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SURVEYING AND MODELLING FORESTS WITH REMOTE SENSING AND GIS METHODS

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1. Introduction

In the current practice of forest management, forests are managed based on parameters assessed in forest planning, subjective impressions, and further measurements. This hybrid method has been in use for nearly two centuries, which has been shown to work well in forests managed with clear-cutting where the stand structure is homogeneous. The statistical sampling provides a reliable background for the forest measurements. The forest inventory is made in 10-year cycles in connection with the Regional Forest Planning. The forest manager gains a more accurate picture of the forest stands only during the field visit, as the forest inventory data mainly describe the forest vertically.

Interpretation of data collected during traditional forest measurements does not necessarily require more detailed local knowledge for decision making if the data collection was done with a representative sample size. In heterogeneous stands, 30-50% more samples are required for some forest measurements methods compared to homogeneous stands. The extra time spent on this and the increase in the administrative burden associated with forest planning have reduced forest inventory quality in recent decades, resulting in the regular application of transitional forest plans in certain regions. Due to the higher turnover of workers, previous local knowledge acquired over a long time, tied only to certain persons, may not be objectively passed on to the successor, leading to a further decline in efficiency in forest management. These problems could be solved at the local level by automating each task, resulting in a similar performance with less labor investment.

In recent years, the number of criticisms from NGOs is increasing on traditional forest management. While these criticisms point to local problems, they are based on views considered more important by society and can no longer be completely ignored in the 21st century, such as climate change. Forest managers should do more transparent management and communication to meet the expectations.

The current forest inventory takes place at the forest compartment level, which covers a few hectares. Due to the homogeneous habitat and uniform forest management, these compartments can be considered uniform in most cases. Uniform forest stands can be modeled, and forest yield and silviculture models have been developed based on their detailed surveys. The planning of the future of forests, which takes place in Hungary within the Regional Forest Planning framework, uses these models. These models usually contain specific values per hectare, so it is essential to know the forest's exact extent.

In 2015, there were almost 60,000 hectares of forest land in Hungary, where the conversion for continuous forest management was started. These forests are more challenging in forest planning, so more attention needs to be paid to their inventory, as traditional methods can only accurately assess them using very dense field sampling.

The problems listed above are allocating the need for an objective forest inventory at the local level, with more frequent updates, with more spatial parameters, thus supporting sustainable and more transparent forest management to lay the foundations for the forest's long-term future. Such a system would only be sustainable with highly automated data collection methods. One possible way to obtain this type of data is through remote sensing.

The basis of sustainable and close-to-nature forest management is to be aware of the precise amount of biomass in the forest and its quality. To meet the professional's and society's expectations, a more accurate inventory needs to be developed that allows us to create as accurate a model as possible of the forest's past, present, and future.

2. Research Objectives

The doctoral research aimed to develop remote sensing based workflows to determine various forest parameters on high-resolution optical satellite imagery in a time- and cost-effective manner.

A detailed formulation of the research objectives:

- To show what form the image of forests visible on high-resolution satellite imagery and what structural and environmental factors influence them.
- To investigate whether it is possible to create time series from the freely available, high-resolution satellite imagery of the Sentinel-2, on which different parameters of forests can be evaluated.
- Investigation of Sentinel-2 products with different pre-processing levels on forests.
- Development of an automated processing chain to produce an analysis-ready, consistent Sentinel-2 satellite image time-series that specifically considers forest's spectral and temporal characteristics during the radiometric correction.
- Development of a time series based remote sensing workflow to accurately estimate the area of artificial and natural treefall gaps on subpixel level.
- To develop a remote sensing workflow for mapping forest types that considers the spectral-spatial-temporal characteristics of forests as much as possible.

The work consists of three case studies focusing on the aimed objectives:

1. Time-series density study of Sentinel-2A satellite imagery on the National Forest Database in Hungary: The imagery of optical earth observation satellites can only be evaluated on the cloud- and cloud-shadow-free images. Above our region, the average cloud cover is high (~ 70%); therefore, only a few completely cloud-free images are available. I created a database based on Sentinel-2A satellite imagery that provides information at the forest compartment level on which dates are available for evaluation. Based on the studies performed on the database, I got a complete picture of the time-series' applicability and limitations.

2. Treefall gap mapping on Sentinel-2 satellite imagery in the Börzsöny Mountains: With the 10 m resolution images of the Sentinel-2 satellite, it was possible to observe smaller-scale silvicultural operations such as artificial treefall gaps. Area detection of small treefall gaps can be evaluated on the subpixel level. Utilizing the high temporal resolution, multiple maps of a forest can be created each year, but the capturing conditions of the images differ. In my research, I used a method that can handle different illumination conditions. This way, the spatial extent of the forest- and treefall gap covered area can be determined with higher accuracy than on a single image. A further aim was to study the impact of different pre-processing levels of Sentinel-2 imagery over the evaluated area.

3. Forest type mapping on Sentinel-2 satellite imagery in the Börzsöny Mountains: The main tree species of the upper canopy level can be determined on a Sentinel-2 satellite image time-series based on its spectral, temporal, and spatial characteristics. Although the time-series only provides information on the canopy surface, the forest type can be inferred from the detected main tree species. In the course of my research, I developed a pre-processing chain for Sentinel-2 satellite imagery that is specialized in forest cover. The forest types were evaluated on the homogeneous forest patches on the pre-processed time series in the Börzsöny Mountains. In the research, I investigated the forestry applicability of image classification methods based on deep convolutional neural networks on high-resolution satellite image time-series, which used the spectral-spatial-temporal characteristics of the time series for each forest type. The achieved classification accuracy was compared with a Random Forest classification model's performance that used only the spectral-temporal image characteristics. The purpose of the comparison was to examine the invested labor required to create the classification models.

3. Research Hypotheses

H1: A denser time series can be created to evaluate forests if the study area is not based on Sentinel-2 tiles (1,000,000 hectare) but a forest compartment (average 3.7 hectare).

H2: Based on the topographically and atmospherically corrected Sentinel-2 satellite image time series, the extent of artificial treefall gaps can be determined and monitored in hilly regions.

H3: The development of the Sentinel-2 satellite image time series pre-processing chain based on the forest cover's spectral-temporal characteristics can enhance the result of remote sensing analysis.

H4: On forest cover, significantly more accurate cloud masks can be created in the Sentinel-2 time series using the Kalman filtering method than in Sen2Cor software based on a single image.

H5: Considering the illumination condition of forests, a time series-based map can be created that shows the extent of treefall gaps in subpixel resolution with high accuracy.

H6: Forest type mapping is possible with high accuracy on Sentinel-2 satellite image time series with deep convolutional neural networks that use spectral-spatial-temporal features.

4. Methods

The case studies are presenting satellite-based remote sensing workflows. Remote sensing is a process of gathering information, in which we usually get a uniform data system via electromagnetic waves, most often from the earth's surface. The sensing instruments, which in the case studies were a satellite-mounted multispectral sensor, record radiation reflected from objects. After the data collection, a pre-processing step is necessary for the imagery which came from the Sentinel-2 high-resolution satellite program. Pre-processing aims to eliminate atmospheric and terrain distractions from images recorded at the top of the atmosphere and to provide recordings or time series ready for analysis. Part of this workflow is an atmospheric correction, cloud and cloud shadow masking, topographic normalization, and filling in data gaps. Pre-processed satellite imagery time series were evaluated in the case studies using data classification methods. During the evaluation, thematic maps and geoinformatics databases were created, which contained some forest parameters.

The aim of the case study entitled Time-series density study of Sentinel-2A satellite imagery on the National Forest Database in Hungary was to investigate the availability of images from one satellite of the Sentinel-2 satellite program (Sentinel-2A) on the forest cover in Hungary. The study was done on forest compartment polygons in the National Forest Database. The cloud masks created by the Sen2Cor software were evaluated on the polygons. A database was constructed from the cloud-free observations on each forest compartment. Various thematic maps were produced from the database, which showed the number of evaluable, completely cloud-free observations. The evaluable recording distribution in a time manner was also examined in the period between 2015-2017 at the forest type level.

In the case study entitled Treefall gap mapping on Sentinel-2 satellite imagery in the Börzsöny Mountains, three different pre-processing levels of Sentinel-2 imagery were examined beside its main purpose. The examination of the different data types was based on the assumption that pre-processing can significantly influence the detected treefall gap size. The time series was made of 9 images made between 2015-2016 in the oak sample areas and 6 in the beech sample area. Treefall gaps were evaluated by spectral unmixing on each image. Differently illuminated parts of the hilly region were categorized into several categories using unsupervised methods to reduce the classification models' standard deviation. Two methods were developed to evaluate the result of the spectral unmixing. One method examined descriptive statistics of gap areas detected at each time point on the time series. The other method considered the proportions of gaps per pixel at each time point as a probability, and then a summary map was made from this. The treefall gaps area was validated using aerial remote sensing materials and field measurements.

In the case study entitled Forest type mapping on Sentinel-2 satellite imagery in the Börzsöny Mountains, an improved Sentinel-2 pre-processing chain was part of the work. As part of the development, a multitemporal cloud and cloud shadow masking algorithm was developed, which filters out clouds and hazy image parts based on the Kalman filter's state vector. Data gaps were filled after masking by a data-driven linear model in the time series. To eliminate topographic shading, the method of empirical rotation was utilized in the pre-processing chain. Forest types were classified using supervised classification methods. The forest type classes were formed based on the main tree species at the upper canopy level from the 12 most frequent types in the Börzsöny Mountains and its surroundings. In this case study, I compared the performance of Random Forest classification models trained with spectral-temporal features and deep convolutional neural network type models trained on spectral-temporal-spatial features in terms of overall accuracy and invested labor. The data used to train the models underwent artificial data argumentation to bring nearly equal samples in the 12 classes selected. Spectral characteristics were derived from the 10 and 20 m resolution bands of Sentinel-2. Spatial characteristics were derived from homogeneous image units generated during Multi-Resolution segmentation, and temporal characteristics were derived from the time series covering one vegetation period. The thematic map was validated based on field measurements and the inventory of the National Forest Database.

5. Results and Conclusions

The research focused on determining various forest parameters from optical satellite images, which can model the evaluability, extent, and type of forest stands. The created methods are scalable, but each has its limitations in use. The classification models created in the case studies cannot be directly transferred to other areas. Their hyperparameters and training datasets need to be tuned on the forest. Nevertheless, the research results represent a step towards fully automated, unsupervised methods that would facilitate forest management's everyday life.

In the presented case studies, time series-based studies were performed. With the help of an interannual time series, it was possible to determine the probability of less clear information on single images or take advantage of the forest's characteristics over time. The Sentinel-2 images already have a spatial and radiometric resolution where the shading at the canopy level does not fade and mix, as in the previous Landsat satellite program with a similar purpose. Due to this property, medium-height and crown-sized stands are so detailed that the stand structure can be inferred from the images, which previously could only be done with very time-consuming field or costly aerial surveys.

The level of pre-processing of satellite images has a major impact on the final result of the analyzes. On Sentinel-2 time series without atmospheric correction, the detected treefall gap size can be several times larger than on corrected images. Improvement of the pre-processing chain shows a few percent improvements in the mapping accuracy of forest types. The multitemporal cloud mask developed in the research has significantly higher user accuracy than the publicly available Sen2Cor program can create.

Based on the study that examined the availability of images on Hungary's forest cover, it can be stated that only one satellite of the Sentinel-2 program cannot make multiple cloud-free images per month in an even distribution, even at the forest compartment level. The analyzed forest type groups showed different distributions in the number of evaluable recordings, partly determined by their vertical distribution and their leaf structure.

The method developed for detecting treefall gaps in the canopy surface can be applied in middle-aged and elderly stands where the canopy closure is high outside the gaps. A suitable method for mapping artificial treefall gaps in oak forests and, in particular, for studying their changes was developed during the research. In beech forests, where the treefall gaps have completely different characteristics due to natural disturbances, the area evaluation is less reliable. However, the time series-based method is suitable for tracking changes. The generated subpixel resolution treefall gap maps showed a high correlation in oak forests with the reference areas (> 0.63). There was a lower correlation in the beech forests due to the different gap characteristics (0.21).

Detection of forest types can also be applied in young forests if the canopy has already closed. The overall accuracy of the mapping reached 88 %. Deep convolutional neural network-based classification methods show a few percent improvements over other machine learning models used previously. A precise area estimation is required in applications, such as cleaning or thinning; a map that is only a few percent more accurate will allow a more accurate preliminary cost estimate. Training and running such models take significantly more computational time than traditional models.

The inclusion of surface height models is essential in most cases. Since both the optical satellite imagery and the aerial photograph only record the canopy surface from which height information can be extracted, it is unnecessary to have more accurate height information based on aerial laser scanning for the entire study area. A very detailed surface model is required in some cases, such as determining the filtering thresholds required for treefall gap detection. These fresher, more accurate surface models could also be used for geometric correction and topographic normalization of satellite images.

A commercially available solution for the full reproduction of the presented case studies is not yet available, so its application in other areas is limited. As technology advances, this will change. During the doctoral research, several platforms have been born to make the presented methods much easier to repeat in the future.

6. Theses

T1: Based on the pixel-level analysis of the cloud cover of the Sentinel-2 imagery made between 2015 and 2017 over Hungary, it can be stated that a very dense interannual time series (several observations per month) can only be constructed at the forest compartment level. The larger the study area', the more difficult it is to create a completely cloudless or low cloud covered time series.

T2: Of the Sentinel-2 satellite images that have undergone various pre-processing, the data type has undergone atmospheric correction and topographic normalization to examine and monitor the area of treefall gaps is the most suitable for hilly regions. During the atmospheric and topographic correction, the nonlinear transformation of the reflectance improves the contrast conditions in such a direction that the spectral distance between the crown surface and the shaded treefall gaps increases. Due to the increased difference, the range where the threshold of spectrally unmixed probabilities can be placed between treefall gap and canopy classes increases, allowing more accurate area estimations.

T3: Several free applications are available for pre-processing the Sentinel-2 satellite image time series, providing a suitable basis for general land cover mapping. With the help of an advanced processing chain developed specifically to evaluate forests, a 5% improvement in accuracy could be achieved when classifying forest types. The development included creating cloud masks on a time series basis, topographic normalization, and data imputation in a data-driven manner. Thanks to the data-driven solutions, the processing chain can be easily adapted to process other areas.

T4: The multitemporal cloud mask based on Kalman filtering showed 74% better user accuracy on the examined image material than the mask created in Sen2Cor software. The developed method is based on the phenomenon that during the vegetation period, the reflectance of trees with high canopy closure recorded in the visible blue range is very stable, so even smaller disturbance already show atmospheric noise.

T5: For each image in the Sentinel-2 satellite image time series, the treefall gap-canopy ratio per pixel can be calculated using spectral unmixing. The separation of treefall gaps and canopy in the time series assumes that the reflectance experienced on gaps is either significantly lower or significantly higher depending on their location and size than the canopy surface's reflectance. A probability value can be derived from the proportions of treefall gaps in the time series, which shows the extent to which the area of a given pixel can be considered a gap. Considering the topography's illumination condition, the errors caused by topographic normalization can be eliminated by dividing the examined area into several illumination categories and then combining the thematic results of the categories at the end of the process.

T6: Mapping of forest types is possible with deep convolutional neural networks that use the Sentinel-2 satellite time series' spectral-spatial-temporal characteristics. In the examined sample area, the classifier achieved an overall accuracy of 88% on 12 types. Compared to other machine learning methods, with the deep convolutional neural network type classifier, similar or better results can be obtained with less labor in mapping forest types.

7. Publications

Peer-reviewed journal articles:

BARTON I., KIRÁLY G., CZIMBER K., HOLLAUS M., PFEIFER N.: Treefall Gap Mapping Using Sentinel-2 Images; *FORESTS 8: Paper 426. 27 p. (2017)*

MOKROŠ M., VÝBOŠŤOK J., MERGANIČ J., HOLLAUS M., BARTON I., KOREŇ M., TOMAŠTÍK J., ČERŇAVA J.: Early stage forest windthrow estimation based on unmanned aircraft system imagery; *Forests 8:(9) Paper 306. 17 p. (2017)*

BARTON I., KIRÁLY G., CZIMBER K.: Lékek kimutatása Sentinel-2A űrfelvételidősorok alapján tölgyerdőben; *Geomatikai Közlemények / Publications in Geomatics XX: 1 pp. 87-97., 10 p.*

BARTON I., CZIMBER K., KIRÁLY G., MOSKAL L. M.: Konzisztens Sentinel-2 űrfelvétel-idősor készítése erdőterületek kiértékeléséhez *Geomatikai Közlemények / Publications in Geomatics XXII. pp. 65-76., 12 p. (2019)*

Proceedings:

BARTON I., CZIMBER K., KIRÁLY G.: Sopron 182B erdőrészlet (Roth féleszálaló erdő) korona és újulat térképezése távérzékelési módszerekkel; *In: Bidló, A; Facskó, F (szerk.) V. Kari Tudományos Konferencia - Nyugat-magyarországi Egyetem Erdőmérnöki Kar;Sopron, Magyarország : Nyugat-magyarországi Egyetem Kiadó, (2015) pp. 61-65., 4 p.*

BARTON I., KIRÁLY G., CZIMBER K.: Sentinel-2A űrfelvétel-idősorozat sűrűség vizsgálata az országos erdőállományra; *In: Bidló, A; Facskó, F (szerk.) Soproni Egyetem Erdőmérnöki Kar VI. Kari Tudományos Konferencia; Sopron, Magyarország: Soproni Egyetem Kiadó, (2018) pp. 123-127., 5 p.*

BARTON I., KIRÁLY G., CZIMBER K.: Képfeldolgozó program fejlesztése nagy mennyiségű földmegfigyelési adat feldolgozásához és kiértékeléséhez; *In: Bidló, A; Facskó, F (szerk.) Soproni Egyetem Erdőmérnöki Kar VI. Kari Tudományos Konferencia; Sopron, Magyarország: Soproni Egyetem Kiadó (2017) pp. 164-167., 4 p.*

KIRÁLY G., BALLA C., BARTON I., MÉSZÁROS G., PETRÁNYI B., SZABÓ K.: Borított felszínmodellek erdészeti felhasználása; *In: Bidló, A; Facskó, F (szerk.) Soproni Egyetem Erdőmérnöki Kar VI. Kari Tudományos Konferencia; Sopron, Magyarország: Soproni Egyetem Kiadó (2018) 266 p. pp. 118-122., 5 p.*

BARTON I., CZIMBER K., KIRÁLY G., MOSKAL L. M.: Faállomány-típusok térképezése Sentinel-2 űrfelvétel idősorozaton Deep learning osztályozóval; *In: Király, Gergely; Facskó, Ferenc (szerk.) Soproni Egyetem Erdőmérnöki Kar VII. Kari Tudományos Konferencia: konferencia kiadvány; Sopron, Magyarország: Soproni Egyetem Kiadó, (2019) pp. 41-47., 7 p.*

BARTON I.: Faállomány-szerkezet vizsgálat a Szigetközben a koronafelszín változatossága alapján Sentinel-2 űrfelvételeken; *In: Gribovszki et al.(szerk) Jankó Sándor Emlékülés 2019 konferencia kiadvány; Sopron, Magyarország: Soproni Egyetem Kiadó, (2019) pp. 29-34., 5 p.*

Books and book chapters:

TANÁCS E., BARTON I., BELÉNYESI M., BURAI P., CZIMBER K., KIRÁLY G., KRISTÓF D.: Távérzékelt adattípusok felhasználásának lehetőségei az erdőállapot-értékelésben; *In: Standovár Tibor, Bán Miklós, Kézdy Pál (szerk.); Erdőállapot-értékelés középhegységi erdeinkben. 612 p. Budapest: Duna-Ipoly Nemzeti Park Igazgatóság, 2017. pp. 37-107.; (Rosalia; 9.) (ISBN:978 615 5241 20 8)*

Oral presentations:

BARTON I., CZIMBER K., KIRÁLY G.: A Sopron 182/B erdőrészlet (Roth féle szálaló erdő) korona és újulat térképezése távérzékelési módszerekkel; *Nyugat-magyarországi Egyetem, Erdőmérnöki Kar: V. Kari Tudományos Konferencia; Sopron, 2015.10.21.*

BARTON I., BROLLY G., CZIMBER K., KIRÁLY G.: 3D GIS tool for visualization and analyze of detailed forest inventory data; *Young Scientist Days on Forestry (YSDoF); Krakow, Poland, 2016.09.15-16.*

BARTON I., KIRÁLY G.: Satellite based monitoring system for observing natural forest dynamic in the fragments of virgin forest of Carpathian region, *4th Forum Carpaticum Future of the Carpathians: Smart, Sustainable, Inclusive; Bucharest, Romania, 2016.09.28-30.*

BARTON I., KIRÁLY G., CZIMBER K.: Sentinel-2A űrfelvétel-idősorozat sűrűség vizsgálata az országos erdőállományra; *Soproni Egyetem Erdőmérnöki VI. Kari Tudományos Konferencia; Sopron, 2017.10.24.*

BARTON I., CZIMBER K., KIRÁLY G., MOSKAL L. M.: Konzisztens Sentinel-2 űrfelvétel idősorozat készítése erdőterületek kiértékeléséhez; *XI. Geomatika Szeminárium; Sopron, 2018.11.8-9.*

BARTON I., CZIMBER K., KIRÁLY G., MOSKAL L. M.: Faállomány-típusok térképezése Sentinel-2 űrfelvétel idősorozaton Deep learning osztályozóval; *Soproni Egyetem Erdőmérnöki Kar VII. Kari Tudományos Konferencia; Sopron, 2019.02.12.*

BARTON I.: Faállomány-szerkezet vizsgálat a Szigetközben a koronafelszín változatossága alapján Sentinel-2 űrfelvételeken; *Soproni Egyetem: Jankó Sándor Emlékülés 2019; Sopron, 2019.06.13*

Poster presentations:

KIRÁLY G., BARTON I.: Pilóta-nélküli repülők, és az általuk készített felvételek felhasználása az erdészeti gyakorlatban, különös tekintettel a folyamatos erdő- borításra; *Nyugat-magyarországi Egyetem, Erdőmérnöki Kar: V. Kari Tudományos Konferencia; Sopron, 2015.10.21.*

BARTON I., KIRÁLY G.: Monitoring system for natural forest dynamic in the fragments of virgin forest of Carpathian region, *ESA Living Planet Symposium 2016; Prague, Czech Republic, 2016.05.09-13.*

BARTON I., KIRÁLY G.: Capturing the dynamics in the fragments of virgin forest of Carpathian region using dense satellite image time series; *6th EARSeL SIG LU/LC & 2nd EARSeL LULC/NASA LCLUC Workshop; Prague, Czech Republic, 2016.05.06-07.*

BARTON I., KIRÁLY G.: Monitoring system for natural forest dynamic in the fragments of virgin forest of Carpathian region; *SCERIN-4 Capacity Building Workshop (CBW); Zvolen, Slovakia, 2016.07.18-21.*

BARTON I., KIRÁLY G.: Monitoring system for natural forest dynamic in the fragments of virgin forest of Carpathian region; *ESA 8th EO Summer School, Frascati, Italy, 2016.08.01-12.*

BARTON I., KIRÁLY G., CZIMBER K.: Műholdas változásvizsgálat hatékonyságának növelése erdőkön árnyékmodellezéssel; *X. Geomatika Szeminárium; Sopron, 2016.11.10-11.*

BARTON I., KIRÁLY G., CZIMBER K., HOLLAUS M., PFEIFER N.: Treefall gap mapping on Sentinel-2A images; *SCERIN-5 Capacity Building Workshop (CBW); Pécs; 2017.06.13.*

BARTON I., KIRÁLY G., CZIMBER K., HOLLAUS M., PFEIFER N.: Kartierung der Löcher im Blätterdach mit Sentinel-2A Bilder; *Angewandte Geoinformatik (AGIT) Symposium 2017; Salzburg, Austria, 2017.07.05.-07.*

BARTON I., KIRÁLY G., CZIMBER K.: Képfeldolgozó program fejlesztése nagy mennyiségű földmegfigyelési adat feldolgozásához és kiértékeléséhez; *Soproni Egyetem Erdőmérnöki Kar VI. Kari Tudományos Konferencia; Sopron 2017.10.24.*

LENDZIOCH T., LANGHAMMER J., BARTON I.: Using Landsat time series for attributing forest disturbance dynamics in Sumava National Park, Czech Republic; *European Geosciences Union (EGU) General Assembly 2018; Vienna, Austria, 2018.04.08.*

BARTON I., CZIMBER K.: Multiresolution image segmentation algorithm development for Sentinel-2 satellite imagery; *University of Washington GIS Symposium; Seattle, USA 2018.05.17.*