Consequently, a study area was chosen, where forest covering the steep slopes of an Alpine valley plays a significant role in terms of protecting settlements and tourism infrastructure. Irrespective its relevance, traditional methods for forest structure assessment based on field inventories and visual air-photo interpretation are limited, both in terms of cost and efficiency.

The Centre for Geoinformatics (Z_GIS), Salzburg University, in collaboration with the Stand Montafon, Austria, has tested and applied advanced methods integrating multispectral optical and airborne laser scanning (ALS) data for forest stand delineation, single tree detection and forest structure analysis (Lang et al., 2006). In this paper we present experiences of a study on the transferability of single tree delineation by region-specific segmentation of ALS data with a varying point density. This approach (discussed by Tiede et al., 2006) generates regions, i.e. rather homogeneous forest structures, by a pre-classification. These regions are treated specifically by an optimized multiscale segmentation. In the resulting region-specific two-level hierarchy the lower level objects represent tree crowns. In other words: profound forest characteristics (e.g. spacious vs. non-spacious forest) control the application of an optimised rule set for tree crown delineation. Rule set design was realised using Cognition Network Language (CNL) of Definiens Developer software.

2. Study Area and Data sets

Study area

The study area is located in the Montafon area in Western Austria (cf. Figure 1) in the federal state of Vorarlberg. The west-facing slope is situated directly above the tourist centre of Gargellen and ranges from 1,400 to 1,800 meters a.s.l with an inclination between 25 and 40 degree. Forests coverage on this slope prevents hotels and houses from damages due to rock-fall or avalanches. In these forests a protection forest rehabilitation project is being carried out for preserving the protection function on a long-term basis. Hence, the study area is predestined as a test site to automatically derive forest structure parameters from ALS and optical data (Maier 2005).

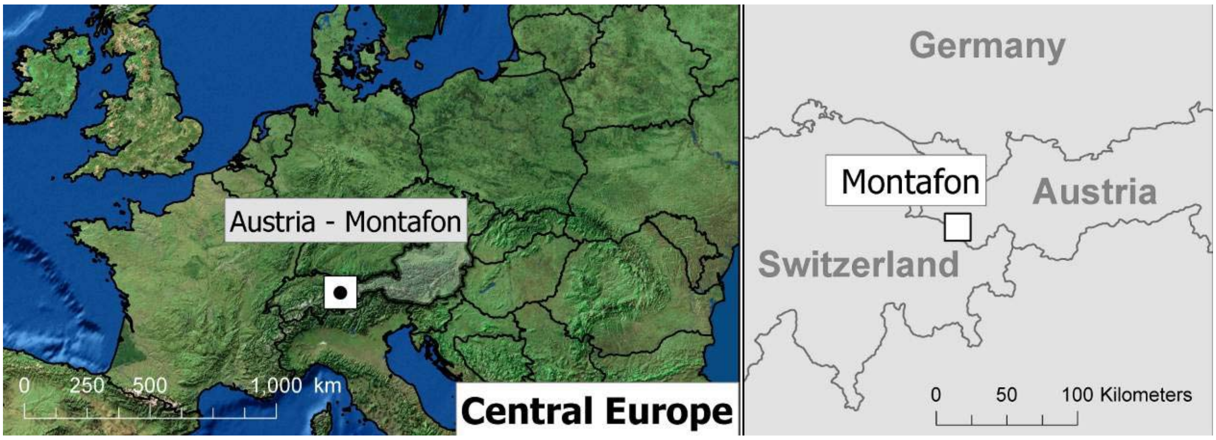

Figure 1: Overview study area

22ha (460m x 480m) in size, the test area stretches from the settlement in the north-west to the forest border in the south-eastern part (cf. Figure 2). Old spacious spruce stands are dominating partly thinned out from windfall due to storms in 1990. Besides this, typical structures of mountain forest still prevail in a pattern of clusters or groups of trees and gaps (German: Rotten). In the north-western part of the area spruce-pole forest occurs.

Data

ALS data was acquired in 2002 by TopScan (Muenster, Germany) requested by the Vorarlberg government. The Optech Airborne Laser Terrain Mapper (ALTM 1225) was applied to collect first and last returns. With a scan frequency of 25 kHz and an average flight height of 1000 m a point density of 0.9 points per sqm and a footprint of approximately 30 cm was achieved (Wagner et al. 2004).

First and last return laser raw data were processed at the Institute of Photogrammetry and Remote Sensing (IPF, TU Vienna). Both a digital terrain model (DTM) and a digital surface model (DSM) with 1 m resolution were interpolated using the software package SCOP++, developed by IPF based on the *hierarchic robust filtering* approach (Kraus and Pfeiffer, 1998).

In this study the DSM and the DTM were subtracted from each other to create a normalised crown model (nCM) with 1 m resolution. The latter serves as basis for the single tree-crown delineation. In addition, we applied a set of FCIR aerial photos (2001) recorded independently with a ground sample distance (GSD) of 0.25 m. Terrestrial mapped structure types and visual interpretation were used for validation purposes.

Figure 2: Left: View from the settlement (Photo: Maier, 2005). Right: ALS data with aerial photographs overlaid

3. Methodology

The presented study on transferability was realised by deploying a rule set developed in CNL. As a modular programming language CNL supports standard programming tasks like branching, looping and variable definition. Specifically, it enables addressing single objects, and the process of generating region-specific objects is supported in a supervised manner (Tiede & Hoffmann 2006).

Region-specific segmentation means utilising a priori knowledge on the very scale domain of the envisaged target features. In the end, we aim at representing the entire scene content in a spatially contiguous one-level-representation (OLR). High-level segmentation and pre-classification of false colour infrared (FCIR) orthophoto mosaic data are applied to generate an initial set of regions, characterised by their spectral behaviour and height information and accordingly assigned to image object domains (i.e. in this case different forest types). This approach, as being discussed by Tiede et al., 2006, has proven to be capable to differentiate between five forest types: coniferous spacious vs. coniferous non-spacious forest, deciduous-spacious vs. deciduous non-spacious forest, and mixed forest. Due to the prevailing natural conditions in our study area, it was required to differentiate between three image object domains, i.e. coniferous spacious, coniferous non-spacious and bare ground (due to windthrow, gaps or outcrop). Regions were specially created with respect to this pre-classification using adapted multi-scale segmentation. In the resulting region-specific two-level hierarchy the lower level objects correspond to single trees or tree crowns, respectively. In other words: the forest characteristics (i.e. spacious vs. non-spacious forest) control the application of different optimised rule sets for tree crown delineation.

Data used in earlier studies (Tiede et al., 2006, Tiede & Hoffmann 2006) differ in terms of accuracy (optical line scanner data and ALS data was acquired simultaneously from the same platform with a laser point density of approx. 10 points per sqm) and also in resolution (same GSD for optical data and ALS data in both studies). Mainly due to the differing GSD of the FCIR aerial photos and the nCM, we had to extend and adapt our workflow from scene-specific high-level segmentation and classification to region-specific multi-scale segmentation of single tree crowns. Definiens Developer will automatically resample all image data to the highest resolution of the loaded data set. This is of advantage for image objects created by segmentation, i.e. groups of pixels by definition. Still, in the second part of our workflow the regions are broken down to pixel sized objects in order to build up new supervised objects (here: tree crowns). This build-up process starts from local maxima derived from nCM. In case these data are resampled to the higher resolution of the FCIR images, local maxima detection is heavily biased. This in particular applies for non-congruent pixels. Figure 3 shows a comparison of local maxima detection of nCM data in Definiens Developer both with and without FCIR images.

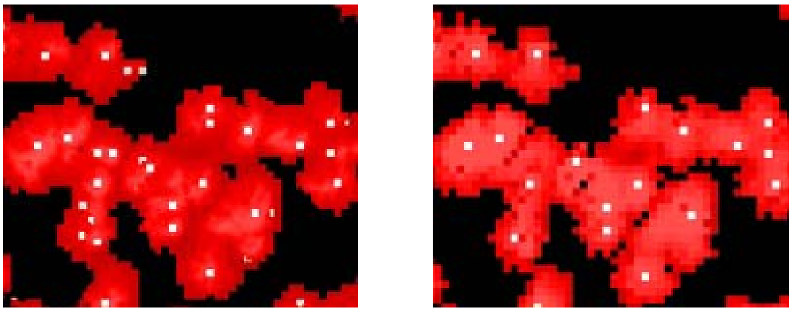

Figure 3: Local maximum detection of nCM data in Definiens Developer using FCIR images (left) and without them (right). White dots indicate local maxima. Errors and overestimation of local maxima in the left picture are caused by software-driven resampling of the nCM data.

The problem has been overcome by dividing the workflow in two different project settings as described below (see also Figure 4).

- *Project setting 1*: **High-level segmentation and pre-classification using FCIR and nCM data**. The initial set of regions was created through segmentation (for segmentation parameters please consult Table 1). In the segmentation process only FCIR data whereas in the classification process both data sets (spectral and height values) were deployed. The results were exported to a vector file (Shapefile) preserving all relevant information regarding the forest types.

L	**SP**	**SW**	**CPW**	**Remarks**
1	**300**	**0.5**	**0.5**	In the segmentation process only FCIR were deployed.

Table 1: High-level segmentation settings (L = Level, SP = scale parameter, SW = shape weighting, CPW = compactness weighting)

- *Project setting 2*: **Region-specific tree crown delineation using nCM data.** FCIR data was not loaded in this step to avoid forced resampling. This time, the modelling of single tree crown objects was carried out in an iterative optimisation process. That means, segmentation and classification are not performed subsequently in a linear, but in a cyclic process (cf. Figure 4). Information about different forest types, which controls the parameterization for each region-specific algorithm, is included by integrating the vector file of phase 1 in the segmentation. This has been done before by Tiede et al. (2006) and implies the following considerations (cf. Table 2): (1) the search radius for the local maximum method is depending on the assigned forest type: taller, spacious trees require a bigger search radius to minimizing false positives, whereas dense coniferous stands require smaller search radii for detecting even closer standing tree tops. (2) A stopping criterion for the region-growing process is realised by starting from the tree top, depending on the underlying nCM data. Neighbouring objects are only taken into account, if height difference not exceeds a defined limit. (3) Finally, a crown width limit prevents uncontrolled growing as a result of falsely identified tree tops.

Parameter	**Finer scale – smaller trees**	**Coarser scale –larger trees**
Local maximum search radius	**-** to detect even tree tops in closed stands	+ to avoid false positives
Sensitivity of the stopping criterion value due to underlying nCM data	+ for small coniferous trees	**-** for large coniferous trees
Crown width limit in segmentation process	**-** for small coniferous trees	+ for large coniferous trees

Table 2: Generalised overview of region specific biased differences in object build-up processes. Plus (+) and minus (-) indicate higher or lower values

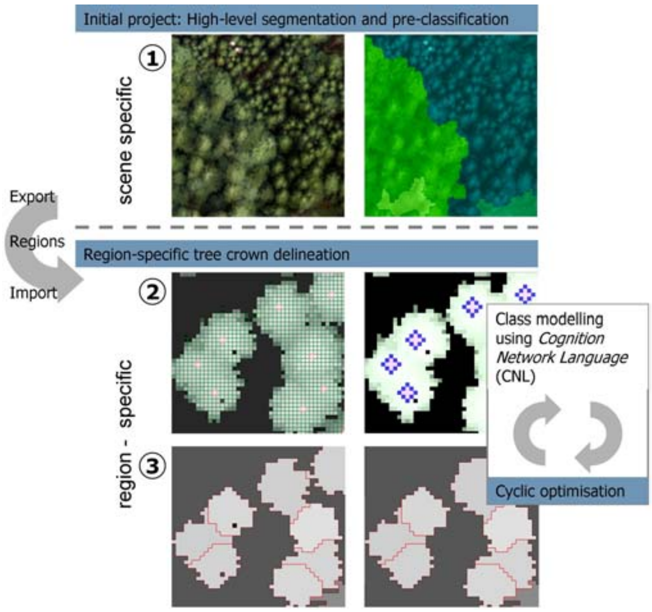

Figure 4: Workflow: (1) High-level segmentation and classification of forest types in an initial phase. Export of regions. (2) Break-down of imported pre-classified forest type domains to small objects (here: pixel level) and extraction of local maxima. Rebuilding of region-specific objects using a region growing algorithm (local maxima taken as seed points) (3) Extracted single tree crowns (holes are mainly caused by the ALS data). Cleaning up the single tree crown objects using neighbourhood information (Tiede & Hoffmann 2006, modified).

4. Results and Discussion

In total 2,344 single trees taller than 5 m were detected, for almost all of which a tree crown was delineated, even in the dense pole forest in the north-western part of the study area (Figure 5). A few local maxima were detected without a following delineation a of a tree crown. This mainly happens with small trees or dead trees, where the given point density of the ALS data fails to represent the whole tree crown.

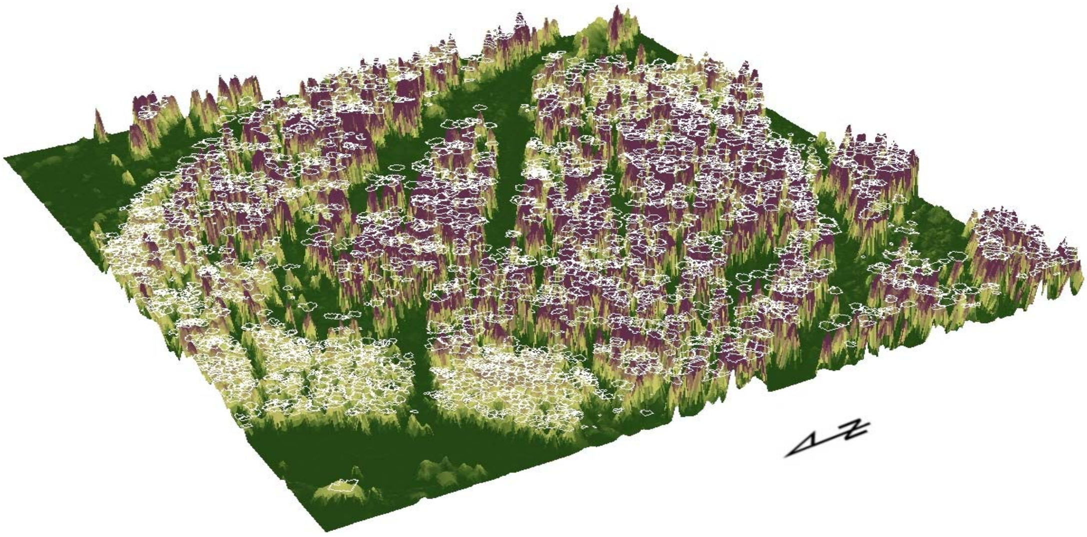

Figure 5: 3D view of the nCM data and automatically delineated tree-crowns overlaid.

Accuracy assessment was performed using (1) ground truth information of a reference sample and (2) visually delineations. Single tree ground truth information was not available for the entire area.

The reference sample covered a circle with a 20 m radius (about 1300 sqm) containing data of 30 trees including exact location and tree height (Maier, 2005). The visual accuracy assessment was done by on-screen digitizing of tree tops using FCIR and nCM data. It was accomplished by an external expert for reasons of objectivity and independence.

Comparing the results with the ground truth control sample revealed that dominant trees were detected correctly. Especially trees with a breast height diameter (BHD) above 25 cm were properly delineated (Figure 6). Smaller trees clustered or grouped with larger trees and double crowns could not be detected, because a distinct local maximum was not detectable in the nCM data. This implies a general problem when assessing forest structure by means of remote sensing. Also, the positions of detected tree tops and surveyed trees on the ground are not the same, which can be attributed to the inclined tree growth in such a mountainous area.

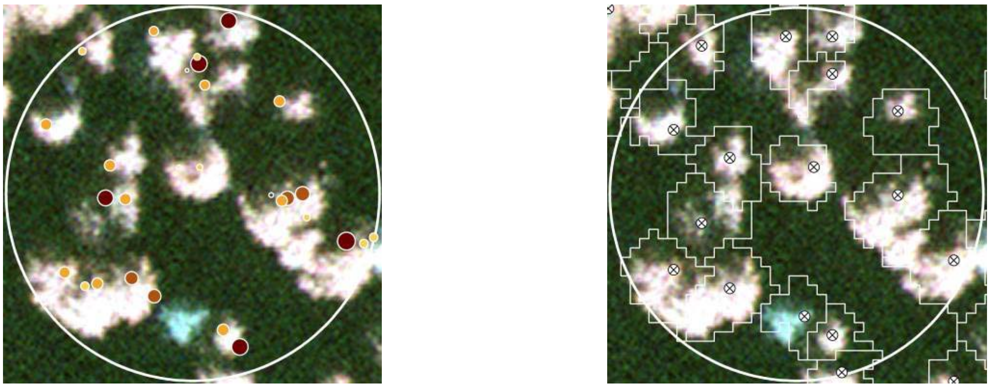

Figure 6: Ground truth sample with measured tree location on the ground (BHD > 25cm). Size and colour are indicating the measured BHD value (left). Automatically delineated tree-crowns and tree-tops (right).

The visual accuracy assessment was conducted for the whole study area by on-screen digitizing tree-tops from "above", which is possibly more suited to evaluate automated tree detection deploying remote sensing data. In a stricter methodological sense, assessing the accuracy of polygonal features through point locations as mere proxies may be considered inadequate to the object-based approach (Schöpfer & Lang, 2006). Hence, evaluation of the delineated tree-crowns as such, has not been performed as yet. To accomplish this in an automated, yet methodologically sound and inter-objective manner is a pertaining challenge for ongoing studies.

Altogether, 1,908 tree-tops were digitized. To obtain spatially explicit results the machine-detected tree-tops and the digitized ones were disaggregated to regular 100 x 100 m raster cells (Figure 7).

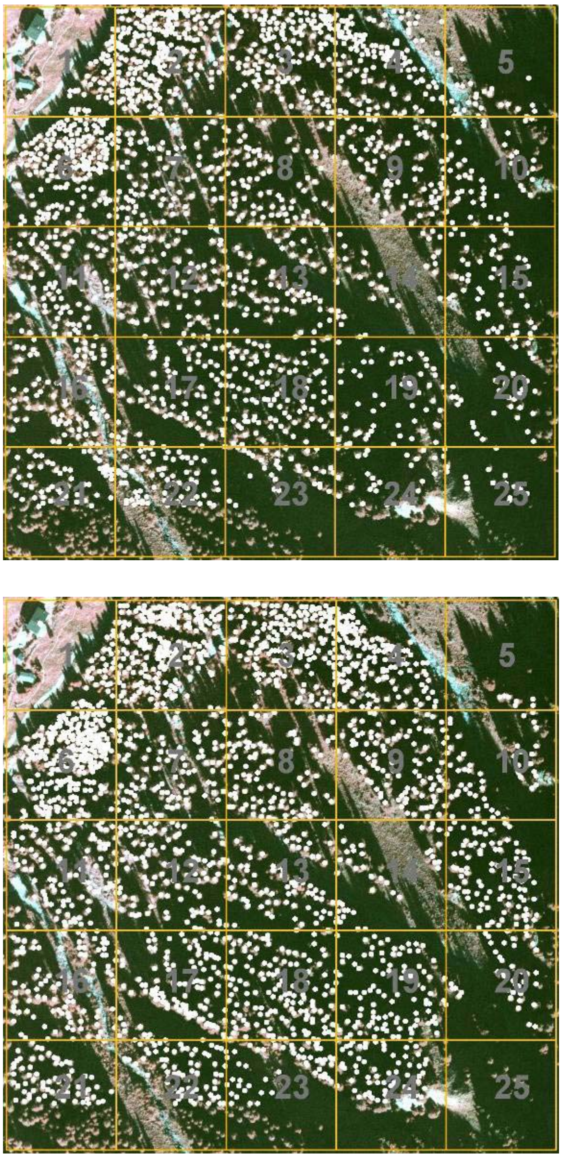

Figure 7: 100 m x 100 m raster cells with manually digitized tree-tops (above). Automatically detected tree-tops (below).

Cell ID	# of tree-tops, manually extracted	# of tree-tops, automatically extracted	%
1	53	42	79.25
2	211	236	111.85
3	148	179	120.95
4	133	145	109.02
5	25	7	28.00
6	167	254	152.10
7	92	107	116.30
8	79	92	116.46
9	76	94	123.68
10	50	51	102.00
11	85	104	122.35
12	81	103	127.16
13	66	80	121.21
14	30	40	133.33
15	54	94	174.07
16	85	91	107.06
17	77	111	144.16
18	97	130	134.02
19	55	97	176.36
20	39	40	102.56
21	57	65	114.04
22	73	66	90.41
23	33	53	160.61
24	27	63	233.33
25	15	0	0.00
	1908	**2344**	**122.85**

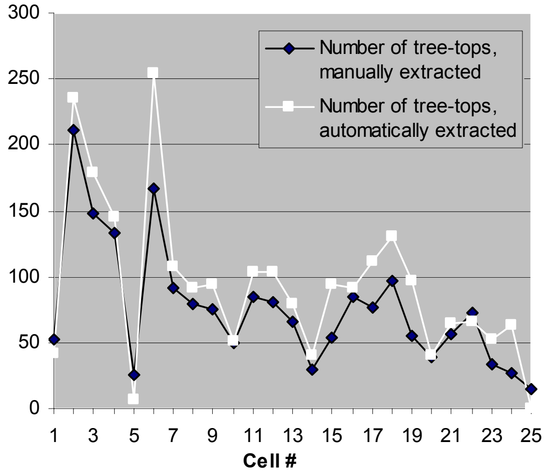

Table 3: Cell by cell comparison of manually and automatically extracted tree tops.

Table 3 shows a per-cell comparison of manually and automatically extracted tree tops. The diagram shows high congruence (correlation coefficient: 0.95) between the two techniques. Automatically detected tree-tops are overestimated by 23 % in average as compared to manual detection. One reason may be seen in the shady condition of the aerial photographs that hampers visual detectability. Highest overestimated areas (cells: 15, 19, 23, 24) are located in the steepest and most shady south-eastern part of the study site. Even in the denser pole forest in the north western part the (cells #2 and #6) the automated approach could compete with the manual interpretation.

In this paper, the transferability of the tree-crown delineation which was discussed by Tiede et al. (2006) could be shown. The different data sets deployed in this study and the different natural conditions (rough terrain, mountainous area) required an adaptation of the introduced workflow. Additionally, the spectral classification of the FCIR data was complicated by shady conditions which also hampered the visual accuracy assessment. Nevertheless we achieved high agreement of detected single trees. Especially the adapted region-growing method shows advantages in the dense pole stands compared to e.g. a watershed algorithm being applied in the same area (cf. Maier 2005). Even in this case single tree-crown delineation was still possible.

Due to the newly adapted and extended workflow, better transferability of the approach has been achieved. A very promising future perspective of this method is an automated assessment of the protection function of the forests in mountainous areas. This may draw advantage from combining methods for automatically extract the amount and size of trees using ALS data and ways to quantify the spatial pattern, manifested by the very arrangement of the trees (see for example Maier et al., 2006).

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