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Occlusion issues in early Renaissance art

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Abstract. Early Renaissance painters innovatively attempted to depict realistic three-dimensional scenes. A major problem was to produce the impression of overlap for surfaces that occlude one another in the scene but are adjoined in the picture plane. Much has been written about perspective in art but little about occlusion. Here I examine some of the strategies for depicting occlusion used by early Renaissance painters in relation to ecological considerations and perceptual research. Perceived surface overlap is often achieved by implementing the principle that an occluding surface occludes anything behind it, so that occlusion perception is enhanced by a lack of relationship of occluding contour to occluded contours. Some well-known figure-ground principles are also commonly used to stratify adjoined figures. Global factors that assist this stratification include the placement of figures on a ground plane, a high viewpoint, and figure grouping. Artists of this period seem to have differed on whether to occlude faces and heads, often carefully avoiding doing so. Halos were either eliminated selectively or placed oddly to avoid such occlusions. Finally, I argue that the marked intransitivity in occlusion by architecture in the paintings of Duccio can be related to the issue of perceptual versus cognitive influences on the visual impact of paintings.

Keywords: perception of overlap, art and perception, incoherence in art, principles of occlusion.

1 Introduction

Occlusion is rarely discussed as a major issue in art, yet it could be regarded as *the* major issue in depicting a three-dimensional scene on a picture plane. By occlusion is meant that in any view of a scene some surfaces are hidden in part by nearer surfaces. In viewing a real scene, stereo and motion are available to segregate surfaces in depth; however, on the picture plane, occluding and occluded surfaces will be adjacent. This raises two problems for a painter trying to represent a three-dimensional scene. The first is how to generate the impression that adjacent surfaces are at different depths and overlapping rather than at the same depth and touching. The common border must be seen to be owned by the nearer surface. A second and related problem in depicting occlusion is that partially occluded objects are represented on the picture plane as incomplete. They need to be seen as continuing behind the occluding surface rather than amputated where they touch it.

Overlap is not only important for resolving depth relations. Lubbock (2006) makes the interesting point that how surfaces overlap fixes the viewpoint of the painting, since a slight movement of the viewer to left or right (for example, in Giotto's painting *The feast of Herod*) would change the occlusions entirely. Hyman (2003) makes the related point that overlaps and occlusions were used by early Renaissance painters such as Ambrogio Lorenzetti to "emphasise chance and happenstance" (p 96). These authors (who are among the few art historians who mention overlap at all) are interested in the influence of overlap on the narrative conveyed by a painting. They do not analyse how overlap *per se* comes to be perceived. In a complementary approach to theirs, occlusion is treated here as a perceptual response that itself needs to be explained. How do painters elicit perceived surface occlusion in a picture?

Since the earliest known cave art, painters have readily depicted surfaces occluding one another, successfully giving the impression that adjacent areas are overlapping with apparent continuation of the occluded object. They clearly discovered features of two-

dimensional images that promote the perceptual segregation of foreground figures from background figures. Very poor segregation is rare. Most artists presumably notice it and correct it—perhaps by trial and error. Yet artists and art historians have written surprisingly little about how this is done. As Kanizsa and Massironi (1989, p 135) have written:

> While the relationships between pictorial representation and other perceptual mechanisms have been comprehensively researched, the same cannot be said of phenomenological stratification. Entire essays and books have been dedicated to analyzing the role that perspective, lighting, chromatic interactions, and optical illusions play in pictorial representation. But much less attention has been given to the phenomenon of continuation or completion of a visible surface behind another surface. The reason for the limited interest in this question is probably that the cause of the phenomenon is taken for granted. The completion is considered to be the result of *cognitive* integration and, therefore, does not require any additional analysis.

Kanizsa and Massironi's article is principally concerned with making a clear distinction between cognitive completion based on object recognition from partial information, and "amodal" completion based on stimulus features. They argue that the latter is perceptual not cognitive and show that it tends to override cognitive interpretations when the two are in conflict. Arnheim (1954) also makes this distinction. It also applies to occlusion perception more generally; perceived occlusion often does not support "cognitive" occlusion or occlusion that is obviously intended but lacks stimulus support. Likewise, perceived occlusion may occur even when the context indicates that it is not logically correct. Duccio's early 14th-century paintings are especially interesting in this regard since occlusion in one part of a picture may be inconsistent with occlusion in anther part. To what extent did this occur because of a lack of interest in cognitive consistency? I shall return to this question at the end of the paper in discussing Duccio's treatment of architecture.

In the early Renaissance there was a burgeoning desire to portray more complex and more realistic scenes than had been attempted by painters in previous centuries; although this desire was anticipated by and probably inspired by ancient Roman art (White 1957). Depicting narratives with multiple overlapping people in more or less natural poses demanded multiple strategies for achieving the stratification of surfaces into in front (occluding) and behind (occluded) with unambiguous border ownership. My concern in this paper is first to discuss some of these strategies, especially as used in fourteenth century Siena and Florence, and to relate where possible their varying degrees of success in representing occlusion arrangements to modern perceptual research. I shall then discuss the related issue of perceptual completion, mainly with regard to the occlusion of faces: an issue that seems to have divided early Renaissance painters. Finally, I shall discuss incoherence in the depiction of occlusion in early Renaissance art.

Later painters, of course, also used the strategies I discuss and often in a more sophisticated way. It is particularly interesting, however, to examine their application in an experimental period for realistic painting.

Two occlusion principles are mentioned as important in Kanizsa and Massironi's (1989) article: T-junctions and the continuation of a contour across an interruption by a surface. These two common features of occluding contours have been analyzed extensively outside the context of art (by Kanizsa [1979], Kellman and Shipley [2001], and Rubin [2001], to name a few). The term T-junction refers to the fact that an occluding edge often forms the top of a T with an occluded contour forming the stem (see Figure 1). The conditions required for contours to be perceptually interpolated across an intervening surface have been studied by Kellman and Shipley (2001) and described as "relatability". Geisler and Perry (2009) studied the natural image statistics underlying observers' judgements that two contours on opposite sides of an occluder came from a single object. Interestingly, T-junctions and relatability are the sole sources of the sense of surface occlusion in much ancient Egyptian art (see Figure 2).

However, despite the fact that relatability seems to work well as an aid to perceived occlusion for narrow surfaces such as the legs in Figure 2, it is not very effective when the relatable contours are more remote from each other (Gillam et al 2008). Furthermore, in many real scenes an occluded contour has no relatable partner on the other side of an occluding surface. We analysed paintings to explore this issue empirically.

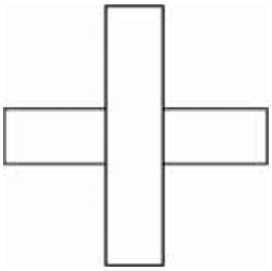

Figure 1. A simple representation of one surface occluding another, forming T-junctions at the occlusions (see text). The occluded bars (stems of the Ts) are relatable across the intervening surface.

Figure 2. Detail from *Peasants driving cattle and fishing,* 2465–2373 BC. The overlap of one leg with another in most cases forms a T-junction. The stems of the Ts in many cases are relatable across an occluding leg. Continuation of contours across an interrupting surface is most effective in supporting the perception of occlusion when the interrupting surface is not too wide.

We used a sample of Renaissance and post-Renaissance paintings from the catalogue of the National Gallery of London (but eliminating paintings with many trees). A naïve student was asked to identify all occluded contours in each painting and then to classify each one with respect to whether it continued across the occluding surface or not. The majority of occlusions did not lead into a relatable contour (see Table 1). We believe that this is also likely to be the case in real scenes, although this issue would need to be investigated using natural image techniques similar to those of Geisler and colleagues.

Painting	Artist	Year	Genre	Type	Continuo	Non Continuo	% Cont	% Non Cont
Saint George and the Dragon	Jacopo Tintoretto	1518-1594	Italian	Exterior	54	85	39%	61%
The Consecration of St Nicholas	Paolo Veronese	1528?-1588	Italian	Interior	56	116	33%	67%
Apollo Pursuing Daphne	Demenicho	1584-1641	Italian	Exterior	32	45	42%	58%
Self Portrait	Salvator Rosa	1615-1673	Italian	Portrait	12	26	32%	68%
Exhibition of a Rhinoceros in Venice	Petro Longhi	1702-1785	Italian	Interior	64	90	42%	58%
The Marriage of Giovanni Arnolfini	Netherlandish	1422-1441	Neth.	Interior	82	86	49%	51%
Portrait of a Man	Dieric Bouts	1448-1475	Early Neth.	Portrait	2	15	12%	88%
Saint Giles of the Hind	Master of Saint Giles	c.15001	Early Neth.	Exterior	32	39	45%	55%
Music	Joos van Wassenhove	1460-1480	Early Neth.	Interior	68	45	60%	40%
The Presentation in the Temple	Master of the Virgin		German	Interior	68	83	45%	55%
Christ Taking Leave of His Mother	Albrecht Altdorfer	<1480-1538	German	Exterior	34	79	30%	70%
Portrait of a Lady	Katharina de Hemessen	1527/8-1566	Flemish	Portrait	18	10	64%	36%
The Holy Family	Jacob Jordaens	1593-1678	Flemish	Interior	30	40	43%	57%
A View of Het Sterckshof Near	David Teniers	1610-1690	Flemish	Exterior	30	20	60%	40%
Peasants With Cattle by an Aqueduct	Nicolaes Berchem	1620-1683	Dutch	Exterior	24	29	45%	55%
Cattle and Sheep In a Stormy	Paulus Potter	1625-1654	Dutch	Exterior	10	10	50%	50%
The Castle of Muiden in Winter	Jan Beerstraaten	1622-1666	Dutch	Exterior	44	21	68%	32%
Canstantijn Huygens and His Clerk	Thomas de Keyser	1596-1667	Dutch	Interior	28	66	30%	70%
A Women Drawing	Gabriel Metsu	1629-1667	Dutch	Interior	18	40	31%	69%
The Grote Kerk, Haarlem	Pieter Saenredam	1597-1665	Dutch	Interior	26	61	30%	70%
The Market Place at Haarlem	Gerrit Berckheyde	1638-1698	Dutch	Exterior	34	47	42%	58%
Margaretha de Goer	Rambrandt	1606-1669	Dutch	Portrait	10	8	56%	44%
				mean=	35	48	43%	57%
Note: An occluded contour that emerged on the other side of the occluder was counted as two separate occlusions								

Table 1. Every third painting from a period of realistic art was selected from the catalogue of the National Gallery of London. A student went through each painting identifying all contour occlusions and classified them according to whether they continued after interruption by a surface. Percentages of continuing and non-continuing contours are shown in the last two columns.

2 Occlusion principles and art

2.1 Perception of occlusion at adjoining surfaces (local factors)

In this section I shall not discuss further the relatability of contours across surfaces, although it is undoubtedly sometimes a factor promoting perceived occlusion (eg, see Figure 2 and the edge of the table in Figure 21). However, looking at the pictures included in the current paper, which were chosen for a variety of reasons entirely separate from the issue of relatability, one can see that it is uncommon for contours to be relatable across an intervening surface, just as it was shown to be uncommon in the data of Table 1. Here I am concerned with how the properties of T-junctions along a single occluding contour influence the impression of occlusion at the contour.

2.1.1 *Properties of the occluded surface*

When human figures intended to appear one in front of the other are adjoined in a painting, perceptual stratification can fail if adequate occlusion indicators are absent. (The intended occlusion can usually be inferred cognitively from the context.) For example, in Figure 3, a fragment of a Giotto painting, the two faces appear joined together rather than stratified in depth. The face on the right is incomplete, indicating that it must be the behind face, but incompletion is clearly not sufficient to produce perception of occlusion. The T-junctions are ambiguous. In Figure 4 it is obvious that the woman in the red dress (indicated by a black cross) is intended to be behind the figures on either side because so little of her dress is visible. Yet she appears joined to these figures rather than occluded by them. How can good occlusion perception be achieved at adjoining surfaces in such scenes? An important clue

lies in the insight that occluded contours and objects normally have no relationship to the occluder.

Figure 3. Detail from Giotto, Arena Chapel, *Meeting at the Golden Gate* (1302–1304). The faces appear attached. Incompletion of the face on the right is not sufficient to support its perceived occlusion. The T-junctions are ambiguous.

Figure 4. Bembo Bonifacio, *Beatrice D'Este e la sua Corte* (c 1494). The woman in red marked with a black cross has a robe that appears attached to, rather than behind the figures on either side. Occlusion indicators are absent. The edges shown by the white arrows are perceived as occluding because they have an orientation unrelated to the contours they occlude. See text. The blue arrow shows perceived occlusion based on the convexity of the nearer surface.

Independence of the orientation or curvature of occluding and occluded contours. An occluding surface occludes any object or contour behind it regardless of its properties. Thus independence between the properties of the occluder and the occluded elements might be expected to facilitate the perception of occlusion. This is indeed the case, as I shall spell out below. A single occluder will normally occlude multiple contours behind it, aligning their ends

at multiple T-junctions. The T-junctions are more likely to represent an occlusion, however, when the top is not orthogonal to the stems or has a different curvature. Gillam (1987) and Gillam and Vecellio (forthcoming) have shown experimentally that perception of occlusion is considerably enhanced if an occluding edge is not orthogonal to the contours occluded. The occluding edge is then much more likely to be extrinsic to the occluded contours—hence an occluder. Whether early Renaissance painters explicitly knew this principle is not known, but it is responsible for many of the successful occlusion resolutions at adjacent surfaces in their paintings. It is particularly common for robes. There are two good examples in Figure 4 (indicated by the white arrows). In both cases the edge of an occluding robe forms multiple T-junctions with a set of contours on the occluded robe of an orientation unrelated to that of the occluder. Perceived occlusion by the intended occluding edge is very strong whenever this occurs. Giotto provided many good examples such as the edges indicated by white arrows in Figure 5 and Figure 9.

Figure 5. Giotto, Arena Chapel, *Judas receives the thirty pieces of silver* (1303–1305). Note the effective occlusion at the edge of the green robe shown by the white arrow. This edge contour forms an alignment of the contours on the red robe that is unrelated to their orientation.

Occasionally a contour will terminate non-orthogonal contours on both sides, and its occlusion polarity will be perceptually ambiguous. Such a case is shown within the area surrounded by an oval in Figure 20.

Entropy contrast. Another corollary of the fact that an occluder is indifferent to what it occludes is that a smooth surface edge terminating a set of objects or contours *unrelated to each other* is overwhelmingly likely to be an occluding edge. Perception strongly reflects this probability (Gillam and Chan 2002; Gillam and Grove 2011). Compare the five sets of shapes on the left column of Figure 6 (taken from a larger number of stimuli used by Gillam and Chan 2002). In the bottom set the shapes are more or less random in width, orientation, separation, and length. The sense that the line to which they are attached is occluding them is very strong. Perceived occlusion becomes weaker in the middle three sets as regularity increases, but it is almost non-existent in the top set, where the regular shapes are orthogonal to the line and appear to rest on it.

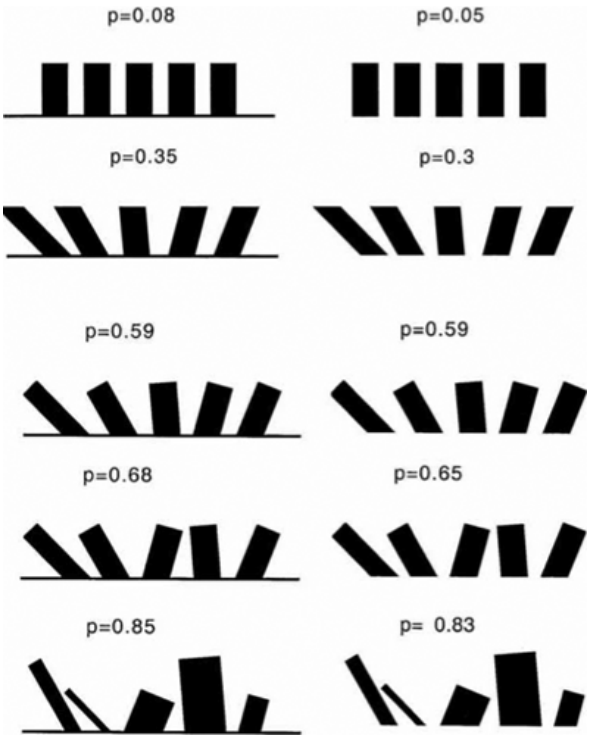

Figure 6. Sets of shapes used by Gillam and Chan (2002) to compare perceived occlusion (left column) and strength of subjective contour (right column) at the bottom of each set. As the shapes become more disordered (from top to bottom), both perceived occlusion and subjective contour strength increase, as shown by the increasing probabilities above each set. (Probabilities are based on the method of paired comparison.) Different observers were used for perceived occlusion and subjective contour judgements.

Figure 7. Piero della Fransesca, *Legend of the True Cross: the Battle of Heraclius and Chosroes* (c 1455–1460). Near figures such as the red man and the horse's legs have very strong occlusion information, terminating a variety of background details.

These impressions are reinforced by the probabilities (shown under each set of shapes) that it was chosen (in a paired comparison procedure [Guilford 1954]) as appearing more occluded than all comparison sets. As the right column of Figure 6 shows, we obtained very similar probabilities when the bottom line was removed from each set and the relative strength of a subjective contour along the bottom edges of the shapes was measured using the same method. (The presence of a subjective contour is an indicator of perceived occlusion.)

We refer to this occlusion principle as “entropy contrast” or “alignment within disorder” (Gillam and Grove 2011). There are many examples of this principle at occluding contours scattered across the paintings in the present paper (see, for example, black arrows in Figures 10, 11, and 13). It is noteworthy that in the very effective 15th-century battle painting by Piero della Francesca (Figure 7) the painter makes several near figures stand out from the confusion of war behind them by having important parts of these figures (an arm or a horse’s leg) terminate many unrelated contours and surfaces of the background, producing a powerful sense of occlusion. One reason why the faces in Figure 3 are not perceptually segregated may be that they lack entropy contrast. I shall return to this principle in considering haloes.

Shading. Sometimes the occluding object casts a shadow on the occluded object, which disambiguates the perception of occlusion and border ownership. An example can be found in a detail (Figure 8a) from Duccio’s Maesta (Figure 17). The Virgin’s lower hand casts a shadow on the baby’s robe. The nearer and further of two surfaces can also be differentially lit by an implicit light source. Massacio, a 15th-century painter, often used differential lighting of adjoined faces to facilitate their perceived stratification (see Figure 8b).

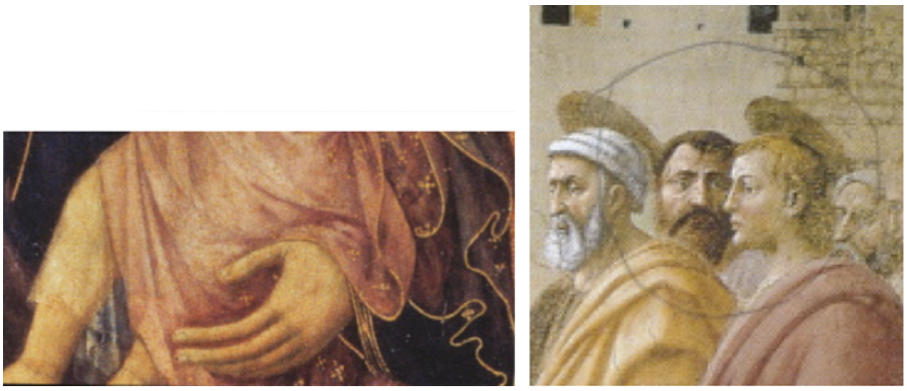

Figure 8. (a) Detail of Figure 17. Mary’s hand casts a shadow on the robe of the baby, which emphasises their depth difference. (b) Detail from Masaccio *Distribution of Alms and Death of Ananis* (1424–1428). Segmentation of the faces surrounded by a circle is facilitated by the difference in their lighting.

2.1.2 *Properties of the occluding surface*

Convexity. When two surfaces abut at a common contour, the surface for which the contour is convex is more likely to be the occluder than the surface for which the same contour is concave. This is an old Gestalt principle that would tend to fall out naturally in painting overlapping figures. A good example of the effectiveness of convexity is shown by the blue arrow in Figure 4, but it is very common.

Extremal edge. Another occlusion principle important in early Renaissance art is the presence of an “extremal edge,” defined by Palmer and Ghose (2008) as the self-occluding edge of a curved surface in depth as indicated by shading or texture. Giotto often painted robes with strong shading giving an impression of curvature or volume leading into the edge (see Figure 9). Palmer and Ghose (2008), using a figure-ground paradigm, showed that extremal edges strongly bias the region with them to be seen as the figure not the ground. In Renaissance art it is common for only one robe to have an obvious extremal edge. This will clearly be seen in front of an adjacent robe that lacks such an edge, thus acting as ground. Unlike the principles of unrelated alignment and entropy contrast, which depend on properties of the occluded elements, extremal edge defines the occluding surface. In some

Figure 9. Giotto, Arena Chapel, *The Magi*. Extremal edges produce a good sense of occlusion for the edges shown by the black arrows. The white arrow shows the additional factor of independence of occluding and occluded contour orientation. The baby's halo is not well segregated from the robe behind because the contours of the robe are approximately at right angles to the halo. Similarly the face of the kneeling magi appears joined to the baby's robe, although he is probably some distance away.

cases adjacent figures may both have extremal edges, especially if the shading/light source relationship is not coherent. In such cases there can be ambiguity about stratification of the figures.

2.2 Global factors in disambiguating occlusion relationships

2.2.1 *The ground plane*

Placing figures on a ground plane, especially if it is textured and in perspective, is a good way of locating them at different depths and thus disambiguating adjoined human figures. One of the first paintings using a (nearly) perspectively correct ground plane to establish figure layout is the Sienese painter Ambrogio Lorenzetti's *Presentation at the Temple*, shown in Figure 10. The ground running under the figures provides "an index for spatial values" (Panofsky 1991). The ground plane also locates figures in Duccio's Figure 11 (top panel). Interestingly the bottom panel in Figure 11 shows that detaching a figure from the ground plane even for a cognitively rational reason (St Peter warming his feet at the fire) can lead to an impression of a perceptual detachment of the figure from its (presumably) intended location. Local occlusion indicators at adjoining robes are weak, and St Peter appears to be floating.

2.2.2 *High viewpoint*

Crowd scenes with many figures at different depths are difficult to segregate in depth. The ground plane is often not visible, and there can be a strong sense of confusion as in Figure 12. It seems that occlusion information such as T-junctions with orientation independence and

Figure 10. Ambrogio Lorenzetti (1342), *Presentation in the Temple*. Placement of figures on the ground plane aids depth segregation. Haloes prevent heads from being confused with the background. See black arrow for perceived occlusion aided by entropy contrast.

entropy contrast, which may readily segregate two adjacent surfaces, cannot be processed perceptually in parallel and in sequence over many figures to sort out the depth layers involved.

One way that painters have dealt with the confusion of depth relationships in crowd scenes is either to have figures going up a hill or to use a high viewpoint—both being techniques for placing figures at different heights on the picture plane with some semblance of realism. This avoids occlusions altogether, at least for the more important upper parts of the figures. Duccio used these techniques—later perfected by artists such as Brueghel—in early realistic scenes such as Figure 13 from his Maesta series, although the high viewpoint applied to the figures on the ground was not applied to the buildings.

Figure 11. Duccio (1308–1311) Maesta series. Top: *Jesus interrogated by Ananias the Priest.* Differential placement of figures on the ground plane aids depth segregation. Note that the soldiers (with helmets) have no feet. This is common in Duccio's paintings (Lubbock 2006) but usually not noticed. Bottom: *St Peter denies being one of Jesus' disciples.* St Peter appears to float in front of the other disciples because he has lost his anchoring to the ground plane and local cues are weak. The black arrow shows entropy contrast between the edges of the halo and the details behind it.

A later Sienese painting by Pietro (Figure 14) also illustrates high viewpoint. This substitutes in early realistic art for the more arbitrary placement of figures, especially angels, at different heights in earlier paintings, such as the Cimabue and Duccio Madonnas, to avoid overlapping faces. Giotto did not use this technique, preferring to produce a realistic impression with extensive and skilful depiction of overlapping figures standing on horizontal ground.

2.2.3 *Grouping*

A technique that can minimize confusion when there are multiple figures at different depths is to group the figures by placing them at the same orientation and overlapping in the scene with parallel occluding contours in the picture plane. This seems to allow occlusions to be processed in parallel. Arnheim (1954) discussed the aesthetic advantages of grouping multiple figures by parallel lines and overlap. Giotto used this technique in a number of

Figure 12. Bartolo di Fredi, *The Adoration of the Magi* (c 1395). Lack of ground plane information. There are many local cues between figures, but they are difficult to process in parallel. Depth relationships are confusing.

scenes in the Arena chapel (see Figures 15 and 16). It is most successful when there is some variation within the overall grouping enhancing the aesthetic effect and sense of realism. The Egyptians sometimes used this technique in depicting overlapping soldiers and horses but generally in a very rigid arrangement.

3 Occlusion and completion—Faces and haloes in early Renaissance art

Haloes were originally used for symbolic purposes to designate someone as holy. However, in early Renaissance painting, haloes had perceptual advantages as well. They could be used by skilled painters to reduce confusion between important heads and the details of the naturalistic background behind them, since haloes were conventionally placed behind the head. They make a flatter, larger, and rounder occluding surface than a head itself would do, producing very good entropy contrast when cutting off a variety of unrelated details behind them. Setting off significant heads from the more mundane aspects of the scene also obviously served an aesthetic function. The effectiveness of haloes as occluding surfaces is clearly shown in Ambrogio Lorenzetti's painting in Figure 10 and in Duccio's painting of the Maesta (Figure 17), where the haloes emphasize the heads.

Different traditions seem to have developed with respect to the role of haloes as occluders. This is bound up with the perceptual and aesthetic issue of whether faces (especially important faces) should be occluded at all. Cimambue and Duccio, in painting their famous Madonnas, arranged all figures, including angels, to avoid occlusion of heads by either halos or other heads.

Figure 13. Duccio Maesta Series *Palm Sunday* (1308–1311). A high viewpoint avoids confusion in the crowd scene by separating the upper parts of the figures. The high viewpoint for the figures is not shared by the buildings however. The black arrow shows entropy contrast between the halo and the details behind it.

This is also true in Duccio's Maesta (Figure 17). The Florentine Giotto on the other hand, in his radically earthier Madonna (Figure 18) treated halos as natural objects that are allowed to occlude faces (see also Figure 16). Allowing faces to be occluded increases the sense of realism in one way, but letting haloes do the occluding gives them a strong and somewhat disturbing physical presence. Perceptual continuation of the faces behind the haloes does not seem to be altogether successful in Giotto's paintings.

One might think that the desire to avoid occlusion of faces is related to their religious significance. However, even in non-religious scenes with ordinary people the figures are often carefully arranged with an apparently natural placement except that facial occlusion is avoided. See, for example, Ambrogio Lorenzetti's *Good Government* (Figure 19). In the Maesta series Duccio generally avoided occlusion of faces except those of soldiers (see Figure 20). As we have seen, Giotto put natural placement first, resulting in frequent occlusion of faces. Even Giotto, however, did not allow haloes to completely occlude the heads of significant figures such as the apostles; he famously placed the halos of the apostles sitting with their backs to the picture plane in front of their faces in several paintings (see Figure 21).

Later Renaissance painters, such as Beato Angelico and the Spanish painter Huguet, in a painting of *The Last Supper,* also placed haloes in front of faces in the manner of Giotto. Duccio on the other hand chose to eliminate halos altogether for heads which would be occluded if haloes were placed behind them (see Figures 22 and 23). Thus in Duccio's paintings half the apostles may have halos and the other half not.

This convention was also applied by other artists of the period such as Simon Martini (Figure 24), who like Duccio was Sienese. It can also be seen in Figure 25 from the late-14th century illuminated manuscript *La Bible Historiale* by Guyot des Moulins. Clearly, there were major aesthetic and perhaps religious issues at stake here. One possible reason for selectively omitting haloes, given that that they would have been shining gold, was that they

Figure 14. Sano di Pietro (1445), *San Bernadino Preaching in the Campo* in 1427. A high viewpoint prevents confusion of the figures.

Figure 15. Giotto, Arena Chapel, *Life of Christ*. The figures on the right indicated by the black arrow are grouped facilitating their depth processing in parallel.

were judged too dominant to be placed in the centre of a painting. A reluctance to occlude detail enriching the story may also have been a factor. Unfortunately, it is not really known what ideas lay behind the two different traditions or whether they were discussed or even controversial at the time.

Figure 16. Giotto, Arena Chapel, *Last Judgment*. Grouping reduces confusion in a crowd scene by allowing occlusions to be processed in parallel.

Figure 17. Duccio, Maesta series, *The Virgin and Christ Enthroned in Majesty with Angels and Saints* (1308–1311). Duccio has carefully avoided occlusion of any heads. Many of the haloes show entropy contrast with their backgrounds.

4 Occlusion incoherence: Duccio's treatment of architecture

Finally, a particularly interesting aspect of occlusion representation is the incoherence of occlusion by architecture, found in the paintings of Duccio, who was a pioneer in placing figures within an architectural setting. Kanizsa and Massironi (1989) argue that if an architectural feature of a coherent structure would occlude an important event or person, Duccio reverses the occlusion relationships so that the event is seen in front of the architectural feature. This renders that feature incoherent with the rest of the architecture. Lubbock (2006) accuses Duccio of playing "fast and loose" with perspective (p 27). In the example in Figure 20, Pilate's hand washing occurs in front of a pillar when it should be behind the pillar in a fully coherent architecture. The perspective looks more or less correct, however, if you only look at the top of the figure, possibly for the same reason that impossible figures, which are globally incoherent (Figure 26), look three-dimensional so long as they are *locally* coherent. Their global incoherence becomes obvious only when the ends are fixated successively. Hochberg (1968) makes the interesting point in relation to impossible figures

Figure 18. Giotto, *Ognissanti Madonna* (1310). Heads are occluded by haloes.

Figure 19. Ambrogio Lorenzetti, *Allegory of Good Government* (1338). Detail showing *Peace and Fortitude*. There is a casual arrangement of figures, but occlusion of faces is avoided.

that depth organization from junctions is resolved very locally. This would be sufficient for veridical perception in a coherent world in which putting locally coherent organizations together would automatically produce global coherence. It would not be necessary to include a process of checking for global coherence.

Figure 20. Duccio, Maesta series, *Pilate washes his hands and Jesus is taken to be crucified* (1308–1311). The soldiers' heads are occluded but few of the other heads are. The fact that the heads at the back are visible means that the figures cannot be standing on the ground plane, although this is not immediately obvious. Within the black oval is a contour with ambiguous surface ownership because it has contours whose orientation is unrelated to it on both sides.

Figure 21. Giotto, Arena Chapel, *The Descent of the Holy Spirit* (1303–1305). Haloes are placed in front of the heads of those figures with their backs to the picture plane.

The fact that seeing global incoherence requires scrutiny perhaps explains why Duccio was able to ignore it in many of his Maesta paintings without destroying the narrative impact.

Figure 22. Duccio, Maesta series, *Last Supper* (1308–1311). The apostles in front do not have haloes.

Figure 23. Duccio Maesta series, *Christ taking leave of the Apostles.* Haloes are absent from the apostles in front.

He clearly did not care about cognitive accuracy. White (1957) said he lacks "interest in the fundamental realism that is typical of Giotto" (p 80). There are other details that one tends not to notice that demonstrate this lack of interest, such as the absence of legs below the soldiers in Figure 11 and in a number of other Maesta paintings. It does not seem adequate to attribute Duccio's frequent failures of coherence simply to the desire to fully depict an important event. As pointed out by Bunim (1940), in Figure 20 not only Jesus but a whole crowd of figures are placed in front of the pillar on the left. The paintings in the Maesta series depicting the appearance of Jesus before various authorities almost all have incoherent architecture. It is striking that while architecture sometimes amodally continues behind human figures the reverse is almost never true (the only exception seems to be in *The Flagellation of Christ*). There are several pictures in which people are rudely cut off by an occluding surface when

Figure 24. Simone Martini, *The Entombment* (c 1312 or c 1337). The figures in front (presumably saints) lack halos. However, the figure on the lower left has a Giotto type halo in front of the head.

Figure 25. Guyart des Moulins, detail from *La Bible Historiale* (French late-14th century). In this illuminated manuscript the apostles with backs to the viewer are without halos in the manner of Duccio.

they should rationally continue behind it (see Figure 27). Duccio's reason for doing this is surely that he wants to tell two different stories with different characters on the two sides of the pillar despite the fact that the space is depicted as continuous. Attention is drawn to the central characters in each story, and one does not notice the failure of continuity of peripheral characters cut off by the pillar unless one scrutinises the picture carefully. It is

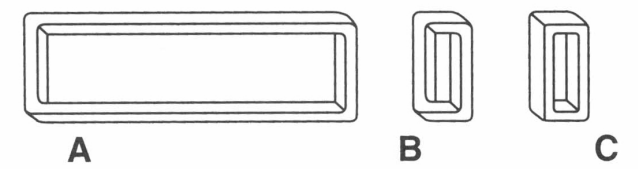

Figure 26. An "impossible" figure (A). Each end looks three-dimensionally coherent. However, the figure as a whole is incoherent. When the two ends are brought closer together and attended to as a unit, it becomes more obvious whether the figure is incoherent (B) or coherent (C). Adapted from Hochberg (1968).

notable that the cut off figures do appear occluded even without relatability on the other side of the pillar, presumably because of strong entropy contrast.

Duccio's tolerance of incoherence in his paintings broadens the issue raised by Hochberg about the role of attention in the global processing of junctions to the perception of entire events.

Figure 27. Duccio Maesta series *Jesus mocked by order of Caiaphus and St Peter's third denial.* The forward column on the left abruptly cuts off figures in the Peter denial story on the left and the mocking of Jesus story on the right despite apparent continuation of the space within which they occur. In this painting there are an unusual number of occluded faces for Duccio. They are the mockers of Christ. Perhaps Duccio more readily allows villainous characters to be occluded.

5 Conclusion

I have chosen the period leading into the Renaissance to examine the methods that foster perception of surface overlap in the two-dimensional representation of a scene. A number of the successful strategies used by painters of this period such as figure-ground principles as well as the principles of unrelated order and entropy contrast have been investigated empirically by perception researchers (although centuries later). Despite the well-known importance of the ground plane in considering perspective, it has not always been recognised that placement on the ground plane, as well as the use of a high viewpoint, are important factors in disambiguating occlusion relationships.

The effect of partial facial occlusion on face perception, especially significant in an era when haloes were prevalent, deserves further empirical investigation. While haloes in naturalistic settings may increase facial occlusion, possibly exacerbating the problem of perceiving continuation/completion of the face, I have argued that they can play a positive role in occlusion perception by improving segregation of heads from their backgrounds and from each other.

Later painters have, of course, further refined the techniques I have discussed and devised others. Occlusion has never ceased to be an issue in representational art, including photography, and occlusion perception is deliberately manipulated with significant effect in both abstract and indigenous art.

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