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Structured Mechanical Collage

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Abstract—We present a method to build 3D structured mechanical collages consisting of numerous elements from the database given artist-designed proxy models. The construction is guided by some graphic design principles, namely unity, variety and contrast. Our results are visually more pleasing than previous works as confirmed by a user study.

Index Terms—3D modeling, collage, shape synthesis, part assembly

1 INTRODUCTION

Digital 3D mechanical collages, such as humanoid robots, are highly demanded in applications such as computer games and sci-fi movies. Such models typically consist of hundreds or thousands of elements or parts. Therefore, building such mechanical models with standard modeling tools, e.g., Autodesk Maya, requires professional skills and is still a tedious task even for skilled users.

Like the production of other art forms, the design of digital mechanical models generally undergoes a coarse-to-fine process. It often starts with a coarse proxy 3D model, e.g., Fig. 2(a), which is used as a starting point for a final model with fine details. Constructing such details is often achieved by manually picking and placing suitable elements, and thus a very time-consuming, tedious process even for moderately detailed models. Hence it poses an interesting research problem of how to speed up the design process by automating part assembly with respect to the proxy model from the artist, such that the artist can focus only on the creative side of the process.

Existing 3D collage techniques [1], [2] may not be suitable for addressing the design problem of digital mechanical collages. When elements of large size, i.e., comparable to the size of proxy components, are used to form a collage of mechanical elements, the resulting models lack sufficient detail as shown in Fig. 2(b). In contrast, when many elements of smaller size are used, the assembled models look chaotic as shown in Fig. 2(d) and fail to inherit the component structure from the proxy model as shown in Fig. 2(a).

To address these issues, we propose a structured 3D collage technique for building visually well-structured digital mechanical collages by automatically assembling elements from a repository of mechanical elements with respect to artist-designed proxy models (Fig. 1). We focus on synthesizing highly detailed mechanical collages, of which proper arrangement of elements is more important (Fig. 2, Fig. 3). Our solution is inspired by some of the graphic design principles, namely: unity, variety and contrast (Section 3.1). We show how these principles can be computationally modeled and used together to produce controllable and structured 3D collages. Visual cohesiveness and interest are achieved by employing these principles at different stages of the assembling process.

We have applied our technique to various artist-designed proxy models of different complexity, shape, structure and style. Results show that our technique is able to automatically produce visually pleasing collages of mechanical elements, leading to highly detailed and structured mechanical collages without user intervention. A user study shows that our technique creates perceptually more visible structures and aesthetically more pleasing collages than the 3D collage technique [1]. In this paper, we mainly use robots to illustrate our ideas due to their popularity in games and movies, but we also show other types of mechanical collages produced by our techniques.

2 RELATED WORK

Existing 2D or 3D collage techniques attempt to solve a common core problem: finding an assembly of elements that maximizes fitting while minimizing the interaction between elements. For example, Gal et al. [1] present an iterative collage updating approach. For each step, it chooses the best surface-fitting element which satisfies the overlap and visibility constraints. The techniques by Theobalt et al. [2] and Huang et al. [3] first divide a target shape or image into segments and then fit to each of them a single shape primitive from a repository of elements. All these techniques do not have any control of perceptual structure in the generated collages and thus simply prefer elements of large size to avoid chaotic appearances. In contrast, our approach concentrates on the arrangement of elements within a proxy model such that the resulting collages are visually structured even when small elements are used.

Our approach is closely related to example-based model synthesis [4], [5], [6], [7] or discrete element texturing [8], [9]. These methods might be used together with a coarse-scale target domain to control the overall resulting shape. However, their goal is to synthesize large models or discrete elements in a large domain according to a small input exemplar. Hence,
Fig. 1: Given coarse proxy models designed by an artist, our technique automatically produces highly detailed and structured 3D collages of mechanical elements, which faithfully reflect the artist’s design intention and are visually pleasing.

Fig. 2: Using large elements, our result in (c) is comparable to that by 3D collage [1] in (b). However, for producing detailed models, our result in (e) exhibits more visual interest and perceptual structure than that by 3D collage in (d).

Another similar problem is discrete element packing, which aims to pack a set of elements into a target domain or shape. The elements used there are often of small size (compared to the target domain) but self-similar (e.g., rocks [10] or text characters [11], [12]).

Our problem is a special problem of assembly-based 3D modeling, for which a variety of user interfaces have been proposed (e.g., [13], [14]). It is only until recently that several automatic part assembly approaches have been introduced for either open-ended 3D modeling [15], [16] or structure recovery from scan acquisition [17]. These approaches heavily rely on part-level semantic information or positional information with respect to entire models in the repository, while there is no such information associated with the elements or parts in our repository.

The perception of visual clutter or complexity has been an important research topic in the fields of cognition and computer vision (e.g., [18], [19]). Recently, Ramanarayanan et al. [20] take the first step to understand the perception of complex aggregates of realistic objects for graphics. Nan et al. [21] present a computational framework to model conjoining Gestalt rules. Although there exist various methods for measuring visual complexity or clutter, how to effectively use such metrics to guide a model synthesis process is still unclear.

3 METHODOLOGY

In this section, we first present several graphic design principles that we have found useful for our problem and then show how to computationally model them towards structured 3D collages.

3.1 Design Principles

Our problem bears strong resemblance to one of the problems in graphic design: the arrangement of visual elements in some type of media (e.g., webpages). While graphic design is a creative process, there exist a few basic principles that appear in every well-designed piece of artwork. Here, we give a brief overview of several such guidelines that are closely relevant to our problem. Note that such principles are interdependent, though they are discussed separately.

Unity generally refers to the overall cohesiveness of element arrangement. Well-designed unity makes separate elements appear to be unified, connected, and interrelated. The design principle of unity is closely related to the Gestalt theory of visual perception [22], [23]. As such, ways to enhance unity include proximity, similarity, symmetry, repetition, and continuation.

Variety attempts to accomplish the opposite of unity [24]. However, if all elements have variety and are different from one another, e.g., in form, size, color, and/or shape, the resulting collages would look chaotic and disordered. On the other hand, too much unity looks boring. Hence, variety must be used together with unity, as seen in most successful designs,
though either of them can be emphasized, up to the
designer.

Contrast is one of the most effective ways to add
visual interest to a design and to create an organi-
ization hierarchy among different elements [25]. It is
often used to attract a viewer’s attention to specific
parts of a design. Contrast is created when elements
are significantly different in terms of e.g., shape, size,
direction and color. For contrast to be effective, it
must be strong and selective. For example, attempting
to apply contrast to all elements often leads to no
contrast at all.

Our work focuses on the application of the above
basic principles to structured 3D collage synthesis,
though we are aware of other principles such as pro-
portion, balance and rhythm. We refer the interested
reader to [22], [24], [25]. To reflect the artist’s design
intention, i.e., the component structure of the proxy
model, we propose to apply unity with variety to
the arrangement of elements within individual proxy
components (Section 3.2) and apply contrast between
proxy components (Section 3.3). This allows artists to
focus on the design of the proxy models and provides
them an easy tool to add visual interest to the collages.

3.2 Unity with Variety
As previously described, unity and variety essentially
compete with each other. We take a two-step approach
to strike a balance between them. First, we create a
well-connected collage but without any unity control
(Section 3.2.1), thus automatically leading to great
variety. Second, we iteratively perform a series of uni-
fication operations until the desired degree of unity
is reached (Section 3.2.2). Compared to an alternative
approach that starts with unity followed by variety,
our approach allows a more precise control on the
style of unity exhibited in the final model.

Element Repository. We downloaded some CAD
models and robot models from the Internet and dis-
sembled them into basic parts as the elements in
our repository. (See their thumbnail images in the
supplementary.) In total, there are 209 elements in our
data set. The reference coordinate system and size of
each element are manually specified. The size of the
proxy model relative to the average size of repository
elements influences the overall collage resolution and
is controlled by the user to suit his/her design intent.

Connectors. Mechanical connections are important
in order for the collage to appear well connected.
In our implementation, we have mainly considered
two types of connectors: male connectors and female
connectors, as shown in Fig. 4. A female connector
is generally a receptacle that receives and holds the
male connector. When a male connector of an element
is connected with a female connector of another ele-
ment, it is said to be a good connection. During the
pre-processing stage, all such connectors are manually
specified for each element in the repository. Here it
may be interesting to note that from our observation,
the relative sizes of the male and female connectors
do not really affect the visual appearance of the con-
nection. This greatly increases the chances of forming
good connections.

3.2.1 Element Assembling with Variety

The input to our algorithm is an artist-designed proxy
model, which roughly depicts a desired global shape
with separate components representing different body
parts of a collage (Fig. 2(a)). Below we first describe
how to select and assemble suitable mechanical ele-
ments from the preprocessed repository to approxi-
mate a given proxy component.

A highly detailed mechanical collage created by
an artist often contains details spread in space such
that internal structures can be partially seen from the
outside. Hence, unlike the approach of Gal et al. [1],
which explicitly searches for best-fit elements with
respect to the proxy surface and simply places them
along the surface, we adopt a hybrid approach and
use the proxy surface only as a soft constraint.

Let \( E \) be a repository of mechanical elements and
\( E' \) a set of elements already placed in the proxy
component. Starting from \( E' \), we use an iterative
growing algorithm to fill the space of the proxy
component until the desired space density is reached
(see the assembling animation in the accompanying
video). As a new element \( e \in E \) is added to \( E' \),
it may intersect with \( E' \) at multiple places forming
several connections \( \{p_k\} \), where \( 1 \leq k \leq N \). While
some connections may form good connections, others
may not. We observed that the visibility of good
connections will influence mechanical plausibility of a
collage, as shown in Fig. 5. This motivated us to bring
good connections near to the proxy surface and bury
poor connections inside.

To achieve this we introduce the following score
function, which is illustrated in Fig. 6:

\[
f(e) = \frac{F(e)}{N} \sum_{k=1}^{N} \left( D_e(p_k)G(p_k) + D_s(p_k)(1-G(p_k)) \right),
\]

where \( D_e(p_k) \) and \( D_s(p_k) \) are the distances from \( p_k \)
to the medial axis and to the surface of the proxy,

![Fig. 4: Examples of connectors and good connections.](image)

![Fig. 5: Without (left) / with (right) hiding poor connections. Elements forming good connections are colored in yellow.](image)
respectively. \( G(p_k) \) indicates if \( p_k \) is a good connection, i.e., 1, or not, i.e., 0. Here, \( F(e) = I(e) \cdot P(e) \cdot (1 - R(e)) \cdot T(e) \), with \( I(e) \) denoting the ratio of \( e \)'s volume not covered by \( E' \) to minimize intersection with the existing elements, \( P(e) \) the ratio of \( e \)'s volume inside the proxy to minimize protrusion, and \( R(e) \) the density of the local unoccupied space surrounding \( e \) to encourage a more uniform distribution of elements in the space. Both \( I(e) \) and \( P(e) \) have minimum cutoff thresholds, below which their values become 0. These are hard constraints. \( T(e) \) is a multiplier that favors elements being oriented along the same direction as the proxy component, defined as \( \alpha (d_e \cdot d_p) \) (\( \alpha = 10 \) in our implementation). \( d_e \) and \( d_p \) are directions of \( e \) and the proxy component, respectively, determined by their longest bounding box edges.

Iterative Growing. Initially \( E' = \emptyset \). The first element in \( E \) that has \( F(e) > 0 \) is selected and placed near the proxy surface where the element locally best matches the surface (similar to [1]). For each growing iteration, we first randomize \( E \) while taking into account the design parameters (Section 3.3). We then select the elements one by one from \( E \) until we identify the first element \( e \) that satisfies the following constraints: at least one element in \( E' \) forms good connections with \( e \); if \( e \) is added as part of the collage, \( e \) should not seriously intersect with the existing elements (i.e., \( I(e) \) is below a certain threshold), and should not protrude too far from the proxy component to respect its shape (i.e., \( P(e) \) is below a certain threshold). To determine the position and orientation of \( e \), we check all possible transformations that translate and rotate \( e \) keeping at least one good connection with an element in \( E' \). To limit the search space, only 48 axis-aligned orientations are used: 6 (positive/negative axis directions) × 4 (rotations along each axis direction) × 2 (mirror reflection w.r.t. a plane perpendicular to an axis direction). \( e \) is finally placed into \( E' \) by the transformation that leads to the maximum value of \( f(e) \). Several iterations are shown in Fig. 7.

First, the degree of chaos can be decreased by similarity and alignment. Second, as the distance between the two elements increases, the degree of chaos decreases due to the decrease in the level of interaction between them. Third, chaos is less noticeable when the elements are partially occluded by other elements. Fourth, when the size of one element is significantly different from that of the other element, the larger simple solution may cause poor connections between elements from adjacent proxy components. A better solution might be to grow the collage component by component, which will be experimented in the future.

3.2.2 Iterative Unification

Now we introduce our iterative unification algorithm, which iteratively modifies the assembled collage within each proxy component to reach the desired degree of unity. As mentioned earlier, there are multiple ways to enhance unity, mainly through some combination of the Gestalt principles. As a proof of concept, our work mainly uses reflective symmetry (Fig. 8), which is widely adopted by graphic designers for a similar purpose. Note that the overall approach described below is general and applicable to other principles or their combinations.

Chaos Metric. We first introduce a metric to measure the amount of chaos between a pair of collage elements. Our metric is based on four observations. First, the degree of chaos can be decreased by similarity and alignment. Second, as the distance between the two elements increases, the degree of chaos decreases due to the decrease in the level of interaction between them. Third, chaos is less noticeable when the elements are partially occluded by other elements. Fourth, when the size of one element is significantly different from that of the other element, the larger
Fig. 9: Elements arranged in decreasing chaos. The reason for chaos reduction is stated below each arrangement.

The amount of chaos for a proxy component is defined as the sum of the amounts of chaos for all pairs of elements in the proxy component. Note that more elements of similar sizes but different shapes generally lead to higher chaos. On the other hand, the amount of chaos is minimized when the collage consists of multiple instances of the same element, uniformly distributed on a regular grid. Our iterative unification algorithm to be introduced next essentially forms a hierarchical organization of the elements in the collage (similar to the symmetry hierarchy in [26]). We measure the amount of chaos for such a hierarchically organized collage using a bottom-up approach, where the chaos metric in Eq. (2) is similarly defined between any two groups of elements.

Iterative Symmetrization. Our iterative symmetrization step is to reduce the amount of chaos for a collage to a desired value. As shown in Fig. 10, each iteration consists of three basic steps: first pick a set of elements or groups of elements to be symmetrized, then symmetrize them, and finally delete or insert new elements to satisfy the desired density. We introduce each step in more detail next.

To effectively reduce the amount of chaos, in each iteration we would like to pick a set of elements (or groups of elements in a hierarchically organized collage) that are rather chaotic (Fig. 10(b)). To this end, we start with a collage element \( e_i \) with \( i^* = \arg\max \sum_{j \neq i} o(e_i, e_j) \). Starting with \( M = \{e_i\} \), we insert elements to \( M \) one by one in a BFS-like manner.

\[
o(e_i, e_j) = O_x \cdot O_d \cdot O_b \cdot O_r.
\]  

Here \( O_x \), \( O_d \), \( O_b \) and \( O_r \) are functions of \( e_i \) and \( e_j \), defined based on the above four observations. Specifically, \( O_x(e_i, e_j) = 2 - I(e_i, e_j) - S(e_i, e_j) \), where \( I(e_i, e_j) = 1 \) if \( e_i \) and \( e_j \) have the same identity; \( I(e_i, e_j) = 0 \), otherwise. Similarly we have \( S(e_i, e_j) = 1 \) if \( e_i \) and \( e_j \) are symmetric; \( S(e_i, e_j) = 0 \), otherwise. \( O_d(e_i, e_j) = 1/(||p_i - p_j|| + \epsilon) \), where \( p_i \) is the centroid position of \( e_i \) and \( \epsilon \) is a tiny value to avoid division by zero. \( O_b(e_i, e_j) = (1 - 2D_{l_{proxy}}/(p_i + p_j))/(2\alpha) \), with \( l_{proxy} \) denoting the diagonal length of the bounding box of the relevant proxy component and \( \alpha = 2 \) in our implementation. Finally, \( O_r(e_i, e_j) = \min(V_i, V_j)/\max(V_i, V_j) \), where \( V_i \) is the volume of \( e_i \). Fig. 9 shows some examples of the effect of these factors.

The amount of chaos for a proxy component is defined as the sum of the amounts of chaos for all pairs of elements in the proxy component. Note that more elements of similar sizes but different shapes generally lead to higher chaos. On the other hand, the amount of chaos is minimized when the collage consists of multiple instances of the same element, uniformly distributed on a regular grid. Our iterative unification algorithm to be introduced next essentially forms a hierarchical organization of the elements in the collage (similar to the symmetry hierarchy in [26]). We measure the amount of chaos for such a hierarchically organized collage using a bottom-up approach, where the chaos metric in Eq. (2) is similarly defined between any two groups of elements.

Finally, we check the density of the resulting collage (Fig. 10(d)). If it is below the desired value, we call the assembling algorithm (Section 3.2.1) until reaching the desired density. If the density is too high, we remove elements one by one, from the proxy center to the surface but without seriously breaking element connectivity. Fig. 11 shows the effect of different amounts of chaos reduction.

3.3 Contrast

While the above approach is able to produce well-structured collages for individual proxy components, assembling all component-wise collages in the same way often leads to a full collage that looks boring, mainly due to the lack of contrast (e.g., Fig. 12(b)). In addition, such resulting collages often fail to reveal the artist’s intention, i.e., the structure of the original proxy model. To address these issues, we propose...
to enhance the contrast between neighboring components of the proxy model. This may be used as a tool to direct the viewer’s attention to specific parts of the collage, which has not been experimented yet.

For simplicity, we assume that the component neighborhood information comes with the proxy model, e.g., manually assigned by the artist. To ensure that all neighboring components have different styles and thus have the contrast effect, we use a greedy graph coloring approach such that no two adjacent vertices (i.e., proxy components) share the same color (i.e., style). We have found that 4 colors are sufficient for all the proxy models used in our experiments. We mainly use the size information to implement the contrast effect and define 4 colors as follows: \( s = (u_v, u_{ar}) \), where \( u_v \) and \( u_{ar} \) are binary digits. All the elements in the repository \( E \) are classified into two groups, labeled as \( u_v = 0 \) or \( 1 \), based on their volumes. Similarly, they are also labeled as \( u_{ar} = 0 \) or \( 1 \) according to their aspect ratios (defined as the length of the longest edge of its bounding box divided by the average length of the other two edges). Each element then has its associated color, denoted as \( s' = (u'_v, u'_{ar}) \).

We notice that for a proxy component with a specific color, simply using the elements with the same color to fill it often leads to a full collage with too strong contrast (Fig. 13(left)). To address the problem, we use the following interpolation equation to relax the contrast: \( s = (1 - \beta)s + \beta(I - s) \), where \( I = (1,1) \), \( \beta \in [0, 0.5] \) is a weight to control the degree of relaxation, \( s \) and \( s = (u_v, u_{ar}) \) are the styles (or colors) associated with each proxy component before and after relaxation, respectively. Fig. 13 shows the effect of varying \( \beta \). \( \beta = 0 \) reduces to the original color assignment, leading to the maximum contrast, while \( \beta = 0.5 \) causes very low contrast, as all proxy components are controlled by the same averaged style. We find that \( \beta \in [0.05, 0.15] \) strikes a good balance in our experiments.

After relaxation, the desired style \( \bar{s} \) for each proxy component no longer consists of binary digits. To determine the appropriate elements needed to achieve the desired style, we sort the elements in \( E \) such that those which can bring the style of the collage in the proxy component closer to \( \bar{s} \) are more likely to be selected first. The sorting is repeated at the beginning of each growing iteration in element assembling (Section 3.2.1). Let \( E' \) be the set of elements already in the partially completed collage. The style of \( E' \), denoted as \( s' = (u'_v, u'_{ar}) \), is defined as the average style over all the elements in \( E' \): \( s' = \sum_{i \in E'} V_i s_i / V \), where \( V_i \) and \( V \) are the volumes of element \( e_i \) and the proxy component, respectively. For each \( e_i \in E \), we check how it helps achieve \( \bar{s} \) if \( e_i \) is added to \( E' \). Let \( s'' = (u''_v, u''_{ar}) \) be the style of \( E' \cup \{e_i\} \). The contribution of \( e_i \), towards the realization of \( \bar{s} \) is then defined as \( \Delta_s(e_i) = w \cdot \Delta_v(e_i) + (1 - w) \cdot \Delta_{ar}(e_i) \), where \( \Delta_v(e_i) = |u'_v - u_v| - |u''_v - u_v| \) and \( \Delta_{ar}(e_i) = |u'_v - u_v| - |u''_v - u_v| \) are the volume and aspect ratio differences, respectively. We use the following interpolation equation to relax the contrast:

\[
|u'_{ar} - u_{ar}| - |u''_{ar} - u_{ar}| = \xi \cdot |\Delta_{ar}| - \min_j |\Delta_{ar}(e_j)| + \xi, \quad \text{where} \quad r \in [0, 1] \text{ to introduce certain degree of randomness to the contrast effect, and} \quad \xi = 0.001 \text{ in our implementation. We assign each element } e_i \text{ a score, which will be used for sorting: } \text{score}(e_i) = r \cdot (\Delta_{ar} - \min_j |\Delta_{ar}(e_j)| + \xi), \text{ where } r \text{ is a random number between } 0 \text{ and } 1 \text{ to introduce certain degree of randomness to the contrast effect, and } \xi = 0.001 \text{ in our implementation. Finally we sort the elements in } E' \text{ in descending order based on } \text{score}(e_i) \text{ and pass the sorted elements to element assembling. Fig. 12 shows an example with and without using contrast.}

4 Implementation Details
Volumetric Representation. The element assembling step in Section 3.2.1 involves repeated intersection tests, which are costly to compute for polygonal meshes. We thus use a volumetric representation to speed up the process. The individual terms in Equation 1 are evaluated using 3D convolution, taking advantage of existing highly optimized GPU libraries.

Functional Elements. A mechanical collage may contain elements to meet its functional requirements, such as joints, wheels and guns. An automatic approach to place these elements requires accurate shape understanding. Instead, we allow the user to manually place these functional elements in the proxy, which are then fixed and connected to elements that are automatically inserted during the collaging process. Fig. 14 shows an example created with manually specified joints.

5 Results and Discussion
We have tested our method on various artist-designed proxy models of different complexities, shapes and styles. As shown in Fig. 1, the collages automatically generated by our algorithm are highly detailed but still visually pleasing and well structured. All of them are generated under both unity and contrast control.
Timings. The unoptimized implementation of our algorithm (in MATLAB with JACKET GPU library) took about 60 minutes to generate the collage shown in Fig. 2(e), which contains a total of 720 elements (360 elements being mirrored). The experiments were conducted on a PC with an Intel i7 3.1GHz CPU, Nvidia GTX580 GPU and 18GB RAM. The assembling step takes about 65% of the total time while the unification takes the rest. Note that the unification stage also calls the assembling algorithm in case of excessive deletion of elements. If such time is counted towards the assembling time, then assembling takes 85% of the total time.

Parameters. A pilot study shows that different proxy components might need different degrees of unity. Generally speaking, the closer a proxy component is to the global symmetry plane indicated by the artist, the lower degree of unity it requires. This is reasonable, since global symmetrization enhances the unity of relevant proxy components, while proxy components that are away from the global symmetry planes need more local symmetrization operations in order to achieve similar degree of unity.

User Study. Compared to contrast, the effect of unity might be visually subtle. We have thus conducted a user study to evaluate the effectiveness of unity alone, i.e., without applying contrast. The state-of-the-art 3D collage algorithm [1] is also included in the user study. We have included three methods for comparison in the user study: the state-of-the-art 3D collage method [1], the naïve method (i.e., our method without unity nor contrast) and our method (with unity alone). For fair comparison, we restrict the orientation of each element in the 3D collage to be one of the 48 orientations.

We used 4 proxy models of various shapes and generated 2 types of collages: highly detailed (i.e., using elements of small size) and moderately detailed (i.e., using elements of medium size). We do not include low detailed collages of large elements in the user study as they already have high degree of unity even without any unity control. We had a total of 97 participants in the user study. Each user was shown eight sets of collages. For each set, we showed the participant three collages (randomly ordered) produced by the three methods. We then asked him/her to indicate the preferred component-wise collage for every part (i.e., proxy component) of the proxy model as well as the whole collage. Fig. 16 shows two sets of collages that we used in the user study. See the supplementary for the other examples.

Fig. 15: Normalized votes for each set of collages. “Overall 1” and “Overall 2” show the total votes for cases using small-sized elements (A1,B1,C1,D1) and medium-sized elements (A2,B2,C2,D2), respectively. “Overall” shows the overall results.

Application to Texture Design. In addition to mechanical collages, our method can also be used to generate 2D or geometric sci-fi textures, which are widely used in futuristic scenes and objects. Such textures are composed of mechanical elements and require certain degree of unity to be visually pleasing. We may generate such textures using a thin proxy, as shown in Fig. 17.

Limitations and Future Works. We manually annotated each element in the repository, which took about 2 minutes for each. A semi-automatic approach for example based on slippage analysis (to detect connectors) might be developed to speed up the process of preparing the element repository. Due to the exhaustive search involved in element assembly, our algorithm is still too slow for interactive control. Our current unification step mainly relies on symmetrization. Thus, the results shown in this paper exhibit similar style of structure. This may be enriched by exploiting more graphic design principles to guide element assembling. Our contrast control is currently applied between neighboring components. This does not guarantee that a viewer’s attention can be directed to a specific part of a collage, which is interesting to explore in the future. Lastly, it is found that artists
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