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Medallions

3D-printed Wall Plaques Featuring Procedurally-generated Ornate Shapes

Abstract

"Medallions" is comprised of a series of wall plaques featuring ornate shapes. In this work, each medallion was procedurally generated, and 3D-printed. This project is an attempt at translation from traditional ornamentation to a modern algorithmic art by using a combination of a procedural approach in Computer Generated Imagery (CGI) and the rapidly expanding field of 3D-printing technology. As an element of the medallions, we used 2D metaballs, which are a kind of modeling method in CGI. A drawing algorithm of the metaballs was modified and optimized to generate complicated ornate patterns. Also, regular-polygonal shapes were used for the process of density calculation of each metaball. However, a generated 2D pattern cannot be converted into a 3D model directly because there is an inconsistency that lines with convex information overlap each other in the intersection points on the 2D pattern. To solve the issue, we used an algorithm that an accurate peak height level is calculated at each pixel; the algorithm enables us to generate lines without overlaps. In this way, generated patterns were converted into 3D models, and then the models were 3D-printed finally. The finished artworks were displayed at several art exhibitions, and gained a certain reputation.

Keywords: 3D Printer, Metaball, Ornament

1. Artist Statement

Producing decorative ornaments is time- and energy-intensive because it usually involves complicated motifs. Therefore, ornaments have tended to be removed from contemporary designs along with the modernization of manufacturing after the industrial revolution[1]. However, it is pointed out that the world of traditional manufacturing may change drastically because 3D-printing technology has been growing rapidly in the past several years[2]. By using the technology, it may become possible exquisite designs which have been difficult and costly in traditional manufacturing. This characteristic seems to also be beneficial in the field of formative arts, especially decorative ornaments.

Also, a procedural approach, which is a technique to produce CGI based on an algorithm, may also be useful for generating ornate shapes efficiently. Procedural techniques have been used mainly to simulate natural objects and natural phenomena that are too complicated to be drawn or animated by artists. However, applications of the approach to artificial entities including decorative ornaments increased gradually in recent years[3]. As CGI becomes increasingly indispensable for feature films and video games, it is said that various artificial entities are desirable to be generated procedurally. For example, Whitehead[4] notes that there is room for further research on a procedural approach for generating decorative ornaments to save production costs, especially for numerous video games set in the medieval period. Considering these situations, it appears that a combination of 3D-printing and procedural approach could be beneficial in the field of decorative ornaments.

Incidentally, as an artist, the author has produced some algorithmic art animations; ornaments were featured in some of the works[5]. We think that one of the attractions of procedural techniques is mesmerized details which are difficult with hand drawing. This characteristic is also applicable in the field of ornaments. This project is an attempt of materializing such a beauty found in procedural approach as a tangible artwork in the real world. Based on these viewpoints, a combination of 3D-printing and a procedural approach was applied in this project to produce wall plaques.

2. Related works

Unlike fine arts, which are based on the artist's sensitivity, most decorative arts are based on highly standardized patterns. They usually have distinct formative rules, and they have been developed and sophisticated according to these rules. Decorative arts can be widely classified from primitive geometric patterns, to exquisite ornaments that consist of realistic motifs. As long as formative rules in ornaments, such as repetition, symmetry, and rhythm, are clear, we can extract rules from some decorative styles, and translate them into a computer algorithm.

Although few research cases deal with a procedural approach for designing decorative ornaments, some previous works pertain to the early years of CGI. For instance, Alexander[6] described a FORTRAN program for generating the 17 plane symmetry patterns. However, most research studies from that time focused on simple geometric patterns or tiling patterns. As applications of CGI expanded in the 1980s and 1990s, advanced representations of ornaments emerged gradually. A popular topic in this field is the guilloche, an ornate motif consisting of woven ribbon. Guilloches are widely observed in various traditional Western designs such as Celtic, medieval Russian and Armenian ornaments. Kaplan et al.[7] attempted to construct an algorithm for generating woven ornaments called "Celtic knots" in an enclosed 2D space. Islamic patterns are relatively popular in procedural generation because a clear geometric rule is applicable in their production. C. S. Kaplan et al.[8] attempted to draw the Islamic star pattern using an exquisite tiling configuration. Another study focused on floral patterns, which are present in medieval Western illuminated manuscripts. Most floral patterns in illuminated manuscripts are filled with repeated motifs based on a complicated iteration rule. Wong et al.[9] proposed a drawing method called "adaptive clip art" to fill an enclosed 2D space with floral ornaments. By changing the rule of stem branching and the type of floral motif, this method can be employed to represent various floral patterns in enclosed spaces. The abovementioned works, however, have focused exclusively on planar decorative patterns, and very few attempts have been made at procedural generation of 3D or semi-3D ornaments, such as reliefs, wall plaques, moldings, and grilles. Havemann et al.[10] attempted to generate Gothic style ornaments using Generative Modeling Language (GML). However, their approach covers a limited number of simple motifs, such as arches and a rosette, and it is impossible to generate complicated tracery patterns from the late Gothic period. The author attempted to generate more realistic Gothic ornaments by use of a motif oriented algorithm[11].

Unlike the abovementioned related works, this project does not intend to simulate historical styles of traditional ornaments; rather, it attempts to generate "ornament-like" shapes efficiently.

3. Medallions

This project focused on characteristics found in carvings such as architectural elements in Western traditional ornaments; it was attempted to construct an algorithm based on the characteristics. One of the popular motifs in Western architectural ornaments is a "medallion." It is a circular object with a geometrical or floral motif based on a rule of rotational symmetry, and it has been widely seen in various styles of decoration, from ancient to modern (Fig. 1). It is also called a "rosette" when this type of ornament is used in furniture decoration. Although expressions of medallions vary based on the number of symmetrical axes and the type of motifs, they usually consist of relief-like elements whose cross section has an acute angle. On the basis of this characteristic, construction of a procedural algorithm that generates complicated medallion-like objects was attempted.

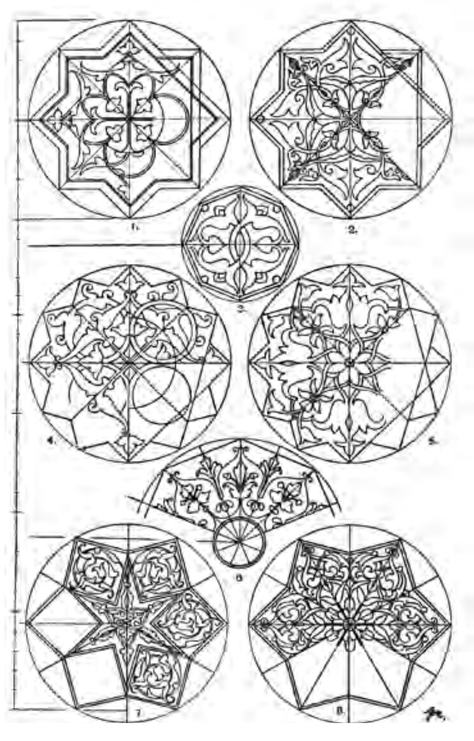


Figure 1 Examples ofmedallions in traditional ornaments
Meyer, Franz S., *Handbook of Ornament*, Dover Publications, 1957

4. Algorithm

Here, an algorithm that is based on medallions' morphological characteristics is constructed. It is desirable for the algorithm to be able to generate various patterns by changing parameters. On the basis of the requirement, this project used a metaball as an element of a medallion. Specifically, we used an algorithm called "stepwise threshold detection[12]." This method can generate more complicated shapes than the regular metaballs; it seems suitable for representing decorative patterns, which are the focus of this project.

4-1. Metaballs

A metaball, a kind of implicit surface, is a modeling technique for representing a smooth curved shape by using density distributions defined in a space[13]. Since it can generate a smooth organic shape whose metaballs merge into each other, like mercury, this technique has been used to represent the human body, animals, and amorphous shapes such as water drops. However, it has been often said that use of metaballs is an unsuitable technique to represent artificial objects such as manufactured products because it is difficult for metaballs to control their merging forms accurately. Although metaballs have been usually used in 3D space, the same method can also be used in 2D space; 2D metaballs can generate a smooth curve. In this project, 2D metaballs are used to generate a procedural 2D pattern, and the pattern is used as a height map for displacement mapping to construct a 3D model. Further, shapes of density distributions in each metaball do not have to be conventional circular shapes; any shapes of density distributions such as squares or hexagons are applicable. This project used metaballs with regular polygonal density distributions as elements of a medallion (Fig. 2). Combining regular polygonal metaballs with the stepwise approach described next can generate a complicated merging shape, which has a mix of straight lines and various curves.

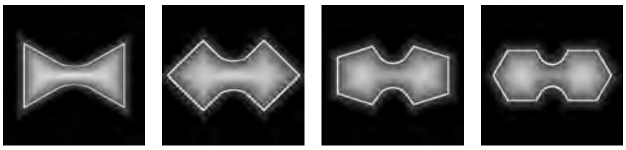


Figure 2 Merging shapes using regular polygonal metaballs

4-2. Metaball using stepwise approach

Unlike 3D metaballs, 2D metaballs can be drawn by calculating a density value of each pixel on the screen. Then, it is determined whether the density value satisfies an optional threshold value; if yes, the pixel is drawn. In a conventional algorithm for drawing 2D metaballs, the total density value in the current pixel is calculated before the threshold detection process (Fig.3, left). Therefore, the resultant shape is always a group of closed curves (Fig.4, left).

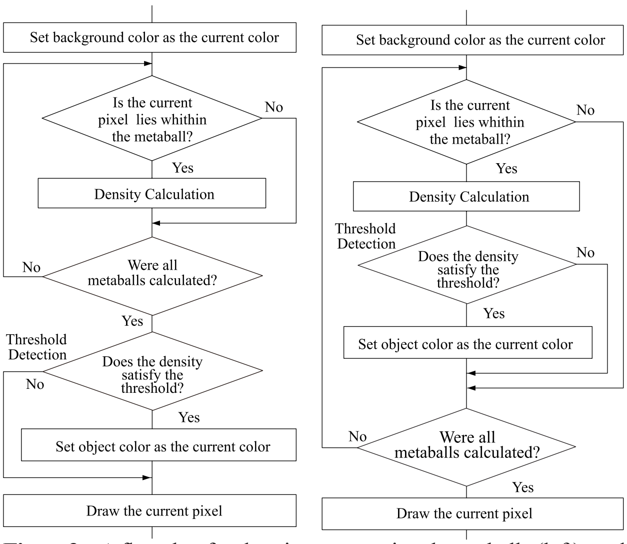


Figure3 A flowchat for drawing conventional metaballs (left), and a flowchart for metaball with stepwise threshold detection (right)

Contrarily, this project used an algorithm termed "stepwise threshold detection" to generate more complicated curves (Fig.3, right). In this procedure, if a metaball including the current pixel is found, the density value of the metaball is accumulated. Then, threshold detection using the accumulated value up to this time is also carried out, and this process is repeated as many times as the number of metaballs that include the current pixel. Consequently, drawing is performed at the pixel having a density value that once satisfied the threshold value. The repetition of this process leads to the generation of complicated curves, like rice terraces, and the curve of each metaball emerges partially (Fig.4, right).

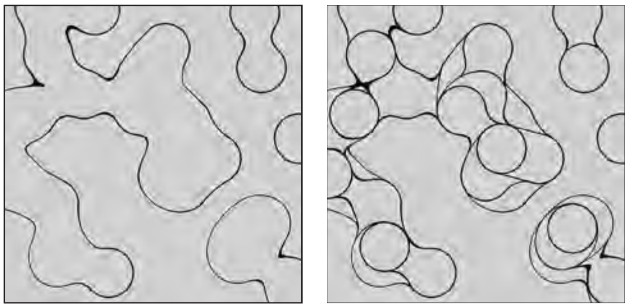


Figure 4 Conventional 2D metaballs (left), and 2D metaballs with stepwise approach (right)

Further, by using numerous metaballs, this algorithm can generate unexpected curves. On the basis of these morphological characteristics, these types of metaballs were used as elements of medallions. As shown in figure 5, in this project, the term "segment" refers to the number of symmetrical axes, and "element" refers to the number of metaballs in each segment. Changing parameters of each segment and element generates various types of symmetrical shapes. Figure 6 shows automatically generated patterns using the techniques. In the images on the figure 6, a black area indicates a lower part of the molding profile, and a white area indicates a higher part.

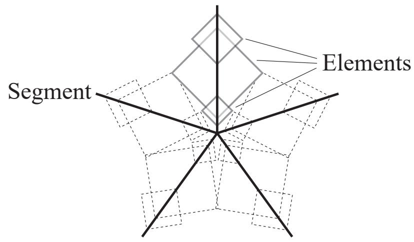


Figure 5 Segments and elements

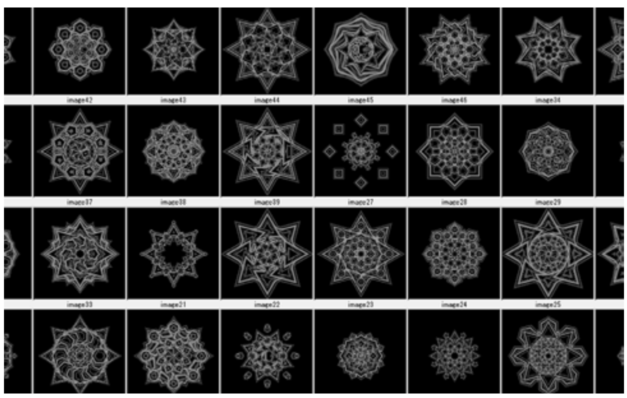


Figure 6 Examples of generated patterns

4-3. Pseudo-3D rendering

As a preview of an appearance of the resultant medallions, a pseudo-3D approach was used in this project. Although the resultant shapes thus far are 2D, a 3D shading can be performed to depict a relief-like effect by applying normal vectors to the shapes. The normal vectors can be calculated based on the density value in each pixel. Figure 7 shows examples of this method.

Figure 7 Medallions rendered with pseudo-3D method

4-4. Displacement Mapping

The shapes generated by using the abovementioned method were converted into 3d models using displacement mapping. Displacement mapping is a method to construct a 3D model using a black and white image which is regarded as a height map. However, there is an inconsistency that lines with height information overlap each other in the intersection points on the 2D image; an incorrect 3D model is generated as a result (Fig. 9, Left). To solve this problem, we used the algorithm shown in figure 8.

Algorithm Height map

```
for each pixel
    define variable p=0
    for each metaball
        calculate a density value
        calculate a height level h based on the density
        if the height level h exceeds p
            p = replaced with the current height level h
        end if
    end for
    output p
end for
```

Figure 8 Pseudocode for calculating correct height map

The algorithm compares the current height value with the peak level up to this time; if the current height level exceeds the peak level, the peak is replaced with the current level. Figure 9 shows a comparison of the resultant appearance. Lines on the right image intersect each other correctly without overlapping.

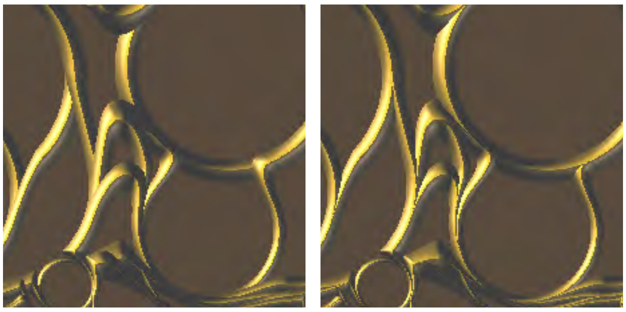


Figure 9 A comparison of the resultant appearance

The generated 2D black and white image described above were converted into 3D models by using displacement mapping (Fig. 10). Also, the generated 3D models were converted into STL data which is the most popular format in the field of 3D-printing. In this project, we used Pixologic ZBrush for displacement mapping and STL conversion.

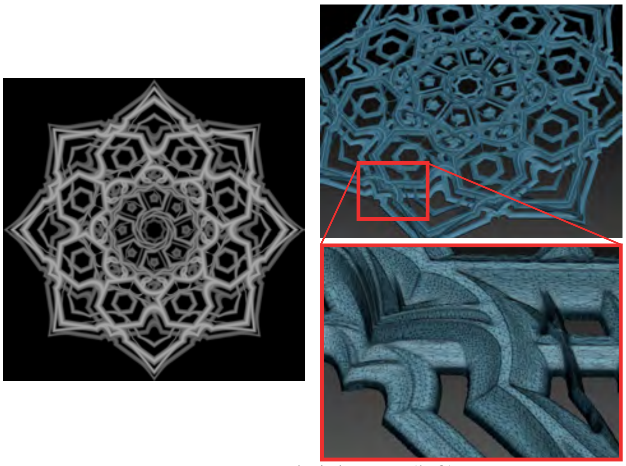


Figure 10 A height map (left),
and the result of displacement mapping (right)

5. Fabrication

The generated 3D models were printed out using professional 3D printers. In this project, Projet1000 by 3D systems was used at the prototype stage. The printer is characterized by using Film Transfer Image (FTI) system; the system can print a high-quality flat plane. The characteristic is expected to be beneficial for printing a relief-like object. However, we found out that the print result does not satisfy the resolution which is required in the field of decorative ornaments. Therefore, we used Projet3500, a more high-resolution 3D printer by the same manufacture, at the stage of finishing. Figure 11 shows a comparison of print results; the dimension is approximately 140mm diameter for each.

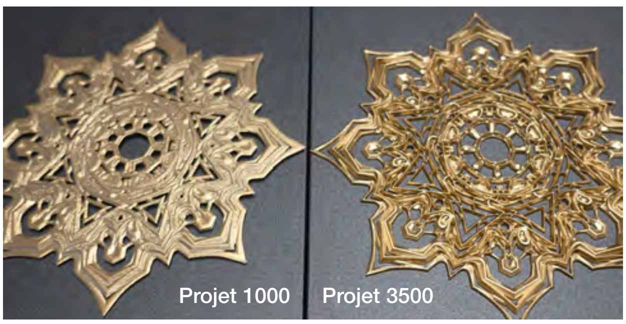


Figure 11 A comparison of print results

Since it was found out that casting and molding were difficult because the printed medallions were ultraprecise, printed objects were coated with gold directly. At the coating stage, a combination of black primer and gold lacquer paint showed the most beautiful gilded appearance as the result of trying various paints. As for colors of the back of the gold frame, color sheets with ultraviolet curable coating were affixed from the backside of the frame. Colorations of the sheets were selected based on the inspirations from historical decoration styles evoked by the resultant medallion shapes. Finally, the finished medallions were mounted on the frame carefully. The finished artwork comprises 6 pieces as shown in the figure 12.

Figure 13 shows another artwork using the similar method. The green patterns surrounding the medallion were also generated by use of 2D metaballs simulating malachite. Namely, everything on the artwork was made from metaballs.

6. Exhibitions

Fortunately, the finished artworks got the opportunity to display at several art exhibitions (Fig.14) including SIGGRAPH Asia 2016 Art Gallery[14]. Among the exhibitions, some were focusing on not only digital arts, but also traditional art forms such as paintings and sculptures. At these exhibitions, this project was the only digital art. Namely, it means that this project was regarded as having an aesthetic value similar to traditional formative arts.

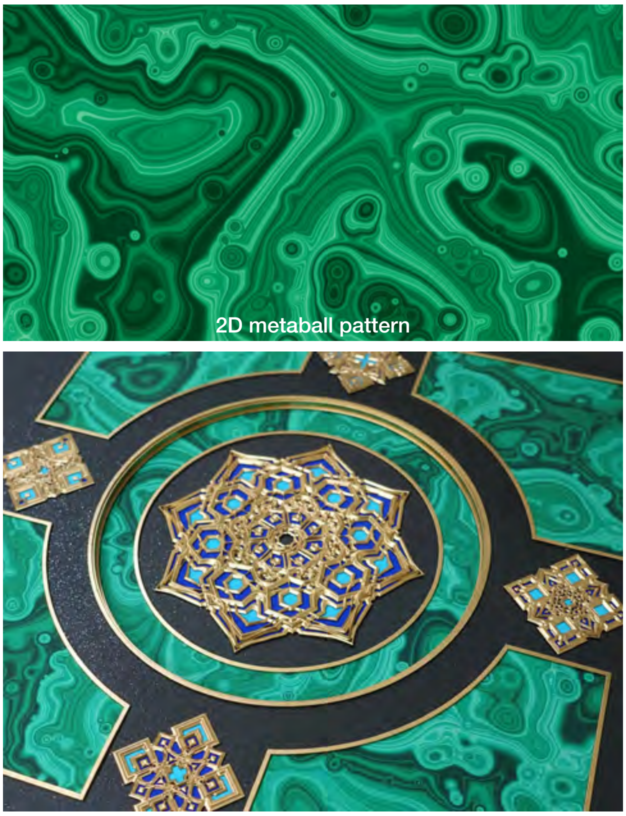
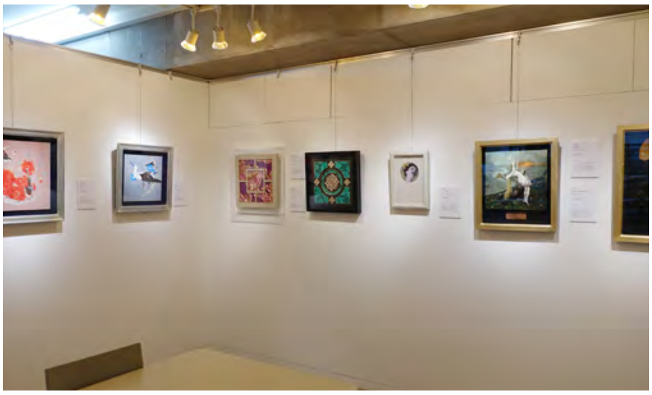


Figure 13 Medallion No.5399 (bottom), and procedural malachite pattern using 2D metaballs (top)

Figure 12 Medallions (2016)

Future Art Exhibition -DOORS-, Isetan Department Store, Feb. 2016



"Painter & Music" Exhibition, Gallery Shorewood, May. 2016

Contemporary Art Launching from Japan, Westin Tokyo, Jun. 2016

SIGGRAPH Asia 2016 Art Gallery: Mediated Aesthetics, Dec. 2016

Figure 14 Exhibitions

7. Conclusion

In this project, it was attempted that a combination of procedural modeling and 3D-printing was used for representing decorative ornaments. Also, the resultant artworks have been displayed at art exhibitions focusing on not only digital art, but also traditional formative arts. From the resultant patterns, it can be seen that a various patterns were generated by changing parameters. In addition, the patterns show exquisite details which are difficult by hand work; it satisfies that attractions of both procedural approach and decorative ornaments. Although the resultant medallions do not imitate historical ornaments accurately, this project was evaluated as having an aesthetic value which is similar to traditional ornaments.

At this time, there is a limitation in our method. Since the resultant shapes were generated by use of 2D data, generating shapes with overhang is impossible. To solve this issue, it will be necessary to construct data in 3D.

In conclusion, it was able to confirm that using a combination of 3D-printing and procedural modeling has a great potential in the field of decorative arts. As a future work, it can be expected that application of this method in not only wall plaques, but also sculptures and architectural elements.

Acknowledgement

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