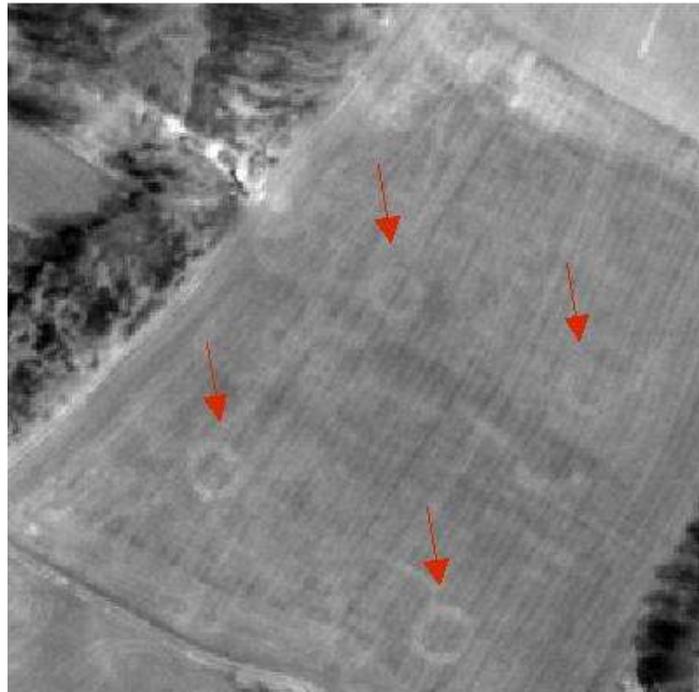


Developing a system for computer-assisted detection of cultural heritage sites



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Satellittbildet på framsiden er av et jorde ved Numedalslågen. De fire sirklene på jordet er tegn på graver. Bildet er tatt av satellitten QuickBird.

Executive summary

The increasingly intensive use and modification of the landscape resulting from modern demands for efficient infrastructure and land use (agricultural production, mining, energy sources, leisure/tourism facilities, etc.) exerts growing pressure on cultural heritage in the landscape. In order to match the political intentions of updated and sustainable cultural heritage management, it is necessary to develop a cost-effective method for locating and monitoring cultural heritage sites. In recognition of this, a project was started in 2002 with the overall aim of developing a cost-effective method for surveying and monitoring cultural heritage sites on a regional and national scale.

The first study area was an intensively exploited, agricultural production area in Rygge Municipality, Østfold County. Later, two geographically separate areas in Vestfold and Akershus counties were chosen. A crucial aspect was that there have been archaeological investigations in these areas. Results obtained in the 2002 pilot project indicated the existence of a correlation between cultural heritage sites and variation in the chemical elements in the soil. The results demonstrated that high-resolution geo-chemical sampling appears to be a promising field for the development of cultural heritage indicators. However, the costs indicated a need for funding which was almost impossible to obtain.

It was then suggested to focus on the development of automated methods, such as pattern recognition, for detecting and locating cultural heritage sites. The working assumption is that cultural heritage sites with no visual apparent manifestations above ground may be detectable in satellite images due to alterations in the spectral signature of the bare soil or of uniform vegetation growing there (crops).

During the last project years the aim was to develop a software prototype, CultSearcher, to provide computerised assistance in the analysis of satellite images. In particular, the software marks possible sites for further inspection by an archaeologist.

The methods currently used in CultSearcher to search for potential cultural heritage sites are performed in three main steps: *Segmentation*, *feature extraction* and *classification*. In the first step potentially interesting locations are detected as image segments, in the second step characteristics of these segments are computed, before the last step undertakes a classification of the various segments by comparing them to inherent class descriptors. Before these main steps are performed, the images have to be imported, and regions/areas of interest must be identified (agricultural fields). After the main steps, the results need to be checked. In addition, the system contains functionality for interactive training of the system to recognise and discriminate between the various region types (classes) of interest and non-interest.

The user site was represented in the project by two organisations, Vestfold County and the Museum of Cultural History (KHM). The aim of their involvement was twofold: Firstly, to test whether the software would be capable of detecting actual archaeological features in satellite imagery; and secondly, it was aimed at testing the suitability and functionality of the software for use in a cultural heritage management environment. The

areas selected consisted of images recorded in Vestfold County and in the vicinity of Gardermoen airport in Akershus County.

The user representatives concluded that CultSearcher is clearly still a prototype software, but with significant potential. It can offer archaeologists a better view of what to expect when prospecting and excavating agrarian landscapes. From visual inspections of satellite imagery it became evident that archaeological features can in fact be seen from space in the form of ring-shaped crop marks. An algorithm for detecting these has been developed and integrated with the system late in the project. It is capable of detecting a significant number of the ring-shaped patterns. The user interface in CultSearcher and the process from creating masks and importing satellite images to extracting the final interpretation of detections is still somewhat complicated. However, it is clear that this prototype has the potential for further development, and CultSearcher will be of great value for archaeologists in the field of cultural heritage management when it is fully developed and made operational.

In the near future (2008) the system will be tested on all the agricultural areas in Vestfold County. This will give a broader overview of potential obstacles and important experience for further development of the algorithms. Since there is international interest in the methodological approach of CultSearcher, further work includes aims of being active in the national and international research arenas. The Directorate for Cultural Heritage will work towards covering all the agricultural areas in Norway with satellite images, resulting in an overview of potential locations of cultural heritage sites nationwide. The year 2013 is suggested as a possible milestone for this.

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1 Introduction

The increasingly intensive use and modification of the landscape resulting from modern demands for efficient infrastructure and land use (agricultural production, mining, energy sources, leisure/tourism facilities, etc.) exerts growing pressure on cultural heritage in the landscape.

In order to match the political intentions of updated and sustainable cultural heritage management, it is necessary to develop a cost-effective method for locating and monitoring cultural heritage sites. Given the enormous costs of surveying the areas in question by traditional fieldwork, alternatives must be sought. The use of modern support technologies is imperative, if such rapid changes are to be balanced against the sustainable management of this resource. One possible approach is through the use of satellite images.

In recognition of this, the Norwegian Directorate for Cultural Heritage (Riksantikvaren, RA), in collaboration with the Norwegian Computing Center (Norsk Regnesentral, NR), the Museum of Cultural History (Kulturhistorisk museum, University of Oslo); Vestfold County Administration (Vestfold fylkeskommune) and the Norwegian Institute for Cultural Heritage Research (Norsk Institutt for Kulturminneforskning, NIKU¹), started in 2002 a project with the overall aim of developing a cost-effective method for surveying and monitoring cultural heritage sites on a regional and national scale. Additional and important funding from 2002-2007 was provided by the Norwegian Space Center (Norsk Romsenter, NRS).

The first study area was an intensively exploited, agricultural production area in Rygge Municipality, Østfold County. Later, two geographically separate areas in Vestfold and Akershus counties were chosen. A crucial aspect was that there have been archaeological investigations in these areas.

Results obtained in the 2002 pilot project indicated the existence of a correlation between cultural heritage sites and variation in the chemical elements in the soil. A central focus in the early project years was the manual analysis of satellite images followed by chemical profiling of sites observed in these images in order to gain experience as to how cultural heritage sites really manifest themselves in satellite images. The results demonstrated that high-resolution geo-chemical sampling appears to be a promising field for the development of cultural heritage indicators. However, the costs involved demanded a need for funding which was almost impossible to obtain.

It was then suggested to focus on the development of automated methods, such as pattern recognition, for detecting and locating cultural heritage sites. The working assumption is that cultural heritage sites with no visual apparent manifestations above ground may be

¹ NIKU was involved in the project in 2002-2004.

detectable in satellite images due to alterations in the spectral signature of the bare soil or of uniform vegetation growing there (crops).

During the last project years the aim was to develop a software prototype to provide computerised assistance in the analysis of satellite images. In particular, the software marks possible sites for further inspection by an archaeologist. This means that the archaeologists may focus their efforts on analysing the identified sites. It is important to bear in mind that the system is designed to detect *candidate sites* and that no claim is made that these candidates are *true cultural heritage sites*. Even human specialists cannot make such an assertion based on satellite imagery alone. The verification of a potential site always depends on some kind of field inspection.

Although the costs connected with acquiring and analysing the satellite data will not be insignificant, and fieldwork will never be replaced entirely by high-technological methods, it seems plausible that an essentially cheaper, and possibly even qualitatively better method for the surveying and monitoring of cultural heritage sites can be developed to target fieldwork to a degree not possible today.

The Norwegian Computing Center has been responsible for developing the automatic detection, methodology and implementing this into a prototype software system, CultSearcher. Vestfold County and the Museum of Cultural History were crucial in selecting areas of interest and in testing the software prototype as a possible tool for future cultural heritage management. The project was funded by The Directorate for Cultural Heritage and the Norwegian Space Center, whose representatives acted as the Steering Committee.

The Norwegian Institute for Cultural Heritage Research was involved in the project during the early years where geochemical soil analysis was the main focus. The representative of NIKU continues that approach in collaboration with Vest-Agder County at chosen areas in southern and western Norway.

2 Marks of cultural heritage seen from the skies

While the detection of cultural heritage sites from space is a rather new discipline, such sites have been observed and detected from the air for about one hundred years. The first reported cases refer to observations of Stonehenge (1906) and Forum Romanum (1906-1908) using balloons. The first reported cases using aircraft are concerning ruined towns and cities in Sinai seen by pilots during World War I. However, the first scientific aerial archaeology started in the 1920s with the British geographer and archaeologist Osbert Guy Stanhope Crawford (1886-1957). Due to his pre-war interest in the cartography of linear earthworks of prehistoric origin and his war experiences as an aerial observer and photographer, it was Crawford who created this new archaeological discipline.

What the aerial archaeologist typically sees are shadow-marked sites and levelled sites. Shadow marked sites are sites cut into the soil or rising above it, like castles, ruins, fortifications (banks and ditches still preserved) or tumuli. The visibility depends on the preserved height, the colour of the objects, vegetation cover, solar elevation and observation angle. Levelled sites are traces left at the surface which are only visible under certain conditions. There are two types: soil-marked sites and crop-marked sites.

Soil-marked sites are typically the remains of ditches, pits, buried walls, etc. A ditch or a pit will disturb the local soil profile, and refilled material usually has different characteristics, like density and composition. The refilled material is in most cases not so compact, and it might contain more humus components, making it looking darker. The refilled material may also affect the soil texture with a grain-size distribution that differs from the undisturbed soil (usually larger number of smaller grain sizes). This results in improved water-storage capacity, so the soil will look darker under certain conditions.



Figure 2.1. Soil marks are due to ditches (left) and roads (right) in aerial photos from Austria (Aerial Archive, Institute for Prehistory and Protohistory, University of Vienna)

In the case of buried structures like walls etc, remaining compact stones and mortar cannot store any water and the soil dries easily. Stones and mortar might also be brought to the surface by ploughing, creating contrast as stones look brighter than the surrounding soil.

Crop marks are an indirect effect of buried archaeological features. Their visibility depends on the soil, climate and vegetation. So-called positive marks are due to more water available which makes plants grow higher and ripen later than the surrounding plants. A colour-tonal contrast may be created because the vegetation stays green for a longer period and/or that the vegetation is darker green. Crop marks may also be due to vegetation relief. Plants grow higher, enough to throw a shadow in slanting sunlight. So-called negative marks appear when plants grow over buried stones (e.g. walls) and run out of water sooner, ripen earlier and stay shorter. Almost any crop can develop marks, if conditions are favourable. Cereals react quickly to Soil Moisture Deficit (SMD) and are growing very close, making the contrasts clearer.



Figure 2.2. Negative crop marks in Austria due to ditches (left) and positive crop marks in the Czech Republic due to building walls (right) in aerial photos (Aerial Archive, Institute for Prehistory and Protohistory, University of Vienna)

Geometrical patterns may also appear in agricultural fields as frost marks and snow marks. Refilled ditches and walls can store heat or cold (having different thermal capacity). Under the right weather conditions, these might be visible as differential thawing and freezing of radiation frost (hoar frost) or a thin snow cover. Such marks are visible just during a few hours time span (typically in the morning).

Even if there are remaining structures rising above the terrain or below the terrain as ditches and pits, they might be hidden by tall vegetation, in particular forest. If the terrain can be mapped accurately enough, such archaeological remains might be detectable in elevation data. These marks are therefore called relief-marked sites.

Sub-surface structures might also be discovered even if they create none of the mark types described above. Remains of constructions (usually stone constructions) often create contrast to the surrounding underground material (soil or sand), and can therefore be detected with sensors emitting and measuring electromagnetic or acoustic signals.

Various types of remote sensing sensors, airborne and spaceborne, are useful for detecting remains or patterns created by cultural heritage sites. Soil- and crop-marked sites can be measured with high-resolution optical (visible and infrared) sensors. With the optimal selection of observation wavelengths, high contrast can be obtained (in particular appearing from reflectance contrasts due to soil moisture or vegetation density). The spatial resolution of these sensors should be of 1 m or better to be really useful. Frost and snow marks are also detectable using optical sensors of similar characteristics. Also, sensitive thermal sensors might be applied.

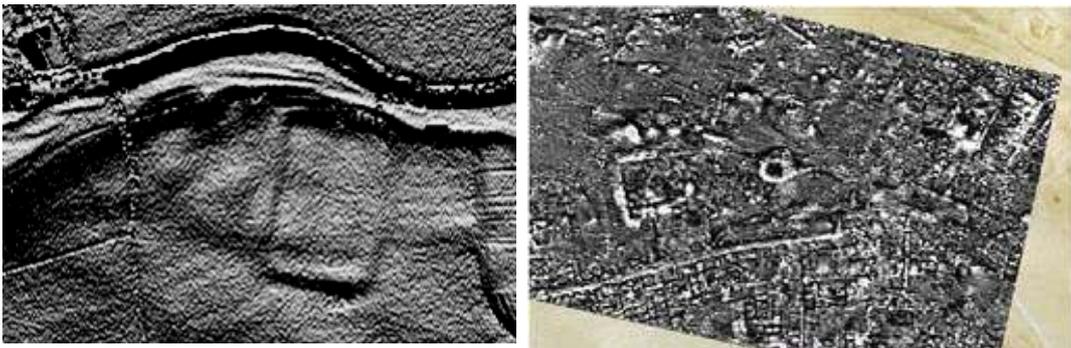


Figure 2.3. A Roman fortress in England as seen in a lidar image (left) and a town buried in the sand of a desert in Syria as imaged with a Synthetic Aperture Radar (English Heritage)

Laser-based sensors, lidars, have got quite a lot of attention recently. Airborne laser scanning is applied for, e.g., forest mapping. A by-product of this mapping is an accurate digital terrain model. Relief-marked sites, invisible under tree-cover, may then appear clearly in such a terrain model.

Radar (in particular Synthetic Aperture Radar) is also of potential interest for remote sensing of remains of or hidden cultural heritage sites. SAR signals penetrating the vegetation might interact with the terrain and show relief-marked sites. For dry-ground conditions, the SAR might also penetrate deeply into the ground. Sub-surface structures might then appear. Roads and buildings have been found hidden under the sands in deserts using SAR.

<p>Shadow marks</p> <p>Everywhere All year Optical and SAR</p>	<p>Soil marks</p> <p>Agricultural areas Spring and autumn Optical</p>	<p>Crop marks</p> <p>Agricultural areas Summer Optical</p>	<p>Relief marks</p> <p>Everywhere All year (dry season for SAR) Lidar and SAR</p>
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Figure 2.4. The main types of marks of cultural heritage sites together with an indication of where they might be found, when they are visible in the annual cycle and with what type of remote sensing sensors they can be detected

3 CultSearcher – a prototype system for the detection of cultural heritage sites

As explained in the previous section, in a satellite image cultural heritage sites may be visible as areas with different radiometric and spectral properties compared to their immediate surroundings. Regardless of their exact cause, cultural heritage sites may show up as patches, with or without particular shapes, which are darker or brighter than their surroundings. This is exploited in the methods used to automatically search for such patches in the satellite images. The CultSearcher prototype is briefly described in the following. A more detailed description can be found in Amlen et al. 2007.

The methods currently used to search for potential cultural heritage sites are performed in three main steps: *Segmentation*, *feature extraction* and *classification*. In the first step potentially interesting locations are detected as image segments, in the second step characteristics of these segments are computed, before the last step undertakes a classification of the various segments by comparing them to inherent class descriptors. Before these main steps are performed, the images have to be imported, and regions/areas of interest must be identified (agricultural fields). After the main steps, the results need to be checked. In addition, the system contains functionality for interactive training of the system to recognise and discriminate between the various region types (classes) of interest and non-interest.

Segmentation is the process of dividing the areas of the satellite image into different image regions based on radiometric/spectral and spatial characteristics. The current segmentation method works on panchromatic images and operates by identifying areas

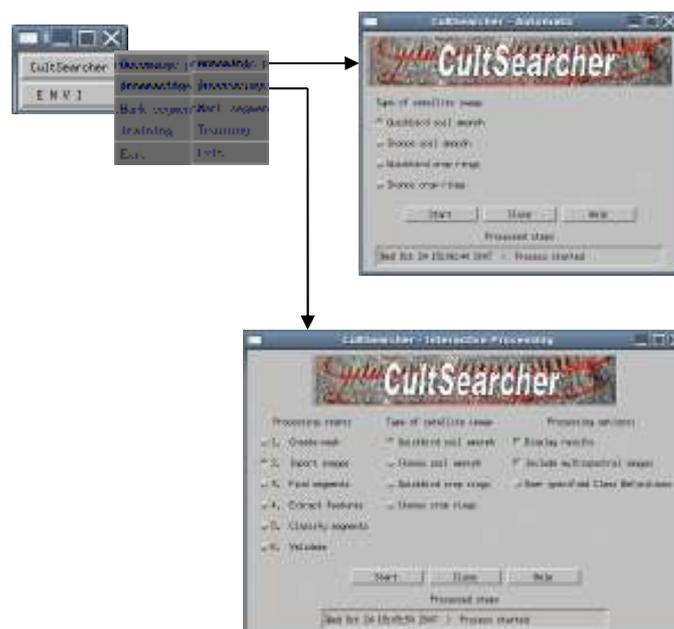


Figure 3.1. Overview of the main menu structure

that are darker or brighter than the surroundings. The method is used in two passes, first to find dark regions and then to find bright regions.

The characteristics or features extracted in the feature extraction step are typically figures describing particular geometrical, radiometrical or textural properties of the image segments extracted in the first step. Examples of such features are complexity, border quality, aspect ratio, uniformity and contrast. Complexity is calculated as the ratio between a region's perimeter and area; border quality is calculated by summing the gradient information along the border of the region (and normalising by the border length); aspect ratio is calculated as the ratio of the lengths of the major and minor axes of an ellipsis adapted to the region; uniformity is the standard deviation of pixel values within the region; and contrast is the difference in mean grey levels inside the region and in an area surrounding the region.

Classification is performed on the regions resulting from the segmentation. In this process, the spatial and radiometric/spectral characteristics of the segmented regions are taken into consideration to determine whether they are potential cultural heritage sites or not. During classification, features are extracted from the segmented regions of unknown class. Based on the statistical class descriptions, a minimum distance classifier is used to determine the most probable class for each region.

The system is operated through a simple graphical user interface (GUI) that provides the user with two different methods for running the system; one fully automatic method and one stepwise method providing some more user control (Figure 3.1). In both approaches care has been taken to keep the necessary knowledge of technical details to a minimum. A user with little knowledge of image processing and remote sensing should still be able to run the system without too much training.

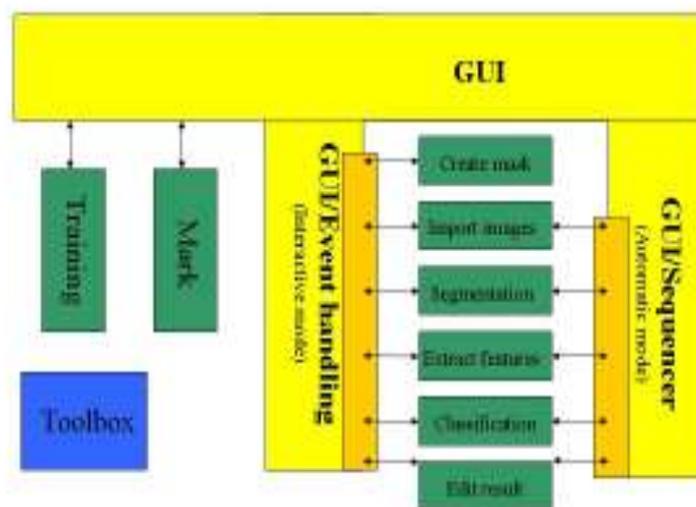


Figure 2. The main modules and the overall system architecture of CultSearcher

In addition to letting the user initiate segmentation and classification of the input images, the interface lets the user generate masks to limit the processing to agricultural fields. These masks are derived from a digital map giving the boundaries of these fields. The interface also lets the user load a mask and a satellite image into a common reference frame.

Finally, the interface provides functionality for training the system (“teaching” the classification step) and manually deleting classified regions that are deemed to be of no interest. Figure 2 illustrates the main modules and the overall architecture of the system. The functionality of each module is briefly described in Table 1.

The user will not need to specify a lot of parameters to the analysis; just a few setup parameters are defined in the Interactive GUI. For each step in the interactive mode the user also needs to enter or confirm the file names. Modules, like *Edit result*, *Mark* and *Create mask*, require more user interaction.

Table 3.1. The main system modules and their functionality

Main GUI	The Main GUI is where the user chooses interactive or automatic mode of processing. In addition, <i>Mark</i> and <i>Training</i> are started directly from the Main GUI.
GUI/Interactive mode	The user controls the processing chain by selecting which processing steps to run.
GUI/Automatic mode	Here the system runs automatically without any user interaction. Note that the steps <i>Create mask</i> and the <i>Edit result</i> are not included here.
Create mask	Allows the user to define which areas in the satellite image that will be analysed. It is available in interactive mode only.
Import image	Imports satellite images and masks and prepare them for analysis.
Segmentation	Detects potentially interesting locations by performing a segmentation of the satellite image.
Extract features	Extracts image features or characteristics of the detected image segments.
Classification	Analyses the extracted features of each detected image segment in order to classify the site as a potential cultural heritage site or something else
Edit result	The user is led through the classified segments one by one, and given the possibility to delete segments that are not believed to represent cultural heritage sites.
Mark	The user is being led through the segments that were identified in the segmentation module in order to prepare <i>Training</i> . For each segment the user is invited to assign a class label.
Training	An automatic function updating the class descriptions that are used by the classification module. This is the way to teach the system what potential cultural heritage sites look like.

4 Examples of CultSearcher results

The current version of the CultSearcher prototype system supports computer-assisted detection of potential cultural heritage sites in agricultural fields as soil and crop marks. The methods used so far are tailored to detect amorphous image structures (“sites”) as soil marks and ring structures as crop marks. The system may be extended to cover a far broader range of structure types as soil and crop marks using the same overall approach. The current version of the system is restricted to processing images from the Quickbird and Ikonos satellites. We will in the following provide examples of detecting amorphous structures as soil marks and ring structures as crop marks in images from both satellites.

We present in the following results from the Oslofjorden region, in particular for areas surrounding the Lågen River in Vestfold County as well as those surrounding the Rygge Municipality in Østfold County in Norway. Both areas are rich in known cultural heritage sites and is also expected to contain a large number of unknown sites. More details can be found in Grøn et al. 2004 and in Aurdal et al. 2006.

4.1 Detection of amorphous soil marks in an Ikonos image

The development of the CultSearcher methodology started with experiments based on an Ikonos image data set of the Rygge Municipality acquired in August 2001. The image data comprised a panchromatic band of 1 m resolution and a set of four multispectral bands (near-infrared, red, green and blue) of 4 m resolution.

The study area is a typical, intensively exploited, agricultural production area with a quite moderate topography in Norwegian terms. The extent of the study area was more than 100 square kilometres (Figure 4.1). This first study concentrated on smaller parts of the total area. In particular, it was known from field studies that the areas around the Gipsund farm, in the north-eastern corner of the total study area, are rich in cultural heritage sites. We therefore extracted a sub-image as shown in Figure 4.2. This sub-image comprises the central farm area along with the neighbouring fields. The figure shows as well an archaeologist’s indication of possible cultural heritage sites.

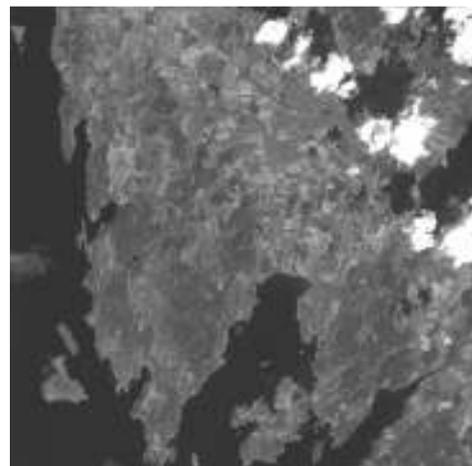


Figure 4.1. The Ikonos image over Østfold county

A three step analysis process was developed based on this data set:

1. *Pre-processing*: Agricultural field masks are derived from land-cover GIS data in order to restrict further processing to agricultural fields only. Each field was then pre-processed in order to suppress artefacts that could interfere with the clustering; in particular plough furrows were removed. We obtained good results using *Fourier analysis* in combination with mathematical morphology.

2. *Segmentation*: An *unsupervised clustering* (k-means) was applied to each field. This clustered the pixels in the field according to their spectral properties.

3. *Feature extraction*: Each structure (object) from the segmentation was then characterised according to shape, size, contrast, etc. resulting in a *feature vector* for each object.

4. *Classification*: We applied unsupervised clustering (k-means) using five classes. An alternative is supervised classification using, e.g., the maximum likelihood approach. Each object is then classified into predefined classes, where the characteristics of the classes are determined from a set of training samples. At least one of the classes should represent *potential cultural heritage site*.

Figure 4.3 shows the result of the classification step, where each class is indicated by a specific colour.

Based on this initial study, it was concluded that a fully automated



Figure 4.2. Sub-image showing the Gipsund farm and surrounding fields. Soil marks that might be of archaeological interest have been indicated by an archaeologist

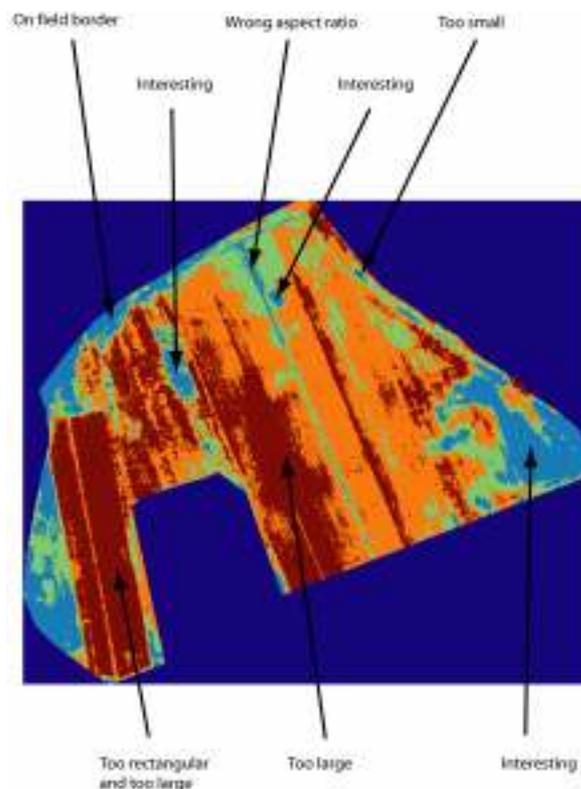


Figure 4.3. The result of the classification step. Each colour indicates a class. The archaeologist's annotations are included

system would be nearly impossible to develop. The decision as to whether a site is interesting or not depends on many details. The spectral signature and shape of the site is only one of several factors that must be taken into account. Knowledge of archaeology and local history coupled with geography and, obviously, knowledge from field surveys will often be of primary importance in the final interpretation. Further work in the project was therefore aimed towards development of a tool for detecting *potentially interesting sites*, leaving the final interpretation to the human specialists. Such a tool would greatly *reduce the burden on the human specialist* as it would be able to guide the specialist from site to site in the images. The specialist would then concentrate on the actual interpretation of the different sites that are detected.

The results from the analysis of the Ikonos image was later compared to the results of a similar analysis of a Quickbird image acquired in July 2003. It was clear from the comparison that details visible in one set of data might be more or less invisible in others. The soil marks seen in the Ikonos image were more or less invisible as crop marks in the Quickbird image.

4.2 Detection of amorphous soil marks in a Quickbird image

The methods developed in the initial experiments were then tested and further improved upon a larger data set based on various satellite images acquired in the regions surrounding Oslofjorden. We present here results from areas surrounding the Lågen River in Vestfold based on a Quickbird image acquired in 27 April 2005.

Figure 4.4 shows the subsection of the Lågen image discussed here. This region contains an excavation site (Iron Age grave mounds) as well as several known cultural heritage site locations within tilled agricultural fields. Map data for the agricultural fields has been transformed into masks delimiting the processing only to agricultural areas. Some potential sites are indicated with red arrows. In the segmentation step we seek to detect these and other potential sites based primarily on their contrast to the local background. The segmentation was changed here compared to the previous experiments, now using Niblack's method (Niblack 1986) for threshold selection. The method is used in two passes, first to find dark regions and then to find bright regions.

Region features are extracted in the feature extraction step from each region in Figure 4.5, and the regions are then analysed in the classification step based on these features. A modified and extended feature set, compared to the previous experiments, was applied here, and the Maximum Likelihood approach (supervised classification) was applied instead of unsupervised clustering. The final class of a region was determined by finding the statistically most likely class given the features.



Figure 4.4. Part of the image. Potential cultural heritage sites will typically appear as indicated, either as spots that are darker or brighter than their surroundings

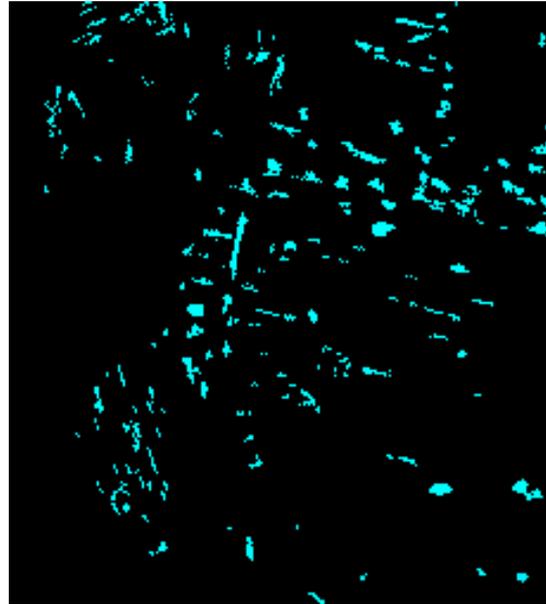


Figure 4.5. Result of segmentation applied to the image shown in Figure 3

The result of the classification step is shown in Figure 4.6 on top of the original image in Figure 4.4. This figure shows only the regions that belong to either class 1 or 2, that is, the two classes corresponding to potential cultural heritage sites.

The current segmentation and classification methods are designed to be quite inclusive. The philosophy is that it is worse to lose one real cultural heritage site than detecting a high number of false sites. However, if the number of false positives becomes too high the user will spend too much time going through the detected sites. Hence, in future work we will seek to reduce the number of false positives. There are numerous ways of achieving this. In collaboration with archaeologists, we will try to tune the system better so that the interesting sites are still detected, while uninteresting sites to a larger degree are rejected.

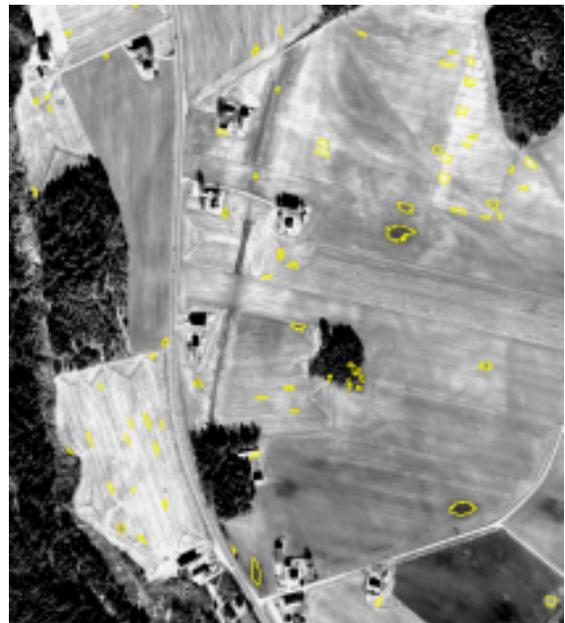


Figure 4.6. Result of the final classification overlaid on part of the original image

4.3 Detection of ring-structures as crop marks in Ikonos and Quickbird images

Ring structures are of great interest to archaeologists as they may indicate the existence of remains of burial mounds and other circular structures. Ring-shaped structures may be the remnants of graves which were originally constructed as burial mounds surrounded by a ditch. In these ditches combustible material was burned over many centuries. Today, the mounds themselves have been destroyed by agricultural activity, but the presence of a thick layer of ashes in the surrounding ditch might still be visible in some regions, see Figure 4.7.

In the final part of this project, we performed experiments for the detection of ring structures in agricultural fields. We here present some of these results from crop mark analysis in Ikonos and Quickbird images acquired 29 July 2003, 13 August 2003 and 30 June 2006. For more details, see Larsen, Trier and Solberg 2008.

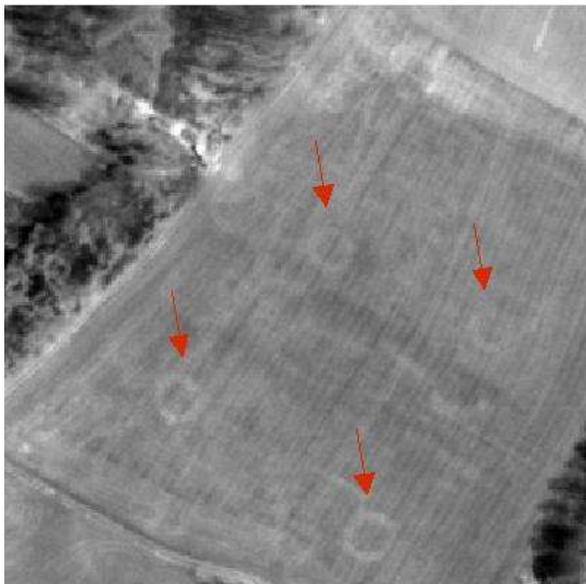


Figure 4.7. Visible ring structures in a satellite image of an agricultural area

The ring structures may appear in numerous different ways. The circles vary in size, i.e. radius and width. Some rings are brighter than their surroundings, while others are darker. The examples in Figure 4.7 are all relatively clearly visible. However, this is not always the case. Sometimes the remains consist of circle fragments only, and/or the border of the ring is more diffuse than what can be seen here. A few other examples are shown in Figures 4.9 and 4.10.

The approach of detecting circular objects is a modification of the approach for detection of amorphous objects described in the previous sections.

The main idea of the segmentation approach is to search the images for

areas that matches a given ring template. Based on visual observations of a series of 0.6 m resolution Quickbird and 1 m resolution Ikonos panchromatic images, we found that the ring radius is typically between 4 and 18 m. We constructed ring filters with radii in this range, see Figure 4.8.

A mask representing the agricultural fields was applied to the image before further processing took place. We then performed contrast enhancement of the images. Template matching was performed by letting the binary filter “slide” across the contrast-enhanced image. For each image position of the template the filter response was recorded. The result was an image of where the locations where the templates match well will have

relatively high or low values. High values indicate a match with a bright ring, whereas low values indicate a match with a dark ring.

The next step was feature extraction. For each candidate ring position we extracted a surrounding sub-image from the original image.

Different features calculated from this sub-image were used to determine whether to reject or accept the candidate as a ring. These criteria were derived from investigation of feature values for known rings. Perhaps the most important feature is ring correlation, which is a measure of how well the sub-image resembles the intensity ring template in Figure 4.8.

Figure 4.9 and 4.10 display some of the sub-images resulting from ring detection. Table 4.1 displays the detection rates.

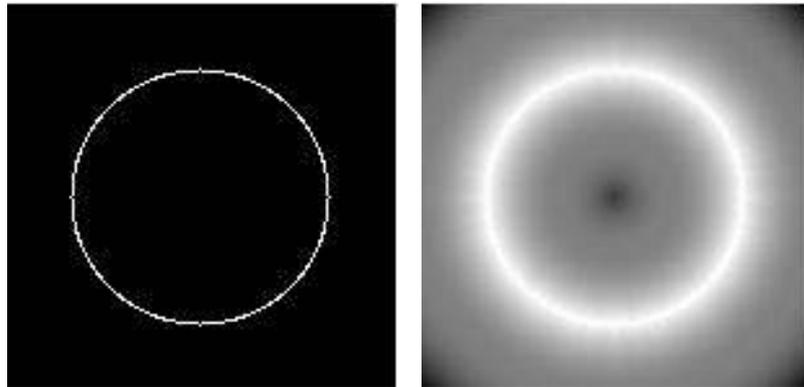


Figure 4.8. Binary (left) and intensity (right) ring templates



Figure 4.9. Sub-images of falsely detected rings

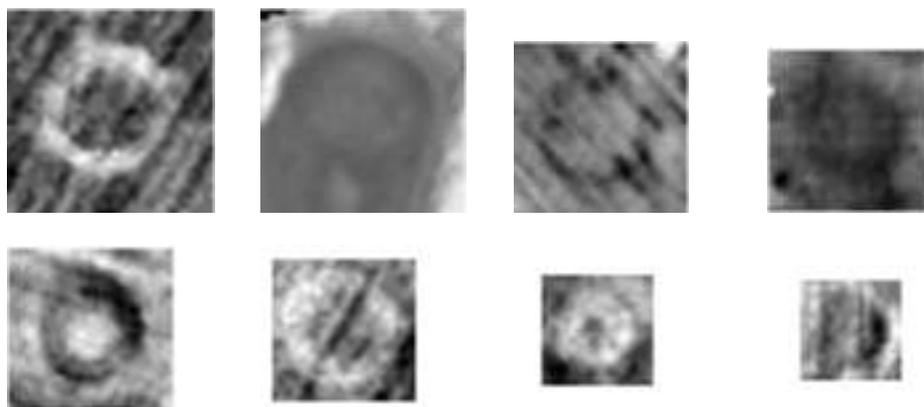


Figure 4.10. Sub-images of detected rings

Image	Number of known rings/disks	Number of correct detections	Number of false detections
1	1	1	12
2	1	0	6
3	1	1	6
4	1	1	6
5	1	0	8
6	1	1	7
7	1	1	3
8	2	1	10
9	4	4	1
10	2	2	2
11	4	4	6
TOTAL	19	16	67

5 CultSearcher from an archaeologist's viewpoint

Vestfold County and the Museum of Cultural History (KHM) in Oslo have been involved in the project since 2003. Vestfold County was in the period 2003–2005 represented by archaeologist Trude Aga Brun, and since 2005 also included archaeologist Christer Tønning. Archaeologist Lars Gustavsen has represented Museum of Cultural History throughout the project period. The archaeologists have contributed in testing and commenting, and thereby shaping the CultSearcher software prototype as a potential tool for future cultural heritage management in agricultural landscapes throughout the country.

The aim of the exercise from the archaeologist's point of view was twofold: Firstly, it aimed to test whether the software would be capable of detecting actual archaeological features in satellite imagery. Secondly, it was aimed at testing the suitability and functionality of the software for use in a cultural heritage management environment.

In order to test the functionality of the software, two geographically separate areas with suitable satellite imagery had to be selected. These had to consist mainly of cultivated landmass and have a reasonably dense population of already recorded scheduled monuments. Further to this, the imagery covering the areas had to have little or no cloud-cover and the images had to have been taken at the right time of year.

The areas selected consisted of images recorded around an area near Tønsberg in Vestfold County and an area in the vicinity of Gardermoen airport in Akershus County. Archival satellite imagery from both areas was inspected in order to select imagery without cloud cover and within a time frame which would be favourable for crop- or soil-mark detection. Both areas were covered by panchromatic and multispectral imagery. The datasets differed, however, in that the Tønsberg coverage consisted of imagery from the IKONOS satellite whereas the Gardermoen images were recorded by the Quickbird satellite.

For the sake of convenience it was decided that the Vestfold imagery was to be inspected by an archaeologist from Vestfold County, whereas the Akershus imagery would be dealt with by an archaeologist from the Museum of Cultural History in Oslo.

5.1 Testing CultSearcher on Quickbird images from the Gardermoen area

5.1.1 The test area

The Akershus area partly covers the municipalities of Ullensaker and Nannestad, an area amounting to a total of some 600 km². Archaeological investigations have revealed that the area has been settled since the Neolithic period (about 4000–1800 BC), and the Askeladden database of scheduled monuments lists over 900 sites of varying types and dates. Of these, approximately 180 consist of burial mounds or cairns dating from the Bronze Age to the late Iron Age. One of the more spectacular monuments in the area is Raknehaugen, a colossal tumulus measuring some 90 m in diameter and 15 m in height. Although its function has never been established, C¹⁴ dates suggest that it was

constructed about 500 AD. In addition, the area is known for an extensive network of prehistoric roads as well as a number of medieval churches.

In addition to this dense concentration of archaeological sites, the area is characterised by easily cultivated moraine landscapes, and is considered a typical eastern Norwegian cultural landscape. The archival imagery selected for this part of the test was recorded on 27 July 2003, a time of year which should be favourable for crop-mark detection. It is the time of year when crops are in the process of ripening and thus turning yellow. The combination of these factors makes the area particularly suitable for detecting potential crop marks.

5.1.2 The test

The first part of the test included selecting and ordering appropriate imagery from the available preview images. A convenient aspect of the Quickbird imagery is that it is possible to select areas by using irregular polygons. These can be based on already available datasets, or can be generated on-the-fly. Thus, it is possible to exclude forested or urban areas from the ordered data. As the imagery of the study area were not geo-referenced to the same accuracy as the available datasets, it was necessary to select areas manually. This was done by importing the images to ESRI ArcGIS, where geo-specific polygons could be drawn over the areas of interest.

When the imagery had become available, it was possible to proceed with the second phase of the software testing. Testing the CultSearcher prototype software involved a series of different steps. Firstly, the selected images had to undergo visual inspection by the archaeologists in order to pick out potential archaeological targets. This involved carefully going through each individual patch of cultivated land in the images trying to identify crop and/or soil marks. As a guide to where crop marks might be visible, data from the Askeladden database in the form of points were exported from the database and overlaid the satellite imagery.

When suitable areas had been selected based on these criteria, the images had to be divided into sub-images of the original image. This was done in order for the software to be able to handle the substantial amounts of data present in the satellite images. These sub-images then had to be imported into the CultSearcher software, and masks had to be created over the areas on which the software was to be tested. When this was done the programme was executed, and contrasting features were detected as previously described.

5.1.3 Preliminary observations

Following the preliminary testing it is my opinion that the software as it stands is unsuitable for use by personnel without specific knowledge of satellite imagery and/or GIS-related software. Furthermore, as the ring algorithm had not yet been implemented in this phase of the testing, the software would only pick out areas with amorphous features. These are features that cannot be positively identified as archaeologically significant without investigation in the field.

Another obstacle for implementing this software in a cultural heritage environment is the user interface and the way the software stores data. The software is currently far too cumbersome and will have to become much more automated in order to work in a normal administrative setting. The most time-consuming aspect of using the software is that of having to select areas of interest and create masks manually. This, in fact takes longer than the actual computational analysis of the image, and will have to become a more automated process.

An ideal process would be as follows: A satellite image is loaded into the software. The software then automatically identifies areas of interest. This would have to identify cultivated landmass and exclude forested and inhabited areas. The software should then split the original image into smaller images which can be analysed more efficiently by 'normal' computers. Following the analysis of the area, the software should then give the user the option to export the results to familiar vector-based formats such as shape or dxf for further use in GIS/CAD packages common in cultural heritage management.

It is clear that this software has the potential for further development. From the visual inspections of the satellite imagery it became evident that archaeological features can in fact be seen from space, in the form of ring-shaped crop marks. Therefore, with a suitable algorithm for detecting these, CultSearcher will be of great value for archaeologists in the field of cultural heritage management.

5.2 Testing CultSearcher on Ikonos images from Vestfold County

5.2.1 The test area

In the first edition of CultSearcher a considerable amount of work had been put into the software to enable the system to detect amorphous objects in Quickbird satellite images. In Vestfold County a Quickbird image of the southern parts of the river Lågen, was used to train CultSearcher to detect amorphous objects. In this Quickbird image an Iron Age grave field located at Odberg farm was the central target, and the surrounding fields were subject to intense investigation and search for other similar or related archaeological objects not visible in situ.

5.2.2 Testing various versions of CultSearcher

In this phase of the project, with CultSearcher detecting amorphous objects where archaeologists did not have any information about the sites detected, it became clear that we had to re-evaluate central issues in developing CultSearcher. Detections of amorphous objects where no verification – either by archaeological survey, excavation or archive data – is clearly of little value and could not bring the functionality of the software further.

Instead of pursuing the search for amorphous objects in unknown territory, the focus was shifted to extending CultSearcher to be able to detect ring-shaped objects where Vestfold County and KHM had information from archives, surveys or excavations on where archaeological objects had been situated, and where possible traces of them could be detected. In this way we may start from a known point of origin and it would be possible

to train CultSearcher to detect similar features in unknown landscapes. A ring ditch surrounding an Iron Age grave mound is a fairly common archaeological feature especially in Vestfold County, but also in Norway in general. The subject matter is plentiful and therefore especially well suited for training CultSearcher in this early phase.

5.2.3 Remarks

The user interface in CultSearcher and the process from creating masks and importing satellite images to extracting the final interpretation of detections is still somewhat complicated. Many similar processes, producing files with similar names can be confusing for the beginner using the software. A clearer structure where archaeological definitions are properly incorporated in the graphical user interface and the output data is necessary for widespread use of the software amongst archaeologists in cultural heritage management.

CultSearcher is clearly still a prototype software, but with significant prospects. It can offer archaeologists a better view of what to expect when prospecting and excavating agrarian landscapes. CultSearcher may offer greater success in actually locating archaeological remains, and better possibilities of understanding the bigger picture of the prehistory of landscapes.

In the future Vestfold County would like to broaden the variety of archaeological remains to be detected in CultSearcher, e.g. houses, cooking pits, walls, wall ditches and roads. The learning process of CultSearcher is still in progress, but we have high expectations and great belief in the ongoing systematic approach where CultSearcher should be a powerful tool in the ever growing archaeological toolbox.

6 Plans for the future

A software prototype for the detection of potential cultural heritage sites in high-resolution satellite images has been developed. The Directorate for Cultural Heritage's aim is that the system will become a key operational tool for cultural heritage management nationwide. Furthermore, it is hoped that this approach will reduce the number of excavations in order to establish in situ protection and management of cultural heritage sites. Additionally, a central perspective of using satellite technology for cultural heritage management is the potential of reporting on national goals for the environmental policy.

The prototype system CultSearcher was presented at an international seminar held by the Directorate for Cultural Heritage and the Norwegian Space Center in Oslo 9–10 January 2008. The reactions of the audience, with representatives including the Norwegian county administrations and researchers from several countries, were positive. Nonetheless, it became clear that the system still has some challenges to overcome.

At present it is obvious that there is still a long way to go to satisfy the demands for good management, as stated in Chapter 5 of this report. It is therefore crucial to continue with the development of suitable algorithms for detecting sites of interest. Furthermore, it is important that more users, such as archaeologists in the county administrations, participate in this development work. CultSearcher will only be accepted if the end users see the value of the tool.

In the near future (2008) we will run the system for all the agricultural areas in Vestfold County. This will give us a broader overview of the obstacles and important experience for further development of the algorithms. For visualisation purposes, we want to create GIS maps for the agricultural areas in Vestfold County showing graded potential locations of cultural heritage sites. We believe that those maps will underline the management aspect within land-use planning purposes. If CultSearcher can help create maps showing potential locations, we can use this information at an early stage in the planning processes, e.g. environmental impact assessments, thus eventually contributing to a more far-sighted planning practice.

Since we understand that there is international interest in our methodological approach, we want to be active in the national and international research arenas. The Directorate encourages all project partners to engage in upcoming research applications, including the cultural heritage management contributing with the user perspective. Participation in national and international research programmes also enables the cultural heritage management to focus on problems which fall outside the current work on developing an operational tool.

If CultSearcher is able to satisfy the demands of the cultural heritage management on a regional level, the Directorate will work towards covering all the agricultural areas in Norway with satellite images, resulting in an overview of potential locations of cultural

heritage sites nationwide. To challenge ourselves – we suggest the year 2013 as a possible milestone.

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