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THE DESCRIPTION OF TEXTURE

by

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ABSTRACT

One of the simpler examples of a textured array is wallpaper. This note first attempts a formal description of wallpaper-type patterns. The constraints of wallpaper design are then liberalized to provide a formal description of texture as a "generalized wallpaper" design.

1. INTRODUCTION

Wallpaper admits of some trivial structural properties if one takes advantage of the manufacturing constraints placed upon it. The existence of a fundamental repeat pattern of less than 26 inches corresponding to the print cylinder makes it possible to trivially impose a rectangular unit cell on the paper. Such an approach, however, is grossly unjust to the pictorial aspect of the paper design in that it will arbitrarily slice images of the design: flowers, people, etc. without regard to their logical contiguity. The manufacturing unit cell furthermore is rarely minimal in the sense that within the manufacturing unit cell smaller unit cells can often be discerned.

The aim here is to develop a syntax-like vehicle for describing something more primitive than the unit cell itself. However it will still be necessary to employ some atomic, black box elements. In the present case these elements could be thought of as printing plates. A few obvious production primitives for specifying overlay position and other parameters of the printing technology enables one to represent the new unit cell with tolerable economy. The use of the mold introduced in Section 2.4 is a convenience rather than an extension of this capability. Once several constituents have been combined into a single unit cell the structural properties required to fill a place with such unit cells are easy to specify, relying on an intuitive result obtained in the raster theorem (Section 3).

The syntactic description of a paper can best be interpreted as a series of local design rules which are applied repeatedly at the direction of the global infinite reproduction rules. With this interpretation it is easy to extend the rules to apply to more random patterns such as tree bark or other textured scenes. Section 4 discusses the various extensions which are required for the syntactic description needed to embody the properties of such textured patterns.

Probability measures are introduced which transmit their values down the syntactic tree to modulate attributes returned by lower productions in the tree.

2. BASIC OPERATIONS OF UNIT CELL FORMATION

2.1 Template

The fundamental black box is of the form of a template,
e.g.

specifying that < x > is to stand for the picture within the frame and have the dimensions of the frame (i.e. it has synthesized attributes of height and length). Other properties implied in this simple sketch are:

center - taken as the center of the frame
color - a template has gray scale only
orientation - as drawn.

2.2 Color, Size, Orientation

Other primitive functions are

color, e.g.:

< y > :: = < x > colored (red) ;

size and orientation changes, e.g.:

< y > :: = < x > height (2/3) ;

< z > :: = < x > height (1/2) ,
 width (1/2) ;

< w > :: = < x > at 30° .

2.3 Overlap

Various functions are provided to overlap or join several nonterminals together to form a larger, more detailed composite. The basic machinery for putting two pictures together is by specifying a vector and a nonterminal (or equivalent), e.g.:

$$\begin{aligned} < \text{man} > \quad :: = \quad < \text{head} > \quad \underline{\text{at}} \quad \underline{x}_1 \\ & \quad \underline{\text{and}} \quad < \text{body} > \quad \underline{\text{at}} \quad \underline{x}_2 ; \end{aligned}$$

($\underline{x}_1$ and $\underline{x}_2$ vectors) .

Similarly overlap may be explicitly mentioned

$$\begin{aligned} < \text{man} > \quad :: = \quad < \text{head} > \quad \underline{\text{at}} \quad \underline{x}_1 \\ & \quad \underline{\text{and}} \quad \left[\begin{array}{l} < \text{body} > \\ \underline{\text{with}} \quad < \text{clothes} > \quad \underline{\text{overlapping}} \end{array} \right] \\ & \quad \underline{\text{at}} \quad \underline{x}_2 ; \end{aligned}$$

(Brackets, e.g. [----], are used to avoid unnecessary nonterminals).

2.4 Mold

Molds are the means of specifying the same border pattern or background with a variety of center pieces.

```
< man > [ < param > ] :: =
                                < param > at  $\chi_1$ 
                                and < body > at  $\chi_2$  ;
```

then

```
< jones > :: = < man > [ < jones head > ] ;
< smith > :: = < man > [ < smith head > ] ;
etc.
```

The mold can be used to some advantage in many papers, e.g. the flower bed type which contains a different flower in each box but in which each box contains essentially the same greenery:

```
< paper > :: = < box > [ < rose > ] at  $\chi_1$ 
                and < box > [ < hydrangea > ] at  $\chi_2$  ;
etc.
```

3. OPERATIONS OF EXTENSION

These operations are provided to define the manner in which unit cells are hooked together to cover a two-dimensional space. In some cases there is only one possible method, e.g. if the unit cell is shaped like

In other cases (e.g. rectangle) the cellular mosaic is of course not uniquely determined. The space filling cells can be satisfactorily described by considering only the center points of each unit cell (a synthesized attribute). This set of points can be described as a group by selecting any one point as origin.

The Raster Theorem

The center points of space filling unit cells form an abelian group under vector addition having two generating elements [1].

Proof (see Figure 1). If a, b are two non-colinear points of the set then since the set of points is identical, whichever point is chosen as origin (regularity condition) the whole coordinate system may be shifted to b without apparent change in the relative positions of points. Accordingly there is a point at a relative to b , hence $a + b$ belongs to set. By similar reasoning $-b$ belongs and the set is a group. It is clearly abelian. Hence by the group representation theorem there are a finite number of generating elements, say

$$\left\{ g_1, g_2, \dots, g_n \right\}$$

Figure 1. Repeat Lattice

Now clearly if the cells are of finite size, $n \neq 1$. Also the group is a subgroup of the group of all vectors with rational coefficients in two dimensions which is generated by two elements. Hence $n = 2$.

The set of points can accordingly be viewed as a mesh of points in which each point is expressible as $mi + nj$ where m, n are integer. (See Figure 2).. This is the only possible representation.

Given the unit cell to specify the paper one thus need only provide the vectors i, j .

Figure 2. Regular Raster of Unit Cell Centers

4. DESCRIPTION OF MORE COMPLEX PATTERNS USING INHERITED ATTRIBUTES

The development so far has concentrated on synthesized attributes, i.e. properties transmitted up the syntax tree. The introduction of the dual properties -- inherited attributes -- does not alter the class of papers which can be described in the notation; however, it does provide a handy method of specifying non-deterministic "papers" in which the features of the result are in some sense random but possess sufficient structure to have a discernable texture.

We have already seen at least one example of an inherited characteristic in the mold of Section 2.4. Parameters passed in this case were merely nonterminals which presumably would be used within the production. (As above notice that molds do not extend the class of pictures that we may describe, only the convenience with which we may do so). Knuth's discussion [2] of inherited attributes is somewhat more complex than we need here. The only attributes of concern here can be handled by parameterizing the nonterminals in a more general way, i.e. by allowing parameters related to size, color, orientation and other properties as desired. Thus for example an infinite checkerboard might be expressed as:

```
mesh is  $2i_k$  by  $2j_k$  of < unit cell > ;  
< unit cell >  ::=   
    < square > [ black ] at ( -1/2, 1/2 )  
and < square > [ black ] at ( 1/2, -1/2 )  
and < square > [ white ] at ( 1/2, 1/2 )  
and < square > [ white ] at ( -1/2, -1/2 ) ;  
< square > [ color ]  ::= =
```

colored (color) ;

5. PROBABILISTIC FUNCTIONS AS INHERITED ATTRIBUTES

By passing a stochastic variable to a nonterminal it is possible to cause it to behave (i.e. take attributes) in a pseudo random way. Various options are available: the nonterminal may not use the parametrized probabilistic function at all, it may use an entirely independent stochastic variable or it may merely calculate probabilities and pass them on to other nonterminals for further processing. It is important to realize that the only paths of communication are to parents and sons in the syntactic tree and that there is no mechanism for passing information between brothers. Thus it is necessary for the parent in any production to insure whatever continuity conditions are demanded by the system being modelled. If for example the texture is simply a black thread on a white background,

then each unit cell may make whatever local perturbations it chooses provided it maintains both position and first derivative at the boundary. It is up to the production which concatenates these unit cells to specify these parameters and pass them to the nonterminal < unit cell >.

Example: a syntax to produce a two-dimensional woven pattern with random noise. (See Figure 3).

P is normally distributed with mean 1/2, variance 0.1.

D is normally distributed with mean 0, variance 0.01.

CP (m,n,d) = if cell (m,n) is full then d (w,n) .posn.

else P ;

CD (m,n,d) = if cell (m,n) is full then d (m,n) .directn ;

mesh is i by j of

< unit cell > [2[CP (m-1,n), CP (m+1,n)] ,
2[CP (m,n-1), CP (m,n+1)] ,
2[CD (m-1,n), CD (m+1,n)] ,
2[CD (m,n-1), CD (m,n+1)]] ;

< unit cell > [p, q] :: =

< thread 1 > [p [1], q [1], X = P, Y = D]

and < thread 2 > [p [3], q [3], p [4], q [6]] overlap

and < thread 3 > [p [5], q [5], p [6], q [6]] overlap

and < thread 4 > [p [7], q [7], p [8], q [8]] overlap

and < thread 5 > [X, Y, p [2], q [2]] overlap ;

For thread productions, see Figure 3.

< thread 1 > [a, b, c, d] :: =

with noise ;

< thread 2 > [a, b, c, d] :: =

with noise ;

< thread 3 > [a, b, c, d] :: =

with noise ;

< thread 4 > [a, b, c, d] :: =

with noise ;

< thread 5 > [a, b, c, d] :: =

with noise ;

Figure 3. Partial Productions for Woven Pattern

The productions for < thread 1 > through < thread 5 > are really black boxes in that the language has no means of specifying a line which retains beginning and end points satisfying certain derivative conditions. (The four parameters passed to these productions specify in turn the left (or top) thread position and its derivative and the right (or bottom) thread position. The "with noise" is intended to allow the production to vary its output according to any probabilistic method it chooses). The production for unit cell is designed to add each thread in a woven pattern. If done in a constructive manner the result at the end of each line would be (see Figure 4). In reality of course given noise it might look something like:

The continuity conditions established by CP, CD then insure that this cell fits in with its neighboring mesh points.

Figure 4. Serial Addition of the Five Threads

SUMMARY

The scheme outlined above provides a means of representing wallpaper. However the appropriateness of this descriptive scheme for the wider context of texture cannot be decided without practical simulation to see if indeed the probability functions provided do indeed adequately abstract the essential characteristics of the textures and patterns of daily life.

The choice of notation ignores possible global consequences arising from action taken at lower levels in the tree. It would be possible to extend the language to be able to handle the restriction that fibres be of a certain length. This aim however is the antithesis of the original aim of the notation, and one is tempted to brand such an extension as inappropriate. A more serious failing of the present language is its inability to deal with dynamic cell sizes. It is not yet clear that such an extension can be done in a neat way. For example suppose one wished to model a woven fabric which had been stretched as shown in Figure 5. The contour lines for the coordinate system provide a distorted lattice, which of itself presents no great problem, but projecting these distortions down to the constituents of the unit cell represents considerable busy work.

Figure 5. Distorted Lattice for Stretch Fabric

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