

OCT structural examination of ‘Madonna dei Fusi’ by Leonardo da Vinci

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ABSTRACT

‘Madonna dei Fusi’ (‘Madonna of the Yarnwider’) is a spectacular example of Italian Renaissance painting, attributed to Leonardo da Vinci. The aim of this study is to give an account of past restoration procedures. The evidence of a former retouching campaign will be presented with cross-sectional images obtained non-invasively with Optical Coherence Tomography (OCT). Specifically, the locations of overpaintings/retouchings with respect to the original paint layer and secondary varnishes will be given. Additionally, the evidence of a former transfer of the pictorial layer to the new canvas support by detecting the presence of its structure incised into paint layer will be shown.

Keywords: Optical Coherence Tomography, overpainting, cross-sectional imaging

1. INTRODUCTION

Optical Coherence Tomography has been used for the examination of cultural heritage objects since 2003.¹ This optical broadband interferometric technique uses light of very low temporal coherence (to ensure high in-depth resolution) and high spatial coherence (to ensure high sensitivity). It originates from medicine diagnostics and at present may be considered a mature technique in this field.^{2, 3} In the most common configuration, also used for collection of the data used in this contribution, the narrow beam of infrared light penetrates the object and is scattered or reflected at structural elements of the target. Before being directed to the object, the probing light is split between the object and reference beams in a Michelson interferometer. The interference signal (obtained from the light returning from the object and the reference beam) may be detected spectrally (Fourier domain systems with the constant length of the reference arm of interferometer) or temporarily at the single detector (Time domain system with the variable length of the reference arm). Details of the construction of the instrument and a review of applications to the examination of cultural heritage objects can be found elsewhere.⁴

The system used for this study is the high resolution custom designed Fourier domain OCT instrument with the spectrograph used as a detector. It was built especially for the examination of cultural heritage objects under 7FP *Charisma* project at N. Copernicus University in Torun, Poland. The axial (in-depth) resolution is 3 μm whereas lateral one is about 13 μm . Therefore, it is especially well suited for the examination of layered structures such as easel paintings. The instrument utilizes the superluminescent multi-diode light source emitting in band 770 nm–970 nm with the intensity at object less than 800 μW . The axial imaging range is 1.4 mm and sensitivity 98 dB. The distance to the object from the most advanced element of the device is 43 mm and the structural information from the area up to 17×17 mm² may be acquired in one measurement. Collecting data for one 2D cross-section (B-scan) takes 0.15 s. The system is equipped with two standard video cameras for the precise documentation of the position of examined area at the object.

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The majority of papers devoted to application of OCT to the examination of cultural heritage concentrate on feasibility studies of structural imaging of various objects. This approach is especially limited by the major drawback of the OCT technique: limited penetration of the probing beam due to the absorption in some of the materials building the inspected object.⁵ In this contribution, following the approach used in one of our previous papers⁶ we concentrate on a slightly different subject – the detection of previous alterations made within the pictorial layer, possibly not authorized by the painter. In our opinion, the OCT technique is especially well suited for this subject, since such alterations are usually present in the sub-surface strata of the painting. In the abovementioned article some alterations to the inscriptions, caused by a changes in a status of the person portrayed, as well as the evidence of a fraud signature were described. In the case of the painting ‘Madonna dei Fusi’ the evidence of a former restoration attempts may be traced and its results evaluated.

2. EXAMINED PAINTING

‘Madonna dei Fusi’ (‘Madonna of the Yarnwider’ – Fig. 1) a spectacular example of Italian Renaissance painting, attributed to Leonardo da Vinci, possibly with aid of one of his pupils. It was probably executed between the years 1501–1507. The exact history of the picture could be traced down since its purchase by Henry Petty-Fitzmaurice, the 3rd Marquess of Lansdowne in 1809.⁷ Since then it was restored at least twice, but previous attempts cannot be excluded. The painting was previously extensively examined with various non-invasive techniques.⁸⁻¹²

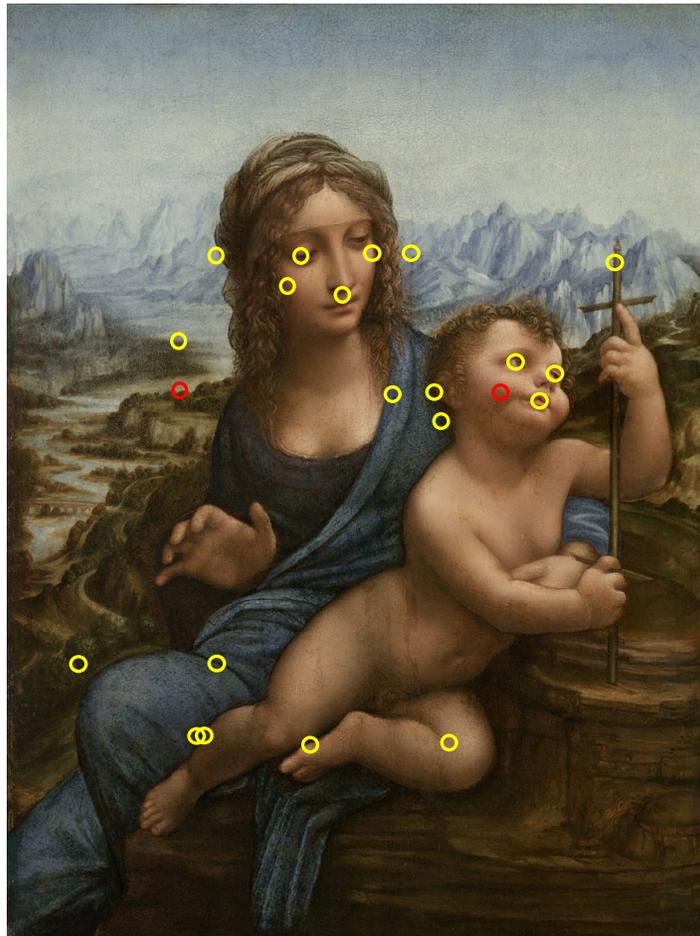


Figure 1. ‘Madonna dei Fusi’ (‘Madonna of the Yarnwider’) attributed to Leonardo da Vinci, oil on panel, 50.2×36.4 cm², private collection. Places of OCT examinations are marked with circles, spots chosen for the analysis in this paper are marked red. Photo: OPD.

3. RESULTS

3.1 Modes of presentation

All the OCT cross-sections are shown in a gray scale (false colours on-line). Light gray areas (warm colours on-line) correspond to high scatter/reflection of the probing light. Dark gray (cold colours) depict areas with low scatter. Perfectly transparent medium (e.g. air above the surface of a painting) or areas located beyond the range of penetration are shown black. An exemplary tomogram collected from the square area ($12 \times 12 \text{ mm}^2$) at the Child's cheek is presented in Fig. 2. All together 100 tomograms were collected from this area, in the figure the whole results panel is reproduced. It's upper part is occupied by the tomogram itself. Beneath scale bars ($200 \mu\text{m}$) show distances in air – in order to recover a vertical distance in medium, the length obtained with the bar must be divided by the refractive index of the medium (usually about 1.5). Additionally, below the tomogram, a reflectogram composed from vertically integrated OCT data is shown with a yellow line indicating the exact position of the cross-section. At the bottom two photographs taken during the data collection are located. The square in the left-hand-side one indicates the exact place of data collection for further reference.

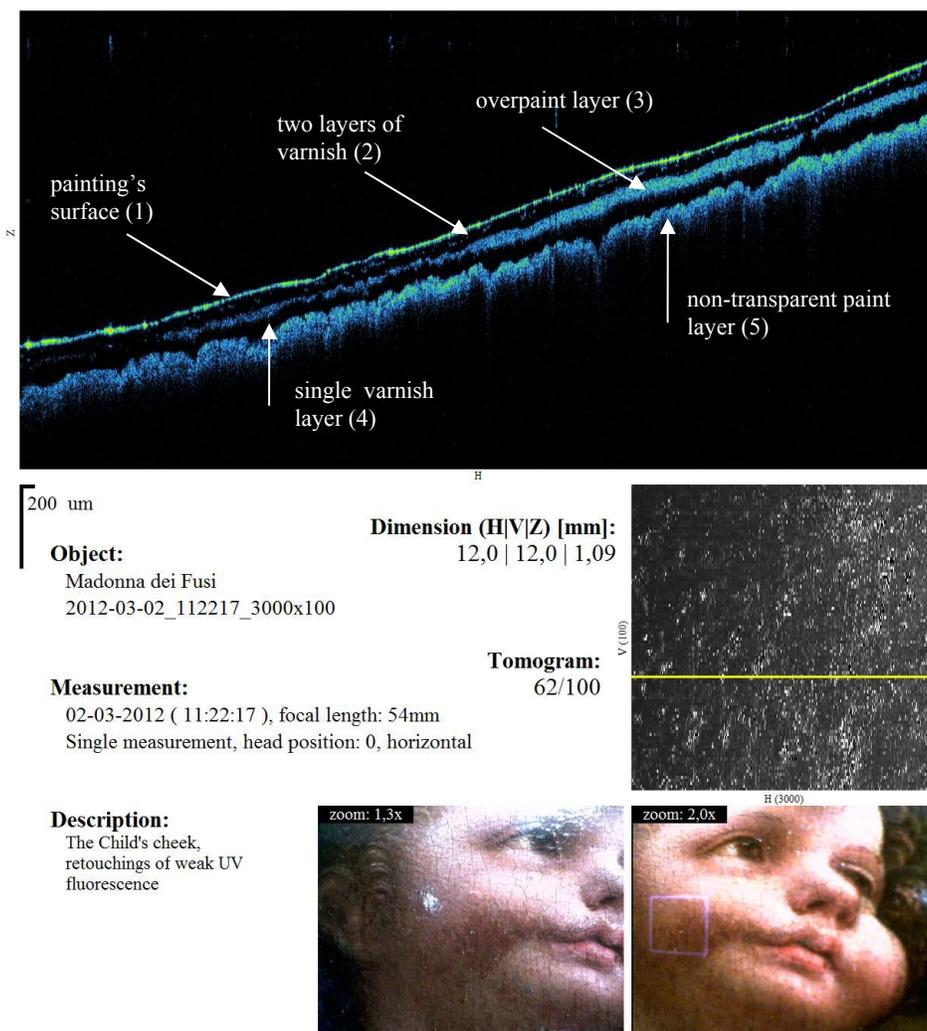


Figure 2. Example of results' panel of the OCT examination. From the top: OCT tomogram; below to the left: scale bars with vertical one elongated for better readability; dimensions: H|V is the size of scanned area where H is a span of the tomogram, Z is a vertical size of the tomogram; below the tomogram – to the right – a reflectogram composed from the OCT data; at the bottom: photographs of the location of scanned area (blue square in the right-hand side photo).

With a 3D cube of volume data (voxels) the further processing is possible. As it can be seen from Fig. 2 a structure parallel to the surface of the painting is present. It must be noted that the painting was tilted for the examination in order to avoid specular reflections from its surface. To analyse this structure closer, firstly the position of the painting's surface was recovered, essentially by detection of the first edge from the top in the image. Knowing the position of the surface, it was possible to extract the slice of data of a given thickness from a given location under the surface. To visualize the structural information from this slice, the maximum of intensity of all voxels of the same surface coordinates (H,V in Fig. 2) is used. The concept of this procedure is shown in Fig. 3.

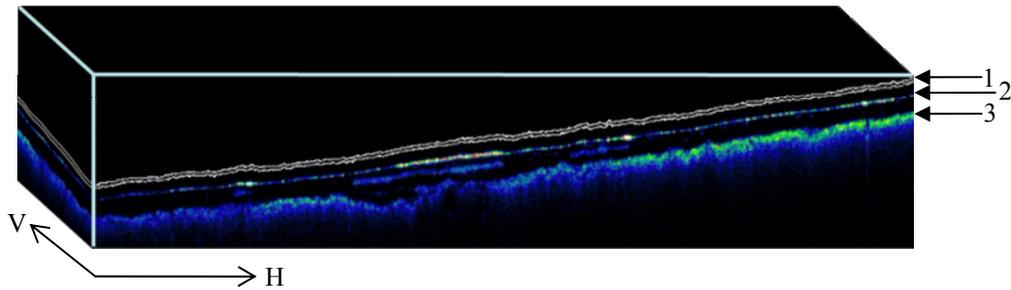


Figure 3. A concept of data slice used for the examination of subsurface structures; (1) – slice position, (2) surface of the painting, (3) upper surface of the paint layer.

The axial separation of data is possible due to the interference principle and thus the minimum thickness is controlled by an axial resolution determined by the temporal coherence of the probing beam and may be described as coherence gating. Therefore, in the following figures the slice position (precisely: it's upper surface) will be referred to as "Gate depth" and it's thickness as "Gate width". Additionally, cross-sectional views in planes indicated by yellow lines in the main image are shown with the relevant position of the slice.

3.2 Analysis of the results

In figure 4 the maps of slices obtained from the Child's cheek (see Fig. 2 for the cross-section) are shown at depths 23, 46 and 54 μm respectively.

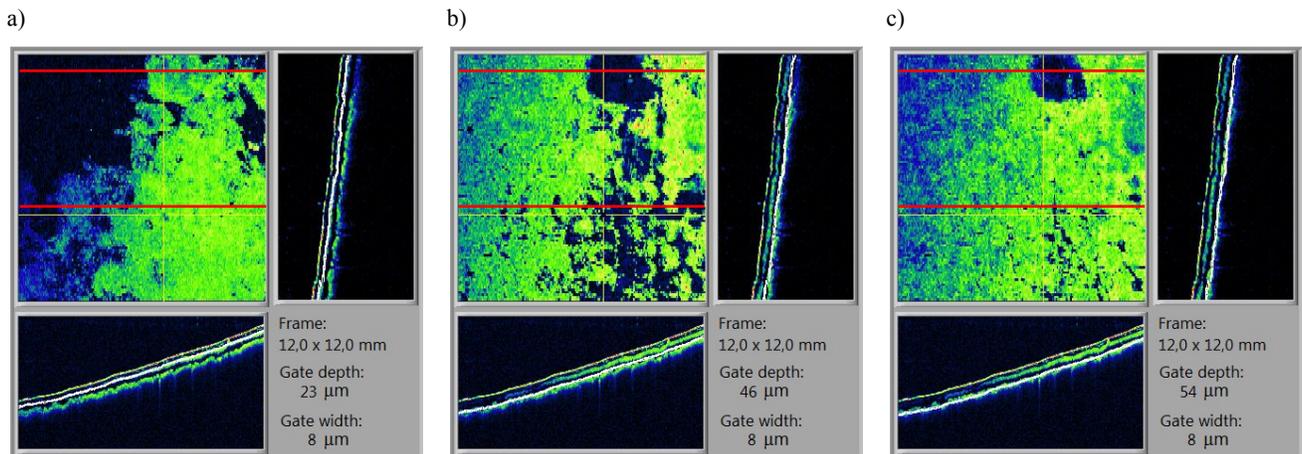


Figure 4. Slices from the 3D data collected from the Child's cheek. The data from the depth of 23 μm (a) reveals the shape of an overpainting located between two varnish layers. Other slices (b,c) belong to the paint layer. Red lines indicate positions of tomograms from Fig. 2 and Fig. 6.

Comparison with the UV-excited fluorescence, photographed in the same place (square in Fig. 5) illustrates the major difficulty in tracing the alterations with the standard technique – they are not clearly distinguishable in this test, probably due to the fact that the overpaint layer is covered with two layers of strongly fluorescing varnish (see the OCT cross-section in Fig. 2).

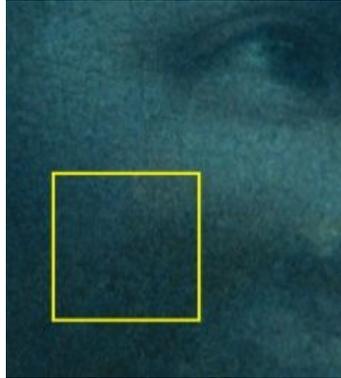


Figure 5. UV-excited fluorescence in the place of examination (yellow square) from Figs 2 and 4. Photo OPD.

Detailed inspection of the results shown in Figs 2, 4, and 5 indicates that the range of the overpaint located between the varnish layers, significantly extends beyond the losses of the paint layer. The dark blue spot, visible at the top of the panels in Fig. 4b,c may be an area of a paint loss but more probably it is just a “shadow” casted by the overpaint layer, very thick in this place. The second possibility is supported by the close examination of another cross-section from the same set, presented in Fig. 6 and collected 0.84 mm below the upper frame of the area (upper red line in Fig. 4). The layer under the overpainting is continuous, therefore it is not an unfilled loss of paint and it is unlikely to be a putty, since putties usually highly scatter the IR radiation.

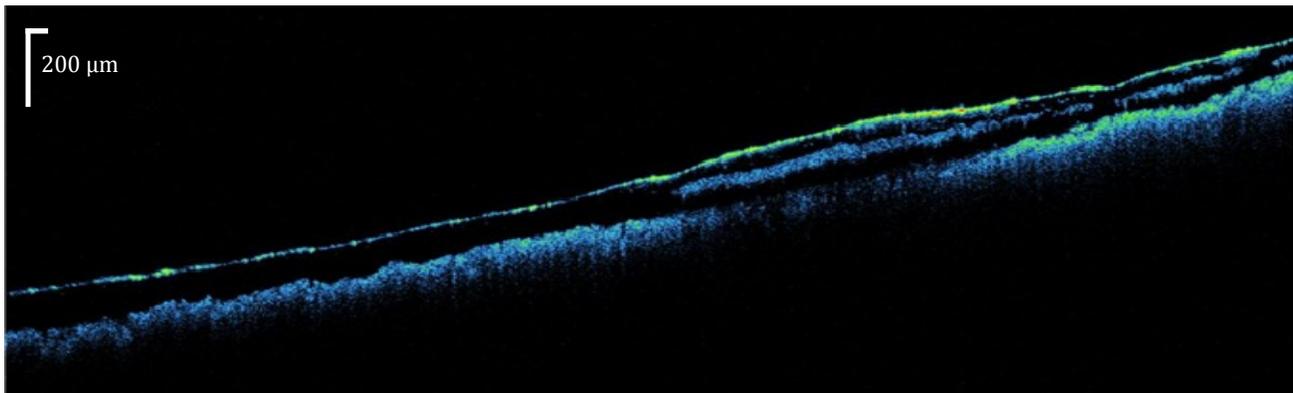


Figure 6. The OCT cross-section collected in the region of the dark blue spot in Fig. 4b,c. Some traces of the paint layer are visible below the thick overpainting.

In case of the second place of examination – the landscape detail (Fig. 7a) the UV-excited fluorescence (Fig. 7b) and the OCT cross-section (Fig. 7c) look similarly to the aforementioned case. The thin retouching layer is located on the thick varnish layer and covered with another two layers of varnish. The paint layer underneath is fairly homogenous in scattering properties, which strongly suggests the lack of paint loss or putty. The analysis of the slices obtained from this data permits precise localisation of the retouched area (Fig. 7d), located 20 μm below the paint surface. The comparison

with the images of deeper strata (Fig. 7e and 7f) confirms the absence of significant paint losses in the examined area. Moreover, the structure of the canvas imprinted in the paint layer is easily discernible in the slice (Fig. 7e) collected from the surface of the paint layer. The origin of this pattern may be explained as follows: during the past renovations the texture of canvas was incised in paint softened by thermal treatment and pressure applied during the process of transferring the pictorial layer of the painting from the primary wooden panel to the canvas support. One should note that the lowest layer of varnish (arrow in Fig. 7c) levels the texture by filling up the hollows of the paint surface.

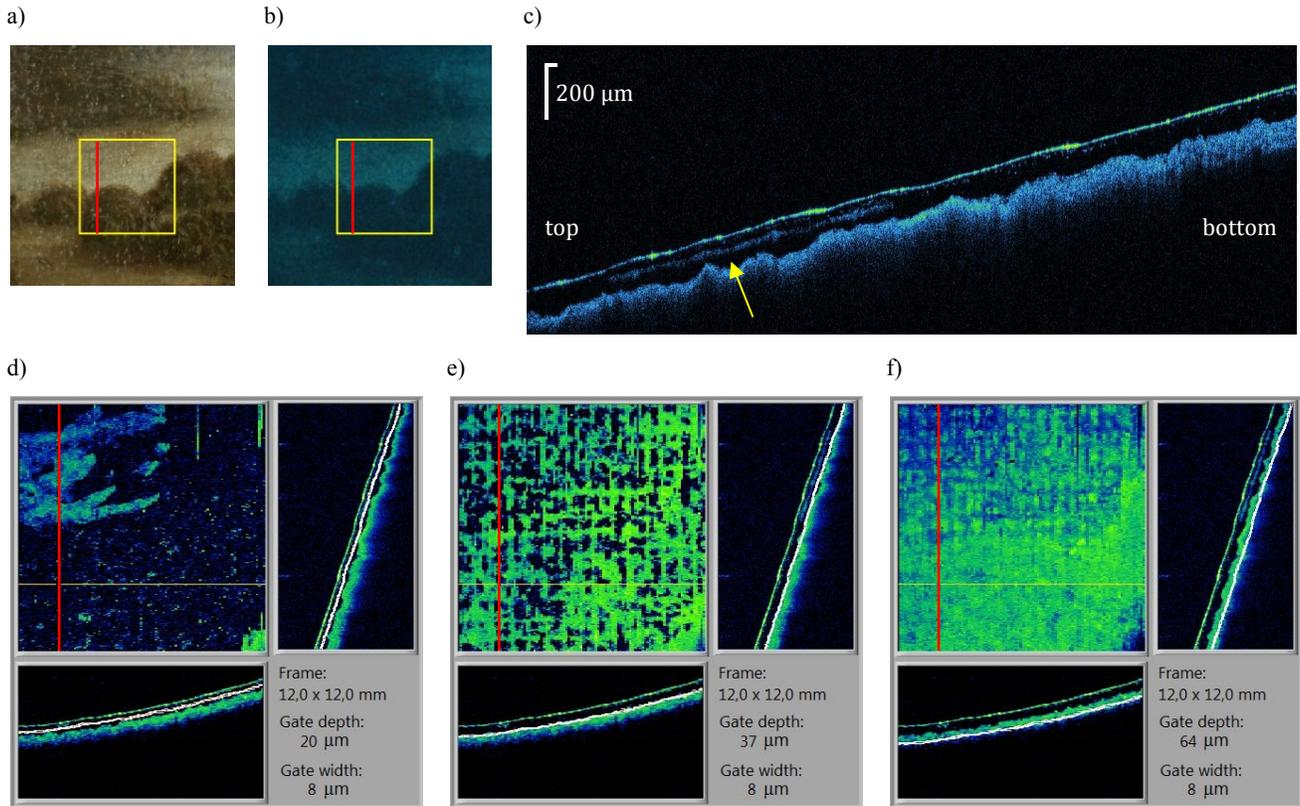


Figure 7. The results of the OCT examination of the landscape detail (red circle in Fig. 1). Location of the scanned area (marked with yellow squares): a) VIS, b) UV-excited fluorescence (photo: OPD); c) one of the OCT cross-sections – its exact location is indicated by the red line; d,e,f) slices from the 3D data. The data from the depth of 20 µm (d) reveals the shape of an overpainting located on the lowest varnish layer. Other slices (e,f) belong to the paint layer.

The average thread counts for the examined area may be determined by Fourier transformation of the data from the thick slice (20 to 65 µm) averaged along the vertical direction. The numbers obtained were 11.4 threads/cm in horizontal direction and 9.4 threads/cm in vertical direction.

4. CONCLUSIONS

In this contribution some account of using OCT for the evaluation of former restoration attempts has been presented. It has been shown that OCT permits the exact localisation of overpaintings and retouchings, both in-plane of the painting and within the strata. The former is especially useful in case of paintings covered with modern varnishes of strong UV fluorescence, as was the case of Leonardo's 'Madonna dei Fusi', when such alterations are not well discernible in the routine UV-excited luminescence imaging. Furthermore, obtained results suggest that the actual size of the paint losses is in the presented examples significantly smaller than the perimeter of the retouchings.

The information about the sequence and thickness of the secondary layers (i.e. retouchings and varnishes) is crucial for the decision making while planning further conservation campaigns. In case of the 'Madonna dei Fusi' the thickness of varnish layers covering the overpaintings/retouchings can be estimated to 20-30 μm , whereas the thickness of the bottom layer of varnish varies from 30-45 μm for the area of the Child's cheek to 25-50 μm for the landscape area. In the second case the large range of measured values comes from the fact that this varnish levels the texture of the paint layer with the canvas imprint.

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