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OLFACTORY AMODAL COMPLETION

BY

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Abstract: Amodal completion is the representation of those parts of the perceived object that we get no sensory stimulation from. While amodal completion is rife and plays an essential role in all sense modalities, philosophical discussions of this phenomenon have almost entirely been limited to vision. The aim of this paper is to examine in what sense we can talk about amodal completion in olfaction. We distinguish three different senses of amodal completion – spatial, temporal, and feature-based completion – and argue that all three are present and play a significant role in olfaction.

1. *Introduction*

Amodal completion is the representation of those parts of the perceived object that we get no sensory stimulation from. For decades, amodal completion has been primarily considered to be a visual phenomenon, and amodal completion indeed plays an important role in the visual sense modality, where it comprises the representation of occluded parts of objects we see. To use the go-to example of visual amodal completion, when we see a cat behind a picket fence, our perceptual system represents those parts of the cat that are occluded by the fence (see Michotte *et al*. 1964 and Kanizsa and Gerbino 1982 for classic studies and Nanay 2010, 2018b, Briscoe 2011, and Helton and Nanay 2019 for philosophical overviews).

Amodal completion also happens in other sense modalities. And non-visual forms of amodal completion are very different from visual ones. Amodal completion plays an equally important role in the auditory sense modality. For example, when we hear a loud bang while listening to a tune, the auditory system continues to represent the tune even in that brief moment when the bang is the only auditory stimulation. Or, to use a more

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evocative example, in the American late-night show host Jimmy Kimmel's segment 'A week in unnecessary censorship', he beeps out completely harmless words from famous politicians, making them sound like expletives.

Note the difference between visual and auditory amodal completion. In audition, we have a form of temporal 'occlusion,' where the bang occludes part of the tune. In vision (and in tactile perception), we have a form of spatial occlusion. In both cases, the completion is perceptual, as both neuroimaging and eye movement studies show (see the next section for more details and references). In the case of the visual completion of the cat behind the picket fence, for example, the occluded contours of the cat show up as early as the primary visual cortex.

Both in vision and in audition, amodal completion is the norm, not the exception. We are very rarely in a perceptual scenario where there is no amodal completion: in natural scenes, we always get occlusion because objects tend not to be fully transparent. And most of what we hear is suffused with various other auditory stimuli. Given that amodal completion is an important part of the vast majority of our perceptual states, no theory of perception can be considered complete if it cannot account for this phenomenon.

This paper is about amodal completion in the olfactory sense modality.[1] Given the importance of amodal completion in the visual, auditory, and tactile sense modalities (where our perceptual system completes the shape of the object we are holding on the basis of just a couple of points where our fingers touch it, see Section 2 for an elaboration of this example), the question arises: Is there olfactory amodal completion?

2. *Three forms of amodal completion*

Amodal completion happens when the perceptual system receives no information about a specific part of the perceived scene from the sense organs. The perceptual system then proceeds to provide this missing information on the basis of top-down or lateral information. To put it very simply, amodal completion provides perceptual processing to compensate for the missing local input. But there are different ways in which the input might be missing and, as a result, there are different ways in which our perceptual system compensates.

We distinguish the following three cases[2]:

1 Amodal spatial completion: the missing and perceptually completed information is spatial information.
2 Amodal temporal completion: the missing and perceptually completed information is temporal information.

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3 Amodal feature-based completion: the missing and perceptually completed information is not necessarily spatial or temporal information.

Amodal completion in vision is predominantly amodal spatial completion. Our visual system gets no spatial information from the occluded parts of perceived objects. And it proceeds to complete this spatial information. We know that this completion happens very early in visual processing, already in the primary and secondary visual cortices (Fiorani *et al.* 1992; Sekuler and Palmer 1992; Kovacs *et al.* 1995; Lee and Nguyen 2001; Nieder 2002; Meng *et al.* 2005; Komatsu 2006; Hegdé *et al.* 2008; Smith and Muckli 2010; Pan *et al.* 2012). And amodal completion in the visual sense modality influences eye movement patterns and reaching movements reliably and often without conscious awareness (Plomp *et al.* 2004; de Grave *et al.* 2008; Troncoso *et al.* 2008; Lommertzen *et al.* 2009; Desanghere and Marotta 2015; Ekroll *et al.* 2016), and it is sometimes (but not always) sensitive to top-down information (Lee and Vecera 2005, 2010; Vrins *et al.* 2009; Hazenberg *et al.* 2014; Hazenberg and van Lier 2016).

Amodal completion in the tactile sense modality is also spatial amodal completion: when I hold a wine glass in my hand, only a couple of my fingers touch the glass, and if I close my eyes, the only spatial information about the glass comes from these couple of points at my fingertips. But my perceptual system nonetheless represents the entire glass, not just those parts of it that my fingers touch. In all of these cases, the missing information, which is amodally completed, is spatial information in the sense that it amounts to properties bound to specific spatial locations.

Amodal completion in audition is often amodal temporal completion. Our auditory system gets no temporal information in the moment when only the loud bang is heard, not the tune, yet the auditory system proceeds to complete the temporal information. The missing information, which is amodally completed, is temporal information in the sense that it amounts to properties bound to specific temporal location.

Amodal completion can be spatial and temporal if the missing and completed information is both spatial and temporal information. An example would be seeing a child disappear and then appear again on a carousel.[3] While we characterized visual amodal completion as spatial amodal completion, temporal amodal completion is very much part of visual perception (as the carousel case shows, see also Yun *et al.* 2018 for experimental support).

Finally, some forms of amodal completion are feature based. By this, we mean that features of the object of perception are not given by direct sensory input and completed information is not necessarily spatial or temporal. For instance, if properties P1–P17 are always presented together to the perceptual system and then properties P1–P16 are presented with P17 missing, then

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the perceptual system may complete this missing property. If it does, this counts as feature-based amodal completion, even if the missing and completed property is neither a spatial nor a temporal property.

Of course, most of our everyday perceptual experience are of a vastly more complex multimodal variety, which nevertheless might be best conceived of as falling under this later type of amodal completion. Here is an example from multimodal completion. Our perceptual system often completes a property in one sense modality on the basis of information in another sense modality. When you watch TV with the sound muted, your auditory system automatically processes the missing auditory information (Calvert *et al*. 1997; Pekkola *et al*. 2005). Very often (especially if the person on TV is someone who we have heard a lot before), we do have conscious auditory experience of this person's distinctive tone of voice. But even if the conscious phenomenology is missing, neuroimaging results show that the auditory system completes the missing stimulus differently from the way it would do so if a different muted scene were seen (Pekkola *et al*. 2005; Hertrich *et al*. 2011; Vetter *et al*. 2014).

In this case, we also have missing information, and the perceptual system completes this missing piece of information, but this information is not necessarily spatial or temporal. We could think of the perceptual object in this case as a mereologically complex perceptual object, which has some auditory and some visual parts. We get information from the visual parts but not from the auditory part, which our perceptual system needs to complete then. Multimodal completion is an example of feature-based completion – making amodal feature-based completion the most prevalent of the three.

With the threefold characterization of the different forms that amodal completion can take: spatial, temporal, and feature based, we now explore which forms, if any, does olfactory amodal completion take.

3. *Spatial completion – Olfactory objects and distal scenes*

Generating examples of olfactory amodal spatial completion within a perceptual scene requires both a specification of the experience of an olfactory scene and how to conceive of perceiving parts of the olfactory object in the absence of direct sensory stimulation of some of its part.[4] Conceived of in this manner, amodal spatial completion provides a multifaceted issue in application to olfaction, as at the very outset it is contentious if there even are olfactory objects of perception (Castro and Seeley 2014; Keller 2017; Barwich 2019), what could be considered the olfactory objects (Carvalho 2014; Mizrahi 2014; Young 2016), and if an olfactory temporally or spatially extended olfactory scene is even possible (Batty 2010a, 2010b, 2010c, 2011; Keller 2017; Young 2016, 2019a, 2019b). Whether we perceive

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smells as spatial entities, let alone within an array, is a vexed issue in philosophy of olfaction. Thus, identifying cases of spatial amodal completion is nuanced depending upon the initial theory of smell one endorses. In what follows, we briefly summarize the non-objectivist theories, contrast these with odor theories, and explain how these theories' stances about the existence of olfactory objects and their spatial properties effect the further consideration of spatial amodal completion for olfactory perception.

Non-objectivist approaches are a disparate group unified by their denial of the object-centric approach of odor theories. Despite their difference, they share the common claim that olfactory perception does not represent chemical stimuli as perceptual objects within the environment.[5] Without an object of perception, it is *prima facie* unobvious that olfactory amodal spatial completion is even possible for these theories. For instance, Keller (2017) argues that smells do not have spatial properties as these are not presented to us within our perception of olfactory quality. While he notes that we use smells in navigating an environment, these are not distal entities but merely inhabit the space as a property of the environment. When combined with his other claims that olfaction does not generate representational objects of perception, it becomes clear that according to his theory, we cannot have olfactory objects that are spatially occluded in a manner that would allow for examples of amodal spatial completion.

Similarly, according to Barwich's process theory, we do not perceive distal olfactory objects. According to process theory, the olfactory system is not designed to accurately represent external particulars, rather the olfactory system tracks information that is instrumental in the guidance of ecological behavior (Barwich 2014). More recently, Barwich has offered further sustained criticism of philosophical theories that posit olfactory objects (Barwich 2019). Using the biological basis of odor sensory encoding, she claims that there is no need for positing olfactory objects. Yet, despite her evidence that olfactory perception is not objective, she maintains that it can still achieve figure-ground segregation when this is understood as 'facilitating perceptual categorization' (Barwich 2019, p. 8). Olfactory perceptual categorization, thus conceived, might not generate spatial cases of amodal completion of olfactory objects, yet it might provide something close. Given that categorization is generated from grouping odorants into smells, her theory might allow for amodal feature-based completion and perhaps even amodal temporal completion depending on how the individual groups the components into their perception of the complex smell across time.

Odor theories are more receptive to the possibility of amodal olfactory spatial completion. Odor theories identify the object of olfactory perception with gaseous clouds of chemical odorants. The theory comes in a variety of forms with different ontological commitments regarding whether we perceived properties of the odor plume or the plume as an entity in itself

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(for a further discussion of the ontological debate, cf. Cavedon-Taylor 2018). Odor theories allow for the perception of olfactory objects, thus making it conceivable that these might be occluded, yet most odor theorists deny that odors are perceived as having spatial properties making it rather difficult, if not impossible, to generate spatial examples of amodal completion.

For example, according to Batty's abstract account, we perceive odors as abstract entities that are existentially quantified as being instantiated features of the immediate surrounding, but without fixed spatiotemporal coordinates. If according to the abstract account, the olfactory object does not have spatial properties, it is seemingly not possible to have the entity be occluded or be filled in as a complete spatial entity. Similarly, Lycan denies that the olfactory object as a gaseous odor cloud presents us with spatial properties of the smell (Lycan 1996, 2000). Even, Richardson (2013) who argues that smell is an exteroceptive sense that enables us to perceive odor clouds that we inhale through our nostrils does not allow for our perception of smells to be of distal objects within an environmental scene. Despite the majority of odor theories denying that olfactory perception is of spatial entities within a scene, their claims are relative to a narrow synchronic timeframe derived by comparison from vision, which leaves open the possibility that they might allow for olfactory amodal spatial completion within a longer diachronic perceptual timeframe and perhaps when considering amodal temporal completion that does not depend upon the spatial properties (or lack thereof) of the olfactory object.

An outlier to these odor theories is Carvalho (2014) and Young (2016, 2019a, 2019b, 2020) who claim that the object of olfactory perception should be conceived of in the light of the chemical structures of the odorant stimuli. These chemical structures determine the type of odor that we perceive and generates the token representation of the odor that is the olfactory object. According to Carvalho, the nuanced temporal development of our experience of smell requires the existence of a spatiotemporally extended object to which properties may be predicated, which would thereby allow for possible cases of olfactory amodal spatial completion. The ramifications of his view are that earlier odor theories are incorrect in both their denial of olfactory objects as particulars and their withholding spatial properties from olfactory experiences.

Building upon previous odor theories and Carvalho's precursor, Molecular Structure Theory (MST) claims that the object of olfactory perception is the molecular structure of chemical compounds composing odor plumes. Both the molecular structures of the chemical compounds and the plume generate object identity and individuation for smell perception. MST provides a way of determining the object of perception in a manner that also generates individuation conditions based upon olfactory quality (Young 2016). Young's theory provides further explanatory purchase of the spatial and temporal dimensions of olfactory perception and scene

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individuation by considering the distal nature of olfactory perception as tracking odor plumes within an overlapping smellscape (Young 2019b, 2020; Young *et al.* 2020).[6]

Extending the spatial scene by considering smells as gaseous plumes composed of chemical compounds that we perceive as unified smells provides a good starting point for considering instances where we perceive a smell (or parts thereof) that are not caused by direct sensory stimulation. Distal olfactory perception involves identifying, individuating, and tracking odor plumes composed from a variety of chemical compounds (odorants) as individual smells within a gaseous sea of chemical clouds that we continually navigate. Naturally turbulent environments generate gaps in the gaseous plume's spatial boundaries. In natural conditions, the odor plume becomes segmented into filaments of the plume and overlapping odor plumes of other types of chemical compounds, as well as odorless air. Tracking the odor plume and perceiving it as a continuous entity requires representing the odor plume as a superordinate object beyond the mere concentration gradients of the token odorants (Young *et al.* 2020). It is arguably the case that we phenomenologically experience the odor plume as a continuous entity emanating from its source despite the gaps and vagaries of concentration of the odor plume. Our olfactory experiences might be thought to present smellscapes, that is, odor plumes within a background chemical sea of environmental odors, as evidenced by insects, crustaceans, rodents, and humans' ability for olfactory tracking and navigation (Young 2020; Young *et al.* 2020). Under natural conditions, we experience the odor plume as a continuous non-gappy entity despite the shifts in concentration within the plume and occluding odors that traverse our nostrils as we spatially navigate our environment. We track and perceive odor plumes as unified smells despite the lack of continual sensory stimulation from the individual plume, as well as its occlusion overtime by other plumes. Our experience of a complete and continuous odorous entity, in most naturally occurring instance, fulfill many of the properties attributed to amodal spatial completion, as well as amodal temporal completion. Thus, if one endorses the view that we smell odors within smellscapes, then it becomes straightforward to generate examples of olfactory amodal completion.

However, a general issue lurks regarding the question of how the olfactory modality should be individuated that goes to the heart of the issue regarding the nature of the olfactory object and if there are instances of olfactory amodal completion. What is considered the sense of smell has implications for what can be considered instances of olfactory amodal spatial completion. As noted by Young *et al.* (2014), whether or not olfactory qualities have spatial properties might depend upon the inclusion of the trigeminal system as part of the olfactory modality. Moreover, if we consider olfaction to be the sensory modality whose proper perceptible has olfactory qualities and limit ourselves to only those aspects of the olfactory system that

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transduce olfactory quality, then both trigeminal and somatosensory stimulation might not be necessary for smell perception (Young 2017). Limiting our sense of smell to minute synchronic experiences of olfactory quality on this conception will restrict the spatial extent of our olfactory experience and make it *prima facie* impossible to generate examples of olfactory amodal spatial completion as evidence from the discussion of Batty's abstract view and Lycan's version of odor theory. On this limited conception of the olfactory modality, synchronic amodal spatial completion might not be possible, but if we diachronically extended spatial and distal perceptual experiences as of smellscapes, we can thereby generate examples of amodal spatial completion of perceptible olfactory objects within a scene (Young 2019b, 2020). Thus, identifying the sense of smell purely in terms of olfactory qualities will generate a range of possibilities about instances of olfactory amodal spatial completion that depend upon which initial theory of smell is endorsed.

Alternatively, if we expand the olfactory modality to include sniffing, motorsensory contingencies, and trigeminal stimulation, then we might even have synchronic smell experiences that are spatially extended (Richardson 2013; Roberts 2016; Millar 2017; Young 2019b). The later conception of the olfactory modality as including influences from other sensory systems within the nose is more in keeping with our pretheoretic intuitions about the nature of smell experiences as presenting non-gappy odors. Additionally, it would allow these other sensory systems to form a constitutive component for amodal spatial completion in a similar fashion to eye movement for visual experiences. Yet this is a non-trivial issue that depends upon our speculation that even within these limited synchronic experiences, the aforementioned theories would endorse our construal of the odor experience as being non-gappy. Whether or not the aforementioned theories would agree to such a conception and the empirical evidence required to support such a view we set aside as an open question. For now, we think that we have provided sufficient evidence that cases of amodal spatial completion in olfaction are certainly possible, yet the full range of examples depends upon the role of contingent sensory systems within the nose in relation to individuating the olfactory modality.[7]

4. *Temporal completion*

Examples of object completion are often specified in terms of parts of an object being spatially occluded. Visual object completion is employed as a classic example of amodal completion within the Gestalt principle of good form. The principle of good form is that we perceive entities as having complete forms relative to the modality of perception. Often this is illustrated visually by spatially displaying overlapping shapes that we nonetheless experience as individual geometric entities that partially occlude each

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other. Yet the application of principle of good form to olfaction is far from obvious even using the examples from the last section of experiencing spatially occluded parts of an odor plume. Thus, it might be worth considering temporal completion effects as these might put olfaction more on par with amodal completion in audition. Examples of auditory amodal object completion relative to the principle of good form require an extended diachronic temporal scene as noted in Section 2.[8] For instance, listening to an interlocutor during a coffee break at a conference requires amodally completing what they are saying throughout the interspersed auditory interruptions of their words due to the clanking of cups, rattling of spoons, and din of others talking around you.

Perfumes might be a good example of olfactory objects that temporally satisfy the principle of good form (Millar 2017), because our experience of their development as a perceptual object is temporally extended and because we perceive them as a unified olfactory object despite interspersed occlusions from other environmental odors throughout their development. Perfumes would be a classic example of an artificial odor generated by a complex set of different chemical compounds designed to generate a unified olfactory perceptual experience as of an object that can be represented as the same across time and presentations. Designing perfumes requires creating an experiential object with a set of olfactory qualities that diachronically develop in a unified manner that generates an aesthetically pleasant experience. According to industry terminology, the top note (the initial olfactory experience of the perfumes olfactory qualities) transitions into the middle notes (an intermediate experience of different olfactory qualities), which then dry down into the bottom notes (the final olfactory qualities). Each stage is meant to evolve into the next in a progressive fashion that if designed and executed correctly should yield a complete experiential object. Millar's claim that perfumes satisfy the principle of good form provides a rather interesting example of a temporal amodal completion whereby the individual must experience the transition between the phases of the perfume as being of the same object despite only being innervated by a small number of the perfumes constitutive parts as it transitions to the dry down.

However, it might be objected that the perfume example earlier of the experience of olfactory good form does not include an occluded component, but rather just the temporal development of a complex olfactory object. Yet, for such a criticism to be successful, it would need to assume a literal spatial interpretation of 'occlusion' that might be overly restrictive in application to cases of temporal amodal completion for both auditory and olfactory cases. The temporal development of a perfume is often overshadowed for short periods by background environmental smells, yet we still perceive the perfume as being the same object of perception despite these temporal occlusions – similarly, the construction noises outside our window might interrupt our auditory experience of music, yet we still experience the song

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we are listening to through the cacophony outside as temporally complete without missing notes or chords. Furthermore, Millar's example certainly satisfies the initial definition of temporal amodal completion, whereby the missing information about the object of perception is temporally completed.

One of the difficulties in generating examples of temporal amodal completion in olfaction is olfactory adaptation, whereby we are no longer able to consciously access an occurrent smell within an environment despite its persistence over time. As the reader might note, the example earlier requires a diachronic shift in the olfactory quality of the mereological complex odor object. If onset of adaptation occurs a few minutes after exposure, we might be able to find examples of temporal completion of a non-dynamic smell (i.e., one that does not have an evolving qualitative character), but this would most likely be done in terms of variance in the concentration gradients of an odor plume across a short period of perception.

Concentration invariance is ubiquitous in smell perception and even occurs in an odorant plume composed of a single chemical component at varying levels of concentration. In these minimal instances where different odorant plumes are composed of the same type of stimulus at varying levels of density, nevertheless, each token plume is perceived as the same type of odor in terms of its olfactory quality. Concentration invariance is the norm in olfactory perception (Uchida and Mainen 2009; Cleland *et al*. 2012) with research on animal models suggesting that it is a learnt effect. Naïve mice perceive odorant plumes of the same components at varying levels of concentration as being of different types of olfactory quality, yet over time they associate the varieties of concentration as being of the same type of odor despite shifts in perceived olfactory quality (Cleland *et al*. 2012). Concentration invariance is also found in complex odor mixtures where more than one type of chemical stimuli generates the experience of a unified odor plume (Uchida and Mainen 2009). Thus, if concentration invariance is required for our average daily perception of smells as unified perceptible objects, then concentration invariance might be a temporally extended form of amodal completion.

5. *Feature-based completion*

The least contentious type of olfactory amodal completion might be constancy effects, whereby aspects of the perceptual experience exceed what is represented by direct sensory stimulation. Most olfactory experiences are generated by a mixture of components at varying levels of concentration, which has led some to think of olfactory object perception as primarily driven by attempts to parse these odorant groupings into uniform perceptual objects (Shepherd, 2012; Wilson and Stevenson 2006). Considering our olfactory perception of complex stimuli composed from disparate types of

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chemical compounds yielding the same experience of a smell across instances generates the strong example of olfactory amodal feature-based completion.

We can observe completion effects for olfactory mixtures when the complex grouping is learnt to indicate an individual odor, yet one or more of the components has been removed. Consider the smell of coffee across tokens with different roasting qualities derived from different geographic origins – despite the variance in the component volatiles reaching the olfactory epithelium, each unique coffee experience is still categorized as falling under the same type. Moreover, it has been demonstrated in experimental conditions that after training, rodents treat two multicomponent mixtures as distinguishable, yet if presented with the stimulus minus a few components, they treat the incomplete mixture as being of the same type and not as a new odor (Barnes *et al*. 2008).[9] In these instances, the organism still perceives the incomplete mixture as being of the same type of odor as the whole mixture. Completion effects indicate that the olfactory system instantiates amodal feature completion, because the incomplete mixture is perceived as being a complete odor of the same type despite missing some constituent elements.[10] Given the ubiquity of completion effects in our everyday experience of smells, it seems safe to conclude that olfactory amodal feature-based completion is the norm in a similar fashion to amodal temporal completion for audition and amodal spatial completion for vision.

These feature-based examples of amodal completion should be neutral enough to be endorsed by even those philosophical theories of smell that deny that olfactory perception is of olfactory objects within a distal spatial array, such as Batty's abstract account or Barwich's process theory. Even within a synchronic olfactory perception without spatiality, olfactory completion effects are possible, thus being within the remit of Batty's theory. Also, non-objectivist theories must allow that our experiences of smells as being of the same type can be realized across a non-homogenous range of similar, but distinct stimulus tokens. Perhaps this is accomplished through a range signal completion or pattern detection processes or perceptual categorization as suggested in Barwich (2014, 2019), however, fully elaborating how each of these alternatives theories might explain olfactory feature-based amodal completion is beyond the scope of this paper, whose primary aim is to introduce possible examples of amodal completion for smell across the range of philosophical theories of smell.

6. *Conclusion*

Here is a simple way of thinking about the three categories of amodal completion we differentiated. In all forms of amodal completion, the perceptual system gets information from some parts of the perceptual object,

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but not others. And it completes the missing information in the latter parts from incoming information in the former parts. The question is this: What is the relation between these parts? Is it a spatial relation? If so, we get spatial amodal completion. Is it a temporal relation? If so, we get temporal amodal completion. And we get feature-based amodal completion if this relation is not necessarily spatial or temporal.

We aimed to show that all these three forms of amodal completion are present in olfaction – although the exact way in which we can talk about them very much depends on our theoretical commitments concerning olfactory objects. But regardless of what commitments we have about olfactory objects, amodal completion is an important part of the vast majority of our olfactory states (just as it is an important part of the vast majority of our visual and auditory perceptual states). Hence, no theory of olfaction can be considered complete if it cannot account for this phenomenon.

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NOTES

[1] In what follows, the relation between amodal completion and mental imagery will not be covered. Arguments that amodal completion should be considered a form of mental imagery can be found in Nanay (2010, 2018a, 2018b, forthcoming); see also Nanay (2015, 2016, 2017, 2021a, 2021b) on the concept of mental imagery involved. Arguments for the existence of olfactory imagery can be found in Young (2019c). While it is quite plausible that olfactory imagery

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depends upon amodal completion, we think it best to establish the plausibility of different types of olfactory amodal completion across a range of philosophical theories of smell independent of their relation to mental imagery.

[2] We take these three possibilities as empirically viable as individual instances of amodal completion, but not necessarily exhaustive of the range of types of amodal completion. For the sake of simplicity, we consider distinct instance of each type for olfaction, as we take this paper as beginning a discussion about the existence of olfactory amodal completion. Perhaps there are cases that cross and blend boundaries – we leave it open to the reader to complete these ….

[3] This is true as long as the carousel is spinning fast enough. If the carousel is very slow, then the occluded child is not represented perceptually, but rather post-perceptually. There is empirical evidence of temporal amodal completion for up to 3 s after stimulus presentation (the regions of the visual cortex that map onto where the occluded child would be spinning is active), but after that, the completion is post-perceptual (the visual cortex is silent).

[4] Although it might be tempting to try to generate examples of olfactory amodal completion by adapting the Roberts (2016) argument that we olfactorily perceive absences, we are doubtful that it will generate convincing examples. Roberts' primary example for his argument are situations in which we both perceive olfactory qualities as odors as well as the absence of smells, such as when we experience fresh air entering an environment that now lacks its distinctive smell. However, these kinds of examples might be interpreted as not being object directed such that what we are smelling is the environmental smellscape that is being interrupted by odorless fresh air followed by our re-experiencing the environmental smellscape again. If this interpretation of the example is viable, then it is arguably the case that there is no olfactory object experienced as amodally completed during the interruption. Given that his primary aim is to generate an argument for olfactorily perceived absences, we set speculative exploratory work of how to adapt the framework aside in what follows.

[5] Castro and Seeley's (2014) theory will be left aside, because they are primarily concerned with the representational nature of the intentional content of olfactory experience and do not account for the distal nature of smells.

[6] Mizrahi's (2014) Stuff account of smell is designed to account for our naïve conception of olfactory perception as having spatial properties, but because it is unclear how an ontology of stuff allows for amodal completion beyond the chemical posits of MST, the theory is left aside here. For a fuller discussion of Stuff theory and how it does not provide explanatory purchase beyond MST, compare Young (2019a).

[7] The thorny issue of how to individuate smell and its spatial character will have further implications for determining if examples of olfactory spatial completion would be considered amodal or multimodal. However, we set this problem aside for future exploration as it will take us beyond the scope of the paper, which is simply to chart out and identify plausible examples of olfactory amodal completion using the theories of smell that are currently on offer within the literature.

[8] For a good discussion of auditory object completion using temporal processing as the primary means of completion, as opposed to spatiality, compare O'Callaghan (2016). However, he does not fully consider examples of temporal completion of complex mereologically structured odor objects whose dynamic evolution allows us to experience the development of the smell over time in a similar fashion to auditory objects.

[9] Of further theoretical interest in these instances is the finding that the cortical structures responsible for encoding odorant identity remain stable in their activation patterns for the complete complex mixture and the incomplete stimulus, which might be taken as evidence that there is amodal odor object completion even within cortical processing. For a more in-depth discussion of the representational format of the odor of olfactory mixtures that suggest olfaction implements a non-conceptual system of compositionality, compare Young (2015, 2019d).

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[10] Completion effects for olfactory mixtures suggest that olfaction obeys some principles of Gestalt psychology's principals of similarity and good form (Millar 2017). The principle of good form is that we perceive entities having complete forms relative to the modality perception. If it is arguably the case that olfaction meets it in everyday instances of perceiving odors composed of a range of different token odorants, yet still perceived of being of the same type of smell (e.g., different varieties of coffer), this would generate further evidence of amodal olfactory perception.

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