# 3D-MODELLING OF DINOSAURS

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**Abstract:** The paper gives a detailed report on investigations of dinosaur skeletons being conducted to collect data on dinosaurs' life history. A large quantity of physiological data can be derived if the properties of living animals are inferred, e.g. body volume (body mass) and body surface area, using the methods of comparative physiology. These values can be determined through the use of some modelling assumptions if precise data on the skeleton are available. Data are measured using laser scanning and additional photogrammetric methods. The dinosaur skeletons are complex objects with irregular structures so that laser scanning technology will achieve best results. To compute the visual appearance and resultant living weight of the dinosaurs it is necessary to model the surface (shape) of the dinosaur bodies with a CAD-program. The dinosaur is subdivided into different rotational solids to approximate the volume.

## 1. Introduction

In previous research projects, which started in the beginning of the 1990th, 5 dinosaur skeletons were reconstructed with photogrammetric methods only (Figure 1) [2] [3]. First experiences on measurements via laser scanner were made by the survey of *Dicraeosaurus hansemanni* and *Diplodocus carnegii* [4].

In the course of the new DFG Research Unit "Biology of the Sauropod Dinosaurs: The Evolution of Gigantism", which started at the beginning of 2004, further skeletons shall be measured to achieve ground truth data for modelling the shape of the dinosaurs. To compute the visual appearance and resultant living weight of the dinosaurs it is necessary to model the surface of the dinosaur bodies with a CAD-program. The modelling turned out to be difficult because present knowledge about the body shapes of dinosaurs is rather limited. Hence two reference objects were used to get a feeling how to model animals. First the surface of an embalmed rhinoceros was scanned and the computed volume was related to the known living weight to infer the specific weight (bodyweight/volume). Secondly a skeleton of an elephant without known surface was measured and modelled in the same way as the dinosaurs. The volume computed and the resultant body mass were compared with the known living weight of the elephant.

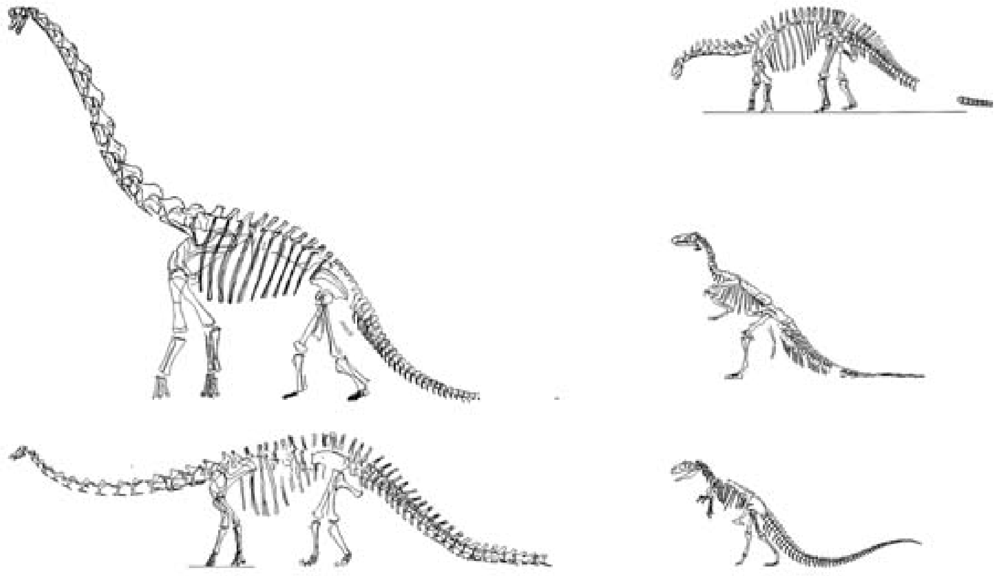


Figure 1: Dinosaurs measured with photogrammetric methods (same scale): *Brachiosaurus* (top left), *Diplodocus* (bottom left), *Dicraeosaurus* (top right), *Iguanodon* (right of centre), *Allosaurus* (bottom right)

## 2. Methodology of Data Recording

Dinosaur skeletons are complex objects with irregular structures so that laser scanning technology will achieve best results to determine the shape of the bones. Due to the size of the skeletons (about 20 m length and 12 m height) the short range laser scanner, S25 from MENSI (Figure 2) was chosen for the measurements. The accuracy orthogonal to range for a measurement distance of 4 m is about 0.8 mm vertical and 0.2 mm horizontal. The accuracy decreases due to the triangulation principle of the scanner to 3.8 mm vertical and 3.4 mm horizontal at 10 m range. The distance accuracy is about 0.2 mm at 4 m and 1.4 mm at 10 m range [1].

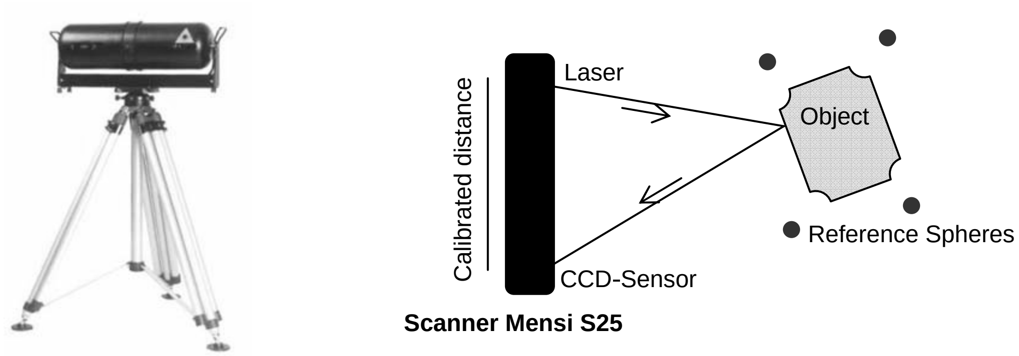



Figure 2: Laser Scanner Mensi S25, triangulation principle

Measurements show, that the registration accuracy for complete objects (25 m²) measured with ranges up to 24 m is less than 1,3 cm. Due to the fact, that modelling of the surface cannot reach this accuracy, the achieved accuracy is sufficient for practical purposes.

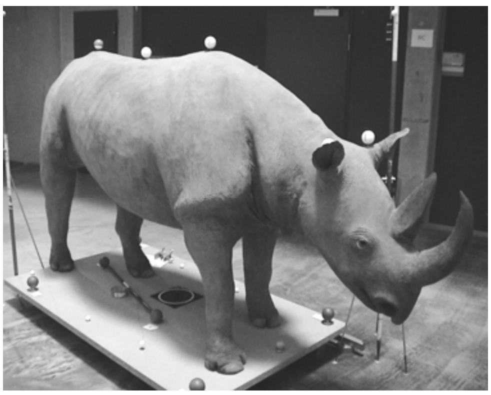
Figure 3: Scanner setup with dinosaur skeleton and reference points

To acquire complete point clouds from the skeletons several scanner positions and reference points for registration were used (Figure 3). Additionally, photogrammetric images were taken with the high-resolution digital camera Canon EOS 1D Mark II. They were used to texture the surface defined by the laser scanner point cloud.

## 3. Data Recording

### 3.1. Reference Objects

Before physiological parameters can be estimated on the basis of the dinosaur skeletons, it is necessary to analyze additional data from living animals allowing to infer those parameters. Hence two reference objects were used to verify the modelling procedure. First the surface of an embalmed rhinoceros was scanned. Secondly a skeleton of an elephant without known surface was measured.



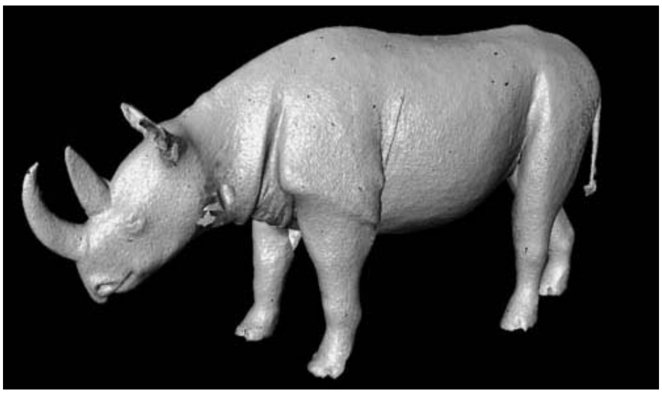


Figure 4: Embalmed rhinoceros Lipsi (left), Scanned 3D point cloud of Lipsi (right)

The embalmed rhinoceros *Lipsi* of Naturkundemuseum Dresden was scanned in May 2004. Two days, 16 scanner setups and 15 reference points were needed to record the surface of

*Lipsi* nearly completely (Figure 4). The result is 700,000 scanned points with registration accuracy less than 3 mm.

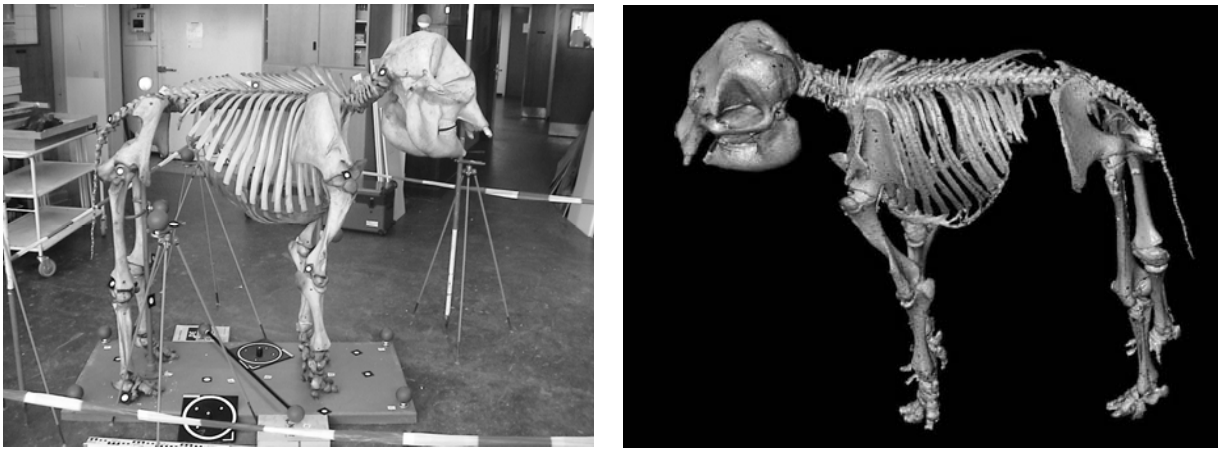


Figure 5: Juvenile Indian elephant skeleton; 3D point cloud of the skeleton

The skeleton of the Indian elephant of Zoological Museum of Copenhagen was measured in August 2004. The juvenile skeleton is of a size of 1.70 x 1.50 x 0.70 m³ and was scanned from 7 scanner positions in two days with 15 reference points used. Over 920.000 points of the acquired point cloud are located on the bones (Figure 5). The registration accuracy is better than 1 mm.

### 3.2. Use of the Reference Objects

To compute the visual appearance and resultant living weight of the dinosaurs it is necessary to get some information about the relation of body volume and living weight. Due to the fact that it is not possible to obtain those data from dinosaurs, other animals have to be used. Therefore, the surface of an embalmed rhinoceros was scanned and the computed volume was related to the known living weight to infer the specific weight (bodyweight/volume). The specific weight of *Lipsi* amounts 1,15 kg/dm³. This is the result of the living weight, which is 1050 kg, and the computed volume of the scanned surface, which is 914 dm³.

To get a training and reference object for modelling animals, the skeleton of the Indian elephant without known surface was measured and modelled in the same way as the dinosaurs' skeletons. The volume computed and the resultant weight were compared with the known living weight of the elephant.

### 3.3. Scanned Dinosaur Skeletons

For determination of physiological data, several dinosaur skeletons are to be scanned within the scope of the research project. It is planned to acquire the data from the different living periods of the dinosaurs. Up to now five skeletons were scanned and analysed (Figure 6). In July 2004, the skeleton of *Plateosaurus engelhardti* was surveyed at the University of Tübingen. It is of a size of 4.30 x 0.80 x 1.90 m³ and was scanned from 10 scanner positions with 17 reference points. The *Atlassaurus imelakei* was measured in November 2004 in Rabat and has a size of 10.00 x 1.90 x 4.50 m³. More than 1.1 million points were scanned from 16 scanner positions. To register the scanner setups 23 reference points were used.

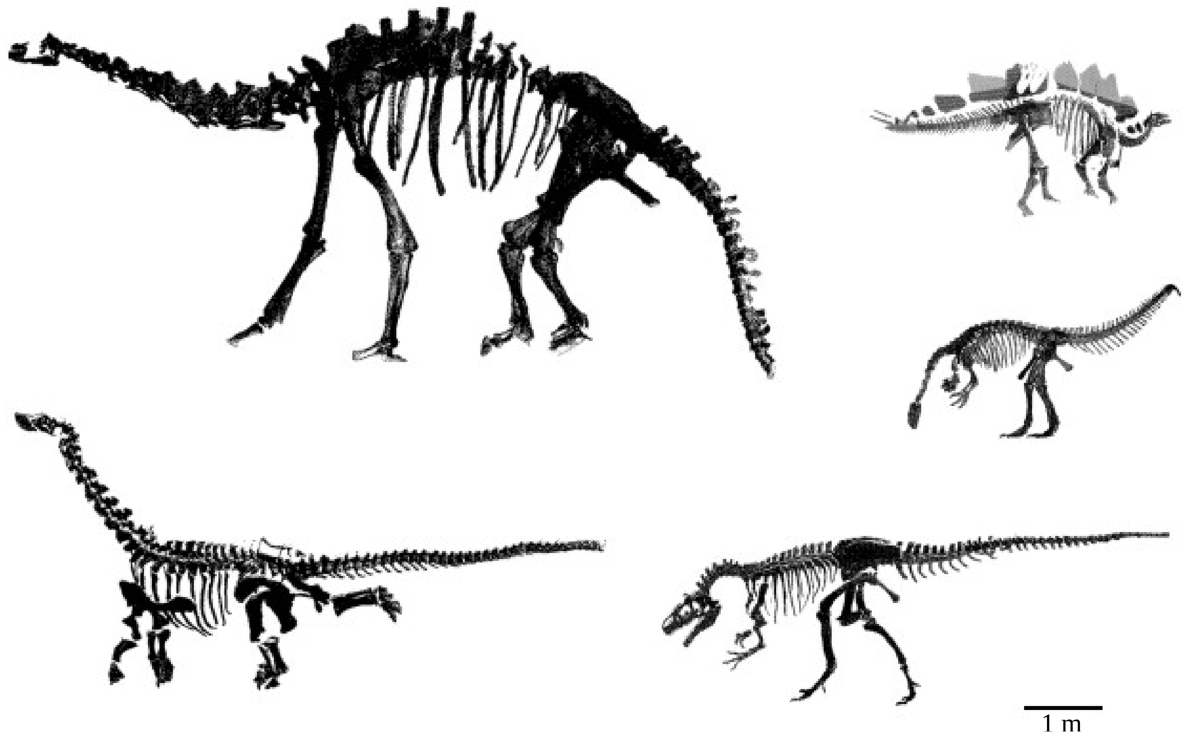



Figure 6: Scanned dinosaur skeleton: *Atlassaurus* (top left), *Stegosaurus* (top right), *Plateosaurus* (right of center), *Camarasaurus* (bottom left), *Allosaurus* (bottom right)

In April 2005 three additional skeletons were scanned in Switzerland. *Camarasaurus* and *Allosaurus* were scanned from only one scanner position and without reference spheres as the skeletons were mounted on a wall. Nevertheless, it is possible to derive some 3D-data of the bones. The *Stegosaurus* was scanned from two scanner positions but also without reference points. The point clouds had to be registered point wise, which is less accurate and more difficult to manage.

Finally, some dinosaur skeletons were scanned in China (Beijing and Zigong) in May 2005 which are still to be analysed. Among them were the *Mamenchisaurus jingyanensis* in Beijing and the *Omeisaurus tianfuensis* in Zigong, just to mention the most important ones.

## 4. Modelling

Present models of dinosaurs are based on photogrammetric reconstructions of the skeletons which were printed and used by physiologists as scaled masters for drawing the shape of the dinosaur. The reconstructed shapes were subdivided into geometrical primitives like cylinders, frustums and spherical horns to compute the surface as well as the volume. Based on these calculations, further physiological data could be derived [2].

### 4.1. CAD Based Calculation

To improve the modelling of the surface rotational solids instead of geometric primitives were applied. The basis for CAD based modelling are the scanned and cleared point clouds of the dinosaur skeletons. According to physiological knowledge the dinosaur is subdivided into constructive rotational solids. These solids ensure an enhanced accommodation to approximate the real shapes, also allowing complex changes of models with reasonable effort. Several rotational solids were diluted and the volume was computed accordingly (Figure 7).

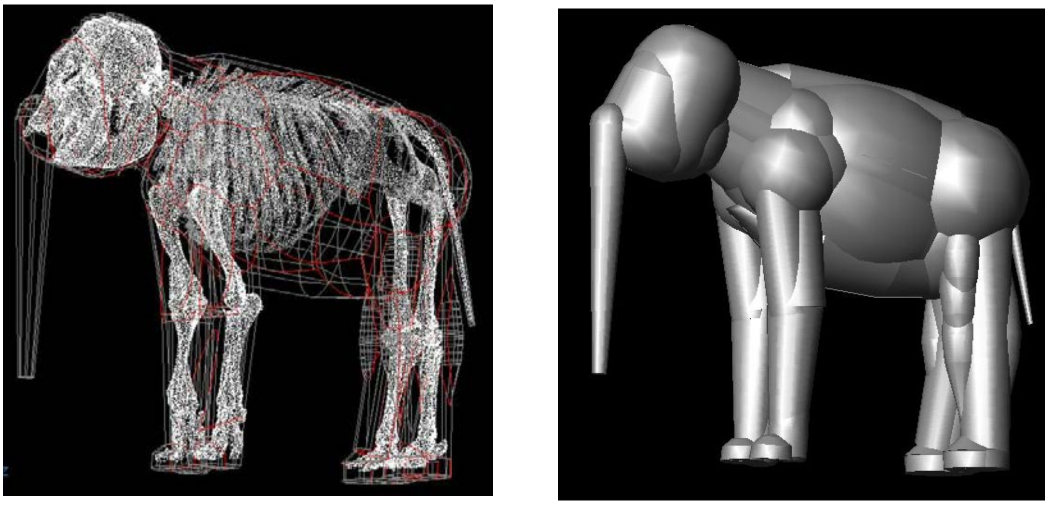


Figure 7: Modelling of the Indian elephant; **left:** CAD based determination of rotational solids; **right:** Modelling result

Shape and volume of the modelled elephant were used to improve the approach to calculate the assumed living weight of animals. Figure 7 (right) shows the modelling result of the elephant with a computed volume of 622 dm³. Adopting the specific weight of 1,15 kg/dm³, which was calculated from the rhinoceros (see section 3.2), a body weight of 715 kg is the result. For comparison, the living weight known to the Zoological Museum of Copenhagen is about 850 kg. The deviation which includes the modelling error of the computer modelling amounts to 16 % which seems to be a reasonable margin of deviation for the weight of mammals.

### 4.2. Modelling Using Fourier Descriptors

To improve the modeling of the surface, instead of rotational solids user-defined surfaces are applied resulting in an increased accuracy. First, the point cloud of the dinosaur skeleton is cut into defined vertical slices. It is then possible to draw a surface free-handedly around the slice. The silhouette of a digitised shape is given by the coordinates $((x_k, y_k),\ 0 \le k \le N_U)$, where $N_U$ is the number of pixels of the silhouette. The *x*-*y* coordinates of each point in the contour to be analysed become complex numbers $x + \sqrt{-1}y$. The contour is now given by the one dimensional vector $\tilde{U}$

$$\tilde{U} = \begin{pmatrix} x_0 + \sqrt{-1}y_0 \\ \vdots \\ x_{N_U-1} + \sqrt{-1}y_{N_U-1} \end{pmatrix} \tag{1}$$

or

$$\tilde{U}_k = x_k + \sqrt{-1}y_k\,,\ 0 \le k \le N_U \tag{2}$$

The shapes of the user defined slices can be described by Fourier descriptors (Figure 8). The Fourier descriptor $\tilde{F}_\mu$ of the silhouette $\tilde{U}_n$ is given by

$$\tilde{F}_\mu = \sum_{k=0}^{N_{U-1}} \tilde{U}_k \exp\left(-\frac{2\pi\sqrt{-1}}{N_U} k\mu\right),\ 0 \le \mu \le N_U\ , \qquad (3)$$

where $\widetilde{F}$ corresponds to the Fourier transform of $\widetilde{U}$ . The discrete Fourier transform can be used as the basis for describing the shape of a boundary quantitatively [5].

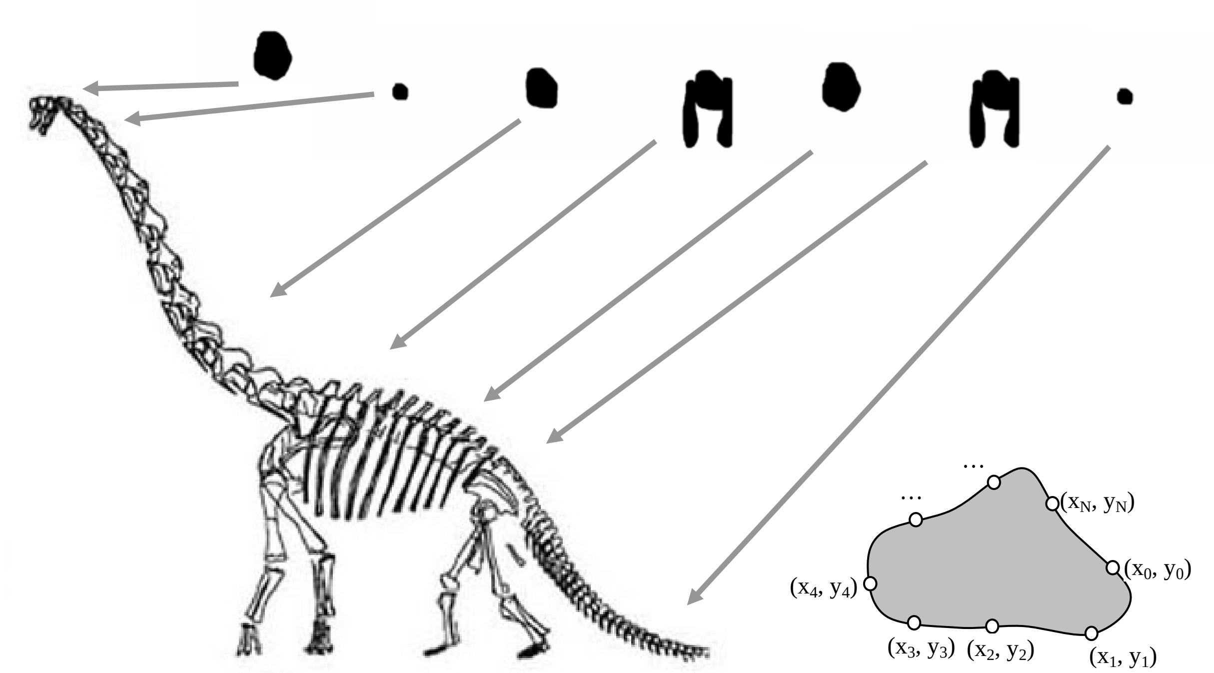



Figure 8: Silhouette segmentation and cutting slices characterised by Fourier descriptors

The advantage using Fourier descriptors is that some algorithms are easier to use in frequency-domain. The representation allows flexible interpolation (regardless the number of points of each slice) as well as filter operations like smoothing or edge extraction. Simple manipulations of the Fourier descriptor frequency-domain representation make the object invariant regarding its original size, position and orientation. Subsequently the slices are connected with morphological operators to compute a final best approximated volume.

First tests are promising good results. Presently, software including a visualisation tool will be developed allowing a comfortable modelling of the surface by the user. One further aim is to implement a software tool which automatically calculates the optimised interval of the user defined slices. An intelligent approach for minimising the quantity of the slices without decreasing the quality of the modelled surface will be developed.

## 5. Conclusions

Modelling of dinosaur skeletons consists of two main phases - first collecting data with a laser scanner, second CAD based modelling of the surface to compute volume and weight of the dinosaurs. It has been shown that laser scanning provides complete ground truth data of the dinosaur skeleton with a good accuracy. Single details can be scanned with a higher resolution allowing to investigate other research goals as well. To model the surface of the dinosaurs close co-operation with physiologists is necessary because they have background knowledge of the distribution of muscles and body masses which is important to infer the shape parameters.

## 6. Acknowledgments

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