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Detection of beacon networks between ancient hill-forts using a digital terrain model based GIS

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25.1 Introduction

Most villages in the Late Yayoi Period (100AD-300AD) were spread over the plains, since people settled near paddy fields. At the same time, a very small number of settlements were sited on hillsides at altitudes higher than 100 metres. These are archaeologically interpreted as hill-forts on the grounds that they were situated for military purposes (Tsude 1989a). More than six hundred hill-forts have been found all over the country. However, their distribution is not uniform across the country, but many are located in a particular region surrounding the Inland Sea. This is a result of the fact that the region was an important stage for many historical events in the ancient period. One of the most exciting views is that beacon networks may have existed between these hill-forts for military purposes. To establish whether this was the case or not, we should first examine the visibility between every pair of hill-forts. Here, visibility means whether there is an unobstructed view from one site to another.

Although the final conclusion of the hypothesis can only be provided by archaeological excavation, examination of visibilities between all sites is nevertheless a very important step. Indeed, a field experiment has already been carried out on a few sites by archaeologists (Tsude 1989b). In the experiment, several people went up to a key site and fired tyres to make smoke. Groups of people at other sites observed the smoke rising from the key site.

The experiment needed much labour and time. Almost all the hill-fort sites are located in the places that cannot be approached by car. Many people had to be co-ordinated in the experiment at the same time over different sites which are 10km or more distant from each other. Another problem was related to the urbanisation of the surrounding land: tall buildings and air pollution caused difficulties even though the topographical shape of the land has not changed since the ancient period.

Taking those problems into account, an appropriate Geographical Information System (GIS) would appear to be more useful than field experiments in this case. As a matter of course, the GIS should be based on a digital terrain model since the topographical data play a key role in examining visibility between sites. In this paper, current progress towards building the specialised GIS will be presented. A small-scale simulation to verify the basic function of our GIS has also been carried out, and compared with the archaeological field experiment.

25.2 Digital Terrain Model

The digital terrain model employed for our GIS is structured as a hierarchy of grids defined over the Japanese Islands (see Figure 25.1). The minimum grid for digitising the terrain consists of a unit squares of 250 by 250 metres. A fixed number of unit squares of a grid are grouped into a unit square at the upper level of grid. The maximum grid consists of 20 by 20km unit squares. The digital terrain data described here are provided by the Japanese government for limited scientific purposes only.

The south-west corner of each unit square of the minimum grid, denoted by a black dot in Figure 25.2, is a representative point for sampling the elevation of the terrain. The elevation of each point is accurately recorded in metres, and the minimum interval between sampling points is 250 metres (Figure 25.2). Obviously, any topographical shape smaller than the minimum unit square cannot be represented by the terrain model. However, a significant proportion of ancient hill-forts are comparable to the minimum unit square in size, making it almost impossible to describe the precise topographical shape of a hill-fort with this grid system. As a result, there may be only one sampling point close to or within a hill-fort site providing a representative value for the whole

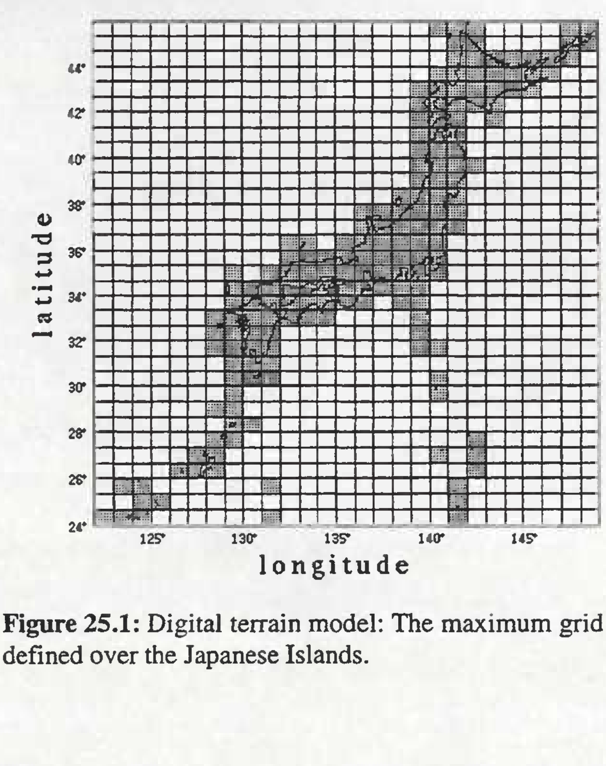

Figure 25.1: Digital terrain model: The maximum grid defined over the Japanese Islands.

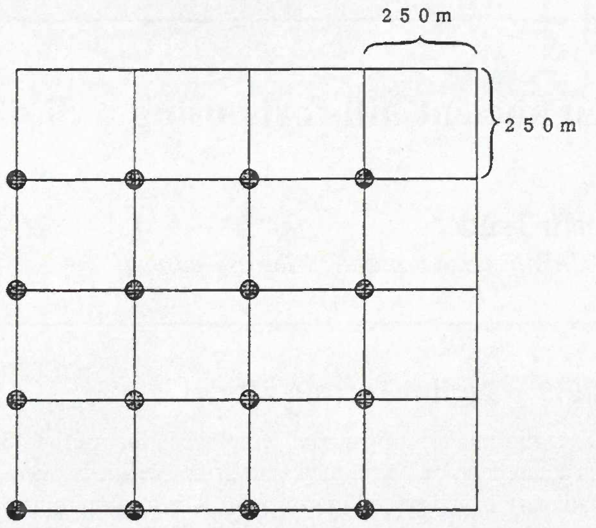

Figure 25.2: Digital terrain model: The minimum grid.

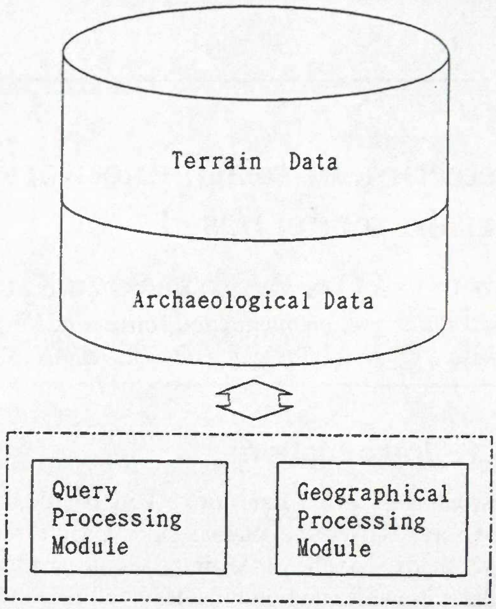

Figure 25.4: Conceptual diagram of the GIS.

site. It follows that the examination of visibility based on such terrain data is likely to be affected by the quantised error due to the grid system. In our GIS, a very simple procedure such as adding a constant value (10 metres, for example) to each site has been introduced to avoid the quantised error. This procedure might, however, produce a new kind of error, in which the system incorrectly identifies two sites as visible, which are in fact topographically obstructed. Minimisation of this kind of error can only be achieved by optimising the constant value through comparative studies between the GIS and field experiments.

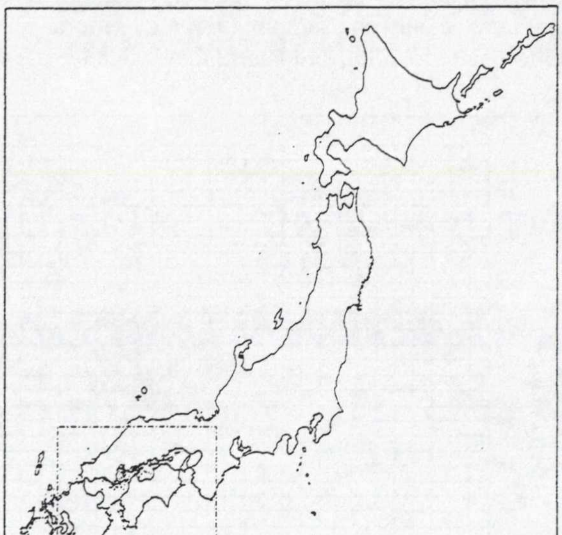

Figure 25.3: Terrain data: The base region stored in the GIS.

The GIS now contains all the terrain data of the region surrounding the Inland Sea (see Figure 25.3). About 50 megabytes are required to store this data on hard disk. Any part of the region can be displayed by simple commands to the GIS. Basic functions of the GIS are outlined in the next section.

25.3 System

Work to build a digital terrain model based GIS started in 1992 mainly to examine the visibility between ancient hill-fort sites. We now have a long term goal of developing our GIS into a generalised system. However, at present it is simply a specialised system related to the ancient beacon networks. In the following, we present a conceptual illustration of the GIS and its basic functions:

Figure 25.4 shows a conceptual diagram of our GIS which consists of two main modules. One is engaged in query operations and in file management. The other concerns the geographical processing which includes display of every part of the region, drawing of distribution maps and examination of visibility between sites.

The database is partitioned into two sub-databases. The first contains the digital terrain data of the region, while the second stores the archaeological data relating to the ancient hill-forts and the keyhole shaped tomb mounds. The current data span a period of 900 years from 300BC to 600AD.

As a result of rapid technical innovation, the latest personal computer has sufficient memory and computing power for our work. Our GIS has been implemented on a notebook personal computer with a 320 megabyte hard disk and a liquid crystal colour graphic display.

25.3.1 Query operations

Figure 25.5 shows a display image for making an inquiry. The table is designed for so-called QBE (Query-By-Example) based inquiries. A user can make an inquiry by entering the required information into columns and rows using a mouse or trackerball and keyboard. Once the

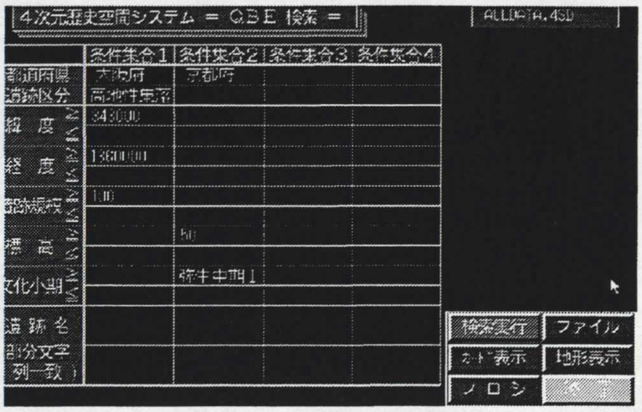

Figure 25.5: QBE-based inquiry table.

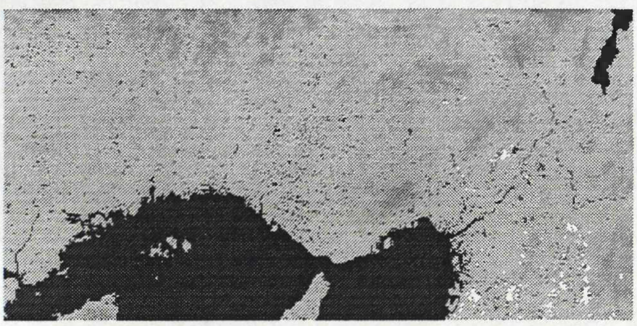

Figure 25.6: Distribution map.

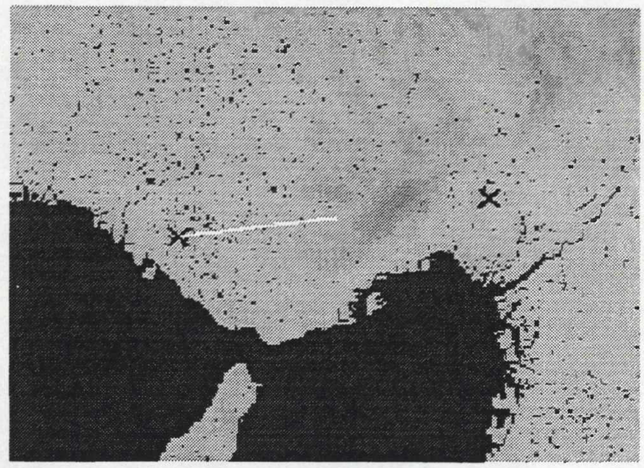

Figure 25.7: GIS-assisted examination of visibility: example of invisible sites.

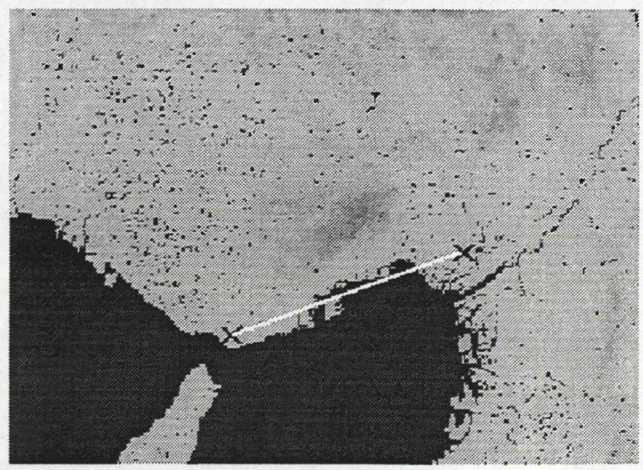

Figure 25.8: GIS-assisted examination of visibility: example of visible sites

enquiry is complete, OR operations between rows and AND operations between the columns in each row are performed. This follows the conventional approach to a QBE system (Wiederhold 1977). The query then extracts a subset of data from the database. Every retrieved subset can be defined as a work file in the system. Combining a work file with the corresponding terrain data, the geographical processing module (Figure 25.4) can quickly draw a distribution map.

25.3.2 Geographical processing

Currently, the geographical processing module can only provide the minimum functions to examine visibility between sites. The base region handled by the GIS is limited to the area shown in Figure 25.3. Any part of this region can be displayed as a two-dimensional image, each pixel of which is coloured according to the elevation. Given a subset of sites in a work file, a distribution map can quickly be depicted by superposing the sites as dots on the displayed map (Figure 25.6). Different subsets of sites can also be superposed on the same map using different colours.

To examine visibility between two sites, the GIS looks through the terrain data to find whether or not there is any topographical obstruction between both sites. Figure 25.7 shows a example where an obstruction cuts visibility between two given sites. Where there is visibility between two sites, a straight line connecting both is drawn on the distribution map (Figure 25.8). For this type of processing, two parameters need to be fixed in advance: the constant value to add to elevation of each site (from our comparative study described below, the optimum value looks to be between 10 and 20 metres), and the limit of vision meaning the distance over which an observer can have a clear view. In our case, the limit of vision is set to 20km.

25.4 Detection of the Ancient Beacon Networks

As mentioned above, the archaeological hypothesis is that beacon networks existed in the Yayoi Period. In order to obtain the basic information to test the hypothesis, a field experiment has already been carried out by archaeologists on a small set of sites located on the hillsides between

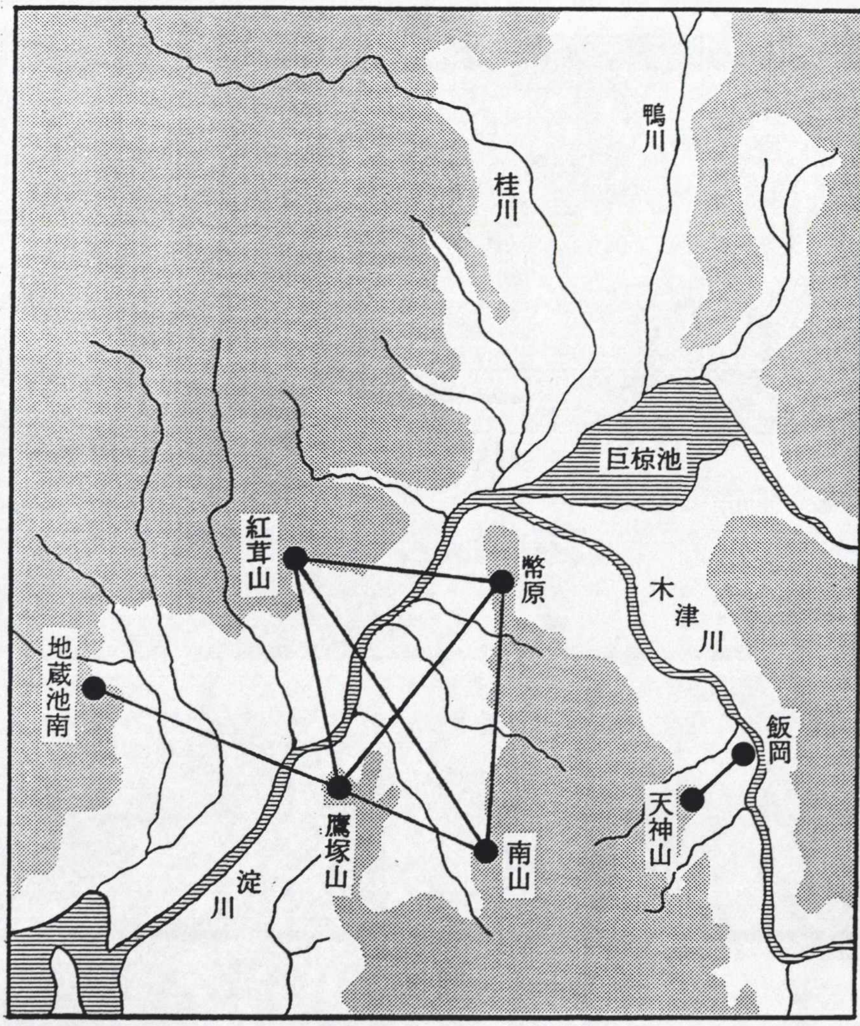

Figure 25.9: A visibility network certified by the field experiment.

Osaka and Kyoto. For our GIS-assisted study, we have extracted seven sites from the set, since they are common to our database. Figure 25.9 shows the seven sites, A-G, with black dots denoting locations of the sites and a hard line connecting two sites indicating that both were confirmed to be visible in the field experiment. The Kanji characters neighbouring a dot indicate the name of the site.

The first step toward GIS-assisted detection of the beacon networks is a comparative study to verify whether the GIS can function as well as the field experiment. Using the GIS, we obtained a similar connecting relationship between the seven sites (compare Figure 25.9 and Figures 25.10 and 25.11). Figure 25.10 shows the connecting relationships associated with site D, and Figure 25.11 is a display image from the GIS, detecting three sites visible from site D. In this example, we added 10 metres to each site as the constant value and let the limit of vision be 20km.

From our comparative study on the seven sites, it appears that the GIS performs as well as the field experiment in identifying visibility between sites. The set of sites handled in our study is, however, too small to verify our GIS completely. Unfortunately, there are no other field results available, and more time will be required to obtain additional experimental results.

When verification is complete, we will be able to look at the ancient beacon networks as a practical problem. Assuming we were now in the position to do this, a simple procedure to detect the beacon network might be as follows.

If the basic requirement for a beacon network was to transmit information to distant places, it will be important to detect a beacon network as a long-distance structure in a given region. However, our geographical processing automatically detects the visibility network of sites which will include many sub-networks; i.e. the short-distance structures of clustered sites. It follows that an additional procedure should be introduced to extract the long-distance structure from such a machine-generated visibility network. One possible way to do this would be by clustering sites: A group of sites close to each other can be considered as a cluster of adjacent and friendly sites, among which information could be quickly spread independently of the beacon network.

Furthermore, if only one site in a given cluster exchanged information with distant sites, then we need a procedure to extract a beacon network, as a long-distance

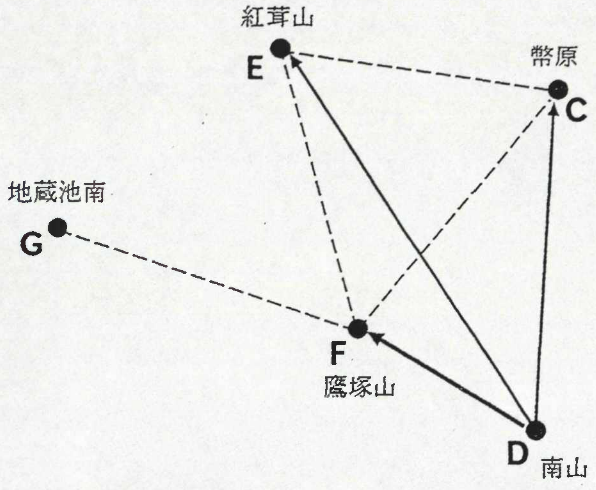

Figure 25.10: Comparative study: the three sites visible from site D in the field experiment.

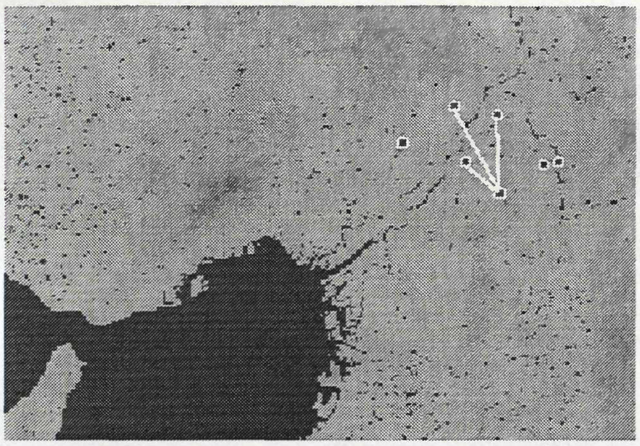

Figure 25.11: Comparative study: The corresponding result for site D given by the GIS.

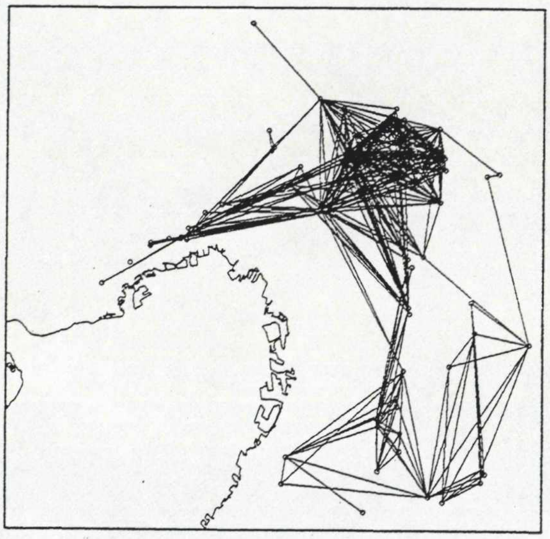

Figure 25.12: Detection of the beacon network: computer generated visibility network.

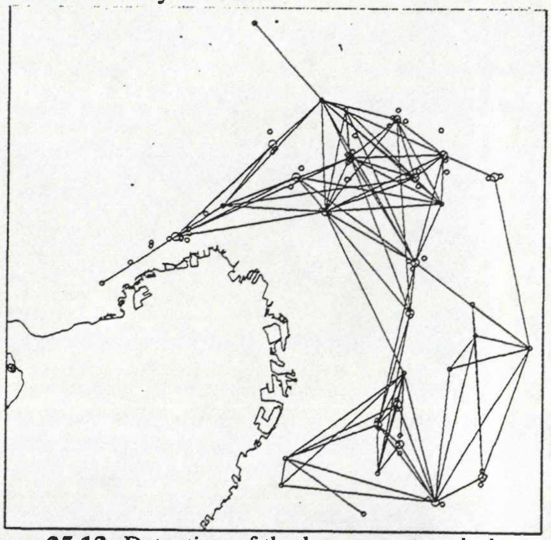

Figure 25.13: Detection of the beacon network: long-distance structure.

structure, from the visibility network: To do this, we first detect clusters of adjacent sites in a given region using the single-linkage method (Ozawa 1983) with the threshold distance to link two sites set at 3km. Then, from each detected cluster, we select one site located around the centre as the beacon station of the cluster. Finally, we define the beacon network in terms of the connecting relationships between the stations. Figure 25.12 shows a visibility network in a region surrounding Osaka Bay. Figure 25.13 presents a long-distance structure extracted from Figure 25.12 using the above procedure. Needless to say, further investigation and discussion is required in order to determine whether or not such a long-distance structure actually represents a beacon network.

25.5 Conclusion

We have briefly described our digital terrain model based GIS designed to detect the ancient beacon networks. We need to verify the ability of the GIS to recognise visibility by comparing its results with more field experiments. Once such verification is completed, there are still many issues involved in detecting the beacon networks. Among them, archaeological investigation will be most important in order to establish that the type of long-distance structure defined in this paper in fact reflects an ancient beacon network.

Another future task concerns developing the present GIS into a generalised system. A GIS associated with digital terrain data which precisely represent the three-dimensional shape of the land will play a very important role not only in the examination of visibility but also in approaching other archaeological research problems.

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