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The Art Bulletin

Vol. 53, No. 4 (Dec., 1971), pp. 461-466

Published by: [College Art Association \(/action/showPublisher?publisherCode=caa\)](/action/showPublisher?publisherCode=caa)

DOI: 10.2307/3048902

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A Musical Canon of Proportion in Leonardo da Vinci's *Last Supper*

Thomas Brachert

"And if you say, music is composed of proportion, then I, too, have followed the same in painting, as you shall see" (trans. from *Leonardo da Vinci. Das Buch von der Malerei*, ed. H. Ludwig, No. 31 [34]).

"Find out," says Leonardo in the *Codex Atlanticus* 132b, of around 1508 "how much a man diminishes at a distance which is the same as his height; and at twice that distance and at three times, and so make your general rule" (Richter ed., No. 104). Thus Leonardo seeks to elicit a law by which the phenomena of optical space are measurable, a law comparable to the musical intervals which, in his era, were conceived as the ordering principles of a creation based on number and proportion. This belief in an omnipresent measure retained its validity for Leonardo for a long time. He sees the microcosm of the human body mirrored in the macrocosm¹ (*Quaderni*, I, 2a); he compares breathing with the ebb and flow of the sea (*Codex Leicester*, 34a), and he correlates the heartbeat in a fixed proportion to the astronomical unit of time (*Quaderni*, II, 11a). With this belief in measure, the work of art to him is a symbol of the ordering forces of the universe, and "painting as science" is a tool for exploring their effects. Music for him, both the mathematical *musica mundana* and the instrumental music practiced by the artist, is closely and significantly related to painting:

"Music cannot be called other than a sister of painting, because it is subject to the ear, the sense second to the eye, and composes harmony by the simultaneous conjunction of its proportional parts which are made to live and die within

one or more harmonious beats; and these beats circumscribe the proportionality of the individual members that compose such a harmony, just as line circumscribes the individual members that make up human beauty" (H. Ludwig ed., No. 29 [32]) ". . . just as music and geometry consider the proportions of stable quantities, and arithmetic the variable ones, so painting considers all the stable quantities as well as the proportional qualities of shades and lights and of distances in its perspective" (H. Ludwig, No. 37). In relation to the *Treatise on Painting* he says in ms 2038 of around 1492: "I grade the things before the eye as the musician grades the sounds that meet his ear. Although before the eye things occasionally appear to touch each other, I shall nonetheless make my rule for distances of twenty braccia as the musician has done for sounds; because, although all these [sounds] are in fact linked and touch upon each other, he has fixed intervals from tone to tone, has called them first, second, third, fourth, and fifth, and has thus named, from step to step, the variety of higher and lower tones."

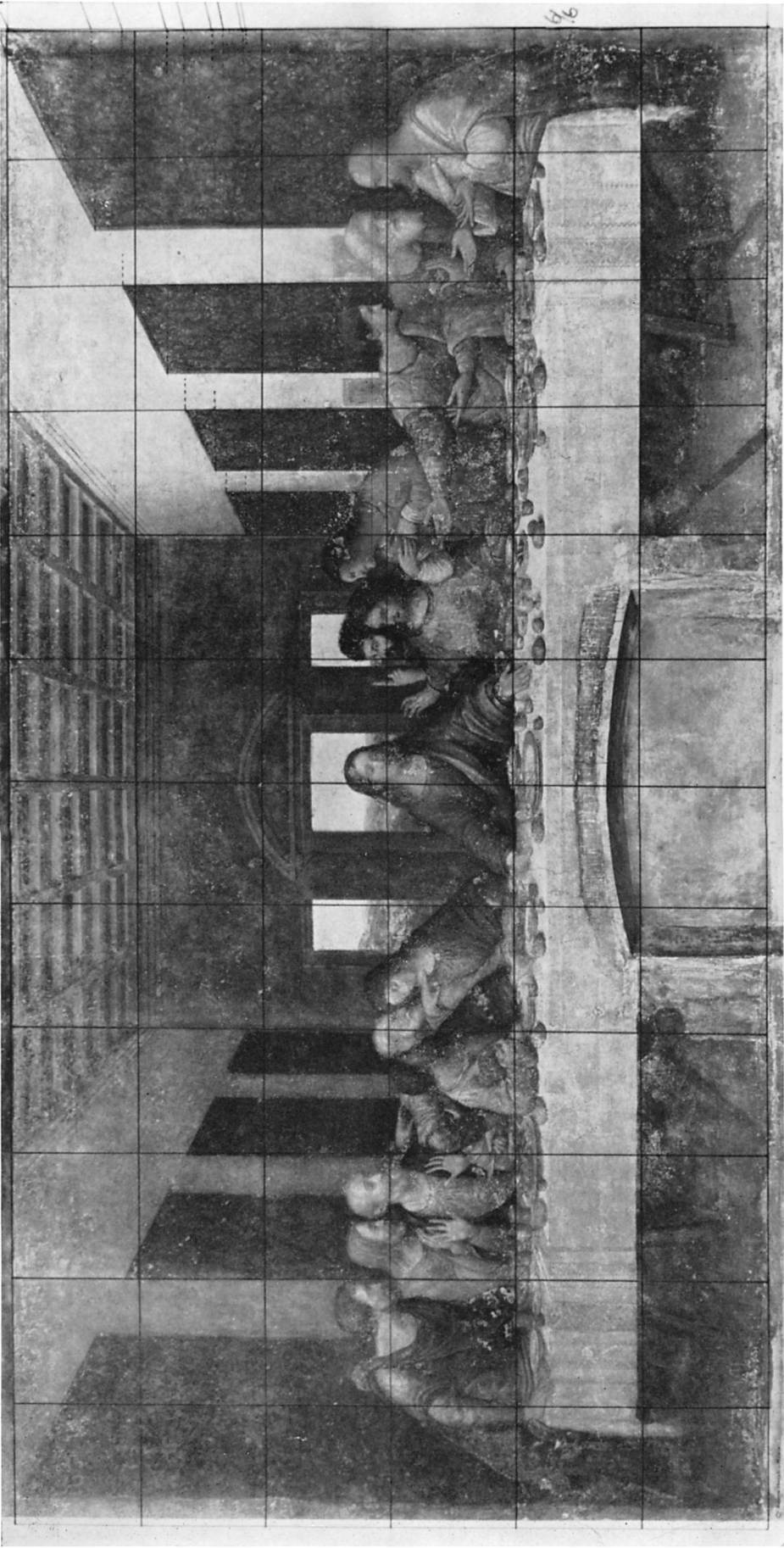
In the science of art, Leonardo's remarks have, by and large, been treated as theory since they are not visibly reflected in his works. Moreover, his formulations are of so general a nature that any attempt at interpreting them has been treated as speculation.² In addition, apart from Leonardo's early works, there is only one painting with an architectonic perspective background against which his theory of perspective can be tested: the *Last Supper*. As early as 1907 Otto Hoerth examined this work in this light.³ However, among other things Hoerth remarked

¹ G. Bilancioni, "La Dottrina del Macro- e del Microcosmo," *Miscellanea . . . in onore di E. Verga*, Milan, 1931. L. H. Heydenreich, *Leonardo da Vinci*, Basel, 1953, 156. J. Gantner, *Leonardos Visionen von der Sintflut und vom Untergang der Welt*, Bern, 1958, 62f., 156, 228. S. Esche, *Leonardo da Vinci, Das anatomische Werk*, Basel, 1954, 16.

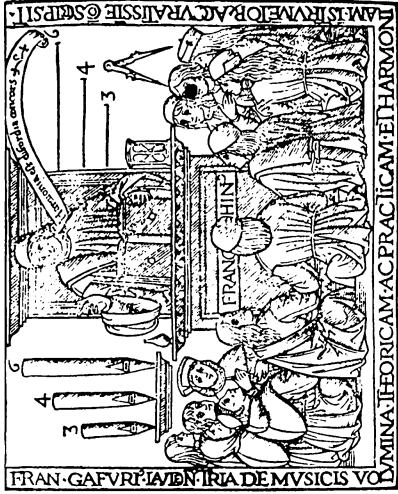
² Although H. Ludwig had already pointed out in 1882 that the number sequences of the passage on perspective in No. 461 of the *Treatise on Painting* must be based on Platonic notions, subsequent research hardly followed up his hints, especially since the corresponding paragraph with the passage "and the third is as far beyond the second, as the second from the third" contains an obvious oversight which the compilers of the *Trattato* transferred literally from the original (ms 2038, Richter ed., 99). Richter amends, "as the second from the first," which is equally wrong. H. Ludwig was forced to alter the text forcibly and later rejected his own interpretation. The passage would be correct if it contained the phrase "from the eye." However, the ensuing text with the progression 1/5, 1/10, 1/20 is mistaken within Euclidian geometry, as anyone can read from the *linea del taglio*. In 1925, Ludwig's interpretation was critically commented upon, in the German edition of the *Trattato*, by Marie Herzfeld, in the light of the original Leonardo notes published in the meantime. Yet she misconstrued the musical nature of Leonardo's perspective progression 1:1/2:1/4:1/8:1/16, which she cites from ms A8b (graph 1, text page 4f) by saying: "A different numeration of the distance produces the ratios of the musical intervals, . . . Leonardo, however, prefers the simple, large proportional rhythms, as those examples show" (*Traktat von der Malerei*, ed. M. Herzfeld after trans. by H. Ludwig, Jena, 1925, xviii). Rudolf Wittkower is more correct in his

interpretation of the controversial Leonardo passage in his paper, "Brunelleschi and Proportion in Perspective," *Journal of the Warburg and Courtauld Institutes*, xvi 1953, 286f. Yet, not having examined Leonardo's paintings in this respect, he concludes rather cautiously: "It appears then, that at this particular moment Leonardo's interest was focused on demonstrating the potency of Pythagoreo-Platonic harmonies in optical space. . .," and he remarks, "It must however be said that Leonardo never mentioned this series explicitly." In regard to the philosophical content of the passages in question, art-historical research has in recent times tended rather to ignore or decline any interpretations. Heydenreich, *Leonardo*, 125, on the one hand considers the problem of proportions in the contemporary theory of art generally as of "central significance," and on the other hand deals with it only in passing and does not take into account Leonardo's relation to Platonism at all. K. Clark, *Leonardo da Vinci*, Cambridge, 1952, recognizes Platonic influence in the *Trattato* passages, but, on page 73, judges Leonardo's findings "abstruse"! This scant regard might result to a great extent from a certain positivistic attitude of research which has placed the emphasis on the futuristic aspects of the *Trattato*; an attitude to be expected in Leonardo's case. Thus, Platonism and the complex spiritual currents of the age have, as yet, not been given due attention, although Platonic notions played a highly important role even in the natural sciences of the following period. Galileo's law of gravity and even Kepler's harmony of planetary orbits are defined in terms of musical proportions!

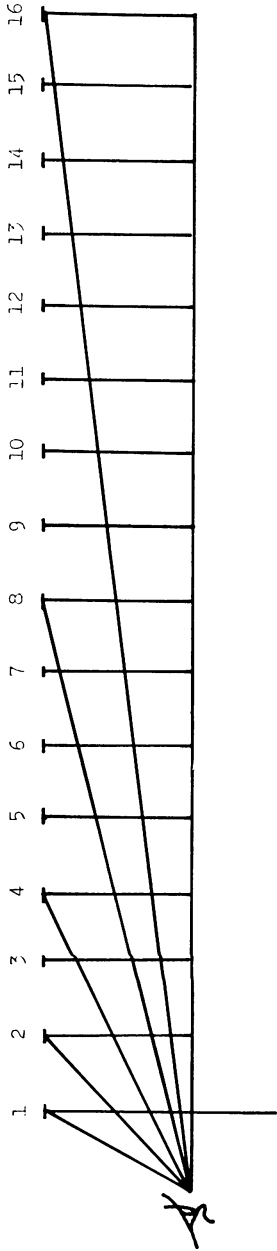
³ *Das Abendmahl des Leonardo*, Leipzig, 1907.



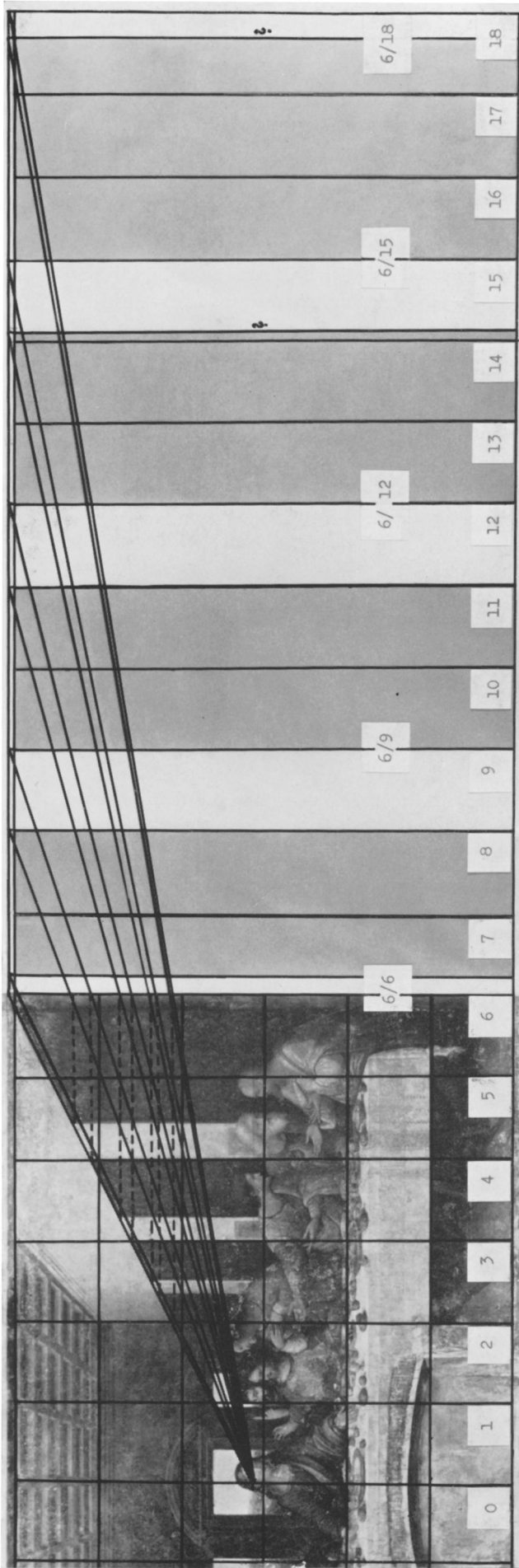
1 Square grid of the *Last Supper* of 6×12 units. The pictorial space is also ordered according to a quadratic cross-section based on the same grid units (cf. Fig. 4)



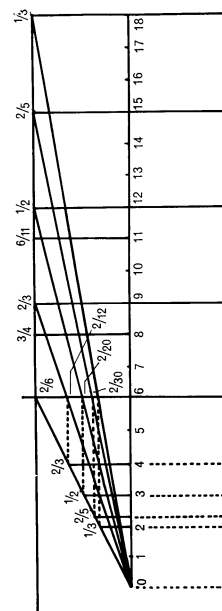
2 Franchino Gaffurio, woodcut from the *Theorica musicae*, 1492



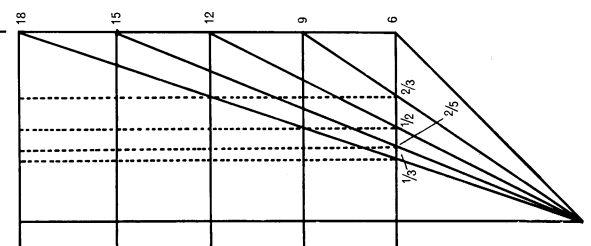
3 Leonardo's rule of perspective from ms A8b. Objects of equal size diminish on the pictorial plane (line No. 1) at equal distances according to the rule $1 : \frac{1}{2} : \frac{1}{3} : \frac{1}{4}$, etc.



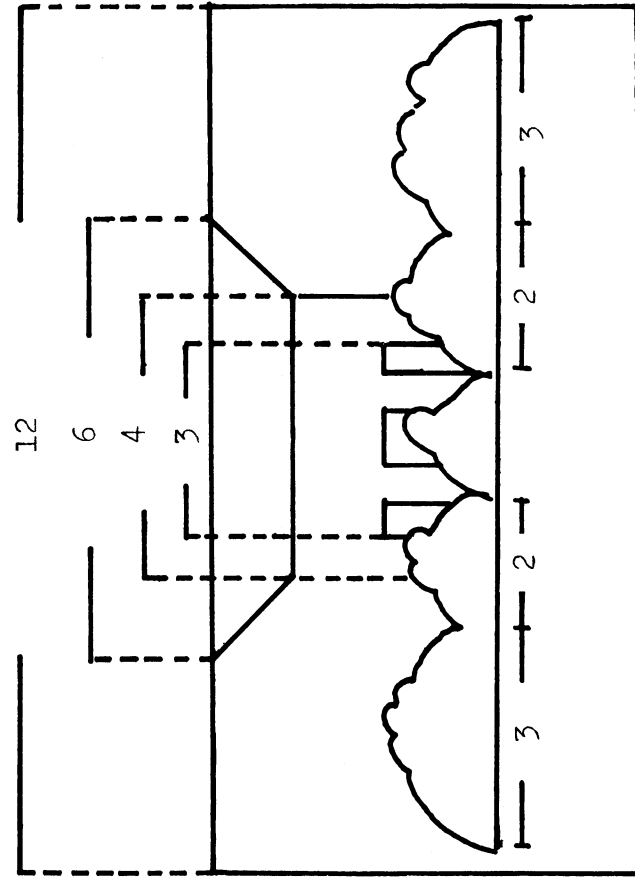
4 Projection of the right-hand lateral wall of the *Last Supper*: the tapestries increase in width towards the back according to the numerical system 12:6:4:3, without, however, exceeding the grid schema (their bottom edge is neglected in this drawing)



5a (above) Foreshortening of the right wall of the pictorial space, represented in vertical projection by the lines 6–18. The foreshortening ratio of the tapestries is indicated by the vertical lines between Nos. 2 and 6



5b (left) Right half of the pictorial space on the same scale as Fig. 5a. Line 6 indicates the picture plane



6 The horizontal proportion scheme of the *Last Supper* follows the ratio 12:6:4:3. The groups of figures occupy two and three units each

with disappointment that Leonardo did not even proceed according to the laws of one-point perspective and instead operated with considerable artistic license. Hoerth based his study not on the original but on the Castellazzo copy by Andrea Solario. His findings were accepted uncritically by Emil Moeller.⁴ Since then attempts have been made again and again to reconstruct the painting's canon of proportion.⁵

The basic unit of the picture, a twelfth of the entire width from wall to wall, is given in the division into six parts of the ceiling along the top (Fig. 1).⁶ The height measured from the uppermost stucco molding to the horizontal bottom line (most easily identifiable on the left half of the picture) is one half or six twelfths of the total width respectively, with minimal divergences. The width of the rear wall has already been calculated by O. Hoerth as one third of the whole width, in other words, four twelfths of the picture's width. The same can be measured from the somewhat slanting hem of the table cloth up to the coffered ceiling. The result is a square, four twelfths by four twelfths. An equal square, one sixth higher than the latter, extends from the upper, that is, far, edge of the table to the top of the picture. The space below the table cloth to the visible horizontal is again one sixth of the height.

On each side of the painting the depth extension of the wall tapestries is also arranged in accordance with the duodecimal sectioning: two tapestries on each side fill out the one twelfth adjoining the rear wall, the following section embraces one tapestry (plus interstice), while the nearest tapestry (plus interstice and outer border) takes up the last two twelfths on each side. Within the framework of the quadrature the proportioning of the widths of the tapestries from the outside inward follows the ratios 12:6:4:3, or $1:\frac{1}{2}:\frac{2}{3}:\frac{1}{4}$. As is known, these proportions find their analogy in the contemporary theory of architecture

and music: for instance in Leon Battista Alberti⁷ and Franchino Gaffurio,⁸ according to whom the ratio 3:4 corresponds to the *sesquitercia* or *diatessaron* and the tonal interval of the fourth; *sesquialtera* or *diapente* corresponds to the fifth with the ratio 4:6; and the octave with 6:12 is called *dupla* or *diapason* (Fig. 2). These proportions appear as a musical key on the Pythagoras tablet in Raphael's *School of Athens*,⁹ where they represent the initial integers of the Pythagorean sequence. Leonardo jots them down on a sketch for the *Last Supper*, Windsor No. 12542, in a not otherwise apparent connection. The notation runs 3.4.6.–6.3–6–4=32. In accordance with the Renaissance theoreticians this sequence of numbers could be interpreted as the ratios of the fourth and fifth within the octave (3:4:6), of the octave (6:3), and of the fifth (6:4) respectively (except that the last two numbers are separated by a dash).¹⁰

In ms A8b and various other notes,¹¹ Leonardo formulates the numerical proportion 12:6:4:3 as an ordering principle he believes to have discovered in optical space. He expresses it on the *linea del taglio* in a sequence of fractions $1:\frac{1}{2}:\frac{2}{3}:\frac{1}{4}$ and so on: "If you place the vertical plane at one braccio from the eye, the first object, being at a distance of four braccia from your eye, will diminish by¹² three quarters of its height at that plane; and if it is eight braccia from the eye by seven eighths; and if it is sixteen braccia off, it will diminish by fifteen sixteenths of its height, and so on, by degrees, as the space doubles the diminution will double" (Richter ed., No. 100) (Fig. 3).

The convergence of the horizontal breadth sections can be established either by rectifying the foreshortened pictorial space in the vertical projection (Figs. 4, 5a), which shows the position of the right-hand tapestries, or by calculating the mathematically similar triangles above the horizon line. Thus the pictorial space is quadratic (sic!) and is conceived on the basis of a spatial grid¹³ given by the grid unit

⁴ *Das Abendmahl Leonardo da Vinci*, Baden-Baden, 1952, fig. 50. Moeller relies on O. Sirén, *Leonardo da Vinci*, New Haven, 1916, 103, and others.

⁵ E. Voigtländer, *Monatshefte für Kunstwissenschaft*, xii, 1919, No. 12, 234ff., and M. Fischer, "Das Abendmahl des Leonardo," *Schweizer Journal*, iv, 1942, believed they could recognize only a general framework. Square-grid structures were discovered by W. Müller, among others, "Neues zu Leonardos Abendmahl," *Das Werk*, xix, Dec., 1932, and C. Bouleau, *Charpentiers, La géométrie secrète des peintres*, Paris, 1963.

⁶ According to my own measurements the wall of the *Last Supper* measures 891cm, which corresponds to fifteen Milanese braccia at 0.595=8.925m. On the Milanese braccio see O. Förster, *Bramante*, Munich, 1956, 279. The dimension of the braccio differs regionally. In Florence it measured about 0.5836m at the time when the metrical system was introduced. See J. White, *The Birth and Rebirth of Pictorial Space*, 1967, 130; *Traktat*, ed. Herzfeld, xxv; G. Calvi, *I Manoscritti di Leonardo da Vinci*, Bologna, 1925, 166; P. Tigler, *Die Architekturtheorie des Filarete*, Berlin, 1963, 47.

⁷ *Die Zehn Bücher über die Baukunst*, ed. Max Theurer, Leipzig, 1912, Bk. ix, 6. In the Cod. Madrid II Leonardo notes, apart from Alberti's *Books on Architecture*, "un libro da misura da Ba. Alberti"; see *Burlington Magazine*, Feb., 1968, 81.

⁸ The numerous writings of Gaffurio on the basis of a Platonic musical theory, e.g. *Theorica musica*, 1496, derive especially from Boethius's *De musica*. See G. Cesari, "Musica e musicisti alla corte Sforzesca," *Rivista musicale italiana*, xxix, 1922, 1.

⁹ O. Fischel, *Raphael*, Berlin, 1962, fig. 100. The diagram appears also in Gaffurio, *Theorica musica*, ii, 96. See E. Praetorius, "Die Mensuraltheorie des Franchino Gaffurio," Ph.D., 1905.

¹⁰ Professor A. Marinoni, Milan, probably the best expert on Leonardo's

numbers, tells me that the series of numbers in the Windsor ms cannot refer to monetary accounts or the like, and that he has found no explanation for them.

¹¹ Forst. II, 48a, Cod. Atl. 132b, ms G 29b. The above-mentioned paragraph on perspective, No. 461 (471) in the *Treatise on Painting* (cf. No. 2) runs differently, as does the faulty original in ms 2038, 23a, of the Institut de France.

¹² Richter has "to" here. Accordingly his text makes no sense since, owing to his oversight, objects increase in height the farther off they are.

¹³ On the grid as a device for proportioning as well as in connection with the perspective and architectural theory of the time, see E. Panofsky, *Dürers Kunsttheorie*, Berlin, 1915, 92ff, 200ff; *idem*, "Die Entwicklung der Proportionslehre als Abbild der Stilentwicklung" *Aufsätze zu Grundfragen der Kunstwissenschaft*, Berlin, 1964, 98ff; reprinted from *Monatshefte für Kunstwissenschaft*, xiv, 1921, 188–219 (English trans. in *Meaning in the Visual Arts*, 1957; *idem*, *The Codex Huygens and Leonardo da Vinci's Art Theory*, London, 1940, 51. See also O. Förster, *Bramante*, Munich, 1956, 135; G. Soergel, "Untersuchungen über den theoretischen Architekturentwurf von 1450–1550 in Italien," University of Cologne, Ph.D., 1958, 29ff; G. Hellmann, "Proportionsverfahren des Francesco di Giorgio Martini," *Miscellanea Bibl. Hertziana*, Munich, 1961, 157ff; A. Blunt, *Philibert de l'Orme*, Paris, 1958, 148ff; R. Wittkower, *Architectural Principles in the Age of Humanism*, 3rd ed., London, 1963, 17; E. Hubala, "L. B. Albertis Langhaus von St. Andrea in Mantua," *Festschrift K. Badt*, 1961, 104ff; K. Freckmann, *Proportionen in der Architektur*, Munich, 1965, 216f; P. Tigler, *Architekturtheorie des Filarete*, 154; T. Brachert, "Symmetria," *Schweizerisches Institut für Kunstwissenschaft, Jahresbericht und Jahrbuch 1967*, 87ff. In Leonardo the grid is mentioned in the *Treatise on Painting*, No. 97 (ed. Ludwig) and in ms E 16 (Richter No. 107); by Pacioli in the *Divina Proportione*, appendix chap. II.

of the composition (Fig. 3). Therefore the depth extension of the pictorial space continues the width of the real space of the refectory, and the figures are arranged in the foreground of the scene near the spatial boundary which coincides with the picture plane. *The tapestries, however, prove to be of unequal breadth*; a fact already observed in earlier reconstructions: they become wider the farther off they are. As the vertical projection shows, the vertical front edges of the tapestries coincide with the grid lines, except for the first one which is slightly displaced backwards. Instead the rear edge of the latter tallies with the second line (No. 8, Figs. 4, 5a); the second tapestry fills the space between lines 9 to 11; the third begins in the middle distance with line 12; and the last tapestry starts out from line 15. While the second tapestry is wholly fitted into the grid schema, the following two increasingly exceed the grid boundaries toward the back. Their extension is approximately ascertainable only by way of reconstruction, that is, by measuring the foreshortening in the picture. As can be seen on the *linea del taglio* (Fig. 5a), lines 6, 9, 12, 15, 18 diminish at intervals of three grid units each according to the ratios $\frac{6}{8}:\frac{6}{9}:\frac{6}{12}:\frac{6}{15}:\frac{6}{18}$, or $1:\frac{2}{3}:\frac{1}{2}:\frac{2}{5}:\frac{1}{3}$. This system of proportioning is analogous to Leonardo's specifications in ms A8b, though with the distance to the picture plane fixed at six units instead of one. The denominators again bear the values 6; 9; 12; 15; 18, or 2; 3; 4; 5; 6; 4:5 being the ratio of third major and 5:6 of third minor. In addition there are the ratios 6:12 or 9:18 as octave intervals and 9:15 as sixth major, while 12:18 is once more the fifth. The visual rays drawn from the visual point to these lines divide the pictorial plane (Figs. 4, 5a, line No. 6) vertically into $\frac{2}{6}:\frac{2}{12}:\frac{2}{20}:\frac{2}{30}$, as can be calculated from the sections. On the *linea del taglio* of the floor plan (Fig. 5b) we again find the proportions $1:\frac{2}{3}:\frac{1}{2}:\frac{2}{5}:\frac{1}{3}$, as in the vertical projection (Fig. 5a), as a result of the duodecimal system that governs the composition.¹⁴

What remains uncertain is the exact proportioning of the projectively foreshortened interstices. Since the far edge of each tapestry stands in no relation to the grid, a precise calculation is impossible. Measurements and geometrical reconstruction have shown that they align most nearly to the ratios 8:5:3; that is, they are determined by the architectonically useful approximative ratio of the golden section.¹⁵ The correspondence of the two sequences 12:6:4:3 (Pythagorean) and 8:5:3 (golden section) is, however, mathematically only a chance approximation. As a relative proportion it is arrived at only with a distance of half a space length and on the basis of a duodecimal square-grid pictorial space,¹⁶ whose four equal space sections are

projected in rhythmic foreshortening (Fig. 5b). If in the *vertical projection* Leonardo had interchanged four equally wide tapestries of two grid units each with one unit as interstice, the foreshortening ratio in the *central projection* would have been an irrational one. Instead the pictorial plane represents – and here we encounter Leonardo's primary compositional interest in employing *numerical proportions* – an alternating interpenetration of the *divina proportione* with the *Pythagorean intervals* which radiate as a harmonic diagram in the sense of a *musica mundana* from the universal center, Christ. The profound significance of this geometrico-cosmological conception from the tradition of the Late Classical Neoplatonists was well known to theoreticians of the Milanese court academy. In the introduction (assembled from older Pythagorean writings) to Nicomachus's *Arithmetic*, Iamblichus had already remarked that the numbers 6, 8, 9, 12 represent the most perfect, threefold, all-embracing equation, for the equation thus contains the arithmetical (6, 9, 12), the harmonic (6, 8, 12), and the geometrical proportion (6:8=9:12), and within the "poles" 6 and 12 comprise the ratios of the octave (1:2), the fifth (2:3), and the fourth (3:4) (Fig. 2). To Nicomachus this, one might say, harmonic "world formula," which had been regarded since Pythagoras as a tetractys¹⁷ symbolizing the world and the universe, was of great use in connection with any kind of musical or scientific investigation. It is found in Gaffurio's *theorica musice* (1496) as well as on the Pythagoras tablet in Raphael's *School of Athens*. Boethius, Gaffurio's source, sees in this formula the *harmonia perfecta maxima* as an image of the world harmony.

The proportioning of the pictorial space is determined by harmonic ratios not only in its depth but also in its width. Thus the coffered ceiling in front is fixed at six within the total of twelve units, the perspectively foreshortened rear wall at four units, and the three windows together at three units (Fig. 1). Again we come upon the ratios 12:6:4:3. The nimbus-like segment behind Christ is also subjected to the quadrature in that its radius measures one grid unit; the circle of which it is a part has its center a little above the visual point, probably due to artistic license. This pivot of the geometrical composition in Christ, the universal center, suggests mystico-geometrical reflections of the Neoplatonic kind advocated in contemporary philosophy, above all by the Florentine Platonists around Marsilio Ficino¹⁸ In Ficino the star symbol of the Pythagoreans reappears (handed down through the Alexandrian Neoplatonists, e.g., Plotinus, and the Gnostics), its concentric circles or spheres radiating from a luminous point. For Nicolaus Cusanus, too, mathematical signs, especially

¹⁴ The schematic floor plan (graph 3) is similar to Leonardo's pictorial spaces in four-part described by H. Ludwig and Herzfeld, *Traktat*, xvi, yet the distance is assumed as two units instead of one. Thus the projection shows not the first four numbers of the musical series by the fractions $\frac{2}{3}, \frac{1}{2}, \frac{2}{5}, \frac{1}{3}$, which, however, contain in their denominators the musical scalar numbers 2, 3, 4, 5, 6, as has been proved above.

¹⁵ The proportionings presented in figure 11 of my study "Symmetria" in *Jahrbuch 1967* of the Schweizerisches Institut für Kunstwissenschaft are partly wrong, because they are based on measurements conducted with too great a tolerance.

¹⁶ For her suggestions and help in the checking of the calculations I wish to thank Miss Renate Keller, Zürich.

¹⁷ P. Kucharski, *Étude sur la Doctrine Pythagoricienne de la Tétrade*, Paris, 18f, 32; A. von Thimus, *Die harmonikale Symbolik des Altertums*, 1, Cologne, 1868, 1, 136; L. Richter, *Zur Wissenschaftslehre von der Musik bei Plato und Aristoteles*, Berlin, 1961, 148ff.

¹⁸ Leonardo possessed Plato's works in Ficino's edition and interpretation; see A. Chastel, *Marsilio Ficino et l'Art*, Paris, 1954, 107ff; *idem*, *Art et Humanisme à Florence*, Paris, 1959; E. Cassirer, *Individuum und Kosmos . . .*, Leipzig, 1927; W. Dress, *Die Mystik des Marsilio Ficino*, Berlin-Leipzig, 1929, 44; P. Kristeller, *The Philosophy of Marsilio Ficino*, New York, 1943.

the circle and the sphere, served as symbols of God “because of their indestructible security.”¹⁹ When Cusanus speaks of the “infinite limit point,” which belongs as such to the transfinite other world and is at the same time the center of all circles, his words might just as well refer to Leonardo’s *Last Supper*.

The width of the windows right and left is determined more or less by the golden section of twelve units, and the distance between their outer edges measures three grid units. Moreover, the apertures of the lateral windows are half as wide as the middle aperture.

Even in the arrangement and proportions of the figures the basic unit of the quadrature appears to have been applied, unless the correspondences are simply intuitive. The two groups of disciples, one to each side of Christ, take up two units each along the far edge of the table (Fig. 6), and the two outer groups are allotted three twelfths each. Again we get a ratio of 2:3. Since Christ’s head measures half a unit, the lengths of the heads might also be seen as sub-units of the quadrature. This would tally with Pacioli’s theory of architecture. For Pacioli considered “the measurements and proportions of the human body, the head and the other limbs the symbol of architecture” (*Divina Proportione, Treatise on Architecture*, chap. 1).

In the more general sense of a “symmetria” ordering all the parts of a picture, Leonardo speaks in the *Treatise on Painting* of “L’armonica proportionalita delle parti che compongono il tutto che contenta il senso.” In this spirit he seeks the omnipresence of mathematical proportions in a universe organized according to the *musica mundana*. He believes it to be possible, through experiment, to recognize numerical laws even in the physiological realm of perception, in certain harmonic sound patterns and in perspective sequences of proportions. He notes in ms A24 (around 1490) “Marvellous is Thy justice, o Prime Mover. Thou hast willed that no force should lack the order and quality of its necessary effects.” And, finally, in the late ms K49 he reformulates his thought as follows: “Proportion is not only to be found in numbers and measures, but also in sounds, weights, intervals of time, and in every active force in existence.”²⁰

Schweizerisches Institut für Kunstwissenschaft, Zürich
(translated by C. P. Casparis)

¹⁹ D. Mahnke, *Unendliche Sphäre und Allmittelpunkt*, Halle, 1937, 66, 71.

²⁰ All the Leonardo quotations, except those from Richter, were translated by the translator of this paper. For his very kind willingness to look through the manuscript in 1970, I would like to thank Professor L. H. Heydenreich, Munich.