

# Sequential Encoding of Tamil Kolam Patterns

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The kolam is a traditional hand-drawn art form in Tamil Nadu and South India comprised of many subfamilies. Kolam patterns are most commonly drawn with chalk or rice powder by women on the thresholds of homes and temples and are of significant cultural importance in Tamil society. Academic investigations of Kolam patterns have used many different terms for different kolam pattern types. I introduce a global typology of kolam types, and present an extension to the square loop kolam (SLK) patterns studied in the past. Square loop kolam patterns are composed of an initial orthogonal matrix of dots, defining a space around which curving lines are drawn to complete one or many loops. SLK patterns can be decomposed into the gestures made by the artist's hand, and previous studies have created sequential languages to represent SLK patterns. Prior kolam languages used a limited gestural lexicon and could not account for the diversity of SLK patterns produced by artists. The current paper introduces an expanded sequential gestural lexicon for square loop kolams, and describes a system for the digitization of SLK patterns using this expanded and expandable language.

**Key words:** Kolam, Tamil Nadu, Sequential Language, Lexicon, Knot Pattern

## 1. Introduction

### 1.1 Ethnographic research

The kolam is a traditional art unique to Tamil society, and an object of ethnographic study. In Tamil Nadu, women of all ages draw kolam (Tamil plural: *kolangal*) patterns. These patterns are often drawn in the early morning on the threshold of the home as a kind of visual prayer for the safety and wellbeing of the household. While the designs are considered by many to have a religious significance, many women think of them mainly as decoration. Some kolam have special significance, or display religious imagery. Special kolam designs are created for the holy day of *Pongal*, the Tamil New Year festival, celebrated during the month of Margazhi, which extends from mid-December to mid-January. Young women often learn to make kolams from older female relatives and neighbors. Many women keep notebooks of their favorite patterns, and some practice them with pen and paper. In Tamil Nadu, small paperback books containing hundreds of kolam patterns are sold as a novel source of kolam designs for local artists.

There are many families of kolam patterns, each with highly distinct geometric details. The north Indian Rangoli, or *pu kolam* (flower kolam) in Tamil, are radial kolam patterns (Fig. 1b). These kolams display radial symmetry, and do not require an initial dot matrix. The spiral kolam family, by contrast, also displays radial symmetry, but is constructed on a star of dots, and drawn as a single line (Fig. 1a). Siromoney and Chandrasekaran (1986) term this family *Hridaya Kamalam*, and analyze its construction, which starts with an *n*-pointed star of radiating dots. Two large and popular families of kolam that are based upon an

initial matrix of dots (or *pulli*). One of these is the tessellated kolam, in which individual line segments or short arcs connect the dots directly, forming a tiled image and often a pictographic representation (Fig. 1c). Tessellated kolam are drawn with both orthogonally and hexagonally packed dot matrices. The family of kolam that has drawn the greatest academic attention is the loop kolam (Figs. 1d and e). The loop kolam is also composed of an initial dot matrix, but unlike other kolam families, curving (*nelevu*, or *sikku*) lines are drawn around the dots to form loops. Both tessellated kolams and loop kolam families may each be divided into two subfamilies based on the packing of the initial dot matrix. Tamil women will often combine aspects of multiple kolam families in a single design, and do not distinguish between these families with rigid terminology and practice. Instead, kolam artists use descriptors to highlight important features, such as *pulli* (dot), *kambi* (line), *pu* (flower), *sikku* or *nelevu* (curving line). Figure 1 presents a truncated typology of kolam families.

The loop kolam family is unique because it contains both sequential and spatial aspects. The final product is a two-dimensional pattern, yet women draw the kolam loops sequentially, acting out a sort of mental recipe for each pattern. These recipes are rarely spoken, but are rather inferred by the learner, and only the patterns themselves are recorded. Loop kolams are composed of a small, identifiable set of gestures common across many patterns. Thus the loop kolam tradition contains a rich gestural language making it suitable for various types of analysis. The tessellated kolam and radial kolam are composed of joints connecting multiple line segments, and cannot be unambiguously mapped into a sequential pattern of execution. Meanwhile, spiral kolam, while sequentially executed, does not contain as much potential for artistic elaboration as the loop

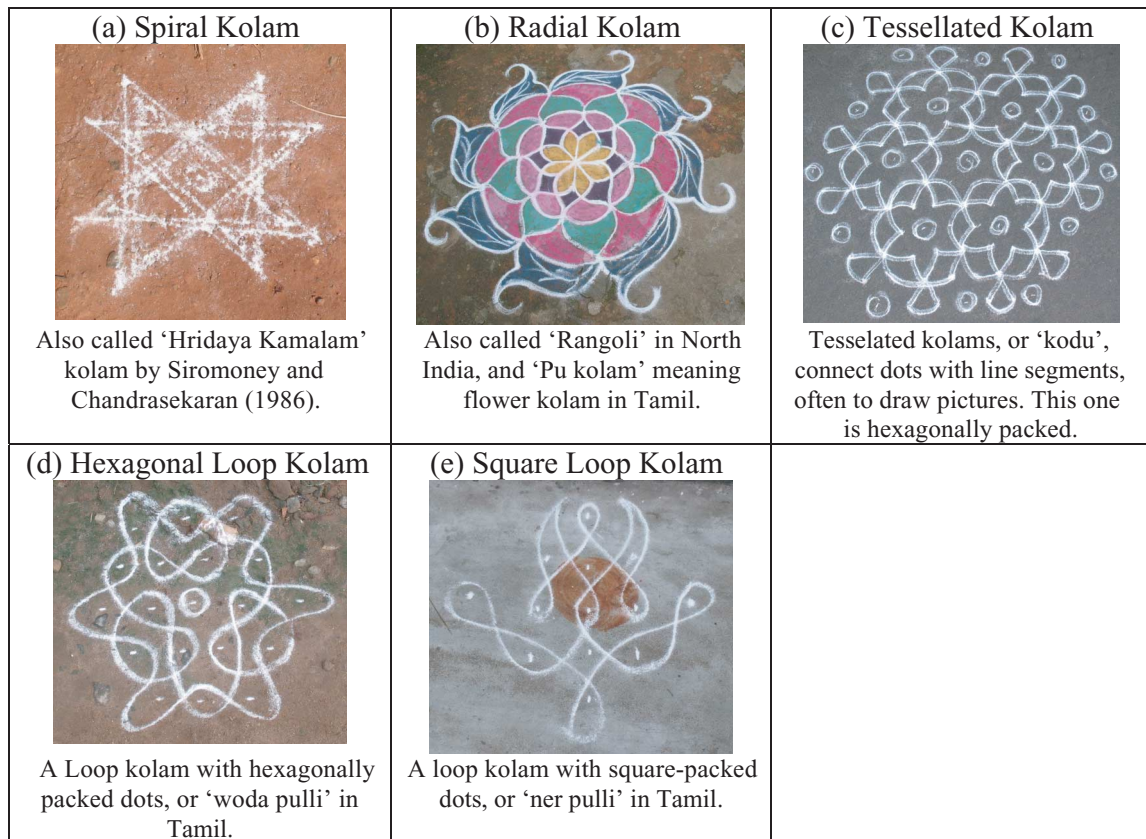


Fig. 1. A typology of kolam patterns. All kolam families save radial kolam (also known as the rangoli or pu kolam) are based on an initial pattern of dots. Spiral kolam patterns begin with pattern of dots in a star. Spiral kolam and tessellated kolam patterns connect and obscure the dots in the final image. Loop kolams have lines that bend around the dots, forming continuous loops. Loop kolams may be constructed on either hexagonally-packed or orthogonally-packed dots. This paper characterizes previously undescribed variation in the square loop Kolam.

kolam. The space for artistic elaboration and the unambiguous sequential mapping of loop kolam patterns, makes them unique, and the best studied of kolam families.

Kolam patterns have been studied by ethnographers and anthropologists since at least 1929 (Durai, 1929; Layard, 1937; Brooke, 1953). Current anthropological research on kolam patterns has explored the meaning of kolam patterns, their symbolic importance in the lives of Tamil women (Dohmen, 2001, 2004; Nagarajan, 2006) and their connection to menstruation, marriage and the generation of auspiciousness (Nagarajan, 2000, 2007). In modern Tamil Nadu the kolam art is very popular, and is practiced by millions of women. Kolam competitions are held, and kolam patterns distributed in small booklets. A Tamil television program of the name "Kolam" features a female protagonist. In short, the Tamil kolam is an active and evolving cultural form of uniquely systematic detail and complexity.

## 1.2 Computer science and mathematical research

In the 1970's and 1980's kolam patterns became a subject of inquiry for computer scientists and mathematicians in Madras (Siromoney and Subramanian, 1983). Siromoney and coauthors created mathematical descriptions and formal generalizations of kolam families (Siromoney and Chandrasekaran, 1986) and explored the properties of mathematical languages designed to represent kolams, including as a cycle grammar (Siromoney and Siromoney, 1987; Siromoney *et al.*, 1989), and as a context-free array gram-

mar (Siromoney *et al.*, 1974; Siromoney, 1987; Subramanian and Siromoney, 1987). Here we are interested in kolam patterns drawn on an orthogonal matrix of dots entwined with loops that do not touch the dots, or square loop kolams (SLK)\*<sup>1</sup>. This sophisticated work also tackled the rewriting rules required to grow similar patterns on any size space (Siromoney *et al.*, 1989). Most of the mathematical literature on kolam patterns focuses on the same SLK family of patterns, likely because they utilize a regular orthogonal grid, and maintain the unique visual aspects of loop kolams. More recently, ethnomathematicians have studied kolam design (Gerdes, 1989, 1990; Ascher, 2002). Ascher (2002) offers a succinct overview of their research.

Still more recently, various Japanese scholars have studied various technical features of kolam patterns, including their use in education (Kawai *et al.*, 2006; Nagata and Robinson, 2006; Nagata, 2006), and schemes for growing tessellations via pattern pasting (Robinson, 2006). Ishimoto (2006) used knot theory in an attempt to solve the search problem of how many possible single-loop kolam patterns can exist in a diamond dot matrix of a given size. These orthogonal diamond matrices are typically represented by

\*<sup>1</sup>Siromoney and Siromoney (1987) use the term "kambi" kolam for what I call a square loop kolam (SLK). Women in Tamil Nadu call this kolam family by various names, including 'kambi,' (line) 'sikku,' (knot) and 'nelevu' (curving) kolam.

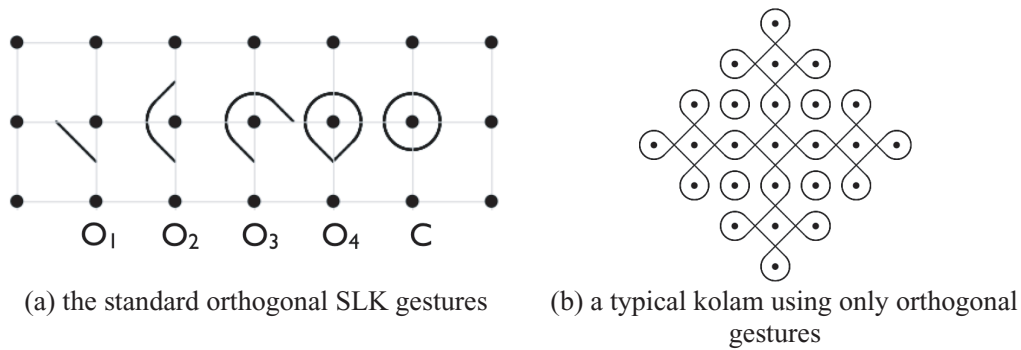


Fig. 2. The standard SLK lexicon. Current lexicons for array, cycle, or sequential kolam languages consist of only those gestures that generate loops that connect dots in orthogonal patterns. These moves are labeled ‘Orthogonal’ and referenced  $O_n$  where  $n$  is a measure of the extent to which the gesture curves around the focal dot in the natural unit of the number of fundamental orthogonal positions (center-points on the line between nearest neighbor dots) traversed.

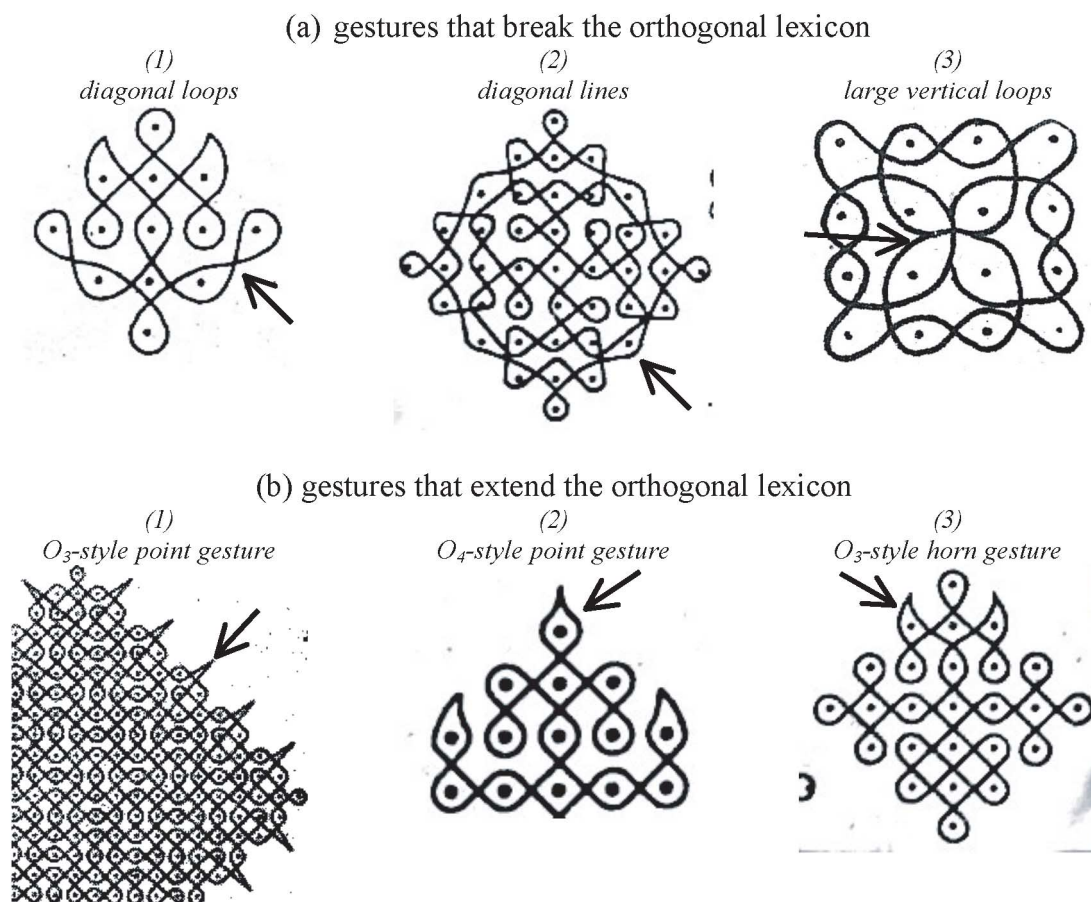


Fig. 3. Square loop kolam patterns containing gestures that break or extend the orthogonal kolam lexicon. This selection is conservative, and includes only patterns that extend or break the orthogonal lexicon in simple ways that are easy to describe. Arrows indicate which individual gestures break or extend the orthogonal lexicon.

kolam artists as (1-3-1, 1-5-1, 1-11-1, etc.) the first and last numbers denoting the height of the dot matrix on the left and right sides at the middle line, and the central number denoting the height of the matrix in the center. A fundamental study of kolam shapes by Yanagisawa and Nagata (2007) revealed a new method for simplifying the search for the number of possible kolam patterns on a matrix of a certain size. Their approach, which involved reducing multiple strokes into ‘navigating lines/N-lines,’ allows the representation of

SLK patterns as tiles such that no basic rules are violated, and no loops are left incomplete. A similar visual abstraction was explored by Siromoney and Subramanian (1983) in their investigation of space-filling Hilbert curves. Ishimoto (2006) conjectures that the single-loop search problem is not NP complete.

As the size of the underlying dot matrix (be it square or diamond) increases, the number of possible patterns balloons exponentially, creating a vast space for artist creativ-

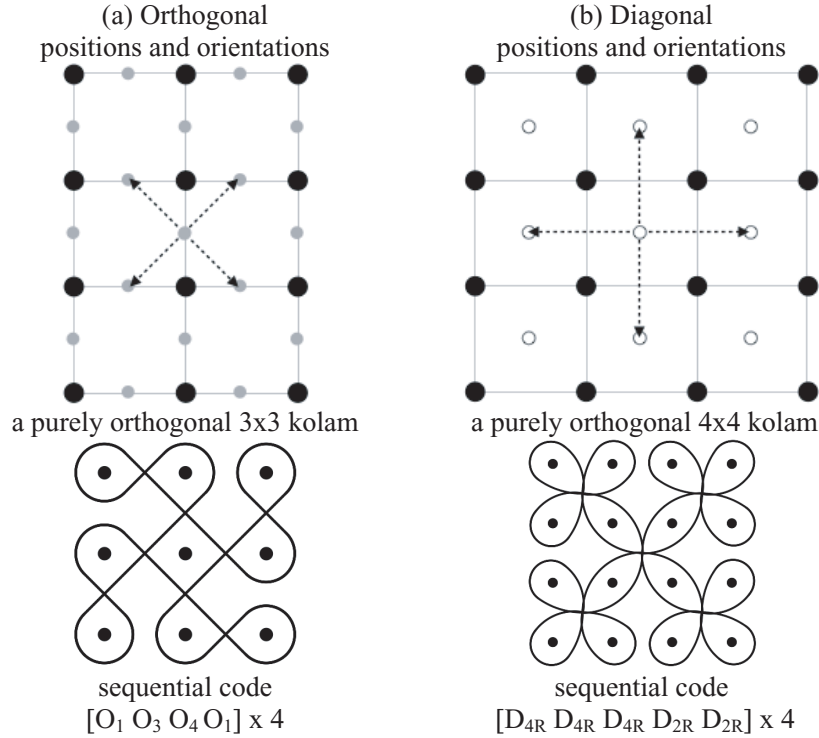


Fig. 4. Two fundamental spaces in kolam geometry are composed of distinct positions and rotations. Large black dots are the *pulli* of an square loop kolam. Drawn kolam gestures start and end with in one of these positions. Dotted lines represent basic no-rotation gestures in each space. Orthogonal space (a) is composed of orthogonal positions (small grey dots). Orthogonal gestures begin and end between two closest-neighbor dots and have fundamental orientations of 45, 135, 225, and 315 degrees. Diagonal space (b) is composed of diagonal positions (small empty dots). Diagonal gestures start and end in the space between 4 dots, and in orientations of 0, 90, 180, and 270 degrees.

ity and variation. For example, using traditional gestural lexicon, a square dot matrix of size  $2 \times 2$  only has five possible multiple loop configurations, while a  $3 \times 3$  matrix has 785 configurations (Nagata, 2006). Women will often draw patterns on 1-11-1 diamonds and larger. During festivals and competitions women have drawn kolam patterns 100 dots in width. Large kolams are often very regular and repeat common motifs many times. The previous research summarized above analyzes SLK patterns that conform to a very limited lexicon of gestures. In this paper we extend the useable kolam lexicon nearly three-fold.

## 2. Gestural Lexicons for Kolam Design

### 2.1 Orthogonal gestures

Previous work has focused on the simplest subset of actual SLK gestures. Usually these lexicons contain only a few distinct gestures, however Tamil women employ a much greater variety of kolam gestures in sequence to produce kolam designs. Many of these gestures are not easily transferable to an array or even a sequential representation. Kolam lexicons to date have focused on the gestures that are easily represented in an orthogonal array (Siromoney *et al.*, 1989; Ascher, 2002; Raghavachary, 2004). These lexicons usually contain between 4 or 7 gestures, always depicting the same shapes (Fig. 2).

### 2.2 Examples of non-orthogonal kolam patterns

By studying only the orthogonal portions of the kolam language, scholars have only been able to explore the extent to which various formal grammars pertain to that limited subset of kolam patterns, and have thereby lost much of

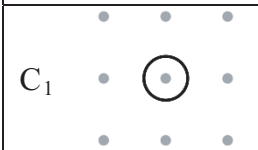


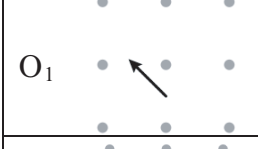
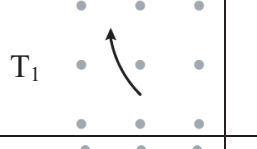
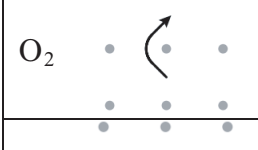
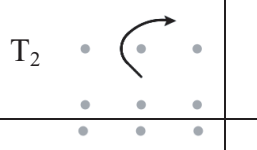
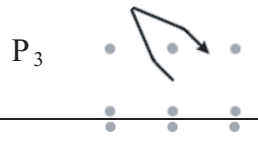
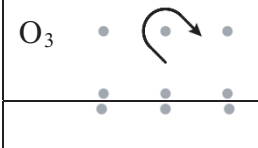
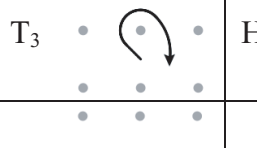

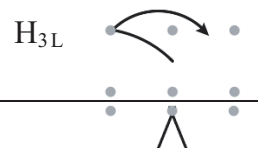
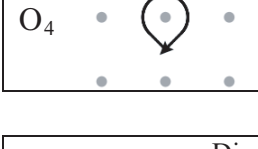
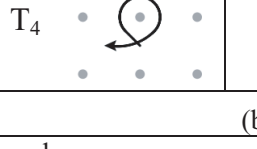
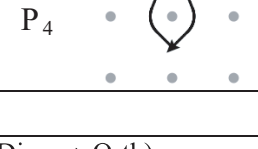
the complexity of the Tamil square loop kolam tradition. Figure 3a presents kolam patterns that cannot be replicated with orthogonal gestures. Figure 3b displays patterns that, although orthogonal, include extra stylistic detail that has been left out of kolam lexicons to date. This small sample makes the case that a more complete, and non-orthogonal, lexicon is needed in order to study the diversity of Tamil kolam patterns.

### 2.3 Kolam geometries

There exist at least two fundamental geometric spaces in SLK patterns, and both have corresponding positions, orientations, and gestures. I define each space in terms of fundamental positions. Fundamental positions are defined as the starting and ending point for gestures, and every gesture starts and ends at a fundamental position. Fundamental positions are described in terms of their location relative to nearby dots, and have no rotational information. The orthogonal and diagonal spaces each have a single fundamental position, and four associated fundamental orientations (see Fig. 4).

Orthogonal positions are located on the center point of two closest-neighbor dots and have orientations of 45, 135, 225, and 315 degrees, while diagonal positions are on the center point of the space between 4 dots, and in orientations of 0, 90, 180, and 270 degrees (see Fig. 4). Because gestures in the orthogonal space start and end at orthogonal positions, and diagonal gestures begin and end on diagonal positions, these two spaces are geometrically disjoint and pure orthogonal and pure diagonal gestures cannot connect

(a)

Orthogonal	Transitional (Orth → Diag)	Stylistic variations	
			
			
			
			
			

(b)

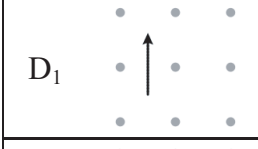
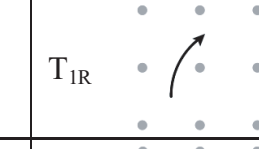
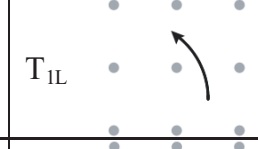
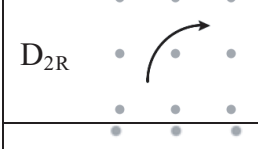
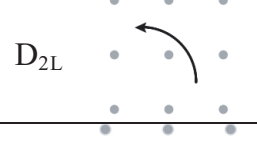
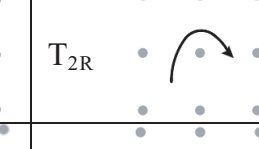
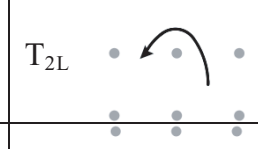


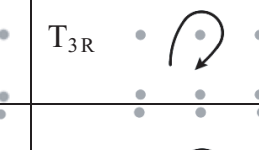





Diagonal		Transitional (Diag → Orth)	
			
			
			
			

Fig. 5. A new kolam lexicon. This lexicon includes 5 orthogonal, 7 diagonal, 12 transitional and 6 stylistic gestures. One important aspect of a kolam lexicon constructed in this manner is the ease by which it may be extended.

to form a loop. However real-world kolam patterns use both gesture types in a single pattern. Thus an additional transitional set of gestures is employed by women to navigate between diagonal and orthogonal kolam geometries.

### 3. A New Kolam Lexicon

Here I present a kolam lexicon consisting of four separate blocks of gestures, (a) the traditional well-studied orthogonal gestures, (b) a new set of diagonal gestures, (c) a

new set of transitional gestures which link the diagonal and orthogonal gestures, and (d) an additional set of stylistic variations on the three basic gesture sets. Multiple rotations of each gesture are not needed because each gesture is itself rotationally independent. However, diagonal gestures and transitional gestures from diagonal space are inherently chiral, and have distinct left and right versions.

The gestures are derived in the following fashion. Gestures which start and end on positions of the same type (di-



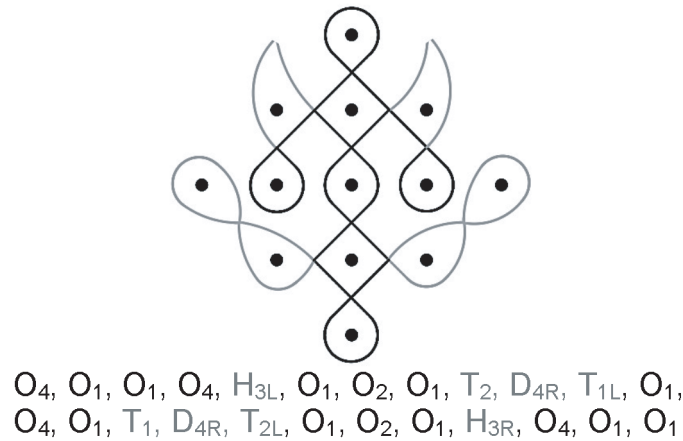


Fig. 6. The ‘temple lamp’ hybrid SLK pattern of Fig. 3a1. The pattern combines traditional, orthogonal gestures (in black) with new gestures (in grey) to create a very common kolam pattern called the ‘temple lamp.’ The sequential code is given below the kolam, beginning with the topmost O<sub>4</sub> gesture.

agonal or orthogonal) are gestures of that type, while gestures that move from diagonal to orthogonal or back are transitional gestures. Each set of gestures (orthogonal, diagonal, transitional) is represented by a letter (O, D, T, respectively), while stylistic variants of these moves are given special letters (C, H, P) denoting their shapes or the shapes of their root gestures (circle, horn, point, respectively). Because both orthogonal and diagonal positions have four fundamental positions around each dot, they are notated in the same way. Within each of the (O, D, T) gesture sets, a subscript denotes the number of sides (out of four) around a focal dot that the gesture has curved. O<sub>1</sub> and D<sub>1</sub> represent passage past the focal dot of along one side of four sides, and both O<sub>1</sub> and D<sub>1</sub> occur without change of orientation. O<sub>2</sub>, D<sub>2</sub> and T<sub>2</sub> represent passing by two of the four sides, and O<sub>n</sub>, D<sub>n</sub> and T<sub>n</sub> likewise represent gestures that curve around *n* sides of the focal dot. In addition, both diagonal and transitional gestures from diagonal positions are chiral, and are additionally denoted with subscripts L and R. Stylistic gestures in the C<sub>n</sub> gesture set must operate as the basic circle gesture, C<sub>1</sub>, in that each must be a single-dot C<sub>n</sub> gesture must be a complete motif in isolation, and not connect with other gestures around nearby dots. The full lexicon of 30 gestures is presented in Fig. 5.

The expanded SLK lexicon, with 30 gestures, is six times larger than the simple orthogonal lexicon used in previous research (see Fig. 2). These additional gestures allow researchers to represent a much greater fraction of real-world kolam patterns than the simple orthogonal lexicon. For example, a common SLK pattern is the simple ‘temple lamp’ kolam. The ‘temple lamp’ is composed of gestures from all four subsets of the expanded lexicon; orthogonal, diagonal, transitional, and stylistic series. Figure 6 displays the ‘temple lamp’ kolam, and the sequential encoding needed to generate that kolam using the expanded lexicon.

#### 4. Analysis

Clearly increasing the size of the SLK lexicon six-fold will have a multiplicative effect on the number of possible patterns within a diamond (e.g. 1-5-1) or rectangular array

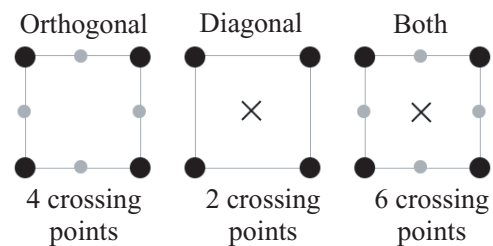


Fig. 7. Crossing points for both orthogonal and diagonal fundamental positions. Black dots are kolam dots (*pulli* in Tamil), grey dots are orthogonal crossing points, and each diagonal line marks a diagonal crossing point. Two diagonal crossing points occur in the geometrical middle of each set of four neighbor dots, with orientations 45° (225°) and 135° (315°).

(e.g. 4x4), and therefore the fraction of the creative space that kolam artists use that may be sequentially encoded.

Previously, various scholars have measured the size of the kolam design space given various initial dot matrices using the orthogonal lexicon. The size of the kolam design space (or the number of possible kolam patterns) increases exponentially with the width of the initial dot matrix. For example, using traditional gestural lexicon, Nagata (2006) calculated that a square dot matrix of size 2x2 only allows five possible multiple loop configurations, while a 3x3 matrix has 785 configurations (Nagata, 2006). Similarly, Ishimoto (2006) found that for the 1-5-1 diamond matrix the number of single loop patterns was calculated to be 240, while for the 1-7-1 diamond matrix the number is 11,661,312. Yanagisawa and Nagata (2007) go further by determining the number of total patterns, and then removing rotational duplicates, counting symmetric patterns, and finally single-loop symmetric patterns. They confirm that for the 1-5-1 diamond matrix the number of single loop symmetrical patterns is only 240, while a total of 65,536 patterns are possible if the number of loops is not restricted. Similarly, out of a total of 68,719,476,736 patterns possible in a 1-7-1 diamond there are 11,661,312 one-stroke patterns, and only 1,520 of these are symmetrical.

Yanagisawa and Nagata (2007) utilized a space-filling

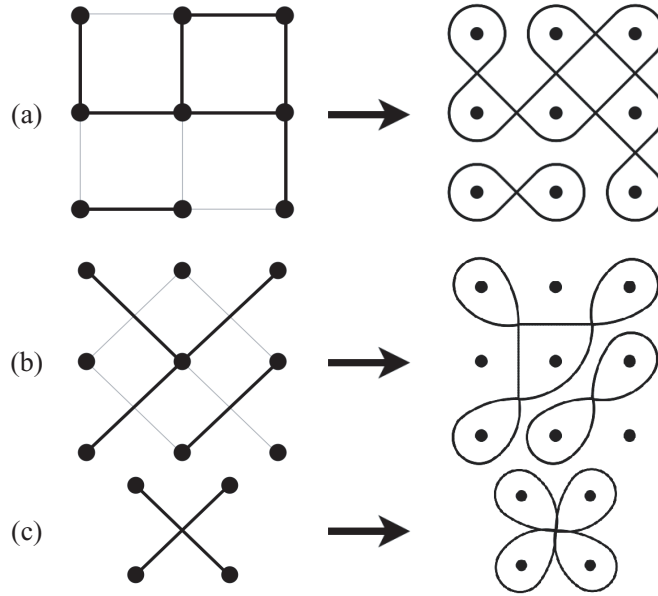


Fig. 8. An extrapolation of the N-line technique to the diagonal kolam space. Examples of (a) Orthogonal N-lines (b) Diagonal N-lines, and (c) a unique challenge that diagonal patterns cause. Note that diagonal N-lines cross, and crossing breaks Yanagisawa and Nagata's first rule (lines never retrace the same route). Despite this rule-break, the pattern (c) is found in practice in Tamil Nadu.

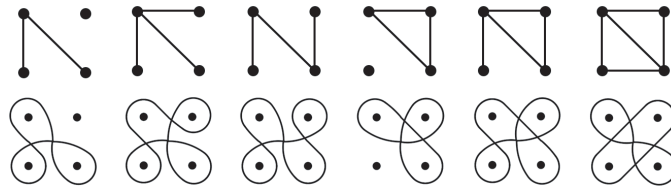


Fig. 9. The unique set of six mixed-gesture kolam patterns on a  $2 \times 2$  matrix. Of the 32 total possible mixed-gesture patterns, only these six patterns and their rotational or chiral duplicates (N-lines displayed above each pattern) do not violate the no-retrace rule, and also contain both orthogonal and diagonal gestures.

tile-based approach to kolam construction to compute the size of kolam design space for dot matrices of various dimensions. Below, I expand upon this approach by including the additional fundamental position and orientation information from the diagonal gestures. The calculations are not influenced by transitional or stylistic gesture sets because neither add new fundamental positions or rotations to the starting and ending points of gestures. Nonetheless, stylistic differences in kolam design are a prominent and important means by which kolam artists distinguish their work.

To calculate the growth of design space that diagonal gestures allow, I follow Yanagisawa and Nagata's (2007) method. Yanagisawa and Nagata calculate the size of design space for orthogonal space-filling kolam by designating crossing points between dots, and represent kolam patterns using a navigating line, or N-line, around with kolam loops are systematically drawn. Orthogonal kolam patterns have one crossing point between every two orthogonal nearest-neighbor dots. There are thus four orthogonal crossing points in a  $2 \times 2$  square dot matrix, and 16 crossing points in a 1-5-1 diamond matrix. Since the lines on each point either cross (1) or do not (0), the total number of possible orthogonal patterns in any size or shape dot matrix is simply, 2 raised to the number of orthogonal crossing points,  $c_o$ . Nagata (2006) calculates  $c_o$  for a rectangular grid

as  $2^{nm-n-m}$ , where  $n$  and  $m$  are the length and width of the dot matrix measured in dots. Diagonal kolam gestures, by contrast, begin and end in the middle of four neighboring dots (Fig. 4b), and thus there are fewer diagonal crossing points,  $c_d$ , per dot. By combining these two sets of binary crossing points we arrive at a total of six binary crossing points on a  $2 \times 2$  dot matrix for the extended lexicon (Fig. 7).

Yanagisawa and Nagata's N-lines help to visualize the realization of a kolam pattern across a given matrix. Figure 8 highlights the differences between the N-lines for both orthogonal and diagonal lexicons. Because diagonal crossing points overlap, so do diagonal N-lines, causing a conflict with standard kolam theory. Figure 9 catalogs a complete set of unique mixed-gesture kolam patterns on the  $2 \times 2$  matrix.

## 5. Results

Analysis reveals both theoretical and empirical benefits of the extended SLK lexicon. The theoretical value of the extended lexicon is that it allows researchers to explore a larger space of possible SLK patterns. Table 1 enumerates the possible patterns using the extended lexicon for a few rectangular matrices, and provides the formulae for the computations. The orthogonal kolam space constrains

Table 1. Enumeration of possible patterns in three different kolam spaces. Calculations of the number of possible patterns in a space-filling square loop kolam drawn on a rectangular matrix after Nagata (2006). Orthogonal pattern numbers are calculated per a slight modification of Nagata's 2006 formula,  $2^{c_o}$ , where  $c_o = (2nm - n - m)$ , rather than  $2^{c_o} - 1$ . Diagonal pattern numbers are calculated as  $2^{c_d}$ , where  $c_d = (n - 1)(m - 1)$ . And,  $c_e = c_o + c_d$ . These numbers do not exclude rotational duplicates, chiral duplicates, or multi-loop patterns.

Matrix	Orthogonal		Diagonal		Extended lexicon	
$n \times m$	patterns	$c_o$	patterns	$c_d$	patterns	$c_e$
$2 \times 2$	16	4	2	1	32	5
$2 \times 3$	128	7	4	2	512	9
$2 \times 4$	1,024	10	8	3	8,192	13
$3 \times 3$	4,096	12	16	4	65,536	16
$3 \times 4$	131,072	17	64	6	8,388,608	23
$3 \times 5$	4,194,304	22	256	8	1,073,741,824	30
$4 \times 4$	16,777,216	24	512	9	8,589,934,592	33
$4 \times 5$	2,147,483,648	31	4,096	12	8,796,093,022,208	43

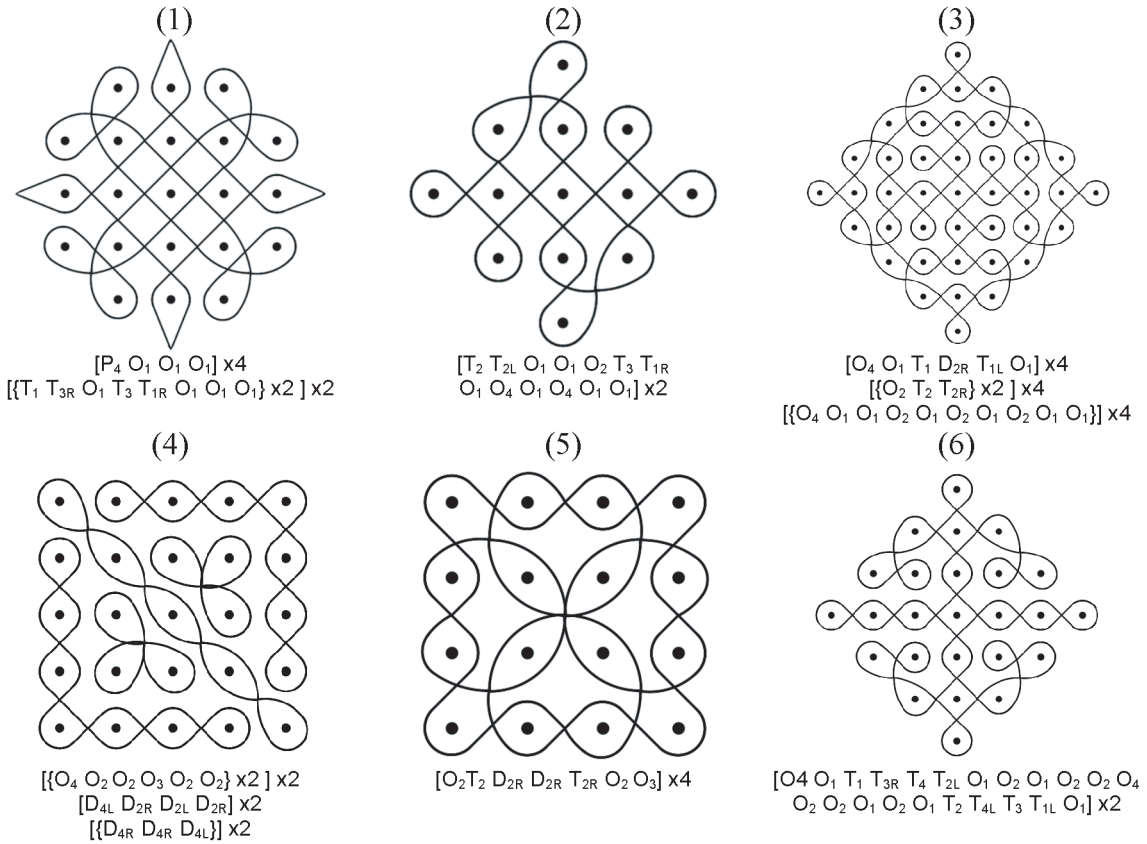


Fig. 10. A sample of extended lexicon SLK patterns. All patterns are from Tamil Nadu, and require the extended SLK lexicon. Sequences of gestures in square brackets  $[]$  each represent a loop, while those within braces  $\{\}$  represent sub-loop sequence repetitions. Both loops and sub-loop sequences have repetitions denoted as “x4,” for example. Pattern 5 and 6 match the patterns Figs. 3a3 and 3a2, respectively.

gestures to the von Neumann neighborhood (from the focal dot a gesture may only connect to dots directly above, below, right or left). The addition of diagonal and transitional gestures allows kolam gestures to move in the Moore neighborhood (from the focal dot a gesture may connect to dots above, below, right, left and all four diagonal directions), creating a much larger number of possible patterns within any size matrix.

The empirical value of the extended lexicon is in the increased representational depth it permits. Scholars can now more precisely encode and analyze the kolam patterns than

appear in the practice of kolam artists. Figure 9 displays a sample of kolam patterns that break the kolam rules of previous studies, but are possible under the new lexicon. Finally, the new lexicon has relaxed previous constraints on kolam representation, and demonstrates how ‘breaking the rules’ of previous kolam studies can be a valuable analytical pursuit.

### 5.1 Illustrations

The extended lexicon enables better empirical studies, since it allows scholars to more precisely represent, recreate and analyze the kolam patterns as they are practiced by ko-



Table 2. Rules after Yanagisawa and Nagata (2007). Clear, precise definitions are required to conduct mathematical analyses, but limit the artistic realism of kolam abstractions. Generalized conditions listed on the right. Future rule sets for kolam design will need to reconsider at least rules 2 and 3.

Yanagisawa and Nagata's kolam drawing rules	Condition
(1) Loop drawing-lines, and never trace a line through the same route.	Closed-loop no-retrace
(2) All dots are enclosed by a drawing-line.	Space-filling
(3) Straight lines are drawn along a 45° inclined grid.	Orthogonal orientation
(4) Arcs are drawn surrounding the points.	Loop kolam family
(5) Lines should not bend in a right angle.	Loop definition

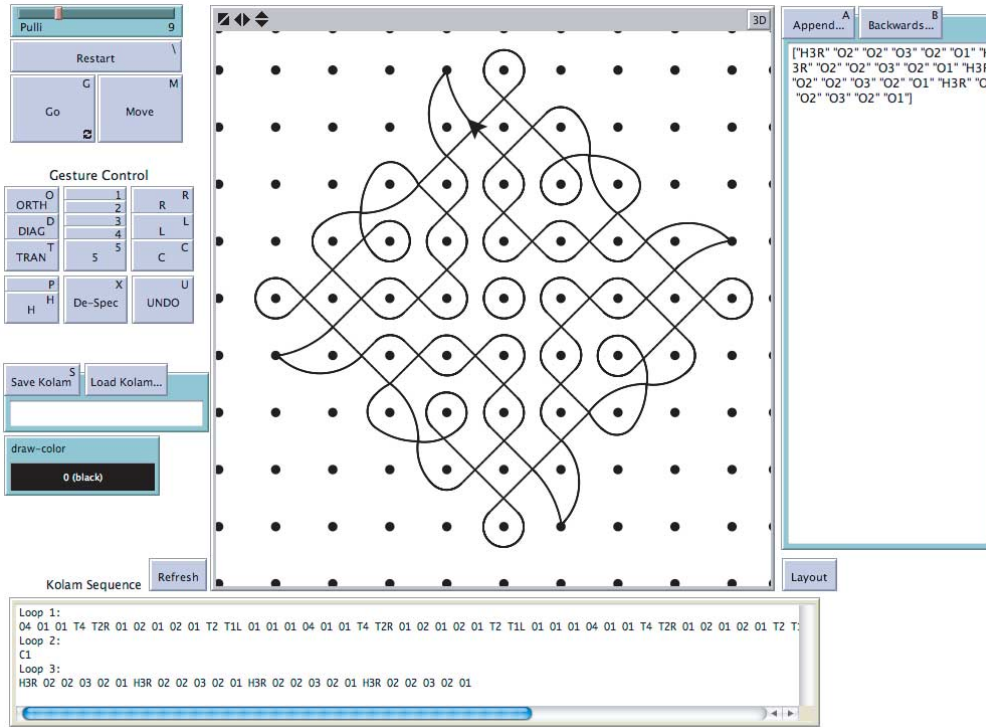


Fig. A1. A software system for encoding SLK patterns using the extended lexicon. The program was written in NetLogo 4.1. The lower kolam sequence window displays the sequential code for each of the three loops in the pattern shown in the visual window. The sequential code for loop 3 is additionally presented in the Append window on the right, which is used for entering large strings of gestures. The user can choose between a graphical kolam drawing method using the mouse, typing gesture names via the keyboard, such as “H3R, O2, O2, O3, O1” or by clicking the blue buttons on the left to specify a gesture. Clicking the “H” then the “3” then the “R” completely specifies the “H3R” gesture. Starting points and orientations are set using the mouse.

lam artists. Figure 10 presents a sample of kolam patterns collected from Tamil Nadu between 2007 and 2009 encoded and reproduced using the extended lexicon. One practical benefit of a sequential language is that symmetry is easy to detect given the presence of repeated subsequences, and easy to summarize. Figure 10 displays one such summary method, denoting loops as gesture sequences within square brackets [], sub-loop patterns as sequences within braces {}, and repetitions of either loops or sub-loops with a multiplicative indicator such as ‘x4.’ This method of presenting the sequence along with the pattern itself, summarizing repetitions facilitates learning the extended lexicon because the diagonal and transitional gestures stand out in the sequence. A great many of the kolam patterns commonly practiced in Tamil Nadu include either stylistic gestures or diagonal and transitional gestures of the extended lexicon.

## 5.2 On breaking the rules for kolam design

Previous studies on kolam patterns have tended not to create additional gestures but rather to scrutinize the gestures that could be represented with the limited orthogonal lexicon available. The extended language for kolam gestures presented in this paper changes that in a few respects. By presenting an open and extensible kolam lexicon to which more stylistic and fundamental gestures may be added, this lexicon brings the empirical focus to the gestures themselves. This new lexicon, particularly the addition of diagonal gestures, also breaks the rule-sets developed in prior studies for kolam analysis. Naturally, these rule sets are not the rule sets of the Tamil kolam artists, but those of the researchers who must use simplifications in order to make discoveries. Artists themselves tend away from hard-and-fast rules, and break conventions in part to gain

attention and introduce novelty. This work recognizes that pattern of rule breaking and provides kolam scholars with tools that can accommodate artistic novelty.

## 6. Conclusion and Future Research

This improvement in the ability to encode and describe kolam patterns using a deep and expandable sequential lexicon opens up a number of novel research possibilities. Ethnographic experience shows that there are further kolam gestures, including very large loops not presented here, which go well beyond the Moore neighborhood by connecting dots with grand arcs at distances of many dots without reference to any matrix, and often outside of the matrix of dots itself. Finally, stylistic variations on individual moves such as the replacement of  $O_3$  for  $H_3$  also expand the possibilities dramatically. Although the stylistic gestures offer no fundamental changes in the Eulerian graph or knot-theory interpretation, they are valid design differences that should be accounted for.

The extended lexicon also presents a means of studying social or regional design variation within a population of kolam artists. With a deeper coverage of fundamental kolam space, and a facility to include additional stylistic variations as needed, the extended lexicon can accurately represent a larger portion of all extant kolam patterns. In combination with the efficient graphical system for data entry presented in the appendix, the lexicon provides a better means of studying kolam art.

The square loop kolam patterns that I have described here are not derived from first principles, but imitated and emulated from Tamil women artists. This suggests that attempts to derive a single common kolam language with a rigorous mathematical definition will always be challenged with ‘new’ gestures and forms. Instead, I suggest a more biological approach in which kolam sequences are treated more as DNA strands that encode proteins. If kolam language descriptions and kolam lexicons be made modular, as I have done here, they may more easily incorporate novel variation.

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## Appendix A. A Software System for Encoding, Editing, and Playback

I additionally present a software system designed to encode, edit and playback kolam sequences using the lexicon described above. The system is coded in NetLogo and uses an interactive graphical interface allowing the user to draw the kolam by clicking on automatically generated gesture-markers. As the user constructs a kolam, the visual representation is simultaneously encoded and displayed in a kolam sequence window. Keyboard entry allows users to type a kolam for faster entry, and additional features allow the user to undo previous gestures, save and load kolam sequences, and copy and paste kolam sequence segments at arbitrary rotations to simplify encoding of repetitive kolam

patterns (Fig. A1). This system also can be deployed to the web for user interaction and data collection.

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