

The Staging of Leonardo's *Last Supper*: A Computer-Based Exploration of Its Perspective

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ABSTRACT

The question of perspective posed by Leonardo da Vinci's *Last Supper* has been addressed by an analysis supported by a computer-aided multi-processor. A three-dimensional space was built within the computer to explore the notion that Leonardo used the 'trickery' of the theater in constructing the non-traditional perspective of this fresco. In this investigation, the compositional elements were manipulated in the computer-created space, and the resulting images were projected into the plane of the fresco. The analysis compared these projected images, as seen from various points in the Refectory, to the painted ones in Leonardo's mural. The results clarify Leonardo's use of an accelerated perspective in his construction of the staging of the *Last Supper* and locate the vantage points at the door and in the viewing plane of the monks, who sat along the side walls of the Refectory.

This paper describes the creation and use of a three-dimensional computer model that encompasses both Leonardo da Vinci's *Last Supper* (Fig. 1) and the Refectory at Santa Maria delle Grazie, where it is painted (see Fig. 4).

In the painting (Fig. 1), there are four key lines. The strong lines of the tapestries must be an extension of the design in the Refectory in order to cause the illusion that the mural is a real room. The orthogonal lines of the ceiling intersect at the center of the vanishing point to the painting, at the level of Christ's face. From this vantage point, the borders on both of the Refectory walls line up to make the mural 'look right'. But this point is more than 15 feet above the floor.

The analysis addresses the major issue that has provoked scholars for over 500 years: How was the painting meant to be viewed? Why did Leonardo position the true vantage point above the viewer? Is there a place from the floor of the Refectory where the painting appears to be an integral, three-dimensional part of the actual viewing space?

Some 75 years before this work was painted, Filippo di Ser Brunelleschi demonstrated that linear or 'true' perspective is simply what a viewer sees when looking at a scene through a window [1]. To perform this demonstration, Brunelleschi

stood with his back to the Baptistry, held up a small flat mirror to reflect the building and painted the reflected image of the Baptistry on a small wooden panel propped up on an easel in front of him [2].

Once Brunelleschi completed his painting, he made a hole in the panel in order to look through it and begin his experiment. With one hand, he held the back side of the panel close to his eye, and with the other he held up a mirror to reflect the painting. The reflected image of his painting produced the same effect as the one from the Baptistry itself. In exhibiting the illusion of depth, Brunelleschi's

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Fig. 1. Leonardo da Vinci, *The Last Supper*, 1498 (Refectory, Santa Maria delle Grazie, Milan, after World War II. Courtesy Soprintendenza per i Beni Artistici e Storici of Milan.)



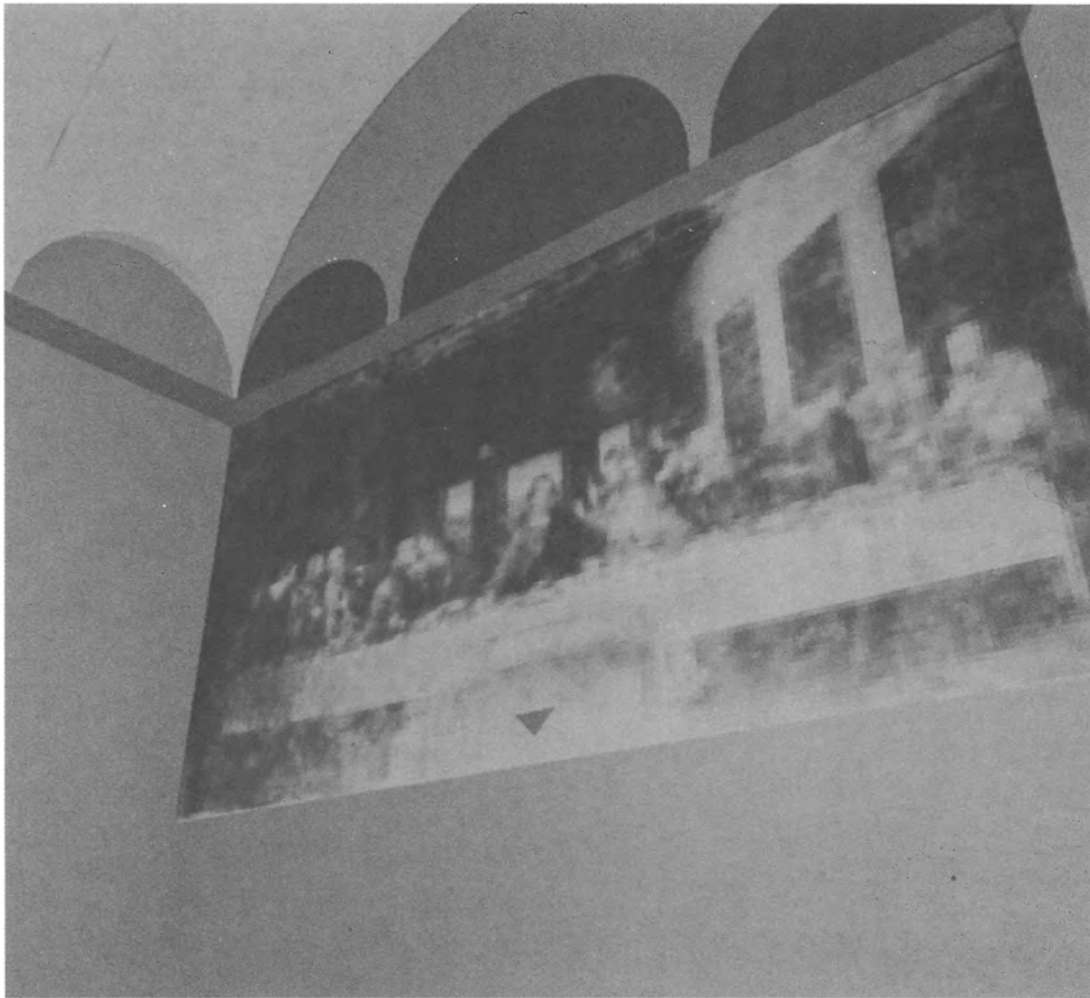


Fig. 2. XYZ = position of eye 9.8, 1.75, 29.0; XYZ = position of where to look 4.42, 5.86, 35.5. The viewing position is at the vantage point near the entrance and looking up at the Fresco. The eye is drawn to Christ's hand, to Christ, to the upper left corner of the picture and, finally, out into the Refectory. All vertical lines slant inwards, emphasizing the position of Christ. Since the viewer is closer to the brighter wall, the wall looks larger than from a frontal view. (Copyright Lilyan Prod. Inc., 1988)

'peep-show' yielded a procedure that painters could follow. These concepts were formalized and published 10 years later by Leon Battista Alberti [2] and ever since have been commonly referred to as 'Albertian perspective'.

Since Leonardo had applied Albertian or 'true' perspective to earlier works [3] and, according to Naumann [4], wrote notes that "resemble Alberti's treatise", some scholars have attempted to interpret the *Last Supper* in the context of these laws but have failed to achieve a conclusive thesis [5]. In addition, Leonardo's own *Treatise on Painting* misleads scholars by specifying that the vanishing point in a mural should be positioned "opposite the eye of the observer of the composition". But, as noted by Pedretti, "whoever looks at the *Last Supper* is far below the axis perpendicular to the vanishing point (in the Christ's head), no matter how far back one can step" [5].

Controversy over the scheme of the Fresco's construction continues to the present day. One historian asserts that there is no exact position to take in the Refectory "to make the picture come

right" [6]. On the other hand, another historian states that "each of the monks sitting at any place of the long tables in the Refectory could view the *Last Supper* with the illusion of standing in front of it in the center of the room" [5]. A third disagrees with both opinions, concluding instead that the perspective for the *Last Supper* not only distorted Leonardo's own written rules of perspective [4] but was so uncommon "that it cannot be generalized or turned into rules" [7].

The apparent inadequacies of descriptions based upon 'true' perspective have led several recent authors to suggest applying an 'accelerated' perspective instead—one in which the scene converges towards the vanishing point more rapidly than it would in the real world [4,5,7].

In this study, I have used the accelerated perspective employed in stage design [8,9] as the basis for comparisons between a computer-generated rectilinear model and the projected plane of the painting in question. This same model contains provisions for the manipulation of viewing points to examine the relationship of the Fresco

to the Refectory. This model is described in the sections that follow the discussion of the painting itself.

THE LAST SUPPER

The *Last Supper* (Fig. 1) was painted in the late 1400s, at the command of Ludovico il Moro, for the Refectory of the Convent of Dominican friars at Santa Maria delle Grazie, Milan. It was immediately hailed as a masterpiece, but one that quickly became the center of scholarly debate. In particular, its perspective construction evoked a host of contradictory interpretations, which remain unresolved to the present day. Even at the level of the vanishing point, where the mural can be viewed as an extension of the Refectory, Steinberg noted that "the projected perspective is disjunctive" [6]. Since the conventional tools of artistic investigation have not enabled researchers to reach a satisfactory conclusion, a resolution of the puzzle appears to require a premise outside the normal laws of perspective.

I began the present investigation by searching for clues in the few preparatory drawings of this work that survive. Leonardo used conventional rules for perspective in at least one preliminary sketch [10]. This sketch was drawn in 'true' perspective, displaying an interior with figures seated along a long wall beneath arches that matched the architecture of the Refectory. But a later sketch was drawn in a more distorted manner, showing figures standing behind a table sloped at an extreme angle [11]. However, in this sketch, an architectural design behind the figures was omitted. What led Leonardo to reformulate these elements in different ways?

In confronting the Refectory's interior, Leonardo faced problems like those found in the theater. The hall was long and narrow. The audience (the monks and prior) sat along the perimeters of the walls, far below the 'stage'. The entrance to the hall was through a small door, near the right side where the Fresco would be painted. The audience of dignitaries and their retinue, the monks and the

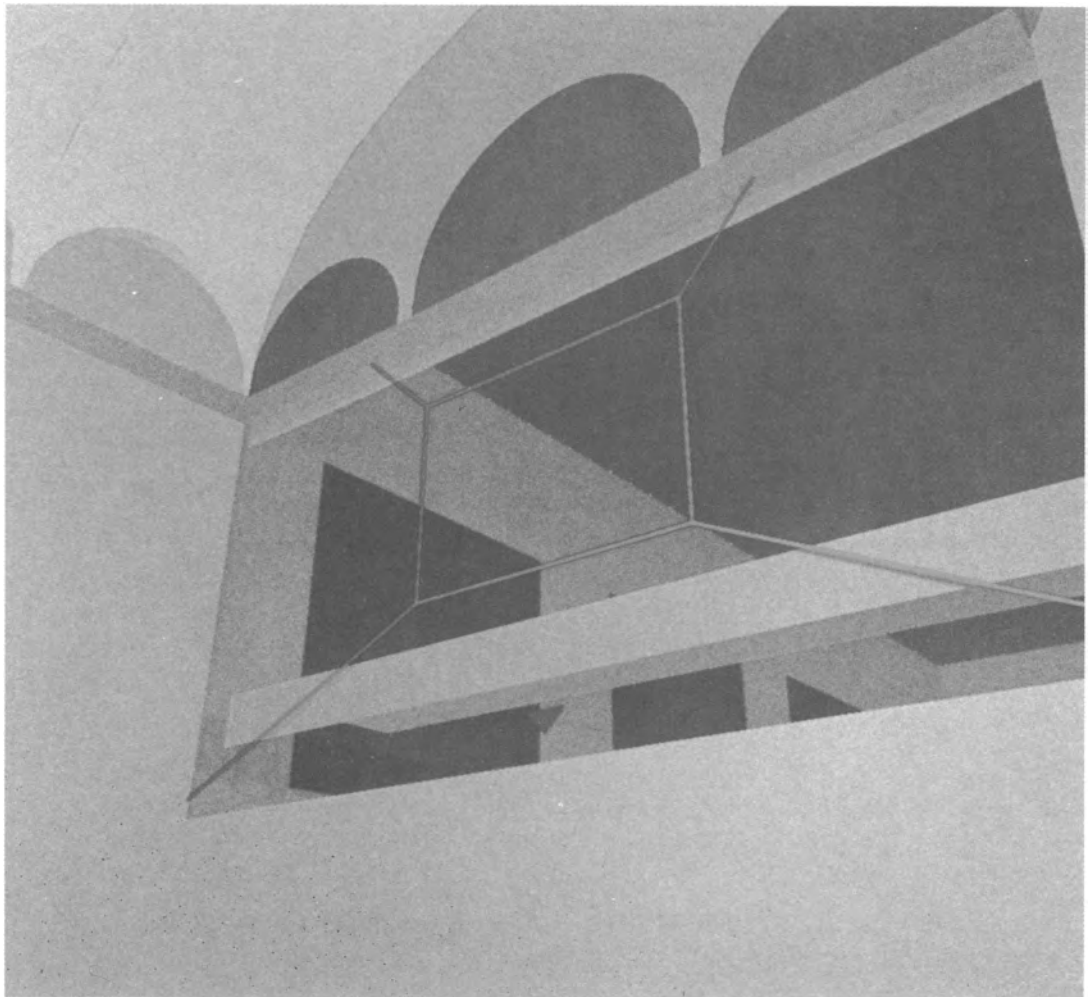
prior, would gain their first view of the stage at the door [12].

Leonardo's genius permitted the audience to participate in the painted action. All who entered through the doorway at the right perceived the left hand of Christ gesturing towards them in welcome (Fig. 1) [11]. When Goethe visited the Refectory, he visualized the monks and their prior seated at the tables along three sides of the Refectory and, on the fourth wall—that of the Fresco—Christ and the Disciples at the "table . . . as though they belonged to the company. At supertime it must have been an impressive sight, when the tables of Christ and the Prior confronted each other as counterparts, . . . the sacred company was to be brought into the present, Christ was to take his evening meal with the Dominicans in Milan" [7]. In order to achieve this effect, the perspective projection had to produce the illusion that audience and stage were united. However, as many scholars have pointed out, this illusion was unattainable with 'true' perspective. A rectilinear room, located in front of an audience, high above their

heads, clearly marks the separation of stage and audience.

The required projection shared many features with the Renaissance theater. The theatrical stage in the late 1400s was a dynamic art. Instead of a 'real' room on stage, the audience was pulled into the performance through the stage designer's use of non-rectilinear rooms to achieve 'accelerated' perspective [8]. The Renaissance stage usually was enclosed by an ornamented architectural facade that obscured the transition between the setting and the audience. A horizontal strip at the top completed a rectangular proscenium. Stage design followed the form of the Roman acting-platform with a narrow acting-area directly in front of the audience. The sets usually were built on a sharply raked platform [8]. A typical platform held the setting of a city street or square, built up with houses placed near the front. To achieve the perspective effect, the size of the houses diminished rapidly towards the rear of the stage, where they stopped at a wall or canvas that was parallel to the front of the stage. To avoid shattering the perspective,

Fig. 3. XYZ = position of eye 9.8, 1.75, 29.0; XYZ = position of where to look 4.42, 5.86, 35.5. The vantage point is located at the entrance to the Refectory. Lines representing the Fresco are superimposed over a rectilinear room. The floor, right wall, and top of the table are not visible in the rectilinear room, whereas the lines representing the painting show that the floor, ceiling and walls are visible. (Copyright Lilyan Prod. Inc., 1988)



the actors performed *against* the scenery at the front of the stage, rather than in the scene, where they would appear too large for the setting.

Since Leonardo had constructed numerous stage settings in Milan for Duke Ludovico and had drawn a study for the stage set of Baldassare Taccone's *Danae* of 1496 [13], we may assume that he was familiar with the novel concepts of perspective used in effective stage design. Furthermore, he probably knew of the writings of Vitruvius or of Alberti's study *De re aedificatoria*, popular at the time, which emphasized theatrical experiments [13].

The distorted perspective of the theater thus could have provided Leonardo with the opportunity to create a new way of handling a painting in the Refectory [5]. His genius allowed him first to construct a linear perspective of the main structure of the room and to position the vanishing point for Christ's head. Then, to accommodate the eye-level vantage point from the doorway—for the most instantaneous perception of the work—he bastardized this perspec-

tive. He hid the lower part of the back wall and most of the floor lines and he changed the left orthogonal ceiling line to a transversal that no longer intersected the vanishing point. The mural still appears legitimate, even though it is geometrically incorrect.

Leonardo painted the back wall the minimum size that could contain windows large enough to reveal an impressionistic landscape, one that appears far away, yet with a clearly defined horizon. He built a work in the style of a classical stage where he had the freedom to change sizes of objects. The actors on a stage cannot be changed in size except by costumes and props, but since he was constructing a painting at the end of a long, narrow hall, he needed to adjust the relative sizes of his actors for the most metaphorically significant impact on his audience. Even the gestures of the figures are designed as if directed for the theater (Fig. 1) [11].

To dress this stage, Leonardo had to use the same elements of theater in order to place Christ and the Apostles in the positions that would not destroy the perspective. He raked the stage so

that Christ's feet are displayed in an upright position and tilted the table to expose everything on it. The freedom provided by theaterlike distortions also gave him the opportunity to introduce a strong depth effect [15].

In medieval and Early Renaissance representations of the same subject, the table is usually round or square, compelling the artist to depict some of the Apostles from behind [10]. If Leonardo had used either the round or square table for this setting (or moved the table around and seated Christ at the end of the table), the perspective would have changed, diminishing Christ. Instead, by using theatrical ideas to stage this event, locating the 'actors' up front, almost upon the audience, thrusting Christ into the Refectory by making Him larger than the Apostles and, at the same time, maintaining a spiritual distance by placing the table in front of Him, Leonardo avoided turned backs and blasphemy.

Theatrical lighting in the late 1400s meant bathing the audience in the same light as the stage, while the props were painted to simulate other bright-

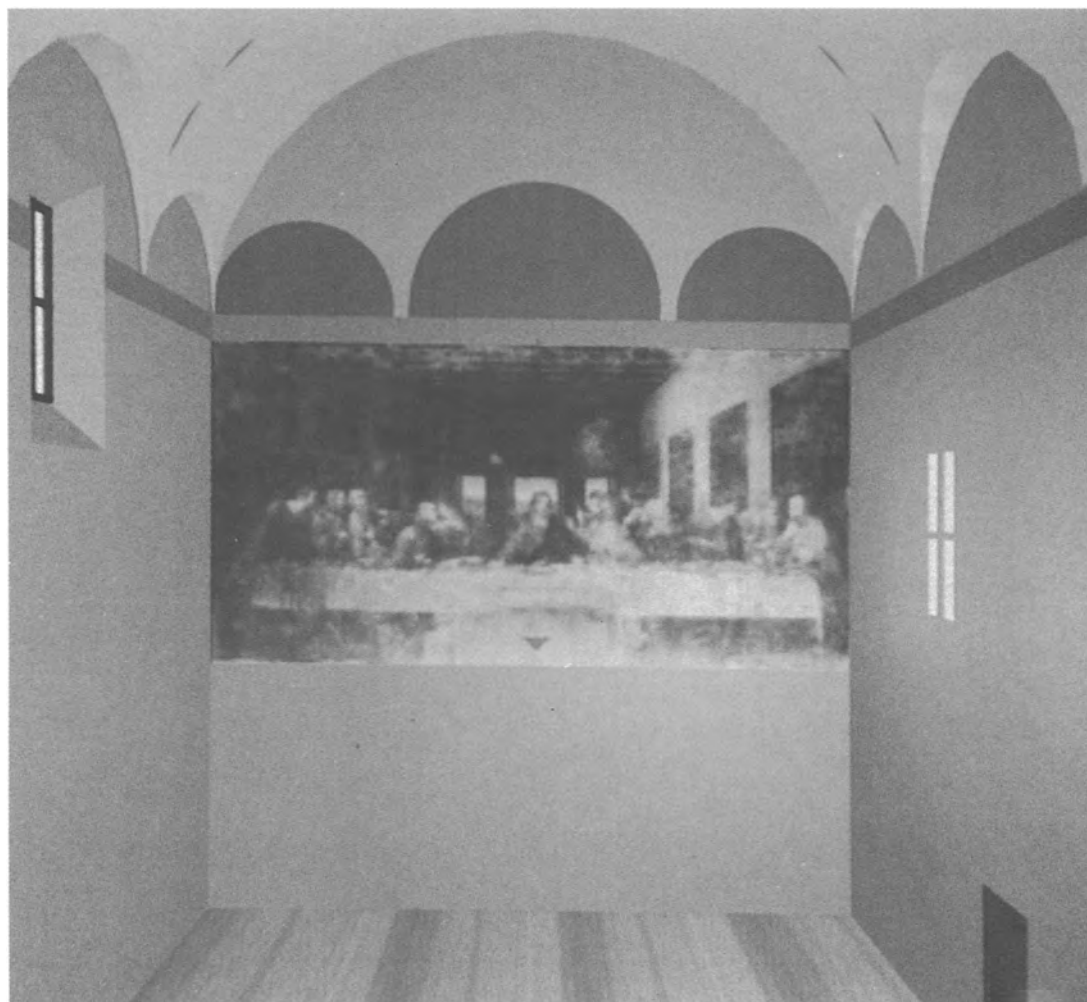
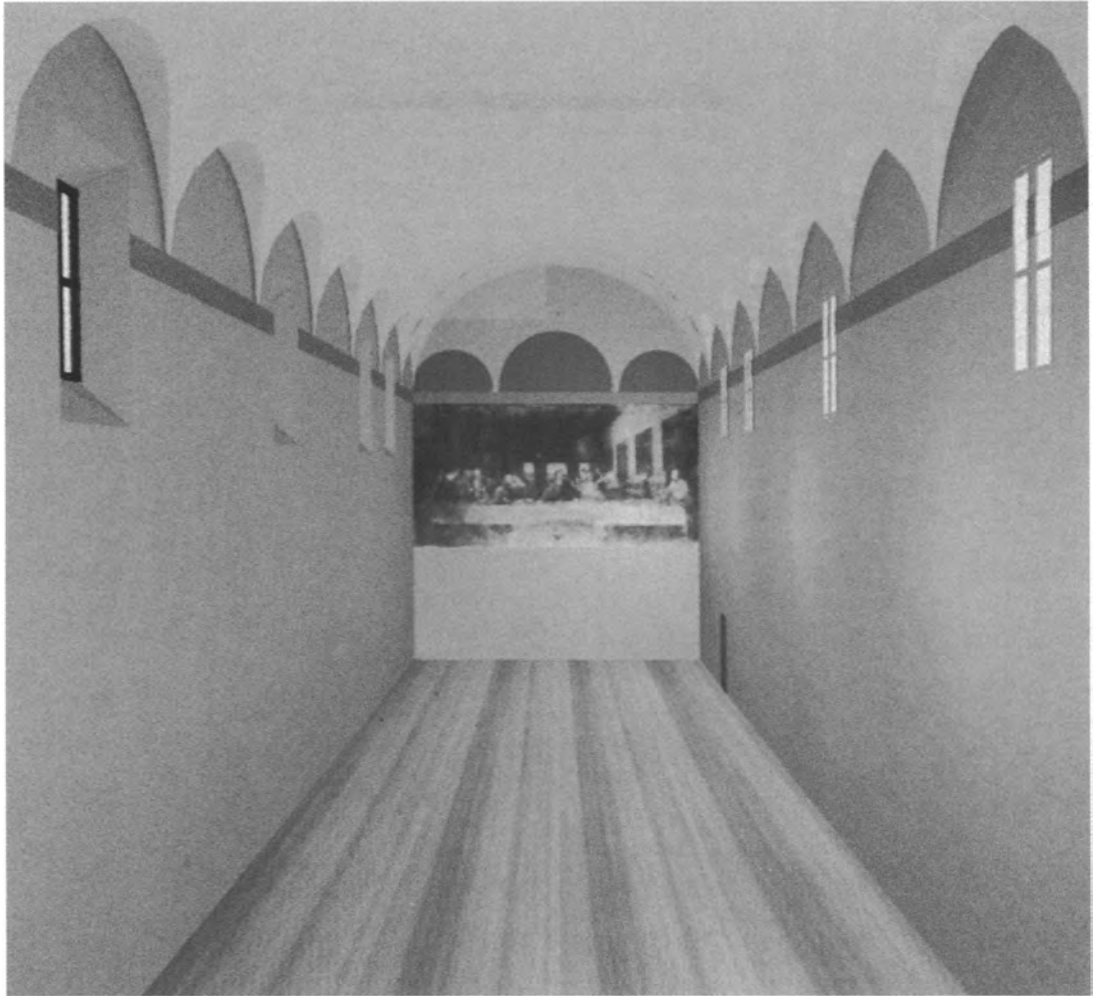


Fig. 4. XYZ = position of eye 4.4, 4.5, 20.0; XYZ = position of where to look 4.4, 4.5, 35.5. The vantage point is placed at the vanishing point behind Christ's head. The tapestries line up. The entrance on the right wall is indicated in black. The lighting is calculated at dusk, 21 April 1500. (Copyright Lilyan Prod. Inc., 1988)

Fig. 5. XYZ = position of eye 4.4, 5.5, 1.0; XYZ = position of where to look 4.42, 5.5, 35.5. The distance is so great that it is difficult to view the painting in any detail, but the brighter wall, the table and a silhouette of Christ's head can be discerned. (Copyright Lilyan Prod., Inc. 1988)



ness or shadow [8]. Leonardo used the trickery of theatrical light in his scenery as well as available ambient light to enhance the perceptual illusions. Steinberg described the light as being “the most magical feature of Leonardo’s illusionism. . . . Even today the effect sometimes returns at the hour of dusk” (see Fig. 4) [7].

The painting captivated visitors even while Leonardo worked on it. The first view of the work was at the entrance to the Refectory through a doorway about 18 feet from the painting. When Francis I visited Santa Maria delle Grazie in 1515, he noted that the “viewer’s attention would soon be focused on the particular loaf of bread in line with the left hand of Christ, open in a gesture of offering directed to the entrance door” [11]. Leonardo directed Christ to reach out in welcome to all newcomers as they entered the Refectory. As will be shown, Francis I, standing at the door of the Refectory, unknowingly unraveled the secret of how to perceive the *Last Supper* less than 20 years after its completion.

PERSPECTIVE MODEL

A three-dimensional computer model was built using a high-performance, multi-processor computing system [16] to track the perspective of the Fresco’s relationship to its painted wall and to the other walls of the Refectory to determine whether Leonardo used a theaterlike ‘accelerated’ perspective in the construction of his *Last Supper*. The computer model provoked the analysis of the work in question and permitted an ‘observer’ to view the painting and its setting from any point in the hall. To locate the different positions, we defined 0,0,0 at the lower left corner of the model. The first set of coordinates XYZ is the ‘position of the eye’. To take photographs of what the viewer would see, we positioned the second set of coordinates XYZ at ‘where to look’. For example, if we are looking at Christ’s hand, we input the XYZ coordinates of that location. To avoid distortions, we kept the view the same as if we were looking through a pin-hole camera without a lens, and with

a normal field of view and an angle of 50°.

A model of the Refectory, called ‘Viewing Room’, was constructed using standard computer programs. The dimensions for ‘Viewing Room’, such as length = 35.5 meters, height = 11.74 meters, width = 8.82 meters, position of door = 5.5 meters; size of windows and their frames and depth of walls [3] were defined as before World War II, when the floor was lower [17] than it is today. Since it is important to show how the strong line of the tapestries matches up with the designs on the long walls of the Refectory, we calculated the position of these designs and marked them with solid colored bands. This same color was selected for the border and the designs above the Fresco.

In ‘Viewing Room’, a wall, called ‘Main Wall’, corresponds to the wall with the Fresco in the real situation and allows for two different views: the painted replica called ‘Fresco’ and a three-dimensional rectilinear room called ‘True Room’. ‘Main Wall’ is 3.57 meters from the floor to the bottom of the Fresco. The space for the

Fresco and the 'True Room' is 4.59 meters.

For 'Fresco' we digitized [18] a photograph of the Fresco (resolution 1280 × 1024), which was then texture-mapped [19] onto the North Wall of 'Viewing Room'. A triangle, representing Christ's feet, was positioned on the digitized painting as based on an early copy of the work [11]. (Christ's legs and feet were eliminated in the 1700s by a door that was cut into the painting.)

We then constructed 'True Room' with the dimensions length = 28.0 meters; width = 9.7 meters; and height sitting up from the floor = 8.16 meters, based on a system of measurement that Leonardo had used, where a unit is equal to about one-third the height of a person [14]. But when I tried to align the back wall of 'True Room' with the back wall of the Fresco, the length was insufficient. It was necessary to extend the length to almost 80 meters to match up the walls. (When 'True Room' is 80 meters long, the ceiling lines match the Fresco. However, it was necessary to 'shorten' the room to accommodate the props essential to the accelerated perspective of the 'depicted' room.) 'True Room' extends beyond 'Main Wall' as in a real three-dimensional room and always is seen in 'true' perspective from any position in the Refectory. In addition, we superimposed lines—positioned as in the ceiling, floor and walls of the Fresco—over 'True Room'. As we moved our point of view, we then could compare the position of the Fresco lines with those in the rectilinear room. Since in the 'depicted' painting the upper ceiling, the top half of the wall lines and only the ends of the floor lines at the bottom of the Fresco are visible, we extended the lines on the lower half and connected them to reveal the differences between the 'true' and 'accelerated' projections.

We began our study by using the model to view the Fresco from different locations to find a position from the floor where the Fresco would appear to be an extension of the actual room. We located the position of the eye at $X = 9.8$, $Y = 1.75$, $Z = 29.0$; and the position of where to look at 4.4, 5.86, 35.5. As soon as we located a vantage point at the door of the Refectory in Fig. 2, it became clear that Leonardo chose this position to lead the viewer to Christ and then to the tapestries on the left wall where they

would line up with the design on the Refectory wall, earmarking the illusion that the Fresco is an extension of the real world. All vertical lines appear to slant inwards, emphasizing the position and size of Christ and His hand ushering us in. Once the vantage point was positioned at the door we continued along the same Y-axis of 1.75 to find that the monks' perception of the painting also allowed for the illusion that the Fresco appeared to be an extension of the Refectory.

For Fig. 3, the vantage point was positioned at the door as in Fig. 2: XYZ = position of eye 9.8, 1.75, 29.0; XYZ = position of where to look 4.42, 5.86, 35.5. A comparison of the elements in 'True Room' with the superimposed lines of the Fresco in 'True Room' reveals that the floor, right wall and top of the table are not visible, whereas the Fresco lines show the floor, ceiling and walls.

For Fig. 4, when the position of the eye is 4.4, 4.5, 20.0 and the position of where to look is 4.4, 4.5, 35.5, the tapestries line up. If the Z coordinate is changed while the X and Y coordinates remain the same, the tapestries continue to line up. However, in order to see this view, the spectator would have to stand on a stepladder 4.5 meters above the floor. The entrance on the right wall is indicated in black. The same model positioned the lights to determine whether the ambient light would fall on the right, brighter wall of the Fresco. It has been noted that Leonardo took advantage of the light streaming in from the windows to illuminate his painting as if the real light were cast on it, thereby enhancing the illusion that the 'depicted' room extended beyond the Refectory [7]. This study was not completed at the time of this paper, but when we calculated the light at noon, at 3 o'clock and at dusk, in April and in September, we found that the light from the windows was cast on the east wall of the Refectory, away from the mural as in this figure. The lighting is calculated at dusk on 21 April 1500 [20].

In Fig. 5, the vantage point for the back of the room is raised above the vanishing point from 4.5 meters to 5.92 meters. The lines of the tapestries and the design in the real room appear to line up, but as Steinberg noted, "A spectator tight-rope-d on the hall's longitudinal axis 15 feet above ground would see nothing wrong; the real and the depicted perspective would appear to him in undisturbed continu-

ity" [7]. It is unlikely, given Leonardo's concern with the perspective and the viewing position, that such a viewing height was his intention. This viewing distance was so great, however, that any angular change did not make a big difference (see Figs. 4 and 5).

The illustrations show that the best views from the floor have been located. Leonardo makes clear his intent in engaging the viewers' perception at the doorway of the hall where they see the painting for the first time. By slanting the ceiling lines at such a sharp angle (the angles are 10% higher in absolute size on the right than on the left), Leonardo could provide a viewing plane at eye level where the spectator is drawn first to Christ's hand, then to His figure and, finally, along the orthogonals from the vanishing point to the tops of the tapestries, which then appear to line up with the designs in the actual room, providing a view of the Fresco as a three-dimensional room. The monks along either wall view the Fresco as a continuation of the Refectory. Leonardo sacrificed the view from the back of the room to attain the proper height for the vanishing point to satisfy the requirements needed to insure the view at the door and along the side walls.

Leonardo may have composed the Fresco by following his own written rules for perspective. But once he determined the locations for the viewing positions at the door and along the perimeters of the hall, the ceiling lines had to be moved. He could afford to relocate the strong lines of the ceiling to modify the linear perspective—disregarding the requirement for converging all parallel lines at the vanishing point—since he did not intend for the mural to be viewed on the horizon of the vanishing point. He would have destroyed the mirage at eye level if he had used 'true' perspective. Fig. 3 shows how little of the panorama would have been visible. Even for the viewer moving back into the room, much of the Fresco would have been out of sight from the sidelines. The essential elements in the mural could be projected only by an 'accelerated' perspective. Leonardo needed to display the floor in order to see Christ's feet, but he also needed to obscure the lines of the floor where they would abut the walls. If he had not hidden these lines—behind the table and figures—the distortion caused by these lines

(Fig. 3) also would have destroyed the total illusion. In addition, if the floor lines could be seen, the viewer's attention would have been diverted away from Christ and the strong vertical orientation of the painting, which is essential to the eye-tracking paths dictated by Leonardo as described in the following section.

DISCUSSION

Since the procedure for finding the true vantage point is usually to position oneself at the level of the vanishing point, the search for the correct position for viewing the *Last Supper*—from a position on the floor—as an extension of the Refectory was directed away from the side entrance. The strong vertical line of Christ also misled scholars into looking for the vantage point from the frontal view, at the level of Christ's head. But the results of this study demonstrate that the painting 'comes right' only when viewed obliquely [15] or at the level of the vanishing point, more than 15 feet above the floor.

Once Leonardo positioned a vantage point for the viewer's first impression, at the entrance to the hall, he had to modify the linear perspective construction, which could not show the entire display of his interpretation of the symbolic and sacramental story. He turned to an accelerated perspective projection to provide a view of all the elements in the *Last Supper*, as well as to provoke the effect that the Fresco appeared to be an extension of the Refectory.

After Leonardo drew the ceiling and tapestry lines, from the point of view of the door and the eye level along the walls, and determined the size and position of the rear wall behind Christ, then everything else was fixed. All Leonardo could do was to connect the rest of the lines and link them to the back wall, effectively building a raked stage with raked walls, ceiling and floor (Fig. 4). However, while the upper lines of the ceiling are visible, the lower lines of the floor, and therefore most of the floor, had to be obscured to insure the desired effect. Steinberg noted that "he leaves just enough floor in front of the table to satisfy the literal requirement of an autonomous space" [7].

Once Leonardo 'fixed' the perspective construction to cause the entering viewer to see the entire panorama as if

it were staged in a three-dimensional room, the monks along the side walls could be included in this same plane. He then turned to the prior's seat, at the back of the room. Leonardo was aware that this viewing position is not a serious problem since the further away the viewer is from the mural the smaller the angular change, with the result that the view is still quite acceptable (Fig. 5). Once Leonardo took care of the viewing positions, he then combined his skill as a painter with the artifices of the theater.

In the theater set, the figures usually are positioned for a transient moment. The action directs us in how we follow the performance. In painting, however, the artist creates the action by influencing the viewer's eye movements [21]. Leonardo choreographs our eye-movements, not only from the moment we first see the mural at the entrance to the hall but from whatever position we take.

As we enter the 'theater' by walking through the doorway, our eye is directed towards Christ and then to the left corner on the wall behind Him. Then a group of lines and objects carries our eye around the *Last Supper*: the tapestries; positions and hands of the figures; the converging lines directed out from Christ's feet [7]; the lines leading to the vanishing point behind His head; and then immediately forward to Christ Himself. The strong vertical line of Christ that draws us from Christ's upper torso and down to His feet guides our eye up and down before the direction is changed either by zooming off to the left on one of the converging lines from His feet that catches our eye or by the orthogonals that pull us to the left side of the painting. Even though we have a number of visual directions away from Christ, we finally have no choice but to start the tracking on the left wall (Fig. 1).

As Steinberg noted, "while the tapestried wall on the left slopes predictably downward, the corresponding slope on the right seems to climb [7]. The wall on the left not only is darker than the wall on the right but also is longer. Furthermore, the tapestries on the right change in size in a more radical way than do those on the left.

The eye reaches the upper right corner of the largest-appearing tapestry on the right wall and is then directed to the center vertical again by following the converging lines to the

feet and straight up to Christ, or by latching onto the hands of the Apostles which point to (and carry the eye back to) Christ.

Because the image is blurred during the movement [21], our eye may start the trip down the tapestries or, at times, be fooled into following a line of a design painted on the Refectory wall that appears to be an extension of the line at the top of the tapestries in the painting. The eye may move back and forth on this line before continuing down the left side of the room to travel the path back to Christ.

It is widely noted that Leonardo painted the margins on the sides of the Fresco in an unclear manner to cause conflicting readings of the position of the table [7]. Therefore, as we track the painting we may be influenced by how we interpret the margins as to whether we view Christ and His table in our space, or whether He is seen positioned in a space of His own. If we see the margins as part of the side walls of the Fresco, then the walls come forward enough to include Christ and the table. But, if the margins appear to be frames outside the Fresco, Christ and His table are halfway between the painted room and the actual space. Besides blurring the contours of the margins, Leonardo again hid his intentions by applying his *sfumato* [22] technique to Christ, the Apostles and the table to hide the discrepancies in their relative sizes.

To add to the ambiguity of the depicted room's relationship to the Refectory, Leonardo painted a top frontispiece to make it more difficult to connect the real and painted ceiling lines. The depth of the ceiling and the disappearance of the coffers beneath the fake painted molding pull us into the Fresco's room, while at the same time keeping us outside. The molding is analogous to the frame in a theater. Just as stage designers disguise their sets, Leonardo resorted to the above devices, as well as to the unevenly sized tapestries on their contrasting 'walls', to add a final dimension to the depth-illusion presented by this unique work of art.

SUMMARY

In creating a painting as if setting a stage, Leonardo tilted the floor, painted an over-sized table and tilted it, designed side walls of uneven

lengths with tapestries of different sizes and spacing, disguised the margins and the disparate sizes of Christ and the Apostles, and positioned his lighting to create the strongest illusion for the desired effect—the visitor's first view of the painting. From that key first impression, the spectator is drawn into the Fresco by Christ's hand. When the monks took their seats along the walls, these principal locations continued the illusion and, in addition, provoked the feeling that Christ was in the room with them.

The view depicts Christ along a vertical line as if crucified. The viewer's eyes are drawn downward to His feet, played on the raked stage, as if nailed to the cross. But this is no ordinary crucifix. This is a stage—raised before the viewer—that foretells the events to come. Leonardo gave all who entered the Refectory a window onto that stage. In Leonardo's theater, as in a successfully designed and directed theater, the audience feels part of the production rather than outside it, by the artist's ingenious handling of the accelerated perspective of a stage set, as described above.

The capabilities of a high-performance, multi-processor computing system have allowed us to re-create Leonardo's stage to examine and view the Fresco from any position in the Refectory. We could compare linear and accelerated perspective projections. The results suggest Leonardo's use of 'false' perspective in the staging of his *Last Supper*. He plucked from the theater the elements of this type of projection to draw his audience into the work. His ploys were disguised by the application of unique artistry.

The analysis, along with the computer model, shows how Leonardo was led to design his own perspective scheme to construct the *Last Supper*, altering the laws of linear perspective so that they could be integrated with the 'accelerated' perspective used in theater. This construction provided optimal vantage points for all who

entered at the door as well as for the monks who sat along both sides of the Refectory [23, 24].

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3. Leonardo's Perspective Study for the *Adoration of the Magi* (Original: Uffizi, Florence) and pen-and-ink sketch for the *Adoration of the Magi* (Original: Louvre, Paris) are reproduced in Bruno Santi, *Leonardo da Vinci* (Scala Books, dist. by Harper & Row, 1981) pp. 19 and 20.
4. Francis M. Naumann, *The 'costruzione legittima' in the reconstruction of Leonardo da Vinci's "Last Supper"* (Arte lombarda, 1979) pp. 63–89.
5. Carlo Pedretti, *Leonardo A Study in Chronology and Style* (Harcourt Brace Jovanovich, 1982) pp. 68–76.
6. Frederick Hartt, *Italian Renaissance Art* (Harry N. Abrams, 1979) p. 401.
7. Leo Steinberg, "Leonardo's *Last Supper*," *Art Quarterly* 36, No. 4, 297, 355–401 (1973).
8. Allardyce Nicoll, *The Development of the Theatre* (Harcourt, Brace & World, Inc., 1966) pp. 69–92.
9. In the modern world, photographers achieve accelerated perspective through the use of a fish-eye lens. The exaggerated size of Christ in the middle of the progressively decreasing sizes of the Apostles, and the sharply tapered walls, ceiling and floor suggest that Leonardo, who understood the principles of lenses, employed some form of a fish-eye lens concept. However, the fact that the table line appears straight argues against this procedure because the use of a fish-eye lens leads to curvature. Instead, the absence of curvature in the Fresco leaves the possibility of an accelerated, rectilinearly based perspective.
10. The original drawing (at Windsor, 12542r) is reproduced in Ludwig H. Heydenreich, *Leonardo The Last Supper* (Viking Press, 1974). See pp. 32–41.

11. Compositional study for the *Last Supper* (c. 1493–94, Venice Academy, 254r) is reproduced in Carlo Pedretti, *Leonardo Studies for the Last Supper* (Cambridge University Press, 1983) pp. 28, 43.

12. Most likely there was a cat-walk or a raised step at the entrance, at the same level as the platform underneath the monk's tables and chairs, designed to protect from the cold beneath. (Such Renaissance catwalks survive to the present day.)

13. *Il Paradiso*, Leonardo's stage design, Codex Arundel 263, folios 224r and 231V, reconstructed for the Elmer Belt Library of Vinciana by Howard Kahl, Dept. of Theater Arts, UCLA; Metropolitan Museum of Art, *Sketch for scene from Baldassare Taccone's play "Danae"*, 1490 by Leonardo.

14. Warman Welliver, "Symbolic Meaning in Leonardo's and Raphael's Painted Architecture", *Art Quarterly* 2, No. 1, 37–66 (1979); 'True Room' is approximately 80.0 meters long by 9.7 meters wide by 7.25 meters high.

15. Rudolf Arnheim, *Art and Visual Perception* (Univ. of California Press, 1969) pp. 268, 269–270, 275, 276, 364, 365.

16. The Pixel Machine™ is a high-performance image computer, which offers super-computer power dedicated to three-dimensional graphics and image processing.

17. Carlo Pedretti, *Leonardo Architetto* (Milan, 1978; London, 1979); Eugenio Battisti, letter to L. Schwartz, 2-3-88: "Consider that the original floor was almost a meter below the modern one." Barcilon and Brambilla, "Il Cenacolo di Leonardo in Santa Maria Delle Grazie" (Olivetti, 1984) p. 4.

18. W.B. Green, *Digital Image Processing* (Van Nostrand Reinhold, 1983) p. 113.

19. Texture-mapping graphics: the addition of texture to an otherwise smooth surface. The digitized image (the photograph of the *Last Supper* was translated into binary form) was positioned on the 'wall' of the 3-D model of the Refectory.

20. Robert Morris, *Sky*: a program that calculates the azimuth and elevation from the latitude, longitude, date and time of day. *UNIX Programmer's Manual* (AT&T Bell Laboratories, 1981).

21. Mark Fineman, *The Inquisitive Eye* (Oxford Univ. Press, 1981) pp. 130, 131.

22. Lillian Schwartz, "Leonardo's *Mona Lisa*", *Art & Antiques* (January 1988) p. 53.

23. The data from which the floor texture and the window dimensions were taken were derived inadvertently from a different epoch. These inaccuracies do not affect the analysis reported above.

24. Note added in proof: Recent findings reported by Pietro Marani, Soprintendenza per i Beni Artistici e Storici di Milan, now indicate that the Refectory floor was actually some 20 cm below the level adopted for the perspective models described above. This new result strengthens the conclusions of the present discussion by bringing the Renaissance viewer's eye closer to the point at which the painted tapestry comes into exact congruence with the lines of the real room.