ARABIC CALLIGRAPHY:
A COMPUTATIONAL EXPLORATION

Hoda Moustapha
School of Architecture, Carnegie Mellon University, Pittsburgh, USA

Ramesh Krishnamurti
School of Architecture, Carnegie Mellon University, Pittsburgh, USA

Abstract: This paper is inspired by Arabic calligraphy, a unique art form conveying beauty as well as meaning; its versatility in design introduces an infinite realm of possibilities involving extensive explorations and numerous transformations. We present a prototype, Interactive Calligraphy Exploration (ICE) that supports a novel approach to calligraphic compositions by manipulating symmetries, simply and rapidly, by means of regulators, an abstraction that captures symmetry information. ICE supports symmetrical transformations of multiple elements thus producing unusual visual effects. We discuss the integration of the various interdisciplinary concepts during the design and implementation of ICE. With our prototype ICE, we illustrate how the eye interacts with the artistic identity of the symmetries while the computing environment interacts with its mathematics.

Arabic Calligraphy

Arabic calligraphy is a fascinating art form giving rise to expressions that combine spiritual meaning with aesthetic beauty. Calligraphic expression is a fundamental decorative element of all forms of Islamic art, ranging from Architecture to ornamental design, and has been widely used throughout historical and modern times (Massoudy, 1981). Numerous styles of script have been developed over time each with a variety of expressions and yielding different compositions. These include several Kufic and Cursive styles (Figure 1).

Figure 1. Illustrating Cursive and Kufic styles of Arabic calligraphy (Sakkal, 1993)

Arabic calligraphy integrates a cultural language with the language of geometry. The fluidity of Arabic script offer indefinite possibilities for designing calligraphic expressions, even within a single word, since letters can be stretched and transformed in numerous ways to create different motifs.

Calligraphic compositions have either true symmetry as a result of applying isometric transformations to a motif, or an implied symmetry resulting from fitting an expression within a symmetrical organisation (Figure 2). Symmetric calligraphic expressions possess either rotational symmetry with 3, 4, 5, 6 and 8-centers of rotation, or bilateral symmetry about a vertical reflection axis. The former is the more common, mainly to preserve handedness and consequent readability; nonetheless, expressions with simple reflectional symmetry yield interesting compositions that are also recognisable (Figures 3b and 3c).
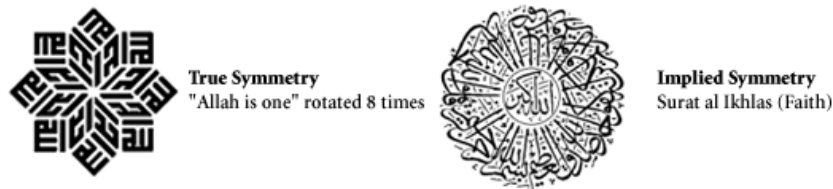

True Symmetry
"Allah is one" rotated 8 times

Implied Symmetry
Surat al Ikhlas (Faith)

Figure 2. Calligraphic compositions have true or implied symmetry

Calligraphic expression is a form of creative design. The composition of such expressions is a non-deterministic iterative process that involves drawing and redrawing to develop, adjust and fine-tune. A calligraphic composition is composed of elements (letters) and relations (relative arrangement of the letters) defining an overall organisation. During the compositional process, in each successive iteration, letters and their relative arrangements are updated, and the organisation redefined.
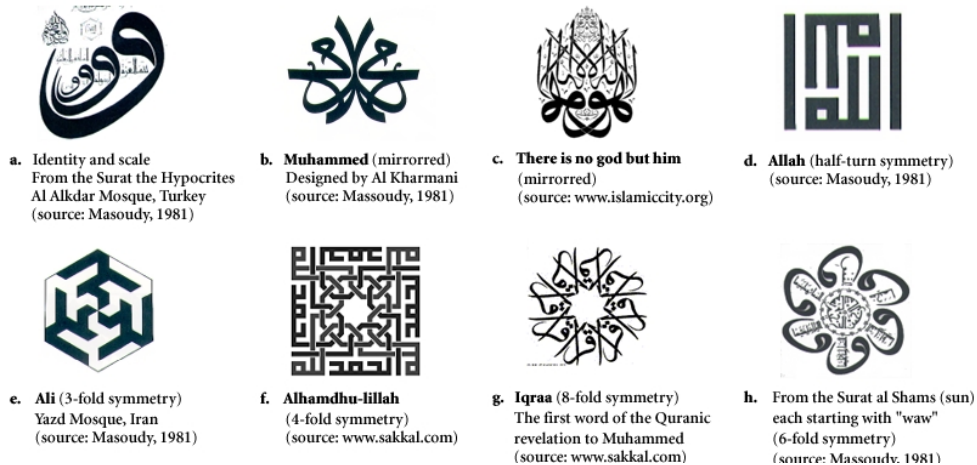

a. Identity and scale
From the Surat the Hypocrites
Al Alkdar Mosque, Turkey
(source: Masoudy, 1981)

b. Muhammed (mirrored)
Designed by Al Kharmani
(source: Massoudy, 1981)

c. There is no god but him
(mirrored)
(source: www.islamiccity.org)

d. Allah (half-turn symmetry)
(source: Masoudy, 1981)

e. Ali (3-fold symmetry)
Yazd Mosque, Iran
(source: Masoudy, 1981)

f. Alhamdhu-lillah
(4-fold symmetry)
(source: www.sakkal.com)

g. Iqraa (8-fold symmetry)
The first word of the Quranic
revelation to Muhammed
(source: www.sakkal.com)

h. From the Surat al Shams (sun)
each starting with "waw"
(6-fold symmetry)
(source: Massoudy, 1981)

Figure 3. Examples of Arabic calligraphic compositions

Exploring calligraphy interactively is our ongoing project to investigate methods of supporting the above process of designing a symmetrical calligraphic composition in all its

various dimensions. For instance, one might like to explore the different kinds of design changes such as converting a composition with a 3-center of rotation to one which is 5-centered while keeping the same word; another might be to add an axis of reflection; in general, changes involve combinations of such transformations. Our approach is to abstract the organisational dimension (symmetry) from the physical dimension (letters) of the composition. In this manner, we can explore the potential of each of these dimensions separately, while preserving the integrity of the calligraphic composition.

The main features of the interactive calligraphy explorations project include:
- Composing the symmetry while designing the calligraphic composition.
- Manipulating the calligraphic elements while maintaining the symmetry of the composition.
- Manipulating the symmetry thereby generating and visualising significant changes in the composition.

With this approach, we are able to explore compositions in a computational environment in ways that were not previously possible, and produce novel compositions that were not already explored. In this manner, we hope to break down the barriers of traditional media for calligraphic design

ICE – The Interactive Calligraphy Exploration Project

Our work is guided by the view that design objects and relations in any configuration must remain flexible at all times in order to accommodate iterative, as yet, undetermined design changes. For our purpose, design is an incremental activity in which decisions about the organisational symmetry occur in steps, integrated with decisions about compositional details. To render calligraphic exploration with a true design environment with flexibility as a prime priority, we visited and developed, in computational terms, the concepts of making, maintaining, transforming, integrating and breaking symmetry.
- *Symmetry making*: Incremental definition of lines and points of symmetry during the process of designing the elements of calligraphic composition.
- *Symmetry maintenance*: Dynamically preserving symmetry when manipulating the calligraphic elements.
- *Symmetry transformation*: Changing the calligraphic composition from one symmetry group to another by changing the organisational symmetry.
- *Symmetry integration:* Superimposition of several symmetry sub-structures within a single composition.
- *Continuous symmetry breaking:* Introducing a dimension of gradation within the symmetry relation, thus, increasing visual interest while creating another order within the symmetry.
- *Discrete symmetry breaking:* Deactivating the symmetry within the various dimensions of the configuration.

Calligraphic compositions are represented as two level abstractions: one for calligraphic symbols and the other for regulating organisational symmetries. These are described in detail in the sequel. Briefly, symbols represent Arabic words and regulators encapsulate symmetry properties of the calligraphic composition. Regulators are graphically depicted by points and lines that specify appropriate isometries. Regulators serve two purposes: (i) to control the position and attributes of symbols, in this way maintaining the dependency of symbols about these points and lines of isometries; and (ii) to propagate changes across symmetrical objects, thereby preserving the integrity of the composition. Calligraphic symbols and regulators can be dynamically associated with each other,

allowing superimposed symmetries within a single composition, and enabling multiple symbols to be associated to a regulator and multiple regulators to be associated to a symbol.

User Interface

The ICE user interface comprise three windows: two to create and transform symbols and regulators, and a main window, which hosts the drawing canvas and widgets for controlling symbol manipulation and symbol regulator associations. The main window contains the navigation and colour controls of the canvas as well as the visibility controls for symbols and regulators. Figure 4 shows the main window illustrating the symbolic composition of the word Nour (light). At this stage, as yet, no regulators have been applied. The symbol and regulator windows are described in the sequel (see Figures 6 and 7).
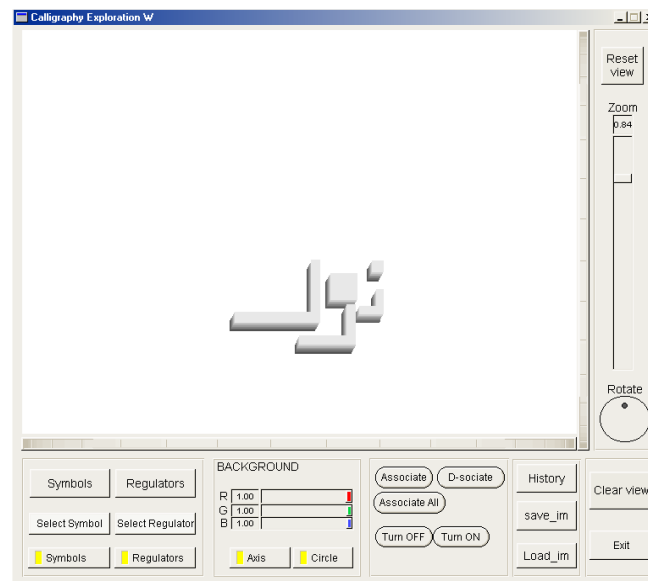
Figure 4. The main window with the drawing canvas and the symbolic depiction of the word Nour (light)

Symbols

Calligraphic symbols are simplified abstractions of letters of the Arabic alphabet. The calligraphic exploration project is divided into several phases: the initial phase focuses on configurational relationships, and the succeeding phases will focus on the manipulation of the Arabic script with its many Kufic and cursive variations.

For the initial phase, we have developed a simplified version of the constituents of the letters that can be easily represented and manipulated computationally. The Arabic alphabet is made up of 18 basic shapes that are augmented with dots to create the variations that make up 28 letters in total. The 18 basic shapes are abstracted by symbols each depicted by a combination of lines, dots, circles, triangles, and crescents (each formed by ovals) appropriately scaled (see Figure 5).
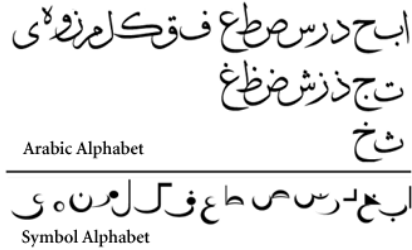
Figure 5. Arabic alphabet and the correponding symbol representation in ICE

The symbol window (Figure 6) contains commands for creating and manipulating symbols. A symbol can be manipulated, geometrically, by translation, scale, rotation, shear, and deformation as well as by changing its colour, fill, line width and transparency attributes. The manipulations are achieved though slider and value inputs. For flexibility, a symbol can be substituted for by another, though a choice menu.
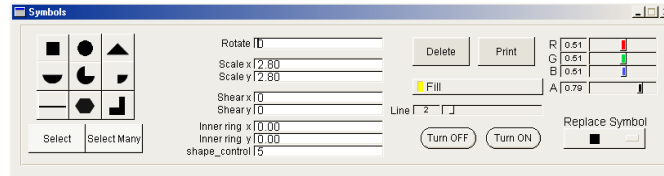

Figure 6. The Symbol window

Regulators

Regulators control the behaviour of calligraphic symbols through their generative and manipulative capabilities. A regulator generates one or more symmetrical image symbols from a (user-defined) seed symbol. A regulator maintains a symmetry relation between a seed symbol and its image symbols upon manipulation of either the seed or image. Changes to regulators transform the configuration of image symbols, and may change the symmetry of the calligraphic configuration.

Regulators represent non-destructive plane isometries – namely, translation, rotation, reflection, and glide transformations – by means of which a seed is preserved and its images (to which successive transformations can be applied) are generated. Regulators maintain a persistent association among symmetrical symbols to provide the necessary control and preserve integrity of the configuration. Each regulator has two sets of parameters, the first being the symmetry preserving parameters, and the second are for gradation effects and include symmetry breaking parameters.

- Translation regulators: $\mathbf{T}(\delta, \theta, n) \bullet (\Delta\delta, \Delta\phi, \Delta s)$
- Rotation regulators: $\mathbf{R}(x, y, \theta, n) \bullet (\Delta\phi, \Delta s)$
- Reflection or mirror regulators: $\mathbf{M}(x, y, \theta)$
- Glide regulators: $\mathbf{G}(x, y, \delta, \theta, n) \bullet (\Delta\delta, \Delta\phi, \Delta s)$

When a seed symbol is associated with a regulator, *n* images are generated according to the isometry associated with the regulator. The parameters have the following definition.

δ refers to the center-to-center distance between successive translated images. For **T**, **M** and **G**, θ refers to the inclination of the axis of translation or reflection; in the latter two cases, the mirror axis passes through the point (x, y). For **R**, θ refers to the angle of rotation about the center of rotation (x, y).

In addition to the symmetry preserving parameters, each regulator has gradation parameters of which at most three relate to transformational changes. Parameters $\Delta\delta$, $\Delta\phi$ and Δs are used to break symmetry and vary the composition. Changing Δs introduces a scale factor that maintains a gradual change in scale for each successive image-symbol. Changing $\Delta\delta$ causes the distance between successive image-symbols to gradually increase or decrease. Likewise, changing $\Delta\phi$ gradually varies the relative rotation of the image-symbols. Other gradation effects implemented in ICE include gradual changes in colour.

Figure 7 shows the ICE regulator window, which contains the creation commands for the four symmetry regulators each color coded on the drawing canvas – **T** (blue), **R** (red), **M** (green) and **G** (yellow) – and commands for specifying their symmetry preserving and gradation (continuous symmetry breaking) parameters. As in the case of symbols, regulator manipulations are achieved though slider and value input, and regulator replacement through a choice menu.
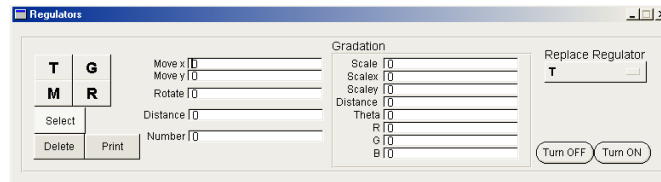

Figure 7. The regulator window

Figures 8a, 9a, 10a, and 11a show examples of generating images of the word Nour for each of the regulators. Figures 8b, 9b, and 10c show the effects of rotating the axis, while Figure 10b shows the effect of moving it. Figure 11b shows the effect of moving the center of rotation. Figure 9c illustrates the translational gradation effect. Figure 10d shows the scale gradation effect.

At this juncture, we remark that no verbal or visual description is a real substitute for the personal experience of interactively manipulating symmetrical elements, nor can we effectively describe the surprising effects resulting from multiple simultaneous changes.
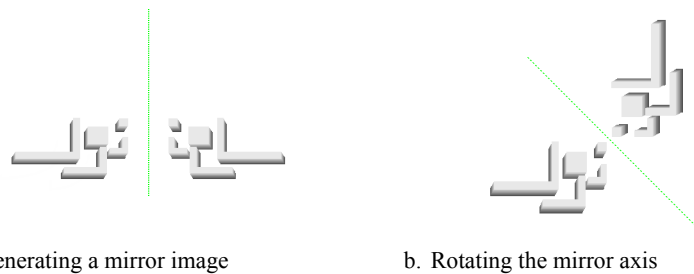
a. Generating a mirror image   b. Rotating the mirror axis

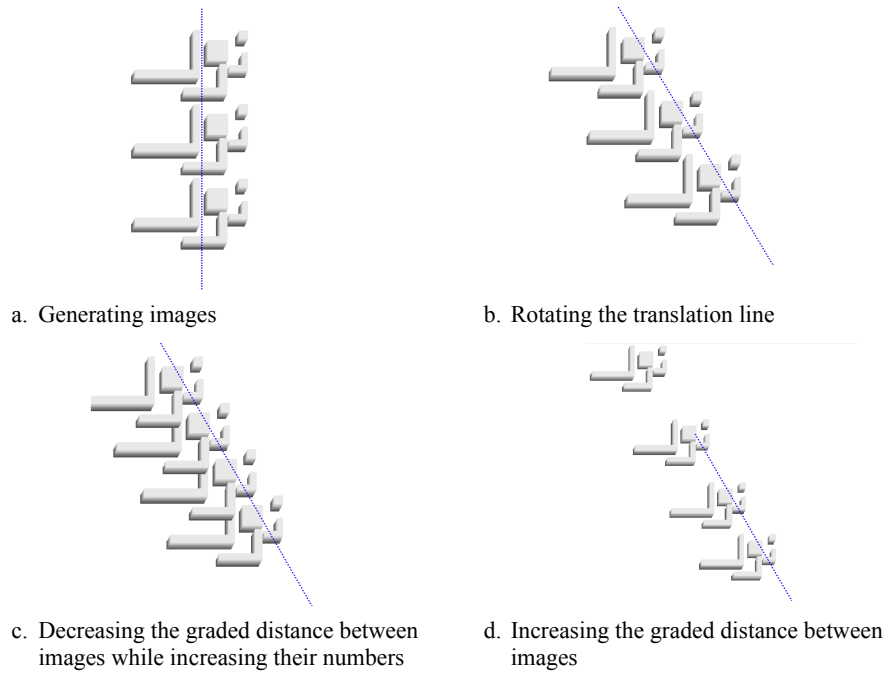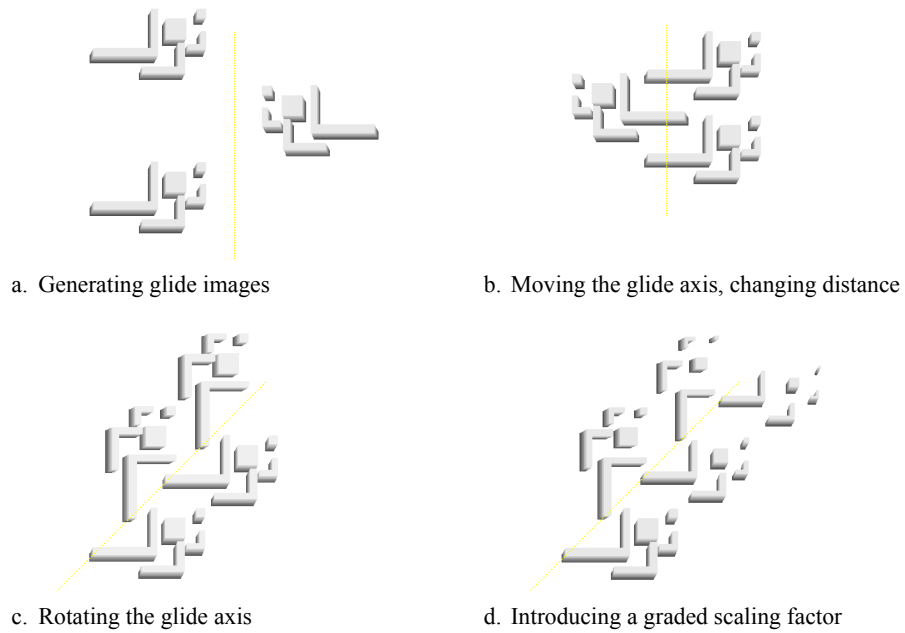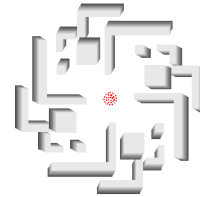*Figure 8. Exploring compositions based on the word Nour using the **M** regulator*

a. Generating images

b. Rotating the translation line

c. Decreasing the graded distance between images while increasing their numbers

d. Increasing the graded distance between images

*Figure 9. Exploring compositions based on the word Nour using the **T** regulator*

a. Generating glide images

b. Moving the glide axis, changing distance

c. Rotating the glide axis

d. Introducing a graded scaling factor

*Figure 10. Exploring compositions based on the word Nour using the **G** regulator*
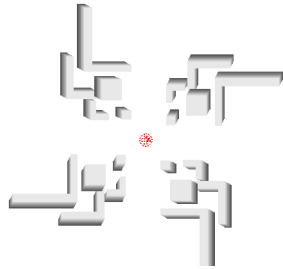
a. Generating rotated images   b. Moving the point of rotation
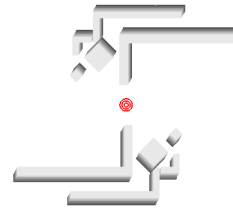
c. Changing the rotation angle to 180˚   d. Scaling and rotating symbols and images

*Figure 11. Exploring compositions based on the word Nour using the **R** regulator*

Dynamic Association

A symbol is associated with a regulator during the development of a design. A symbol may be associated with multiple regulators, and a regulator may be associated with multiple symbols. Symbols maintain a list of regulators. Likewise, regulators maintain a list of associations consisting of a seed symbol and its n image symbols. Image symbols are indexed. These indices are active variables in its regulator formula. These identify the position of translated or glided images, and additionally, the orientation of rotated images. Indices also identify gradation effects.

Consider symbols associated with a horizontal translation **T** regulator. If the position of the seed symbol is (x, y), then the position of the i-th image symbol as $(x+i\delta, y)$, where δ is the distance of translation. Similarly a gradation in scale would cause the size of the i-th image to be ifs, where s is the scale of the first symbol, and f is the scale factor. Computationally, manipulating a seed symbol is different from manipulating an image symbol; changing an image requires the inverse transformation to update the seed and then to update the remaining images according to the updated seed.

Change Propagation and Multiple Regulators

Regulators encapsulate the rules for the behaviour of symbols: these compute the position/orientation of symbols according to the isometry specific to the regulator, thus

controlling the relation between a seed symbol and its images. The transformation is used to generate the images from the seed, and to update images whenever the seed is manipulated. The inverse transformation is used to update the seed when the images are manipulated.

To maintain this level of control, each regulator 'observes' the symbols (seeds and images) that are associated with it. As a symbol changes, it 'notifies' its regulators, which propagate changes to the remaining symmetric symbols (symmetry maintenance). The mechanism by which regulators maintain control over symbols is an adaptation of the 'observer' pattern (Gamma et. al. 1997).

A symbol can be associated with any number of regulators; thus, in a multiple regulator scheme symbols can take on the role of both seed and images simultaneously. For a symbol, this is represented by a regulator tree, of which the root is the first seed, intermediate nodes are images of the regulator above and seeds of the level below; and leaf nodes are images of the last regulator. A change in one symbol will initiate a chain reaction of changes that propagate across the regulator tree to update all associated symbols.

When a symbol is associated with multiple regulators, its images are subject to a composition of isometries. In principle, there is no limit to the number of regulators that can be composed. Of course, the number of possible compositions is 4^r, where r is the number of regulators in the composition. In the implementation, when associating symbols to subsequent regulators, it is optional to associate only a single symbol, or all the symbols (seeds and images) of the antecedent regulator. Figure 12 shows the regulator tree that represents an **RTT** composition like the one illustrated in Figures 14a and 14b.
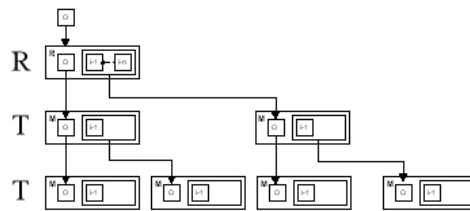

Figure 12. The regulator Tree

Changes in regulators are propagated forward so that these affect images of subsequent regulators, whilst changes in symbols are propagated forwards and backwards and affect images of subsequent as well as antecedent regulators. Recursive notification flows in both upward and downward direction until all members forming the regulator tree are notified. If an image-symbol is changed, its seed is updated, consequently the change is propagated upward though the remaining regulators of the seed; similarly the other image-symbols are updated and propagate the change downwards though their regulators.

It is important to remark that when a symbol is associated with multiple regulators, the regulator tree is a tree data structure; when multiple symbols are associated with multiple regulators, the data structure is, in fact, a directed acyclic graph. However, image generation and change propogation still function in the same way.
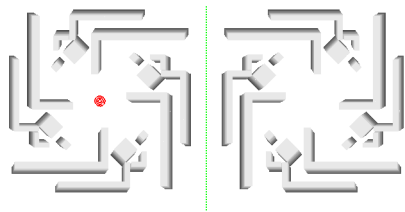
Figures 13 and 14 show more compositions of the word Nour by using multiple regulators. Figure 13a starts by applying an **M** regulator to Figure 11d, which is a composition defined by an **R** regulator. Figures 13b and 13c show the effects of altering the **R** regulator on the composition.
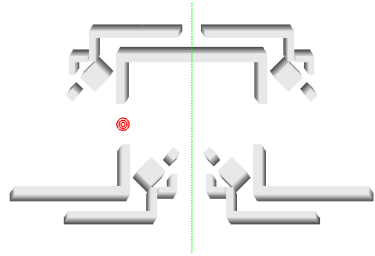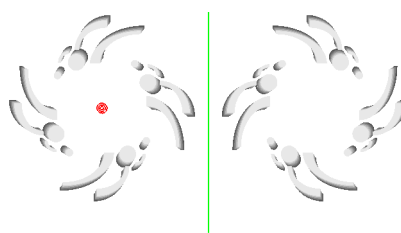
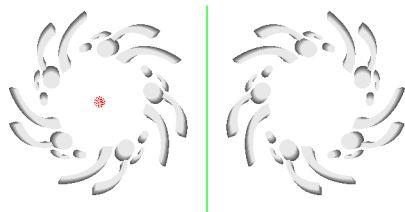a. Generating a mirror image
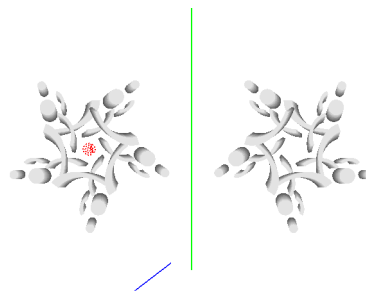   – from figure 11d
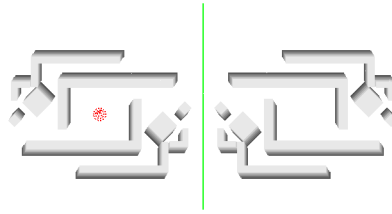
b. Moving the point of rotation

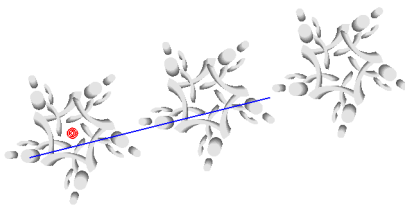c. Changing the rotation angle to 90˚

d. Replacing rectangular symbols by
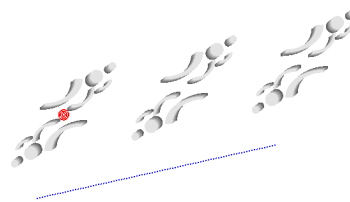   circular symbols, and adjusting their
   sizes

e. Changing the rotation angle to 90˚

f. Moving the point of rotation

g. Replacing the **M** regulator by **T**

h. Changing rotation angle to 180˚

Figure 13. Exploring compositions based on the word Nour using multiple regulators

Symmetry Groups

Interesting configurations result from the use of multiple regulators. These give one an opportunity to design complex calligraphic compositions that were not previously explored, to study the degree of complexity without affecting readability. For instance, one can explore calligraphic composition within the symmetry groups of frieze and wallpaper patterns. In fact, Figures 13g above is an example of the frieze pattern *p112*. Figures 14a and 14b below show wallpaper patterns, *p2* and *p3,* respectively. Figure 14b is derived from 14a by rotating the **T** regulator and changing the angle of rotation of the **R** regulator, thereby illustrating that manipulations of regulators can yield the transformation of one wallpaper pattern into another, in this case from *p2* to *p3*.

    a. *p2* wallpaper pattern   b. *p3* wallpaper pattern
      – from figure 13h by translating images   – changing rotation angle to 120˚ and
                                               rotating the **T** regulator through 60˚ (cw)
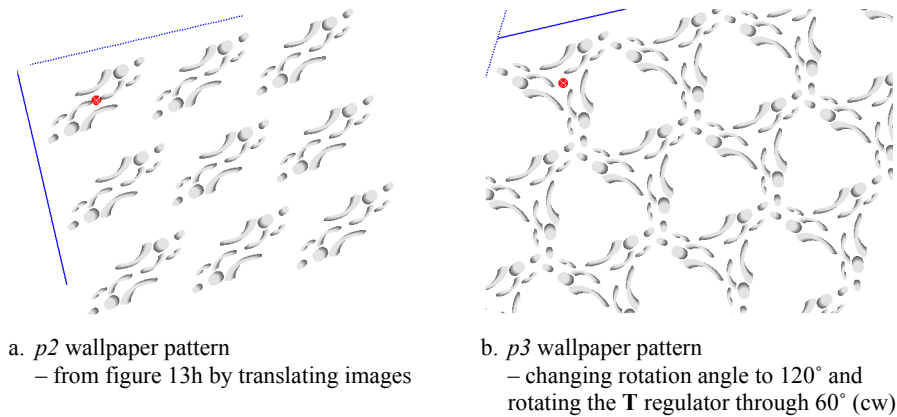
Figure 14. Exploring symmetry groups of compositions based on the word Nour

Flexibility and Changeability

In order to support calligraphic exploration as a design activity, we established flexibility as a prime priority. This notion inspired us to design a system in which every element and every relation can be changed at any time during the development of the calligraphic composition.

- Parameters of symbols and regulators can be changed at any time.
- Symbols and regulators can be replaced, respectively, by other symbols and regulators. This changes the configuration dramatically. Figure13d shows the effects of replacing the rectilinear symbols with curvilinear ones and Figure 13g shows the effect of replacing an **M** regulator with a **T** regulator.

The sequence of designing does not affect a calligraphic configuration because a symbol can be changed after being associated to any number of regulators and any regulator can be changed after successive associations. However, there are two exceptions to this.

- The order of associating multiple regulators in a configuration is fixed. Since isometries do not commute – associating to the isometry **R M** is not the same as associating to the isometry **MR** – we are currently evaluating whether the ability to permute regulators within multiple regulator schemes would be a desirable feature.

- When multiple regulators are defined, additional implied symmetries might appear in the configuration. These are perceived by the user, but are not captured by the system, therefore cannot be manipulated directly in the same manner as those defined with the regulators.
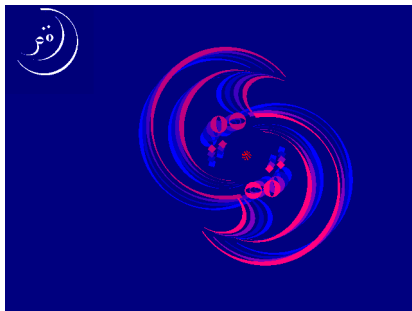
Calligraphic Examples

Figure 15 shows compositions of three Arabic words using regulators. Notice the variations in the compositions of the same words, which are achieved by adding and replacing a regulator and adjusting a few parameters.
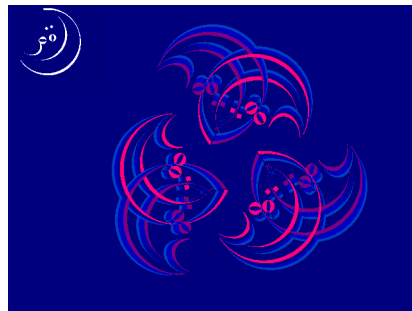

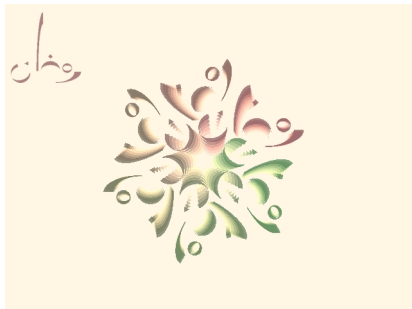a. Al Jamal (beauty) using **G**
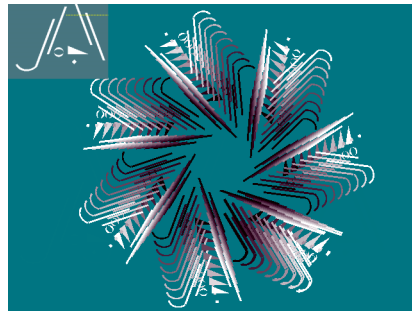
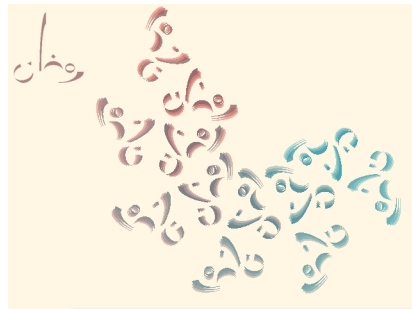b. Al Jamal (beauty) using **TR**

c. Al Qamar (moon) using **TR**

d. Al Qamar (moon) using **TMR**

e. Ramadan using **TR**

f. Ramadan using **TMR**

Figure 15. Calligraphic compositions generated using ICE

Conclusion

We have introduced computational abstractions for generating and manipulating calligraphic compositions organised by symmetry within an interactive environment. These abstractions were implemented in a prototype that supports dynamic calligraphic compositions. Any change in a symbol brings about a symmetrical change in associated symbols. As the user manipulates the symbols in a composition, the computational environment calculates the changes in numerous associated symbols then displays the updates, in real time, thus giving the impression of changing all these simultaneously. Such symmetrical changes, in particular, simultaneous symmetrical motions that are triggered by multiple regulators, bring about an exciting visual experience.

Dynamic abstractions present interesting new venues for design exploration. These provide designers with computational systems in which to work directly and interactively with relational spatial properties of design configurations. Regulators, as implemented, facilitate fine-tuning of design configurations and support radical transformations in configurations in a few simple steps. In the case of calligraphic designs, such explorative computational support goes beyond traditional means.

Our approach introduces a novel method of interaction with compositional elements, and demonstrates how controlled change propagation can be used to promote design exploration. The concept of regulators can also be applied to other design disciplines such as Architecture, which often uses symmetry as an organising principle. The first author is investigating the use of dynamic regulators that encapsulates ordering principles to generate, maintain or transform three-dimensional architectural design configurations.

On a personal note, the future phases of the calligraphy exploration project appear to be promising. We intend to pursue methods of improving calligraphic support, augmenting regulator functionality, and extending the system to three-dimensional designs.

References

Abbas, S, Salman, A. *Symmetry of Islamic Geometrical Pattern*. World Scientific, Singapore, 1998.

Gamma, E., Helm, R. *Design Patterns: Elements of Reusable Object-Oriented Software*. Addison Wesley Publishing Co., Holland, 1994.

Hargettai, Istvan. *Symmetry2: Unifying Human Understanding*. Pergamon Press, Oxford, 1989.

Khatibi, Abdelkebir, Sijelmassi, Mohammed. *The Splendour of Islamic Calligraphy*. Thames and Hudson, London, 1977.

(http://www.islamiccity.org/Culture/Calligraphy/ default.htm)

Massoudy, Hassan. *Calligraphie Arabe Vivante*. Flammarion, Paris, 1981.

Martin, George E. *Transformation Geometry*. Springer-Verlag, New York, 1982.

Sakkal, Mamoun. The Art of Arabic Calligraphy.

(http://www.sakkal.com/ArtArabic Calligraphy.html), 1993.