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Geometer's Angle

Dynamic Root Rectangles *Part One: The Fundamentals*

Keywords: descriptive geometry,
diagonal, dynamic symmetry,
incommensurate values,
Lindisfarne Gospels, root
rectangles

Abstract. Incommensurable ratios cannot be stated in finite, whole number fractions. But such ratios can organize spatial compositions so that the same ratio persists through endless divisions. We explore this proportioning principle, which Jay Hambidge calls "dynamic symmetry," as it appears in "root rectangles" of incommensurable proportions.

I Root Rectangles

Incommensurable ratios orchestrate diverse spatial elements through endless divisions, achieving unity without compromising the integrity of individual parts. "Dynamic symmetry" is the term given by Jay Hambidge to describe this proportioning principle which he observes in ancient Greek and Egyptian art, the human figure, and other forms of organic life.¹ Dynamic symmetry governs the relationship between individual elements and the relationship they bear to the whole. It is the "perfect modulating process," imparting rhythm and movement to the transition from one level of composition to the next.² We outline the fundamental components of Hambidge's system, looking to future columns to explore specific design applications.

Definitions:

"**Incommensurable**" is an adaptation of the medieval Latin *incommensurabilis* (*in-* "not" + *com-* "together" + *mensura* "a measure"). Quantities that lack a common measure or factor, expressed as never-ending fractions, are incommensurable [Simpson 1989].

Square root is the number that produces a specified number when multiplied by itself. The square root of 25 is 5, and is written $\sqrt{25} = 5$.

Root rectangles are rectangles based on square root proportions. Their edge lengths are incommensurable and cannot divide into one another. But a square constructed on the long side of the rectangle can be expressed in whole numbers, relative to a square constructed on the shorter unit side [Hambidge 1967, 18].

"Dynamic symmetry" appears in root rectangles whose side lengths in ratio are incommensurable, but are commensurable or measurable when expressed in square. [Hambidge 1960, 22-24; 1967, 17-18].³ A square constructed on the long side of a root-two rectangle ($1 : \sqrt{2}$ or $1 : 1.4142...$) is double the area of a square constructed on the shorter unit side (fig. 1a). A square constructed on the long side of a root-three rectangle ($1 : \sqrt{3}$ or $1 : 1.732...$) is three times the area of a square constructed on the shorter unit side (fig. 1b).

$$AB:BC :: 1:\sqrt{2}$$

Fig. 1a

$$AB:BD :: 1:\sqrt{3}$$

Fig. 1b

A square constructed on the long side of a root-four rectangle ($1 : \sqrt{4}$ or $1 : 2$) is four times the area of a square constructed on the shorter unit side (fig. 1c).⁴ A square constructed on the long side of a root-five rectangle ($1 : \sqrt{5}$ or $1 : 2.236...$) is five times the area of a square constructed on the shorter unit side (fig. 1d).

$$AB:BE :: 1:\sqrt{4}$$

Fig. 1c

$$AB:BF :: 1:\sqrt{5}$$

Fig. 1d

II Root Rectangles Outside a Square

A series of expanding root rectangles can be generated from a square, where each diagonal of the square or rectangle equals the long side of the next larger four-sided figure.

- Draw a horizontal baseline AB equal in length to one unit.
- From point A, draw an indefinite line perpendicular to line AB that is slightly longer in length.
- Place the compass point at A. Draw a quarter-arc of radius AB that intersects the line AB at point B and the open-ended line at point C.
- Place the compass point at B. Draw a quarter-arc (or one slightly longer) of the same radius, as shown.
- Place the compass point at C. Draw a quarter-arc (or one slightly longer) of the same radius, as shown.
- Locate point D, where the two quarter-arcs (taken from points B and C) intersect.
- Place the compass point at D. Draw a quarter-arc of the same radius that intersects the indefinite vertical line at point C and the line AB at point B (fig. 2).
- Connect points D, B, A and C.

The result is a square (DBAC) of side 1 (fig. 3).

Fig. 2

Fig. 3

- Draw the diagonal BC through the square (DBAC).

The side (DB) and the diagonal (BC) are in the ratio $1 : \sqrt{2}$.⁵

- Place the compass point at B. Draw an arc of radius BC that intersects the extension of line BA at point E (fig. 4).
- From point E, draw a line perpendicular to line EB that intersects the extension of line DC at point F.
- Connect points D, B, E and F.

The result is a root-two rectangle (DBEF) with short and long sides in the ratio $1 : \sqrt{2}$ (fig. 5).

Fig. 4

Fig. 5

$$DB:BE :: 1:\sqrt{2}$$

- Draw the diagonal BF through the root-two rectangle (DBEF).

The side (DB) and the diagonal (BF) are in the ratio $1 : \sqrt{3}$.

- Place the compass point at B. Draw an arc of radius BF that intersects the extension of line BE at point G (fig. 6).

Fig. 6

- From point G, draw a line perpendicular to line GB that intersects the extension of line DF at point H.
- Connect points D, B, G and H.

The result is a root-three rectangle (DBGH) with short and long sides in the ratio $1 : \sqrt{3}$ (fig. 7).

$$DB:BG :: 1:\sqrt{3}$$

Fig. 7

- Draw the diagonal BH through the root-three rectangle (DBGH).

The side (DB) and the diagonal (BH) are in the ratio $1 : \sqrt{4}$.

- Place the compass point at B. Draw an arc of radius BH that intersects the extension of line BG at point I (fig. 8).

Fig. 8

- From point I, draw a line perpendicular to line IB that intersects the extension of line DH at point J.
- Connect points D, B, I and J.

The result is a root-four rectangle (DBIJ) with short and long sides in the ratio $1 : \sqrt{4}$ (fig. 9).

$$DB:BI :: 1:\sqrt{4}$$

Fig. 9

- Draw the diagonal BJ through the root-four rectangle (DBIJ).

The side (DB) and the diagonal (BJ) are in the ratio $1 : \sqrt{5}$.

- Place the compass point at B. Draw an arc of radius BJ that intersects the extension of line BI at point K (fig. 10).

Fig. 10

- From point K, draw a line perpendicular to line KB that intersects the extension of line DJ at point L.
- Connect points D, B, K and L.

The result is a root-five rectangle (DBKL) with short and long sides in the ratio $1 : \sqrt{5}$ (fig. 11).

$$DB:BK :: 1:\sqrt{5}$$

Fig. 11

- Draw the diagonal BL through the root-five rectangle (DBKL).

The side (DB) and the diagonal (BL) are in the ratio $1 : \sqrt{6}$.

- Place the compass point at B. Draw an arc of radius BL that intersects the extension of line BK at point M (fig. 12).

Fig. 12

- From point M, draw a line perpendicular to line MB that intersects the extension of line DL at point N.
- Connect points D, B, M and N.

The result is a root-six rectangle (DBMN) with short and long sides in the ratio $1 : \sqrt{6}$ (fig. 13).

Fig. 13 displays the root rectangles in series, with their long sides relative to a unit side of 1.

Fig. 13

Civil engineer A. E. Berriman observes ancient Egyptian units of measure in the square and the root-two and root-three rectangles. If the edge of the square equals 14.58 inches, or one Egyptian remen, the long edge of the $1 : \sqrt{2}$ rectangle equals one royal cubit (20.625 inches); and the long edge of the $1 : \sqrt{3}$ rectangle equals one Palestinian cubit (25.25 inches).⁶

III Square Root Numbers in Three Dimensions

Square root numbers can also be observed in three dimensions.

- Draw or construct a cube of side 1.
- Locate a diagonal of a square face.
- Locate a diagonal through the body of the cube.

If the edge of the cube equals 1, the diagonal of a square face equals $\sqrt{2}$, and the diagonal through the body of the cube equals $\sqrt{3}$ (fig. 14).

- To the original cube, add a second cube of equal size, as shown.
- Locate a long edge of the double cube.
- Locate a diagonal of a double square face.

If the short edge of the double cube equals 1, the long edge of a double square face equals $\sqrt{4}$, and the diagonal through a double square face equals $\sqrt{5}$ (fig. 15).

Fig. 14

Fig. 15

- Locate a diagonal of a double square face.
- Locate a diagonal through the body of the double cube.

If the short edge of the double cube equals 1, the diagonal through a double square face equals $\sqrt{5}$, and the diagonal through the body of the double cube equals $\sqrt{6}$ (fig. 16).⁷

Fig. 16

Fig. 17

Figure 17 summarizes the appearance of square root numbers in a double cube.

- 1 Edge of cube
- $\sqrt{2}$ Diagonal of square face
- $\sqrt{3}$ Diagonal through body of cube
- $\sqrt{4}$ Long edge of double square face
- $\sqrt{5}$ Diagonal through double square face
- $\sqrt{6}$ Diagonal through body of double cube

IV Division of Root Rectangles into Reciprocals by the Diagonal

Incommensurable ratios replicate through endless spatial divisions and express the relationship between one level and the next. In Hambidge's system, this is evident in the way that root rectangles divide into reciprocals of the same proportion.

Definitions:

The **diagonal** is the straight line joining two nonadjacent vertices of a plane figure, or two vertices of a polyhedron that are not in the same face. The Greek for "diagonal" is *diagónios* (from *dia* "across" + *gónia* "angle"), which means "from angle to angle" [Liddell 1940, Simpson 1989].

The **reciprocal** of a major rectangle is a figure similar in shape, but smaller in size, such that the short side of the major rectangle equals the long side of the reciprocal [Hambidge 1967, 30, 131].

The diagonal of a major rectangle intersects the diagonal of its reciprocal at right angles in an arrangement that locates endless divisions in continued proportion.

V Diagonal and Reciprocal of the Root-Two Rectangle

A root-two rectangle divides into two reciprocals in the ratio $1 : \sqrt{2}$. The area of each reciprocal is one-half the area of the whole.

- Draw a square (DBAC) of side 1. (Repeat figs. 2 and 3.)

Fig. 2

Fig. 3

- Draw a rectangle (DBEF) of sides 1 and $\sqrt{2}$, as shown. (Repeat figures 4 and 5.)

Fig. 4

$$DB:BE :: 1:\sqrt{2}$$

Fig. 5

- Locate the diagonal (BF) of the rectangle DBEF.
- Locate the line EF. Draw a semi-circle that intersects the diagonal BF at point O, as shown.
- From point E, draw a line through point O that intersects line FD at point G.
- From point G, draw a line perpendicular to line FD that intersects the line BE at point H.
- Connect points H, E, F and G.

The result is a smaller rectangle (HEFG) with short and long sides of $1/\sqrt{2}$ and 1 ($\sqrt{2}/2:1$ or $0.7071...:1$). Rectangle HEFG is the reciprocal of the whole rectangle DBEF.

The major $1:\sqrt{2}$ rectangle DBEF divides into two reciprocals (HEFG and BHGD) that are proportionally smaller in the ratio $1:\sqrt{2}$.

- Locate the diagonal (BF) of the rectangle DBEF.
- Locate the diagonal (EG) of the reciprocal HEFG.

The diagonals BF and EG intersect at 90° at point O (fig. 18).⁸

$$\begin{aligned} GF:FE :: FE:EB :: 1:\sqrt{2} \\ EG:BF :: 1:\sqrt{2} \end{aligned}$$

Fig. 18

The diagonals EG and BF divide at point O into four radii vectors (OG, OF, OE and OB). The radii vectors emanate from the pole (point O) at equal 90° angles and progress in continued proportion in the ratio $1 : \sqrt{2}$.⁹

A root-two rectangle of any size divides into two reciprocals in the ratio $1 : \sqrt{2}$. If the process continues indefinitely, the side lengths of successively larger rectangles form a perfect geometric progression ($1, \sqrt{2}, 2, 2\sqrt{2} \dots$). The radii vectors locate where the divisions take place (fig. 19).

$$\begin{aligned} OG:OF &:: OF:OE :: OE:OB :: 1:\sqrt{2} \\ KJ:JI &:: JI:IG :: IG:GF :: GF:FE :: FE:EB :: 1:\sqrt{2} \end{aligned}$$

Fig. 19

VI Diagonal and Reciprocal of the Root-Three Rectangle

A root-three rectangle divides into three reciprocals in the ratio $1 : \sqrt{3}$. The area of each reciprocal is one-third the area of the whole.

- Draw a rectangle (DBGH) of sides 1 and $\sqrt{3}$, as shown. (Repeat figures 6 and 7.)

$$DB:BE :: 1:\sqrt{2}$$

Fig. 6

$$DB:BG :: 1:\sqrt{3}$$

Fig. 7

- Locate the diagonal (BH) of the rectangle DBGH.

- Locate the line GH. Draw a semi-circle that intersects the diagonal BH at point O, as shown.
- From point G, draw a line through point O that intersects line HD at point I.
- From point I, draw a line perpendicular to line HD that intersects the line BG at point J.
- Connect points J, G, H and I.

The result is a smaller rectangle (JGHI) with short and long sides of $1/\sqrt{3}$ and 1 ($\sqrt{3}/3:1$ or $0.5773...:1$). Rectangle JGHI is the reciprocal of the whole rectangle DBGH.

The major $1 : \sqrt{3}$ rectangle DBGH divides into three reciprocals (JGHI, LJIK and BLKD) that are proportionally smaller in the ratio $1 : \sqrt{3}$.

- Locate the diagonal (BH) of the rectangle DBGH.
- Locate the diagonal (GI) of the reciprocal JGHI.

The diagonals BH and GI intersect at 90° at point O (fig. 20).¹⁰

$$IH:HG :: HG:GB :: 1:\sqrt{3}$$

$$GI:BH :: 1:\sqrt{3}$$

Fig. 20

The diagonals GI and BH divide at point O into four radii vectors (OI, OH, OG and OB). The radii vectors emanate from the pole (point O) at equal 90° angles and progress in continued proportion in the ratio $1 : \sqrt{3}$.¹¹

A root-three rectangle of any size divides into three reciprocals in the ratio $1 : \sqrt{3}$. If the process continues indefinitely, the side lengths of successively larger rectangles form a perfect geometric progression ($1, \sqrt{3}, 3, 3\sqrt{3}...$). The radii vectors locate where the divisions take place (fig. 21).

$$OI:OH :: OH:OG :: OG:OB :: 1:\sqrt{3}$$

$$PN:NM :: NM:MI :: MI:IH :: IH:HG :: HG:GB :: 1:\sqrt{3}$$

Fig. 21

VII Diagonal and Reciprocal of the Root-Four Rectangle

A root-four rectangle divides into four reciprocals in the ratio $1:\sqrt{4}$. The area of each reciprocal is one-fourth the area of the whole.

- Draw a rectangle (DBIJ) of sides 1 and $\sqrt{4}$, as shown. (Repeat figs. 8 and 9.)

$$DB:BG :: 1:\sqrt{3}$$

Fig. 8

$$DB:BI :: 1:\sqrt{4}$$

Fig. 9

- Locate the diagonal (BJ) of the rectangle DBIJ.
- Locate the line IJ. Draw a semi-circle that intersects the diagonal BJ at point O, as shown.
- From point I, draw a line through point O that intersects the line JD at point K.
- From point K, draw a line perpendicular to line JD that intersects the line BI at point L.
- Connect points L, I, J and K.

The result is a smaller rectangle (LIJK) with short and long sides of $1/\sqrt{4}$ and 1 ($\sqrt{4}/4 : 1$ or $0.5 : 1$). Rectangle LIJK is the reciprocal of the whole rectangle DBIJ.

The major $1 : \sqrt{4}$ rectangle DBIJ divides into four reciprocals (LIJK, NLKM, QNMP and BQPD) that are proportionally smaller in the ratio $1 : \sqrt{4}$.

- Locate the diagonal (BJ) of the rectangle DBIJ.
- Locate the diagonal (IK) of the reciprocal LIJK.

The diagonals BJ and IK intersect at 90° at point O (fig. 22).¹²

$$\begin{aligned} KJ:JI &:: JI:IB :: 1:\sqrt{4} \\ IK:BJ &:: 1:\sqrt{4} \end{aligned}$$

Fig. 22

The diagonals IK and BJ divide at point O into four radii vectors (OK, OJ, OI and OB). The radii vectors emanate from the pole (point O) at equal 90° angles and progress in continued proportion in the ratio $1 : \sqrt{4}$.

A root-four rectangle of any size divides into four reciprocals in the ratio $1 : \sqrt{4}$. If the process continues indefinitely, the side lengths of successively larger rectangles form a perfect geometric progression ($1, \sqrt{4}, 4, 4\sqrt{4} \dots$). The radii vectors locate where the divisions take place (fig. 23).

$$\begin{aligned} OK:OJ &:: OJ:OI :: OI:OB :: 1:\sqrt{4} \\ TS:SR &:: SR:RK :: RK:KJ :: KJ:JI :: JI:IB :: 1:\sqrt{4} \end{aligned}$$

Fig. 23

VIII Diagonal and Reciprocal of the Root-Five Rectangle

A root-five rectangle divides into five reciprocals in the ratio $1 : \sqrt{5}$. The area of each reciprocal is one-fifth the area of the whole.

- Draw a rectangle (DBKL) of sides 1 and $\sqrt{5}$, as shown. (Repeat figures 10 and 11.)

Fig. 10

Fig. 11

- Locate the diagonal (BL) of the rectangle DBKL.
- Locate the line KL. Draw a semi-circle that intersects the diagonal BL at point O, as shown.
- From point K, draw a line through point O that intersects line LD at point M.
- From point M, draw a line perpendicular to line LD that intersects the line BK at point N.
- Connect points N, K, L and M.

The result is a smaller rectangle (NKLM) with short and long sides of $1/\sqrt{5}$ and $1 (\sqrt{5}/5:1$ or $0.4472... :1$). Rectangle NKLM is the reciprocal of the whole rectangle DBKL.

The major $1 : \sqrt{5}$ rectangle DBKL divides into five reciprocals (NKLM, QNMP, SQPR, USRT and BUTD) that are proportionally smaller in the ratio $1 : \sqrt{5}$.

- Locate the diagonal (BL) of the rectangle DBKL.
- Locate the diagonal (KM) of the reciprocal NKLM.

The diagonals BL and KM intersect at 90° at point O (fig. 24).¹³

Fig. 24

$$ML:LK :: LK:KB :: 1:\sqrt{5}$$

$$KM:BL :: 1:\sqrt{5}$$

The diagonals KM and BL divide at point O into four radii vectors (OM, OL, OK and OB). The radii vectors emanate from the pole (point O) at equal 90° angles and progress in continued proportion in the ratio $1 : \sqrt{5}$.

A root-five rectangle of any size divides into five reciprocals in the ratio $1 : \sqrt{5}$. If the process continues indefinitely, the side lengths of successively larger rectangles form a perfect geometric progression ($1, \sqrt{5}, 5, 5\sqrt{5} \dots$). The radii vectors locate where the divisions take place (fig. 25).

Fig. 25

$$OM:OL :: OL:OK :: OK:OB :: 1:\sqrt{5}$$

$$XW:WV :: WV:VM :: VM:ML :: ML:LK :: LK:KB :: 1:\sqrt{5}$$

A root-two rectangle equals $1 : 1.4142 \dots$. Its reciprocal ($\sqrt{2}/2 : 1$) equals $0.7071 \dots : 1$.
 A root-three rectangle equals $1 : 1.732 \dots$. Its reciprocal ($\sqrt{3}/3 : 1$) equals $0.5773 \dots : 1$.
 A root-four rectangle equals $1 : 2.0$. Its reciprocal ($\sqrt{4}/4 : 1$) equals $0.5 : 1$.
 A root-five rectangle equals $1 : 2.236 \dots$. Its reciprocal ($\sqrt{5}/5 : 1$) equals $0.4472 \dots : 1$.

IX Root Rectangles Within a Square

A series of diminishing root rectangles can be generated from a quarter-arc that is drawn within a square.

- Draw a square (DBAC) of side 1. (Repeat figures 2 and 3.)

Fig. 2

Fig. 3

- Locate the quarter-arc drawn from radius BA. Remove the other three.
- Draw the diagonal BC through the square DBAC.
- The quarter-arc (from radius BA) and the diagonal (BC) intersect at point E.
- Draw a horizontal line through point E that is parallel to line CD and intersects the line AC at point F and line DB at point G.
- Connect points G, B, A and F.

The result is a root-two rectangle (GBAF) with short and long sides of $1/\sqrt{2}$ and 1 (fig. 26).

Fig. 26

$$GB:BA :: 1:\sqrt{2}$$

- Draw the diagonal BF through the $1:\sqrt{2}$ rectangle (GBAF).
- The quarter-arc (from radius BA) and the diagonal (BF) intersect at point H.
- Draw a horizontal line through point H that is parallel to line FG and intersects the line AF at point I and line GB at point J.

- Connect points J, B, A and I.

The result is a root-three rectangle (JBAI) with short and long sides of $1/\sqrt{3}$ and 1 (fig. 27).

$$JB:BA :: 1:\sqrt{3}$$

Fig. 27

- Draw the diagonal BI through the $1:\sqrt{3}$ rectangle (JBAI).
- The quarter-arc (from radius BA) and the diagonal (BI) intersect at point K.
- Draw a horizontal line through point K that is parallel to line IJ and intersects the line AI at point L and line JB at point M.
- Connect points M, B, A and L.

The result is a root-four rectangle (MBAL) with short and long sides of $1/\sqrt{4}$ and 1 (fig. 28).

$$MB:BA :: 1:\sqrt{4}$$

Fig. 28

- Draw the diagonal BL through the $1 : \sqrt{4}$ rectangle (MBAL).
- The quarter-arc (from radius BA) and the diagonal (BL) intersect at point N.
- Draw a horizontal line through point N that is parallel to line LM and intersects the line AL at point O and line MB at point P.
- Connect points P, B, A and O.

The result is a root-five rectangle (PBAO) with short and long sides of $1/\sqrt{5}$ and 1 (fig. 29).

$$PB:BA :: 1:\sqrt{5}$$

Fig. 29

The long side of each root rectangle is 1. The short sides progress in the series $1/\sqrt{2}$, $1/\sqrt{3}$, $1/\sqrt{4}$, $1/\sqrt{5}$ ... (fig. 30).

$$\begin{aligned} DB:BA &:: 1: 1 \\ GB:BA &:: 1:\sqrt{2} \\ JB:BA &:: 1:\sqrt{3} \\ MB:BA &:: 1:\sqrt{4} \\ PB:BA &:: 1:\sqrt{5} \end{aligned}$$

Fig. 30

X Complementary Areas

In Hambidge's system, each rectangle has a reciprocal and each rectangle and reciprocal have complementary areas. These component shapes become evident when the rectangle is produced within a unit square.

Definition:

The **complementary area** is the area that remains when a rectangle is produced within a unit square. If the rectangle exhibits properties of dynamic symmetry, its complement will also.¹⁴

XI Complementary Patterns in the Root-Two Rectangle

- Draw a square (DBAC) of side 1. (Repeat figures 2 and 3.)

Fig. 2

Fig. 3

- Locate the root-two rectangle GBAF of sides $1/\sqrt{2}$ and 1, as shown. (Repeat figure 26.)

$$GB:BA :: 1/\sqrt{2}:1$$

Fig. 26

- Locate the rectangle DGFC that remains.

Rectangle DGFC is the complement of rectangle GBAF.

- Locate point E where the diagonal BC intersects the top edge of the root-two rectangle (GBAF).
- Draw a vertical line through point E that is perpendicular to line FG and intersects the line BA at point Q and line CD at point R.
- Locate the square GBQE within the rectangle (GBAF) and the square REFC within the complementary area DGFC (fig. 31).

$$GB:BA :: 1/\sqrt{2}:1$$

Fig. 31

$$\begin{aligned} RD:DB &:: DB:BT \\ 1/\sqrt{2}:1 &:: 1:\sqrt{2} \end{aligned}$$

Fig. 32

- Draw the diagonal BF through the root-two rectangle (GBAF).
- Extend the diagonal from point F until it intersects the extension of line DC at point S.
- From point S, draw a line perpendicular to line SD that intersects the extension of line BA at point T.
- Connect points D, B, T and S.

The rectangle (DBTS) that results is in the ratio $1 : \sqrt{2}$ (fig. 32).

DBAC is a unit square.

Rectangle DBTS is a root-two rectangle of sides 1 and $\sqrt{2}$.

Point E on the diagonal BC locates the squares GBQE and REFC.

Rectangle GBAF is a reciprocal of sides $1/\sqrt{2}$ and 1.

Rectangles GBAF and RDBQ are equal

Rectangle DGFC is the complement of the reciprocal (GBAF).

Rectangles DGFC and QACR are equal.

Rectangles DGER and QAFE are equal.

Rectangles QAFE and ATSC share common diagonals and are similar.

The root-two rectangle DBTS divides into two reciprocals (RDBQ and SRQT).

Definition:

Rectangles are **similar** if their corresponding angles are equal and their corresponding sides are in proportion. Similar rectangles share common diagonals.

XII Complementary Patterns in the Root-Three Rectangle

- Draw a square (DBAC) of side 1. (Repeat figures 2 and 3.)

Fig. 2

Fig. 3

- Locate the root-three rectangle JBAI of sides $1/\sqrt{3}$ and 1, as shown. (Repeat figures 26 and 27.)

$$GB:BA :: 1:\sqrt{2}:1$$

Fig. 26

$$JB:BA :: 1:\sqrt{3}$$

Fig. 27

- Locate the rectangle DJIC that remains.

Rectangle DJIC is the complement of rectangle JBAI.

- Locate point U where the diagonal BC intersects the top edge of the root-three rectangle (JBAI).

- Draw a vertical line through point U that is perpendicular to line IJ and intersects the line BA at point V and line CD at point W.
- Locate the square JBVU within the rectangle (JBAI) and the square WUIC within the complementary area DJIC (fig. 33).
- Draw the diagonal BI through the root-three rectangle (JBAI).
- Extend the diagonal from point I until it intersects the extension of line DC at point X.
- From point X, draw a line perpendicular to line XD that intersects the extension of line BA at point Y.
- Connect points D, B, Y and X.

The rectangle (DBYX) that results is in the ratio $1 : \sqrt{3}$ (fig. 34).

$$JB:BA :: 1/\sqrt{3}:1$$

Fig. 33

$$\begin{aligned} WD:DB &:: DB:BY \\ 1/\sqrt{3}:1 &:: 1:\sqrt{3} \end{aligned}$$

Fig. 34

DBAC is a unit square.

Rectangle DBYX is a root-three rectangle of sides 1 and $\sqrt{3}$.

Point U on the diagonal BC locates the squares JBVU and WUIC.

Rectangle JBAI is a reciprocal of sides $1/\sqrt{3}$ and 1.

Rectangles JBAI and WDBV are equal

Rectangle DJIC is the complement of the reciprocal (JBAI).

Rectangles DJIC and VACW are equal.

Rectangles DJUW and VAIU are equal.

Rectangles VAIU and AYXC share common diagonals and are similar.

The root-three rectangle DBYX divides into three reciprocals.

XV Complementary Patterns in the Root-Four Rectangle

- Draw a square (DBAC) of side 1. (Repeat figures 2 and 3.)
- Locate the root-four rectangle MBAL of sides $1/\sqrt{4}$ and 1, as shown. (Repeat figures 26-28.)

$$GB:BA :: 1/\sqrt{2}:1$$

Fig. 26

$$JB:BA :: 1:\sqrt{3}$$

Fig. 27

$$MB:BA :: 1:\sqrt{4}$$

Fig. 28

- Locate the rectangle DMLC that remains.

Rectangle DMLC is the complement of rectangle MBAL.

- Locate point Z where the diagonal BC intersects the top edge of the root-four rectangle (MBAL).
- Draw a vertical line through point Z that is perpendicular to line LM and intersects the line BA at point A' and line CD at point B'.
- Locate the square MBA'Z within the rectangle (MBAL) and the square B'ZLC within the complementary area DMLC (fig. 35).

$$MB:BA :: 1/\sqrt{4}:1$$

Fig. 35

- Draw the diagonal BL through the root-four rectangle (MBAL).
- Extend the diagonal from point L until it intersects the extension of line DC at point C'.
- From point C', draw a line perpendicular to line C'D that intersects the extension of line BA at point D'.
- Connect points D, B, D' and C'.

The rectangle (DBD'C') that results is in the ratio $1 : \sqrt{4}$ (fig. 36).

$$B'D:DB :: DB:BD'$$

$$1/\sqrt{4}:1 :: 1:\sqrt{4}$$

Fig. 36

DBAC is a unit square.

Rectangle DBD'C' is a root-four rectangle of sides 1 and $\sqrt{4}$.

Point Z on the diagonal BC locates the squares MBA'Z and B'ZLC.

Rectangle MBAL is a reciprocal of sides $1/\sqrt{4}$ and 1.

Rectangles MBAL and B'DBA' are equal.

Rectangle DMLC is the complement of the reciprocal (MBAL).

Rectangles DMLC and A'ACB' are equal.

Rectangles DMZB' and A'ALZ are equal.

Rectangles A'ALZ and AD'C'C share common diagonals and are similar.

The root-four rectangle DBD'C' divides into four reciprocals.

XIV Complementary Patterns in the Root-Five Rectangle

- Draw a square (DBAC) of side 1. (Repeat figure 2 and 3.)
- Locate the root-five rectangle PBAO of sides $1/\sqrt{5}$ and 1, as shown. (Repeat figures 26-29.)

$$GB:BA :: 1/\sqrt{2}:1$$

Fig. 26

$$JB:BA :: 1:\sqrt{3}$$

Fig. 27

$$MB:BA :: 1:\sqrt{4}$$

Fig. 28

$$PB:BA :: 1:\sqrt{5}$$

Fig. 29

- Locate the rectangle DPOC that remains.

Rectangle DPOC is the complement of rectangle PBAO.

- Locate point E' where the diagonal BC intersects the top edge of the root-five rectangle (PBAO).
- Draw a vertical line through point E' that is perpendicular to line OP and intersects the line BA at point F' and line CD at point G'.
- Locate the square PBF'E' within the rectangle (PBAO) and the square G'E'OC within the complementary area DPOC (fig. 37).

$$PB:BA :: 1/\sqrt{5}:1$$

Fig. 37

- Draw the diagonal BO through the root-five rectangle (PBAO).
- Extend the diagonal from point O until it intersects the extension of line DC at point H'.
- From point H', draw a line perpendicular to line H'D that intersects the extension of line BA at point I'.
- Connect points D, B, I' and H'.

The rectangle (DBI'H') that results is in the ratio $1:\sqrt{5}$ (fig. 38).

$$\begin{aligned} G'D:DB &:: DB:BI' \\ 1/\sqrt{5}:1 &:: 1:\sqrt{5} \end{aligned}$$

Fig. 38

DBAC is a unit square.

Rectangle DBI'H' is a root-five rectangle of sides 1 and $\sqrt{5}$.

Point E' on the diagonal BC locates the squares PBFE' and G'E'OC.

Rectangle PBAO is a reciprocal of sides $1/\sqrt{5}$ and 1.

Rectangles PBAO and G'DBF' are equal.

Rectangle DPOC is the complement of the reciprocal (PBAO).

Rectangles DPOC and F'ACG' are equal.

Rectangles DPE'G' and F'AOE' are equal.

Rectangles F'AOE' and AI'H'C share common diagonals and are similar.

The root-five rectangle DBI'H' divides into five reciprocals.

XV: Application: Matthew Carpet Page, the Lindisfarne Gospels

One of the great painted manuscripts of early Christian Britain is the illuminated book known as the Lindisfarne Gospels. Produced in honor of Saint Cuthbert between the late seventh and early eighth centuries at the monastic center of Lindisfarne on Holy Island,¹⁵ it is believed to have been written and decorated essentially by a single hand, likely that of the Bishop Eadfrith. The Lindisfarne Gospels contain two versions of the four Gospel texts: the Latin text attributed to Eadfrith; and a translation in the mid-tenth century into Old English by the priest Aldred, inserted between the lines of original text. To some, the book is an *opus dei*, or work of God, the result of intensive labor, revelation and prayer.¹⁶

The manuscript is one of the outstanding works to survive the Insular period of the early Middle Ages (sixth to ninth centuries) in Ireland and Britain, an era noted for book painting, jewelry, building design and sculpture and characterized by rich ornamentation and the blending of Celtic, Germanic, early Christian, Mediterranean and other influences. Insular manuscript art typically integrates script, text and decoration. Detailed patterns combine zoomorphic figures, plaited interlace, knot and spiral work [Brown 1994, 74, Brown 2003, 272].

The Lindisfarne Gospels contain fifteen primary decorated pages, including five decorative cross-carpet pages, so named for their similarity to oriental carpets, in which a cross is featured as the dominant motif, against a background of interlace fill. The manuscript contains 259 leaves or folios of fine calfskin vellum, assembled in groups of eight and one additional flyleaf. Back-pages reveal traces of prickings, compass holes, divider marks, rulings and grid lines, suggesting geometric guides to layout and design composition. Michelle Brown, former Curator of Western Manuscripts at The British Library, believes that preliminary designs were drawn in reverse on the back and viewed with the aid of backlighting. Back-drawings exist for almost every decorative element in the manuscript, permitting guidelines to be viewed even after pigment is applied to the front.¹⁷

The Matthew carpet page (folio 26v) introduces the Gospel of Matthew and is the longest of the illuminated carpet pages, measuring 186 mm x 249 mm across a double rectilinear frame [Bruce-Mitford in *Evangelium Quattuor Codex Lindisfarnensis* 1960, 2: 232]. Six terminals are laid in the form of a Latin cross, in 4 x 3 fashion. Five terminals resemble chalices or bells; the sixth terminal at the hub is circular. All have centers marked by circles of blank vellum, possibly intended for gilding. The cross and background panels consist of bird, animal and abstract interlace and spiral work.¹⁸ It is noteworthy that the distance between adjacent terminal centers is a uniform 59 mm, except the lowest terminal, which measures 64 mm from the one directly above [Stevick 1994, 143, Brown 2003, 298, 325-327]. (See figure 39a, below, and Fig. 39b.)

Fig. 39a. The Matthew Cross-Carpet

At least three scholars have proposed specific geometric frameworks for the layout of the Matthew carpet page.¹⁹ Rupert L. S. Bruce-Mitford, whose commentary accompanies a 1956 facsimile of the manuscript, utilizes prickings and other back page markings to establish a grid of circles and rulings that situate specific ornamental motifs. He does not delineate a primary spacing unit, nor does he resolve the proportions of the overall frame, the location and relative sizes of key elements, or the “irregular” placement of the lowest medallion [Bruce-Mitford in *Evangelium Quattuor Codex Lindisfarnensis* 1960, 2: 226-30, fig. 59, Guilmain 1987, 41].

Fig. 39b. Matthew Cross-Carpet Page. Lindisfarne Gospels, fol. 26v, with geometric overlay by Rachel Fletcher

The scheme proposed by Jacques Guilmain identifies a primary spacing unit that is used throughout. An overall grid of 61 x 82 units encompasses the double frame and situates individual panels.²⁰ Guilmain's intent is to illuminate the design's additive and repetitive components, where patterns and combinations of patterns repeat within a defined space. His proposal is consistent with regularly spaced pricking and rulings that are evident on the blank recto of the folio [Guilmain 1987, 41-47].

Of the three, Robert D. Stevick alone proposes how individual elements relate by geometric proportion to the composition as a whole. His analysis is supported by traces on the reverse of 45° diagonal rulings that intersect at all six terminal centers. Stevick observes that the outside measure of the double frame (249 x 186 mm) is slightly more than 4 : 3 in ratio and proposes a 3 : √5 rectangle for its proportions [Stevick 1994, 142- 150].

Stevick's diagonal grid extends slightly beyond the inside frame on three sides, but the baseline of the composition is unresolved. And while the grid locates all six terminal centers, the relative sizes and proportions of masses are not addressed. The geometric layout in figure 39b proposes an additional layer of interpretation that complements Stevick's and other studies, describing the proportions of individual components in relation to one another and to the composition as a whole. A striking interplay of elements of √2 and √3 dynamic symmetry is evident.²¹

The study is confined to the composition within the double frame of the Matthew carpet page.

- Draw a square whose top edge coincides with the top inside edge of the double frame.
- Draw vertical and horizontal lines through the center of the square. Extend the vertical center line indefinitely.
- Draw 45° diagonal lines through the center of the square.

The center of the square locates the terminal center at the hub of the Matthew cross.

- Place the compass point at any corner of the square and draw a quarter-arc of radius equal to half the length of the square, as shown.
- Repeat at the remaining three corners.
- Locate the four points where the quarter-arcs and diagonals intersect.
- Draw vertical and horizontal lines through all four points.

The vertical and horizontal lines divide the Matthew carpet page into respective cross and background panels.²²

- Place the compass point at the center of the square. Open the compass to a bottom corner of the square and draw a quarter-arc, as shown.

The quarter-arc and vertical center line intersect at the center of the lowest terminal of the Matthew cross.

- Place the compass point at the midpoint of the left edge of the square. Open the compass to the center of the quarter-arc, as shown. Draw an arc that intersects the extension of the left edge of the square.
- Repeat from the right edge of the square.

- Connect the two points of intersection.

The baseline that results locates the bottom inside edge of the double frame of the Matthew carpet page.

Elements of $\sqrt{2}$ and $\sqrt{3}$ dynamic symmetry appear to dominate the composition. Root-two rectangles appear on either side of the vertical center line, marked above by the center of the Matthew cross, and below by the center of the cross's lowest terminal. Reciprocal root-two rectangles are contained within each quarter square. The remaining complementary areas define the width of the Matthew cross. The total composition divides at the center of the cross into a square, above, and a root-three rectangle, below, on either side of the vertical center line. The study is supported on the blank recto of the folio by prickings and rulings that coincide with key elements of the geometric layout.²³

It is not self-evident that the artist of the Matthew carpet page adopted any of the proposed geometric techniques, for the ability to demonstrate how a design can be constructed does not prove that it was done in that fashion.²⁴ But the precision with which dynamic $\sqrt{2}$ and $\sqrt{3}$ proportions appear in the composition is compelling. It is interesting to note that the Latin cross features six distinct terminals, as if to suggest the faces of an unfolded cube. The fact that $\sqrt{2}$ and $\sqrt{3}$ proportions are also present in the cube implies a new layer of symbolism. (See fig. 14.) Stevick observes that the leaves of the illuminated manuscript are in 1 : $\sqrt{2}$ ratio [Stevick 1994, 90]. Designed to lie flat, they form a root-two rectangle divided into two reciprocals.

XVI Summary

When a square divides into diminishing root rectangles, or when root rectangles expand from a square, elements of dynamic symmetry become apparent. We have experienced the relative spatial characteristics of root-two, -three, -four, and -five systems of proportion and are familiar with diagonals, reciprocals, complementary areas and other components. We have observed these at play in the Matthew carpet page of the Lindisfarne Gospels. In future columns, we explore new ways to utilize these elements in dynamic space plans.

Notes

1. P. H. Scholfield's name for "dynamic symmetry" is "repetition of similar figures," which he traces to the works of Vitruvius and Alberti, and in the late eighteenth and nineteenth centuries to the theories of A. Barca, William Watkys Lloyd and August Thiersch. For Thiersch, "the repetition of the fundamental form of the plan through its subdivisions" contributes to the best of art throughout history [quoted in Scholfield 1958, 102]. Scholfield identifies such other theorists and practitioners as Heinrich Wölfflin, John Beverly Robinson, and more recently Harry Roberts, Sir Edwin Lutyens, Corbusier, William Schooling and Sir Theodore Cook. See [Scholfield 1958, 102-120].
2. [Hambidge 1967, xii, xiv-xvi.] In contrast, static symmetry is accomplished by dividing a linear measure into even multiple units or by the radial subdivision of regular geometric figures, crystals or flowers. Dynamic symmetry, found in shell growth or the arrangement of leaves on a plant, is a more vital and flexible organizing system [Hambidge 1960, 3, Scholfield 1958, 117].

3. Hambidge was unfamiliar with ancient Greek when he chose the term “dynamic symmetry” to describe this characteristic. Later, he discovered Thomas Heath’s edition of Euclid, where the Greek *dunamei summetros* or *summetrôs dunama*, previously translated “commensurable in power,” is “commensurable in square” [Euclid 1956, III: 11 (bk. X, def. 2), Hambidge 1967, 129, Liddell 1940].
4. The long side of a root-four rectangle ($\sqrt{4}$ or 2.0) is commensurable in length, but the root-four rectangle exhibits dynamic symmetry in other ways.
5. The calculation of the diagonal BC is based on the Pythagorean Theorem. Triangle CDB is a right triangle. $CD^2 + DB^2 = BC^2$ [$1^2 + 1^2 = 2$]. Thus, $BC = \sqrt{2}$. The diagonal of a square of side 1 is equal to $\sqrt{2}$. The diagonals that appear in figures 6, 8, 10 and 12 can be calculated in similar fashion. See [Fletcher 2005b, 44-45] for more on the Pythagorean Theorem.
6. [Berriman 1969, 29.] John Michell proposes a more comprehensive system, but specifies different values for each unit of measure. In Michell’s version, one Egyptian remen (the side length of the square) equals 1.2165 feet or 14.598 inches. One royal cubit (the long length of the root-two rectangle) equals 1.72 feet or 20.64 inches. One Palestinian cubit (the long length of the root-three rectangle) equals 2.107 feet or 25.284 inches. One Roman pace (the long length of the root-four rectangle) equals 2.433 feet or 29.196 inches. One megalithic yard (the long length of the root-five rectangle) equals 2.72 feet or 32.64 inches. Virtually one yard (the long length of the root-six rectangle) equals 2.98 feet or 35.76 inches [Michell 1972, 106]. For more on the Megalithic yard, discovered by Alexander Thom, see [Thom 1976, 34].
7. In fig. 14, the three lengths of 1, $\sqrt{2}$ and $\sqrt{3}$ form a right triangle. In fig. 15, the three lengths of 1, $\sqrt{4}$ and $\sqrt{5}$ form a right triangle. In fig. 16, the three lengths of 1, $\sqrt{5}$ and $\sqrt{6}$ form a right triangle. This is evident by the Pythagorean Theorem.
8. By the Pythagorean Theorem, BF equals $\sqrt{3}$ and EG equals $\sqrt{3}/\sqrt{2}$.
9. The radius vector is the variable line segment drawn to a curve or spiral from a fixed point of origin (the pole or eye) [Simpson 1989]; see also [Fletcher 2004, 105]. For more on the root-two rectangle and its inherent proportions, see [Fletcher 2005b, 55-56].
10. By the Pythagorean Theorem, BH equals $\sqrt{4}$ and GI equals $\sqrt{4}/\sqrt{3}$.
11. For more on the root-three rectangle and its inherent proportions, see [Fletcher 2004, 102-105; and 2005a, 153-157].
12. By the Pythagorean Theorem, BJ equals $\sqrt{5}$ and IK equals $\sqrt{5}/\sqrt{4}$.
13. By the Pythagorean Theorem, BL equals $\sqrt{6}$ and KM equals $\sqrt{6}/\sqrt{5}$.
14. Hambidge says, “[The] complement of a shape is that area which represents the difference between the selected figure and unity. The complement of any number is obtained by dividing the number into unity to find the reciprocal and subtracting that reciprocal from unity” [1967, 128].
15. Holy Island is located in northeastern England, Northumbria.
16. [Backhouse 1981, 7, 12, 14, Brown 2003, 280, 283-4, 397, 399.] Janet Backhouse dates the manuscript just prior to 689 when Eadfrith became bishop of Lindisfarne. Michelle Brown’s more recent investigation dates Eadfrith’s work to 710-720. The book resides today at The British Library in London, where it is known as Cotton MS Nero D.iv.
17. [Brown 2003, 200-203, 217-220, 290-98.] One exception is the series of Canon Tables that repeat a basic layout and reveal prickings and rulings in another fashion.
18. Eric George Millar [1923, 37] counts sixty-six animals and fifty-eight birds in all. For Brown on the theological significance of the Matthew and other carpet pages, see [Brown 2003, 297-298, 312-327].
19. Others such as John Romilly Allen, George Bain and Eric George Millar [1923, 36-38] offer guides or techniques for accomplishing ornamental elements, but do not consider individual elements as they relate to the composition as a whole. See [Guilmain 1987, 21-22, Stevick 1994, 146]. In addition, Swenson [1978, 9-11, 14-15, fig. 12] provides examples of rotational and reflexive symmetry.

20. In Guilmain's scheme, a primary unit measuring 3.04 mm wide and 3.05 mm long is required to conform to Bruce-Mitford's measure of 186 x 249 mm for the double frame.
21. The study utilizes scaled photographs of the original manuscript, courtesy of Janet Backhouse, The British Library. COTTON.NERO.D.IV f26v © British Library Board. All Rights Reserved. Geometric overlay: Rachel Fletcher.
22. The baseline of the square does not align with the base of its adjacent terminal, but is indicated on the reverse by a distinct ruled line and prickings.
23. Rulings that do not delineate a finished pattern likely serve to advance a geometric layout. These include a full-length, ruled vertical center line and a full-length ruled horizontal line that coincides with the baseline of the square. Traces of horizontal rulings through the center and left terminals of the Matthew cross coincide with the horizontal line through the center of the square. Compass holes or prickings are evident at the midpoint of the left edge of the square and at the intersection of the left edge and baseline. Possibly, these were used to draw a $\sqrt{3}$ radius arc. A ruled horizontal line coincides with the bottom inside edge of the inner frame. Numerous prickings suggest its importance to the layout.
24. [Guilmain 1987, 22-23, Stevick 1994, 145-146]. Brown concedes that technical innovations used to produce the Lindisfarne Gospels, such as leadpoint, backlighting and reversed design, developed under solitary working conditions and may not have been widespread. Leadpoint, the precursor to pencil, enabled the design to be laid out *in situ*, rather than through the cumbersome transfer from secondary vehicles, such as slate, stone, wood or wax tablets used by other artists of the period [Brown 224-226, 290, 298].

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