

# What Counts as Touch?

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In front of me sits a warm mug of coffee. I perceive the mug using a variety of senses. I see the mug, becoming aware of its particular shape, size, and color. I touch the mug, feeling its heft, warmth, and solidity. I also smell the aroma of the coffee in the mug, and taste its chocolate undertones. It seems obvious that we experience the world using distinct senses. This gives the appearance that individuating the senses should be a relatively straightforward affair.

The situation is much more complicated. The philosophical project of individuating the senses faces numerous difficulties.<sup>1</sup> Proposals for individuating the senses must address a host of potential counterexamples. In addition, recent empirical work has increasingly focused on the deep interconnections between sensory systems. Much recent work has pointed to deep interconnections among the senses, and suggests that our perceptual experience of the world is multisensory in ways that are sometimes not immediately apparent to the perceiver. These considerations seem to undermine the intuitive idea that the senses are easily distinguished from one another.

Despite these difficulties, I want to address the question of what we mean by “the sense of touch.” In particular, I am interested in whether there is any way of motivating the intuitive distinction between plausible candidates for touch—for instance pains, itches, tingles, throbs, and the like—from those qualities usually associated with touch, like pressure, texture, shape,

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<sup>1</sup> For an excellent introduction to the issues, see the essays in MacPherson (2011).

and thermal perception. The reason for asking this question is not because I believe it will help individuate the sensory modalities. Instead, my belief is that, despite the multisensory nature of perceptual experience, there remains something important about the individual sensory modalities, and touch in particular. The question of which qualities contribute to touch is one that raises a number of important issues about the relationship between seemingly distinct sensory subsystems and how they interact. It also plays an important role in understanding how some features become *externalized* (in a sense to be explained) whereas others seem to be only brute sensations. This issue takes on special importance in light of our understanding of the senses as fundamentally connected. Even if the individual sensory modalities are not separate modular channels, they (or more accurately, their constituent subsystems) do hang together in a special way that ought to be emphasized as we move to a more connected, multisensory view of perception. Using touch as an example, I want to suggest one way that the individual senses provide us with a kind of unique perceptual contact with the world. This contact is characterized by the way that the constituent systems group the perceived properties of objects, which I shall refer to as *phenomenal properties*.<sup>2</sup>

The purpose of this chapter is to suggest a relatively straightforward way of determining which features belong to touch and which to separate modalities (or fail to belong to a sensory system at all). My view is that the sensory systems that belong to touch are those that *group* or *associate* a specific set of sensory features, generating a unified representation of tangible objects. This grouping does not occur for the phenomenal properties (if there are any) found in typical pains, itches, tingles, throbs, and the like. This allows for us to give a robust means of

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<sup>2</sup> Here I'm following Austen Clark's (2008) initial characterization of such properties (italics in original): "In the first instance phenomenal properties characterize how the *world* seems: how the entities that one perceives in the world *appear* to the subject who perceives them" (407).

separating of distinguishing certain bodily sensations from perceptual touch, while providing independent motivation for accepting just the features we do as part of touch. This special grouping relation is not exotic or surprising in vision, where it is referred to as *sensory binding*. My claim is that touch also involves the grouping of features into coherent object representations. There is a special set of tangible features that enter into relations of sensory feature binding and the systems that code for these features are the ones that constitute the sense of touch. The systems that code for pains, itches, tingles, and other bodily sensations do not group their features into coherent assignments on external objects, which explains both their seemingly subjective nature, and distinguishes them from genuine tangible properties.

### **Individuation**

What are the necessary and sufficient conditions for something to count as touch rather than vision or hearing? Many philosophical proposals for answering this kind of question have been provided over the years. For example, Brian Keeley (2002) argues that the sense modalities can be defined this way:

On my account, to possess a genuine sensory modality is to possess an appropriately wired-up sense organ that is historically dedicated to facilitating behavior with respect to an identifiable physical class of energy (6).

Keeley uses this account to ground his criterion for sensory individuation. Any two putative sensory modalities that differ along these four criteria count as distinct senses. Vision, for instance, seems to possess a distinct sensory channel starting with the eyes and leading to the visual cortex, and it facilitates a unique set of behaviors relative to a unique class of physical

energy (namely, visible light). Keeley's view provides a means of deciding how many senses a creature has and whether two sensory systems count as part of the same sense or not. Given its focus on measurable criteria and its explicit denial of a role for qualitative experience in individuating the senses, the view seems especially useful in assessing the sensory capacities of non-human animals. While there is some question about whether this view ultimately succeeds in general as a way to properly individuate the senses (especially given that the senses do not seem to involve wholly distinct informational channels), it immediately runs into difficulties with the sense of touch. The view seems to suggest that what we call the sense of touch is actually several separate sensory modalities. This is because touch does not have anything resembling a single, "appropriately wired-up sense organ." While the skin is a plausible candidate for such an organ, the skin itself is not a sensory transducer. Instead, a variety of distinct sensory channels are located in the skin. And these transducers are sensitive to distinct types of physical energy (thermal properties, solidity, elasticity, etc.). In addition, the skin includes receptor channels that code for pains, itches, tingles, and other bodily sensations. According to Keeley, it seems that each of these separate transducer populations would qualify as a distinct sense. What is missing from this view, I want to suggest, is a role for the grouping of distinct channels, for how distinct transducer populations work together, coordinating and blending their operations in a unified, coherent manner.

An alternative view, advocated by Matthew Nudds (2003), claims that the significance of sensory individuation is rooted in convention. Nudds argues that this significance is grounded in the unique set of properties a person can come to know about through a particular modality, and the conventional importance accorded to these sets of properties. On this view, touch is distinguished from the other senses because there is a unique set of properties that touch allows a

person to know about. Learning that someone touched a vase rather than saw or heard it tells us which properties of the vase of which that person might have become aware. While this is a plausible account of sensory significance (that is, why we conventionally divide the senses into the five that we do), and it seems correct in dividing the senses by the properties unique to each sense, it does not yet explain the particular constitution of features unique to each sense, especially those that belong to touch. A similar concern arises for Fred Dretske (1992). He argues that the sensory modalities are distinct channels that represent certain classes of information. While it is plausible that each modality involves the representation of a unique set of sensory information, he does not yet provide an explanation for why the sense of touch consists of just the features that it does (that is, why include thermal properties but not pains?).

While these views offer plausible accounts about what individuates or is significant about the distinct sensory modalities, they do not yet account for the one thing that interests me most about touch: is there some principled explanation for the classification of certain features as belonging to the sense of touch? The goal of this paper is to suggest why certain sets of features hang together as part of touch, and why others, despite also being mediated by receptors in the skin and body, should be excluded. It is not intended as a challenge to the accounts of sensory individuation or significance described above. It is rather an attempt to fill a gap not addressed by those views.

### **The “Sense” of Touch**

While touch is typically included among the major sensory modalities—along with sight, hearing, smell and taste—there is reason to question whether touch is a single sense. The sense of touch involves a number of distinct sensory systems that could be considered separate (though

interacting) senses. Consider thermal perception. Our experience of hot and cold surfaces through our skin is typically included as part of touch. While the receptors involved in thermal perception are located within our skin, this awareness is actually mediated by a distinct physiological channel largely separate from discriminative touch. Now consider many pains: most nociceptors are also located in the skin and bodily surfaces. In fact, they share many important physiological characteristics with thermal receptors. But pains are often taken to be distinct from the sense of touch proper. The status of other bodily sensations—tingles, itches, tickles, hunger pangs, etc.—is unclear. They too have distinct physiological channels, but they nevertheless seem closely associated with touch. The situation is more difficult for those properties clearly connected with touch, since features like vibration, surface solidity, and texture are coded by more or less distinct channels and in some cases can be clearly dissociated from one another. It is rather puzzling why we count these specific components as belonging to touch given the many systems involved and the fact that we seem to have, at best, a vague intuition about which constituents belong to touch.

The question hardly arises for the other senses in exactly this way (though as we'll see, the issues to follow are not unique to touch). The reason for the difficulty with touch is that it seems to possess a greater functional complexity than the other senses, a complexity that codes a larger range of distinct phenomenal qualities. This point has been noted in several discussions on how we ought to individuate the senses, dating back to Aristotle. He held that there were five senses, each with their own “proper” defining feature, a feature that was unique to each sensory modality. Touch, however, unlike the other senses, did not seem to possess a single defining property. According to Aristotle, the class of tangible properties did not form a single genus (*De Anima* bk 2, ch 11).

There is a legitimate question about what sensible qualities properly belong to the sense of touch. There seems to be some clear intuitive answers: thermal properties, solidity, vibration, and spatial properties. These are almost universally included as parts of touch. Pain is almost always thought to be distinct from touch (though it is occasionally included). There is a large set of features that could go either way: itches, tingles, twinges, proprioceptive properties, kinesthetic awareness, hunger, and so on.

### **The Positive Account**

How can we determine which sensory features or systems belong to the sense of touch? I start with the assumption that the sensory modalities assign features to objects in the world.<sup>3</sup> These assignments are structured; they occur in particular ways that can be measured and described. For instance, in vision science binding strength can be measured by its effect on error rates in selection tasks using bound and unbound sensory features (some of these studies are discussed in Ashby *et al*, 1996). Appealing to this structure offers a robust means of characterizing touch experiences: those constituent systems that co-assign tangible features count as touch; those that do not should be considered separate. According to this criterion, thermal perception counts as part of touch because we feel objects as hot and cold along with the other tangible properties. But pains, tingles and itches are never assigned as features of anything external to the experience. While pains might carry information about tissue damage, say, they do not typical group with other representations concerning external objects. Warmth, while also a simple signal, does

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<sup>3</sup> It is possible that there are sensory systems that exist that do not assign sensory features. An example might be human vomeronasal perception. These are problematic cases, and in what follows I shall simply assume that being a genuine perceptual modality involves some assignment of features of qualities to the world (whether those assignments need to be consciously available is a separate and unexplored issue).

combined with externalized properties like shape, weight, and texture, and so it too comes to represent features of items external to the experience itself.

My proposal is that we can classify those systems together that function to co-assign features to items external to the experience.<sup>4</sup> This argument makes some assumptions about perceptual experience. Granting these assumptions enables a way to unify the constituent elements of touch into a single, coherent sensory modality. The assumptions, not defended here, are these: I assume that perception provides awareness of the world. This awareness involves sensory experience of certain features or qualities of the world. Given these assumptions, my proposal is that we can classify sensory systems together based on whether or not those systems engage in the binding of basic sensory features. The binding relation is empirically tractable, clear, and provides a strong account of touch that aligns nicely with our pre-theoretic conception of what counts as the sense of touch. The notion is not a means of providing necessary or sufficient conditions for the individuation of sensory modalities. Instead, I think that a relatively basic notion of sensory binding offers an explanatorily robust criterion of sensory classification. Such classification does not purport to individuate the senses into natural kinds or find the essential properties of each of the sensory modalities. Instead, I want to illuminate and justify the way in which certain sets of sensory systems are already classified in cognitive science. While such classification is always relative to theoretical practice and explanatory needs, and while there could be equally legitimate alternative classification schemes, it nevertheless tracks an important feature of systems that are grouped as individual modalities. The goal here is to offer a strong theoretical justification for this system of classification. Sensory feature binding seems to justify our classificatory practices, for all of the sensory modalities. While my focus here is on

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<sup>4</sup> The phrase “external to the experience” leaves open the possibility that the body itself, despite not being “an external object,” can be the bearer of grouped or bound properties.

the sense of touch, I believe that the focus on sensory binding allows for a robust means of explaining and justifying our current classification of sensory systems.

These basic features seem to engage in special relations of binding or joint assignment that other sensory features do not. While visual shape and colors are often bound or joined together, higher-level kind properties like *being a police officer* or *being my childhood home* (if they are also represented in experience) are not. Only basic sensory features that can be picked out in virtue of determinate values along a qualitative dimension enter into relations of sensory binding. This assumption does not require any strong representationalism. That is, there is no need to suppose that the represented features exhaust the phenomenal character of the perceptual experience. Nor need it require a strong way of individuating basic from non-basic features. I am, for example, sympathetic to the idea that some complex kind properties enter into the contents of visual experience (Siegel, 2011), but whether this view is true should not undermine the fact that certain visual features play a more fundamental role in the constitution of visual experience (i.e., shapes, colors, illumination, motion, etc).

As I'm using it, feature binding is "the process of linking together the attributes of a perceptual object" (Ghose and Maunsell, 1999). Such binding is most often discussed in visual perception, and refers to the way in which features or attributes are assigned to distinct particulars by a perceptual modality. In vision, for example, features like color, shape, texture, motion, size, orientation, etc. are attributed to individual visual objects. To see a cup on the table is to see a particular object possessed of a range of features that belong to the cup. We see the cup as a separate object from its surroundings because we experience its various features as belonging to a distinct object from the other objects around it. If we close our eyes, and reach out to the table, feeling with our hands the various objects, we would also experience the features of

the cup—its heft, solidity, warmth, texture, size, etc.—as belonging to the cup and not to the other objects in the vicinity.<sup>5</sup>

The assignment of sensory features to objects is also discussed in non-visual sensory modalities. For example, the assignment and grouping of features are well studied in audition, where it is known as auditory scene analysis (Hall, *et al* 2000).<sup>6</sup> Similar grouping effects occur in olfaction and taste. In haptic processing, the notion of sensory binding is not as prominent. In fact, it's almost never discussed. Yet touch also involves the co-assignment of features to objects, and these assignments play a prominent role in object segmentation, grouping, and identification. Like the other senses, touch involves the co-assignment of various sensible features. When we feel an object *squishy* or *slippery* or *metallic* we are feeling a blended combination of several distinct tangible features. Feeling something as metallic for example involves feeling a cool, smooth, solid surface. The unified, blended nature of these feelings indicates that these features have been co-assigned and bound to an object (Sullivan, 1923; Zigler, 1923) in much the same way that visual features are.

While each of the senses, including touch, seems to involve the assignment of distinct sensory features to objects, they assign these features in unique ways, according to distinct principles of sensory grouping. For example, the binding of visual features seems largely subpersonal and automatic. No action in particular needs to be done (by us) in order to bind features. This means that visual binding is (largely) non-volitional:

**Non-volitional binding:** Features  $X$  and  $Y$  are non-volitionally bound to an object,  $o$ , if (1)  $o$  is sensed as having both features  $X$  and  $Y$ , and (2) (at that moment) sensing  $o$  as  $X$

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<sup>5</sup> The literature on sensory binding is enormous. The interested reader is encouraged to start with the highly influential work of Anne Treisman (e.g., her 1998).

<sup>6</sup> Similar effects have been studied in olfaction. See Wilson and Stevenson,(2006).<sup>11</sup>

without sensing it as  $Y$  (and vice versa) cannot be achieved by a simple volitional act (for example, blinking or closing one eye).

When one sees a painting with its various colors and shapes and textures, one cannot simply subtract out just the colors (or a particular color) by moving one's head just so or snapping one's fingers, etc. The bound features are seen as part of or essentially belonging to the objects, and they can't be easily separated. While touch also involves the assignment of features directly to objects, it differs from vision in requiring a volitional act in order to bind tangible features.

Features are bound in touch by the unifying and coordinating effects of specialized exploratory actions. By altering the exploratory actions we perform, we can change the set of features assigned to tangible objects. Touch thus seems to involve *exploratory binding*:

**Exploratory Binding:** Features  $X$  and  $Y$  are exploratorily bound to an object,  $o$ , if (1)  $o$  is sensed as having both features  $X$  and  $Y$ , and (2) sensing  $o$  as  $X$  and  $Y$  (at that moment) is a result of a specific act of perceptual exploration.

Touch, unlike vision, requires that we reach out and explore the world with our sensory surfaces. And which features we experience is a result of which exploratory actions we deploy. Haptic exploration unifies the signals coming from the distinct receptor populations, signaling that the disparate information coming from these different channels concerns the same object. It is through such exploration that the distinct features involved in touch are properly assigned to the objects around us.

Touch involves a specialized class of exploratory actions that coordinate and unify the separate subsystems classified as touch. When we reach and pick up various objects in our environment, the reaching and grasping action unifies and co-activates the various processing streams, allowing for the experience of several distinct tangible features of an object all at the same time. Susan Lederman and Roberta Klatzky (1987) proposed that haptic touch involves a

specialized set of actions they call “exploratory procedures.” They suggest that haptic touch involves eight distinct exploratory procedures (Lederman and Jones 2008 reduce the list to six). They demonstrated that there is a close relationship between the particular exploratory movements used to tactually perceive and object and the set of features that are assigned to it. The experience of some individual features—fine shape, for example—require the performance of specific exploratory acts. Other movements are “redundant,” they allow a range of object features to be experienced through a single exploratory act. Such actions ground tangible object recognition, which depends on the co-presence of certain sets of salient features. When we pick up a hammer and recognize it as such through touch, this recognition occurs very quickly and involves the pickup of several sets of features at once (Klatzky & Lederman, 2008; Klatzky, *et al*, 1993; James, Kim, & Fisher, 2007). For example, when we grasp and lift an object, the very motion of picking up the object allows us to feel its heft, shape, size, material constitution, texture, and thermal profile. Such motions allow us to quickly and very accurately identify and recognize objects through touch by co-assigning or binding distinct features to individual objects. This binding, while exploratory in nature, is analogous to the assignments of sensory features found in the other senses

We can now apply this concept of sensory binding to the proper classification of touch. My proposal is that the various functionally distinct systems that should count as touch are those that can assign their features to external objects in relations of exploratory sensory binding. What counts according to this criterion? This is ultimately an empirical question, to be determined by careful experimental investigation. Yet, we can get a good sense of how things will play out by considering a typical tactual experience, like holding a pen. In holding a pen, one comes to experience a range of features that feel to belong to the pen. They are co-assigned or bound to

the object, allowing us to recognize and make use of the object. The features assigned to the pen might include its temperature, heft, weight, size, solidity, texture, and several others. These features all seem to be “bound” to or assigned to the pen in virtue of our holding it a particular way. A less technical way of putting this is simply to say that we feel a particular set of the pen’s actual features in virtue of picking it up. The features assigned to the pen in virtue of this exploratory action should, according to the criterion above, be classified as part of the sense of touch. By considering the full range of tangible actions we should be able to determine which features routinely enter into relations of exploratory binding. Importantly, this allows us to separate out other potential tangible features like pains, itches, and tingles. This is because the properties assigned by pains are never associated with external objects or bound along with other tangible features. When a sharp needle is inserted into one’s arm, the pain it causes is never experienced as a property of the needle. While other features like sharpness, size, and temperature may be experienced as properties of the needle, stinging pain is never experienced as a property of the object. By applying this simple test of sensory binding, we should be able to say which systems belong to touch, and which belong to separate modalities.

Using this test, we should be able to say precisely which features should be classified as part of touch. Sensory binding involves a set of features that can enter into relations of binding with one another (they can be co-assigned to objects), and we can use this set to characterize a unitary mode of experience: it is one that involves members from a single set of qualitative features, defined by their ability to bind with one another. Such relations between features can be described as *a binding set*:

**Binding Set:** A binding set is a set of determinable qualitative features, all of whose members can enter into relations of feature binding. More formally, let  $\beta$  be a binding set

such that: for any two classes of qualitative features  $q$  and  $q^*$ , if determinate values of  $q$  and  $q^*$  can be bound together in experience, then  $q \in \beta$  and  $q^* \in \beta$ .<sup>7</sup>

There is a more or less uniform set of feature types that can be bound in visual experience. These features include motion, texture, colors, shapes, and several others. The binding between these features can be empirically measured, and forms the basis for the most plausible accounts of object segmentation, grouping, and recognition. The totality of these feature types constitutes the set of basic, determinable visual features. This set is not exhaustive of visual experience, for there could be other non-basic features represented in visual experience that do not enter into relations of feature binding. For example, there is no reason to rule out a creature that can only see a single color. Similarly, there are many visual experiences that do not involve feature binding (a uniform color field or Ganzfeld would presumably not involve binding). Instead, the idea is that one of the primary functions of the sensory modalities is to provide robust coordinated information about certain classes of object properties, and this important function provides a strong motivation for classifying physiologically distinct sets of sensory systems as parts of a single sensory modality.

While all of the senses in general perform similar functions, the groupings performed by the individual modalities are stronger and distinct in kind from those in the other modalities. Each of the individual senses, despite being composed by distinct functional subsystems and entering into many multisensory interactions with each other, have their own unique set of features that enter into relations of sensory binding (the distinction between these relations and those involved in multisensory integration will be discussed shortly). It is the coordinated

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<sup>7</sup> To be clear, the members of the binding set are not individual qualitative values, but rather kinds of features, such as colors or textures. This is because some individual qualities cannot be bound together in experience: red and green, for instance.

assignments, what I'm here calling sensory binding, that constitutes their membership in the set, and gives a robust way of distinguishing the features in one modality from those in another, even when those features overlap. In other words, part of what it means for a feature to be a *visual* feature is that these features can bind together in appropriate ways with the other visual features to provide a unified visual representation of the object. While textures may be associated in different ways with odors, textures and odors never bind in experience. Textures and colors do. Similarly, we could perhaps distinguish visual shape from tactual shape in virtue of the fact that the former, but not the latter, are capable of binding to other visual features. That is, they are members of different binding sets, and therefore have different qualitative relations with other basic phenomenal qualities.

### **Classifying Touch**

The account sketched thus far serves two explanatory purposes. First, it offers a principled reason for classifying thermal, surface, and vibration features as parts of touch, while excluding pains, itches, and tingles as separate forms of bodily awareness. Second, it offers a way of distinguishing those components of touch from analogous systems in other modalities that code for the same features. For example, texture and shape are processed by both vision and touch. It is this second goal that is the focus of this section.

The binding view described above offers of way of distinguishing touch from the other senses, even when they code for the same features. Here is the difficulty: if binding involves *just* the assignment of sensory features to objects, then it now seems we will have difficulty separating touch from the other senses—especially vision—since both touch and vision seem to assign properties, often the very same properties, to the same external objects. This is a serious

worry, but thankfully there are relatively easy ways to distinguish intermodal feature binding from multisensory integration (MSI).

For one thing, the overlapping features found in vision and touch are members of distinct binding sets. Tangible texture, for instance, is coded by a distinct system that unifies its representations with thermal, surface texture, solidity, and other such properties. It is not a feature that becomes bound to colors, sounds, or tastes. Second, the systems that code for these features function in distinct ways that can be isolated and distinguished. Visual binding occurs according to certain sets of principles and relations that are different from those operating in touch. Touch, as we've seen, involves the co-assignment of features that result from specific exploratory interactions with objects. These distinct relations—all rooted in the function of co-assigning properties to objects—allows us to classify tangible texture as belonging to a distinct modality from visual texture, and so on.

That the senses perform their co-assignments individually serves an important purpose. The senses often provide information about the same objects or events in the world. Sometimes this information is complementary or reinforcing, providing distinct but useful information about an object or event. Seeing a dog while hearing it bark, for instance. Other times, the senses provide redundant information about objects. For instance, audition, touch, and vision can all provide information about an object's location; vision and touch can both provide information about an object's texture; and smell and taste can both provide information about an object's palatability. In these redundant cases, the information provided by the individual senses can sometimes disagree. These discrepancies need to be resolved by our perceptual systems in order to generate a coherent and unified percept of the world. The way this is resolved is through integration of the information provided by each of the senses.

While vision and the other senses also assign features to external objects, the features that they assign are not bound together with tangible features, and the processes and systems involved in cross-modal integration are functionally distinct from those involved in the binding of sensory features. There is a clear difference between the function performed by feature binding in the individual modalities and the function performed in multisensory integration. One way to show this is by examining the different ways in which touch and vision code for roughness. Klatzky and Lederman (2010) argue that vision encodes roughness in a manner that is distinct from touch, but that these distinct representations can be integrated at later stages of processing. As they summarize:

Studies of visual texture perception suggest that roughness is judged from clues that signal the depth of and spatial distribution of the surface elements. People find it natural to judge visual textures, and few systematic differences are found between texture judgments based on vision vs touch. In a context where vision and touch are both used to explore a textured surface, vision appears to be biased towards encoding pattern or shape descriptions, and touch toward intensive roughness. The relative weights assigned to the senses appear to be controlled, to a large extent, by attentional processes (222).

Sensory binding involves the co-assignment of features to objects, and these assignments generated in each of the sensory modalities. While both touch and vision provide information about the texture of objects, they do so (at least initially) in isolation of one another. Usually these distinct representations are coherent and facilitate perceptual tasks like object recognition and grouping. Sometimes, however, they come into conflict with one another and various processes of integration serve to reconcile and coordinate these representations according to precise algorithms and attentional processes.

Looking at the individual modalities, including touch, we can see that there is a constrained set of features that enter into the unified, bound object representations. Multisensory integration (MSI) then coordinates this already grouped information. Such reconciliation is not

the only kind of multisensory interaction. There are many distinct processes, including facilitation, summation, suppression, vetoing, and dominance. These processes seem to involve already present streams of information from the individual sensory modalities that make some difference to the other sensory modalities. While similar in some respects, these various multisensory interactions involved in MSI do not function in the direct assignment of basic sensory features, but rather operate on such assignments. The sensory assignments in the individual modalities are subject to a range of coordinated processing, allowing for a coherent, unified experience of the world.

Thus, while vision and touch both assign features to the same objects, they do so separately, with their own weights and coordination. The resultant unified representations are then reconciled and coordinated. This function is seen most clearly in cases of cross-modal dominance. When touch and vision provide contradictory information about the size or shape of a distal object, these incompatible assignments must be corrected and brought into harmony (see, e.g., Klatzky and Lederman 2010; Calvert, 2004; Rock and Victor, 1964). The processes involved in multisensory integration serve to correct these initial assignments. One of the going theories of how this occurs involves a Bayesian model whereby the information from the senses is coordinated relative to the general reliability of the modality in a particular context. In other words, the system responsible for MSI receives the feature assignments from the individual modalities, and reconciles them according to a complex algorithm. The individual sensory modalities are responsible for these individual assignments, though they can be altered or overturned by the processes involved in MSI.

These functional differences in the structure and processes of sensory binding provide a strong reason for separately classifying the features coded by touch and by vision. Each sensory

modality assigns its features to objects, and these assignments are then corrected or brought into alignment at later stages of processing by primarily multisensory areas. So while both vision and touch assign features to the same sets of objects, they do so by binding their individual representations independently, prior to passing them along to multisensory areas of processing. It's for this reason that we don't see visual features becoming bound to tactual features (even though certain visual features can influence or alter the values of tactual features). As Klatzky and Lederman (2008) note, concerning object perception in vision and touch:

Visual and haptic object recognition share basic mechanisms, such as a progression from sensory primitives to abstract representations and use of prior knowledge and context where possible. But these general similarities notwithstanding, the two channels turn out to be quite different, and the emergent model of haptic object identification is fundamentally different from its visual counterpart (186).

The individual modalities perform similar functions, assigning (sometimes the same) features to the same objects, but they do this in diverse ways, according to different rules, with distinct sets of connected and bound features. These independent assignments then feed into dedicated multisensory areas that reconcile and coordinate the information provided by the distinct sources of perceptual information. One way to think of this is that the individual sensory subsystems that code for individual sensory features are clustered into little bundles. The first major level of clusters involves sensory feature binding, which in turn allows for object segmentation, grouping, and ultimately recognition. These bound bundles are then compared and coordinated (and corrected if needed), and then used to generate coherent, unified representations of the world.

The features involved in haptic touch are indeed processed together, leading to unified, bound assignments of sensory properties. When we engage with objects in our environment, the

exploratory actions serve to co-activate the distinct receptor populations, allowing them to assign features to the same object. That is, when we grasp the mug, the very act of grasping brings our cutaneous receptors into contact with mug with both spatial and temporal unity, generating a unified percept of the object. These movements do not typically co-activate the receptor populations that code for pain, itch, tingles, hunger, tiredness, and the like, and none of these features are assigned to the external objects of tactual awareness. This gives a principled reason for holding such systems (and features) as separate from the sense of touch proper.

## **Conclusion**

My argument is that there is a good reason for treating some sensory features as belonging to the sense of touch, and for excluding others. I began with the assumption that none of the extant accounts of sensory individuation are capable of providing a clear account of why we should count certain features—including solidity, temperature, and texture—as part of touch, while excluding pains, tingles, itches, tickles, and hunger pangs. Mere externalization is not enough, since it does not offer a means of separating tangible features from visual or auditory features, which are also externalized. My argument has been that touch, like the other senses, functions to produce unified, bound representations of objects, and that the structure and coordination among these features provide a principled means of classifying certain sensory systems as belonging to touch. When we explore the world through touch, we represent a range of objects and their features, and these representations involve the co-assignment or binding of certain sensory features. While thermal profiles and textures are assigned to objects in this manner, pains and tickles are not. Similarly, while touch and vision, for example, assign features to the same

objects, they do not bind or co-assign these features. Instead, features are assigned within each modality, and then reconciled or coordinated at later stages of multisensory processing. The binding of sensory features has been discussed almost entirely in the visual domain. It is my belief that such coordinated assignment of features occurs as well in touch, and that it occurs as distinct processing units are coordinated by coherent exploratory actions. Such an expansion of the concept to the realm of touch offers a promising starting point for understanding the processes and interactions that bring together the wide variety of sensory systems typically lumped together as part of touch.

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