

## CONTENTS AND VEHICLES IN ANALOG PERCEPTION

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**SUMMARY:** Building on Christopher Peacocke’s account of analog perceptual content and my own account of analog perceptual vehicles, I defend three claims: that the perception of magnitudes often has analog contents; that the perception of magnitudes often has analog vehicles; and that the first claim is true in virtue of the second—that is, the analog vehicles help to ground the analog contents.

**KEY WORDS:** analog content, analog vehicle, magnitudes, perception of magnitude, recognizability

**RESUMEN:** Sobre la base de la explicación de Christopher Peacocke sobre el contenido de la percepción analógica y mi propia explicación de los vehículos de la percepción analógica, defiendo tres tesis: que la percepción de magnitudes tiene a menudo contenidos analógicos; que la percepción de las magnitudes tiene a menudo vehículos analógicos; y que la primera afirmación es verdadera en virtud de la segunda, es decir, que los vehículos analógicos ayudan a fundamentar los contenidos analógicos.

**PALABRAS CLAVE:** contenido analógico, vehículo analógico, magnitudes, percepción de la magnitud, reconocibilidad

### 1. *Introduction*

In work spanning the past four decades, Christopher Peacocke has argued that perception has analog content (Peacocke 1986, 1989, 1992, 2019). This idea certainly has intuitive appeal. Perception *seems* to have much more in common with paradigmatic analog representations, such as pictures, than paradigmatic digital representations, such as strings of zeros and ones. But there are also aspects of Peacocke’s position that will strike many as puzzling. In particular, while it is fairly standard to take representational *vehicles* to be analog (or digital), it is less common to take representational *contents* to be analog (or digital). Are these supposed to be distinct claims? If so, what distinguishes them? Moreover, assuming that sense can be made of both analog contents and analog vehicles, the question arises

of how the two are related. Are they genuinely independent? Is one explanatorily primary?

My aim is to address these questions while simultaneously building upon Peacocke's latest account of analog content and relating it to my own account of analog vehicles (Beck 2019). In so doing, I will argue for three claims: that the perception of magnitudes often has analog contents; that the perception of magnitudes often has analog vehicles; and that the first claim is true in virtue of the second—that is, that the analog vehicles help to ground the analog contents.

## 2. *Two Concepts of Analog*

I begin with some clarificatory remarks about the concept *analog*. Even a cursory exploration of the literature reveals dozens of competing accounts of this concept. It's easy to feel bewildered. But we can bring some order to the chaos by distinguishing three broad conceptions of analog representation, which I will call the *continuous conception*, the *practical conception*, and the *mirroring conception*.<sup>1</sup>

The continuous conception treats representations as analog when they are continuous, or at least very tightly packed, as opposed to discrete. The classic account is Goodman's 1968, according to which analog representations are syntactically and semantically dense; between any two characters or values there is a third.

Goodman further noted that if analog representations are dense they will not be finitely differentiable, meaning that it will not be possible, even in theory, to determine the precise value of any given mark on an analog representation. Thus, if I were to measure your height by marking a rope, I might be able to get it right within a centimeter, or maybe even a millimeter if I were extraordinarily careful; but there would be a limit. It is not the case that, for any two marks on the rope, we can always tell which more accurately corresponds to your actual height. In a similar vein, Haugeland (1981) argues that analog representations are distinguished by the fact that they cannot be copied with perfect precision. Our ability to reproduce them—to precisely read them or write them—is unreliable. I count these accounts as falling under the *practical* conception of analog representation since they characterize analog representation in terms of how they can, or cannot, be used. They concern limitations in what can

<sup>1</sup>In earlier work (Beck 2018, 2019), I distinguished the continuous conception from the mirroring conception, but failed to mark the practical conception as its own category, instead folding the views it covers into the continuous conception. I now think it's more perspicuous to set these views apart in their own category.

be done with analog representations. As we'll see, Peacocke's account of analog content also falls under the practical conception.

Finally, the mirroring conception maintains that analog representations mirror, or bear a structure-preserving mapping towards, what they represent. For example, Shepard (1978) invokes the notion of an isomorphism in his account of what makes mental imagery analog. Relatedly, Maley (2011) maintains that one quantity is an analog representation of a second quantity when they covary in the right way. As the represented quantity increases or decreases, so does the representing quantity. This conception fits with Peacocke's claim that analog representation involves "the representation of magnitudes, by magnitudes" (2019, p. 52).

As Lewis (1971) noted, a representation can be analog in the mirroring sense without being continuous. Consider a clock with rotating hands that advance in discrete steps. The angle of the hour hand mirrors the time of day, and so the clock is analog according to the mirroring conception. But because it advances in discrete steps, it is not continuous and is finitely differentiable. The mirroring conception thus comes apart from both the continuous conception and the practical conception (Peacocke 2019, p. 64).

The practical conception can likewise come apart from the continuous conception. While all continuous representations cannot be copied with perfect precision, the converse does not hold. A representation might not be reliably reproducible for any number of reasons.

Given these three conceptions, how are we to interpret the claim that perception is analog? Which conception is the relevant one? I'll argue that while perception has *contents* that are analog in a sense derivative from the *practical* conception, it has *vehicles* that are analog in a sense that answers to the *mirroring* conception. The analysis I'll be defending will thus allow us to reconcile at least two of these three traditions of defining *analog* for the case of perception.

### 3. *Mental Format*

To assert that a mental representation is analog is to stake a claim to its format. Claims about representational format, in turn, can be understood in either of two ways: as claims about the representation's *content* or as claims about the representation's *vehicle*. When pitched at the level of content, claims about a representation's format concern how the content is structured, which in turn answer to high-level patterns in the abilities afforded by the mental representation (in

a way that I will soon explain). Such claims take no stand on the medium that carries the representation's message. When claims about mental format are pitched as claims about representational vehicles, by contrast, they directly concern the medium itself.

Before we discuss how the distinction between analog contents and analog vehicles might be applied to perception, it will help to first clarify the distinction through its application to thought. Many readers will be more familiar with this application, and so it can help guide the application to perception.

A number of philosophers, including Peacocke (1992) and Evans (1982) before him, have argued that thought has *conceptual content*. This is, at least in large part, a claim about the format of the abstract objects (the contents) that individuate thoughts. According to these philosophers, the contents that individuate thoughts have a special structure—very roughly, a sentence-like structure that is familiar from natural and formal languages. Why do these philosophers assign sentence-like contents to thoughts? Because they think that such contents most perspicuously capture the structure of the abilities that thinkers exhibit. This is well captured by what Evans calls the *generality constraint*. The ability to think some thoughts is systematically related to the ability to think other thoughts. For example, the ability to think that *a* is *F* and that *b* is *G* goes hand in hand with the ability to think that *a* is *G* and that *b* is *F*. This is a claim about the general patterns embodied in the thoughts that a thinker can entertain. Because these general patterns in abilities are best modeled by abstract objects that have a sentence-like structure—that is, conceptual contents—these philosophers maintain that thoughts have conceptual content.

As Heck (2007) has argued, this line of reasoning is a special case of the more general thesis that abstract objects should be selected to mirror the structural properties of the domains they characterize. Whenever we want to use abstract objects to individuate the members of a domain, we face a selection problem: which of the endless abstract objects floating about (propositions, sets of possible worlds, rational numbers, integers, ordinals, the Latin alphabet, etc.) should we use to individuate those members? All things equal, one reasonable principle is to choose abstract objects whose structural properties mirror the relevant structural properties of the domain at hand. For example, if you wanted to individuate temperatures, you would be better off choosing rational numbers than integers because temperatures and rational numbers are both dense (between any two

temperatures or rational numbers there is a third temperature or rational number) whereas integers are not. If, however, you wanted to individuate the members of a basketball team, then positive integers (as are commonly displayed on players' jerseys) would be more appropriate. Applying this general principle to psychological capacities such as thinking yields the idea that representational contents should mirror the "structure" of those capacities —the general patterns that they support. Thus, where a thinker satisfies the generality constraint, conceptual contents are appropriate.

Note that so far nothing has been said about the vehicles of thought —the medium of thinking. But it's natural to want to push things further and appeal to sentence-like vehicles to explain the patterns in abilities captured by the generality constraint. Thus, we might follow Fodor (1987) in maintaining that a language of thought is the best explanation of the systematicity of thought. This is, however, a further claim. The thesis that thought has conceptual content does not entail that there is a language of thought —an internal medium of representation with a sentence-like syntactic structure. In theory, the systematicity of thought could be a coincidence; the vehicle for each thought could be an unstructured atom. Or the systematicity of thought could be an emergent property of a vast neural network. Still, if there were a language of thought, that would help to explain why the abilities of thinkers conform to the generality constraint, and thus why thought has conceptual content. A plausibility argument could thus be advanced in favor of the existence of a language of thought. And if that's right —if there is a language of thought— then the format of the content of thought is grounded in the format of the vehicle of thought. Thought has conceptual content in virtue of being supported by a language of thought.

I've been rehearsing these familiar claims about the format of thought because I'll be arguing that something similar is true about the format of perception. Perception has analog content in virtue of having analog vehicles.

First, however, I want to address a potential worry. It might seem that my distinction between analog vehicles and analog contents overlooks a third option: that analog representation concerns how vehicles *relate* to contents.

But as I'm understanding vehicle approaches, this "third" option isn't really a new alternative. It's a species of the vehicle approach. Vehicle approaches to format are committed to a medium of representation. That is what distinguishes them from content approaches.

A further question is whether format is an intrinsic property of vehicles, like mass, or an extrinsic property, like weight. On mirroring accounts of analog representation, being analog is an extrinsic property of the vehicle — a property it has in virtue of its relation to other things.

This point sometimes seems to cause confusion. In an earlier paper, I said that I was taking format to be a property of representational vehicles rather than contents (Beck 2019, p. 323). Lee et al. (2022, p. 3) criticized my approach, saying that we should instead favor an “interpretation function approach” that holds that format is “a matter of how vehicles represent contents” (pp. 3–4). But that just is my view redescribed. Lee et al. might think it was misleading for me to describe my account as concerning vehicles. But it is clear from the context that I intended that description merely as a contrastive to the content accounts of philosophers such as Peacocke and Evans on which vehicles never enter the picture. On the account I developed, format is a property of vehicles, albeit an extrinsic one.

#### 4. Peacocke on Analog Content

In this and the following three sections, I will interrogate the thesis that perception has analog content. My starting point will be Peacocke’s latest account of analog content in *The Primacy of Metaphysics*. I’ll first explain his account (section 4), then raise a concern (section 5), and then finally recommend a friendly revision to Peacocke’s account in light of the concern (sections 6–7).

Peacocke’s account of analog content centers on the perception of *extensive magnitudes*, such as distance, duration, area, orientation, velocity, luminance, and number. According to Peacocke, extensive magnitudes are characterized by a ratio structure (2015; 2019, pp. 39–46). Given any two extensive magnitudes, there is a fact of the matter not only about which is greater, but also about how many times greater it is. For example, a distance of 30 meters is three times as great as a distance of 10 meters.<sup>2</sup>

While we do not *only* perceive extensive magnitudes, extensive magnitudes are almost always among the things we perceive. Moreover, the perception of non-magnitudes, like shape, often depends on

<sup>2</sup> Geoff Lee pointed out in comments on Chris Peacocke’s talk at York University in 2018 that there is also a historically prominent mereological conception of extensive magnitudes, and the two do not always line up. For example, density is extensive in Peacocke’s sense since it has a ratio structure but it is not extensive in the mereological sense.

our perception of extensive magnitudes. Extensive magnitudes are thus of central importance to perception. Following Peacocke, I will therefore focus on the analog perception of extensive magnitudes even though this may only be a species of a broader genus of analog perception that also includes the analog perception of some intensive magnitudes, such as temperature, and some non-magnitudes, such as shape. As Peacocke remarks, “We have to walk before we can run” (2019, p. 40).

Peacocke’s account of analog content revolves around the idea of recognizability. He argues that perception has digital content when it affords perceptual recognition and analog content when it does not. Recognition is *perceptual* when it is afforded solely on the basis of perceptual capacities; extra-perceptual capacities are not needed. For example, your perception as of three vertical strokes has digital content because you can recognize the presence or absence of three strokes just by looking.

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The exercise of extra-perceptual processes, such as counting, are not required. By contrast, your perception as of 29 vertical strokes is analog because you can’t recognize the presence or absence of 29 strokes just by looking.

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If you were presented with 28 strokes instead, you wouldn’t know the difference just by looking. You would need to count them. Peacocke calls this the *recognizability condition*.

Given the recognizability condition, Peacocke concludes that the perception as of continuous magnitudes, such as length, angle, and duration, is analog. So is the perception of discrete number except at very small values. Peacocke writes, “Magnitudes themselves are perceived; particular magnitudes slice more finely than just noticeable difference; so perception of magnitudes [...] can outrun the perceiver’s recognitional capacity” (2019, p. 65).

In other words, although we perceive precise magnitudes, our ability to perceptually reidentify magnitudes is relatively coarse. Thus, we are not able to perceptually recognize the precise magnitudes that we perceive.

Peacocke's account of analog content is in the tradition of the practical conception of analog representation. He explicitly takes inspiration from Goodman (1968) and Haugeland's (1981) emphasis on the link between digital representation and the ability to differentiate the characters from which a representation is composed, and thus reliably reproduce it. For Peacocke, however, the critical concept is not differentiation in principle, but differentiation in practice—that is, recognizability. In principle, 28 strokes can be differentiated from 29 strokes; but in practice, humans do not have the perceptual capacity to recognize the difference.

By labeling perceptual content as analog, Peacocke is thus marking a general pattern in our perceptual capacities. Just as thought's conceptual content marks patterns of systematic recombinability, perceptual experience's analog content marks patterns in recognizability (or the failure thereof). The former patterns are enshrined in the generality constraint; the latter in the recognizability condition.

### 5. *Recognizability Is Graded*

Peacocke treats perceptual recognizability as all or none. Three strokes are recognizable; 28 strokes are not. But recognizability is really a graded phenomenon. For one thing, it depends on background conditions—for example, the contrast, size, distance, and duration of the stimulus. But let's stipulate optimal conditions. Still, there is the problem of defining reliability: how much reliability is required for recognizability? Suppose you can perceptually recognize  $n$  strokes 85 percent of the time. Is that sufficient for you to satisfy the recognizability condition, and thus for your perception of  $n$  strokes to be digital? What if it's only 75 percent of the time? Or 51 percent? This question is pressing because after three items (the limit for “subitizing”), the ability to recognize the number of items decreases gradually. But in theory, it never falls below chance so long as observers are given a sufficient number of trials. Considering the ability to distinguish two numbers of dots on a screen,  $n_1$  and  $n_2$ , the psychologists Justin Halberda and Darko Odic write:

The actual behavioral data [...] and the modeled ideal behavior [...] suggest that the subjects will always be above chance no matter how small the difference between  $n_1$  and  $n_2$  (e.g., in theory, even a baby will be “above chance” at seeing that 10,001 black dots is numerically more than 10,000 gray dots; see Green and Swets, 1966); what changes is not whether an observer will succeed or fail to make a discrimination but rather the number of trials an experimenter would have to run in



order to find a statistically significant difference in performance on the most difficult trials. (2014, p. 317)

Thus, given enough trials, 28 and 29 strokes should be distinguished above chance.

This point is sometimes obscured by talk of “just-noticeable differences” (as in the passage from Peacocke quoted above). This phrase suggests a fixed binary distinction, such that you either can or cannot just notice a difference between any two magnitudes with respect to their intensity. But matters are not that simple. Psychophysicists determine the just-noticeable-difference threshold for a magnitude by selecting an arbitrary criterion —say, 75 percent of trials in which a test stimulus has to be successfully discriminated from a standard stimulus. To say that two magnitudes cannot be discriminated because they exceed a subject’s just-noticeable-difference threshold is thus to say that they cannot be discriminated on some arbitrary percentage of trials. Were the criterion lowered, the just-noticeable-difference threshold would decrease, and the two magnitudes might emerge as discriminable. Were the criterion increased, the just-noticeable-difference threshold would increase too.

These observations matter because they suggest that if we follow Peacocke in defining the analog-digital distinction in terms of recognizability —i.e., *reliable* recognition— then the distinction between analog and digital content will be graded rather than binary. Thus, consider the perception as of seven strokes.

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Does your perception of these strokes have analog content or digital content? According to Peacocke, that depends on whether you can reliably recognize that the strokes total exactly seven without recourse to counting or other extra-perceptual capacities. But as we have seen, there is no simple answer to that question. It depends on where we set the threshold for reliability. Thus, unless we imposed some arbitrary threshold, the most we could say is that the experience is more analog and less digital than the experience as of six strokes, and less analog and more digital than the experience as of eight strokes. We couldn’t count the experience as of seven strokes as analog or digital simpliciter.

Whether this is a problem for Peacocke’s account will turn on whether the analog —digital distinction should itself be interpreted

as binary or graded. While it is typically treated as binary (*prima facie* the distinction seems to mark a difference in kind), there are dissenters. For example, Lee et al. (2022) maintain that analog representation is graded along multiple dimensions. In defense of this claim, they construct hypothetical cases of artificial representational systems and argue that a graded account best accommodates the intuitions that these cases engender. My own intuitions do not always track theirs. But I want to focus on a different concern, which is that their cases and intuitions are generated in a context that is divorced from explanation in the cognitive sciences. In particular, they do not attempt to show that the graded account of analog representation that they develop finds fruitful application in perceptual psychology. But that is exactly the context that matters to Peacocke since his goal is to explain human perceptual capacities.

The ordinary concept *analog* is vague and inchoate. There is thus little reason to think that there is one true concept of analog representation. More plausibly, the concept *analog* can be precisified in a variety of ways. On some of those precisifications, the concept will emerge as graded. Lee et al. (2022) provide one account of what such a graded precisification might look like. Kulvicki (2015) provides another. But there are also ways of precisifying the concept on which it will emerge as binary. To choose the right precisification for a given application, we need to attend to the relevant explanatory context. For Peacocke, that context is characterizing capacities of human perception. The relevant question is thus whether those human perceptual capacities are best illuminated by a graded precisification or a binary precisification.

In the next section I will show how Peacocke's account can be amended to accommodate a binary distinction between analog and digital content, and that when it is so amended it captures important and psychologically real patterns in human perceptual capacities that a graded distinction would lose.

## 6. *Patterns of Recognizability*

To see how Peacocke's account can be fruitfully amended, it helps to distinguish three different patterns of recognizability for magnitudes.

*Gradual*: as the magnitude increases or decreases, its recognizability changes gradually.

*Static*: as the magnitude increases or decreases, its recognizability stays the same.

*Sudden*: small changes in the magnitude lead to large changes in recognizability.

These patterns capture three ways that the ability to recognize a magnitude can change as the magnitude increases or decreases.

My proposal is that we should say that perceptual contents are analog when they're associated with gradual patterns, and digital when they're associated with static or sudden patterns. For example, the perceptual experience as of length, luminance, and many other continuous magnitudes would emerge as analog because they're associated with gradual patterns: as the magnitude increases, the ability to recognize it decreases gradually. So would the perceptual experience of discrete numbers above three. Nine strokes are a little harder to recognize than eight strokes, which are a little harder to recognize than seven strokes, etc. The perception of number within the subitizing range, by contrast, would exhibit a static pattern and thus count as digital since there is little or no cost to recognizability over changes within that range. Perceivers are about as good at recognizing one, two, or three items.

A different pattern emerges in *categorical perception*, which involves superior discrimination across a category boundary compared to within a category. For example, while the light from a rainbow varies continuously, you see it as a series of discrete bands. As a result, you are not equally good at detecting the physical differences in wavelength at any two points along the rainbow. You're better at discriminating two points across a color boundary (e.g., red to orange) than two points within a category (e.g., two red points) even if the physical difference between them is the same. In categorical perception, recognition thus changes suddenly; small changes in the magnitude (e.g., wavelength) give rise to large changes in recognizability. Categorical perception thus has digital content.

Whereas Peacocke seeks to ground analog and digital content in recognizability itself, my suggestion is that we should instead ground analog and digital content in *changes* in recognizability. Perceptual content is digital when recognizability is stable or changes suddenly and analog when recognizability changes gradually. This allows us to honor the insight Peacocke finds in Goodman and Haugeland that the analog-digital distinction for perceptual content can be understood in terms of differentiability while simultaneously respecting the idea that the analog-digital distinction is binary. For example, the experience as of seven strokes is analog simpliciter because recognizability changes gradually for numbers above three.

At this point, one might wonder whether the objection I raised against Peacocke's view doesn't re-emerge for the view I have just outlined. Isn't my account of the analog-digital distinction just as graded as Peacocke's? There are, after all, degrees of gradualness. Precisely how much does recognizability need to change as the stimulus changes for the change to be big enough to count as sudden as opposed to gradual? Won't any answer be just as arbitrary as an answer to how reliable recognition has to be for a stimulus to count as recognizable in the first place?

There is, however, a natural way to address these questions. It just is a fact of perceptual psychology that changes in recognizability reliably cluster. They are not evenly spread across the space of possibilities. We can thus allow nature to make the relevant cuts for us.

As we'll see soon, the recognizability of many magnitudes—including duration, length, area, luminance, sound wave amplitude, and chemical concentrations—obeys Weber's Law. Technically: the standard deviation in same/different judgments increases linearly with the value of the magnitude. Less technically: recognizability decreases gradually as the magnitude increases. You're more likely to confuse seven strokes with six strokes than you are to confuse six strokes with five strokes.

Weber's Law captures one common pattern that changes in recognizability often take. Categorical perception captures another. As we saw, the ability to discriminate colors changes abruptly across certain borders. The same is true of phonemes. Whether one hears an utterance as a /da/ or a /ta/ is determined by the voice onset time, the duration that passes between the release of a stop consonant (when your tongue leaves the roof of your mouth) and the onset of voicing (when your vocal cords begin vibrating). The ability to recognize whether two utterances have the same voice onset times is significantly facilitated across the /da-/ta/ border. Across the border, a very small change in voice onset time leads to a big change in recognizability. Categorical perception can also be induced for arbitrary stimuli through perceptual learning. It is a common way that perceptual systems chunk continuous signals into discrete categories to create equivalence classes (Goldstone and Hendrickson 2010).

Thus, there is no need to impose arbitrary criteria to discriminate gradual from sudden (or static) patterns. Nature makes the distinctions for us. Analog and digital content emerge as natural kinds.

In section 5, I observed that Peacocke's account renders the distinction between analog and digital content graded rather than binary. Although some have argued that the distinction between analog

and digital should indeed be construed as graded, we are now in a better position to see why the binary distinction I have been defending is preferable for perceptual content. It carves nature at its joints.

### 7. *Analog Scenario Contents*

The patterns of systematic recombining enshrined in the generality constraint constrain accounts of conceptual content; but they do not constitute an account of conceptual content. Likewise, the gradual patterns of recognizability constrain an account of analog content; but they are not on their own an account of analog content. So, what might an account of analog content itself be like? In his presentation of the recognizability condition, Peacocke (2019) doesn't say. But one of the great virtues of Peacocke's earlier work on perception is that it doesn't merely argue that perception has nonconceptual content; it also provides a detailed account of what that nonconceptual content consists in. We can look to this earlier work for hints of how analog content might be constituted.

Peacocke (1992, Ch. 3) develops multiple levels of perceptual content. One of these —the most basic— is what he calls *scenario content*, which is a way of filling in space around the perceiver, relative to an origin and set of axes, that are consistent with the experience being accurate. A scenario content is thus a spatial type. For example, the scenario content for visual experience might be given by egocentrically specifying the hue, saturation, brightness, texture, orientation, and other features at points in space relative to the point on the perceiver's face that is centered between the two eyes. A *positioned* scenario is then a scenario assigned to a specific location and time. Only a positioned scenario is assessable for accuracy (in something like the way that "I am happy" is only assessable for accuracy when uttered by a specific speaker on a particular occasion). According to Peacocke, the most basic type of perceptual content is constituted by positioned scenarios.

In his discussion of scenario content, Peacocke offers the following aside:

Actually, in giving the content, we should strictly consider a set of such ways of filling out the space. By doing so, we can capture the degree of the experiencer's perceptual acuity. Greater acuity corresponds to restriction of the set of ways of filling out the space whose instantiation is consistent with the correctness of the representational content. (1992, p. 63)

When you remove your glasses, the spatial acuity of your vision decreases. There is thus an expansion in the set of scenarios that are compatible with the accuracy of your experience. Not all failures of recognizability are caused by limited spatial acuity. But we can still appeal to sets of scenario contents to model them. For example, the visual perception as of seven vertical strokes might be given by a set of scenarios that include not only scenarios with seven strokes, but also scenarios with five, six, eight, and nine strokes. Since the content is given by the set, it wouldn't take a stand on which of these scenarios is correct. It would be accurate if any of them were correct. The perception as of 27 strokes, by contrast, would consist of a more expansive set of scenarios —perhaps including scenarios with 20 to 34 strokes. More generally, as the number of perceived strokes increased, the set of scenarios that capture its content would expand, thus capturing the gradual degradation of recognizability associated with Weber's Law. On this proposal, scenario contents are *indeterminate*, and scenario contents are analog when they're associated with particular patterns of indeterminacy —namely, patterns in which the indeterminacy changes gradually as the represented dimension increases or decreases. Scenario contents are digital, by contrast, not necessarily when they're entirely lacking in indeterminacy, but rather when the indeterminacy is static or changes suddenly.

An alternative approach would capture failures of recognizability with probability distributions over sets of scenarios. For example, we could take the perception as of seven strokes to be given by a bell-like probability distribution over a set of scenarios that peaks at the scenario with seven strokes, and the perception as of 27 strokes to be given by a much flatter and broader bell-like probability distribution over a different set of scenarios that peaks at the scenario with 27 strokes. This approach could be developed by taking the content to include the probability distribution itself, or alternatively the probability assignments could be incorporated into the attitude, in which case the content would remain a set of positioned scenarios. Whether probabilities should be incorporated into perception in either of these ways remains controversial.<sup>3</sup> For present purposes, the point is simply that this is one of multiple ways to constitute perceptual content compatible with reflecting a distinction between analog and digital contents.

<sup>3</sup> I have expressed skepticism myself about whether probabilities are assigned in perceptual experience (Beck 2020b).

It is important to note that I am not claiming that perceptual contents are analog because they are continuous as opposed to discrete. I take it to be an open question whether perceptual contents consist of sets containing a finite number of scenarios or a continuum of scenarios. And while scenarios themselves are plausibly continuous, that is not what makes perceptual contents analog on the view I am developing. Rather, perceptual contents are analog because they have a structure that makes it perspicuous how recognizability changes gradually—for example, a structure that consists of gradual changes in indeterminacy.

### 8. *Analog Vehicles*

I have thus far been arguing that we can enforce a distinction between analog and digital perceptual contents, where analog contents are marked by gradual changes in recognizability. I will now argue that these gradual changes in recognizability are best explained by analog vehicles. As I have defended this claim at length elsewhere (Beck 2015, 2019), I will present the argument in an abbreviated form here.

I mentioned earlier that the perception of magnitudes is often characterized by Weber's Law. This means that the ability to discriminate two magnitudes changes with their ratio—the further from 1:1, the better. For example, if you're asked which of two lines is longer, you'll find it increasingly difficult to answer as the ratio of their lengths changes from 1:2 to 2:3 to 3:4 and so on. But you'll find it just as easy to discriminate a 4-inch line from a 5-inch line as a 40-inch line from a 50-inch line. What matters is the ratio, not the absolute differences. This same ratio sensitivity is present for many other magnitudes, including luminance (brightness) in vision, sound wave amplitude (loudness) in audition, pressure, weight, and temperature in touch, and chemical concentrations (e.g., of salt, sucrose, or citric acid) in taste and olfaction. The ratio sensitivity is also present in many magnitudes that can be perceived through multiple modalities, including distance, duration, and number (greater than three).

In accordance with the mirroring conception of analog representation, suppose that these magnitudes (length, number, etc.) are represented in the brain by some neural magnitude, such as neural firing rate. As the represented magnitude (e.g., line length) increases or decreases, the neural firing rate increases or decreases along with it. Suppose in addition that this process is noisy. A given line length

doesn't always elicit the very same firing rate. Often a length of 40 inches elicits a firing rate of 40Hz (say), but sometimes it elicits a firing rate of 39Hz or 41Hz, or (less often) 38Hz or 42Hz, and so on. In other words, we're supposing that a given length is associated not with a single, precise firing rate, but with a bell-shaped distribution over firing rates. In that case, the ability to reliably discriminate two line lengths would decrease as their ratio approaches 1:1, just as Weber's Law says.<sup>4</sup> For example, it would be very easy to discriminate a 40-inch line from a 20-inch line since the distributions of firing rates associated with each would barely overlap. But it would be much harder to discriminate a 40-inch line from a 39-inch line since the overlap between their distributions would be almost complete.

Now suppose, by contrast, that the brain instead used binary digits to represent magnitudes, so that a length of 40 inches was represented by the string 101000. Assuming that noise enters the system by randomly flipping digits (changing a 0 to a 1 or a 1 to a 0), there is no obvious reason to expect the representation of 40 to be more likely to transition to a representation of 39 (100111) than to a more distant representation. For example, the representation of 32 (100000) is actually more similar to the representation of 40 since it only requires one digit to be flipped as opposed to four.

The assumption that the brain uses vehicles that are analog according to the mirroring conception thus delivers a natural and compelling explanation of Weber's Law. Driving this explanation is the idea that similarities in the magnitudes represented are mirrored by similarities in the vehicles (e.g., neural firing rates) that do the representing. As a result, when noise alters the vehicles, it causes greater confusion as the two represented magnitudes become more similar. By contrast, because digital vehicles are not structurally similar to the magnitudes they represent, there is no reason to expect confusion to increase as the two represented magnitudes become more alike.

The upshot of this argument is that Weber's Law is best explained by positing analog vehicles in the brain. These vehicles are analog in the mirroring sense. They involve magnitudes representing magnitudes, such that the two magnitudes covary with one another (Maley 2011). As one increases or decreases, so does the other.

Like the argument from systematicity for the language of thought, the argument from Weber's Law for analog vehicles is non-demon-

<sup>4</sup>Technically, Weber's Law requires scalar noise if the mapping from worldly magnitude (e.g., length) to internal magnitude (e.g., neural firing rate) is linear, or constant noise if the mapping is logarithmic. See Beck 2019.



strative. The mere fact that perceivers obey Weber's Law with respect to their magnitude discriminations does not necessitate that their representations are analog. It is possible to imagine digital representations being implemented in a way that would also give rise to Weber's Law—for example, by tailoring the noise just so. But any such digital implementation would seem to require *ad hoc* assumptions. The argument from Weber's Law is thus compelling even though it is non-demonstrative.

### 9. *Grounding*

I have argued that the perception of magnitudes has analog content insofar as it exhibits gradual changes in recognizability. Because magnitude perception is so often characterized by Weber's Law, which involves such gradual changes in recognizability, it turns out that a good deal of magnitude perception has analog content. I further argued that Weber's Law is itself best explained in terms of analog vehicles—for example, some neural magnitude that covaries with the magnitude represented. Thus, perception has analog content because it has analog vehicles. The analog vehicles help to ground the analog contents.

It bears emphasis that two different *analog* concepts are being deployed in the claim that perceptual content is analog and in the claim that perceptual vehicles are analog. As we saw earlier, the concept of analog relevant to analog content has its roots in the practical conception—and more specifically, the notion of differentiability familiar from Goodman (1968) and Haugeland (1981). Peacocke turned this into differentiability in practice, i.e., recognizability; and I then suggested that *changes* in recognizability would serve better than recognizability *per se*. By contrast, the concept of analog that attaches to analog vehicles traces instead to the mirroring conception (e.g., Maley 2011), and is a matter of magnitudes mirroring magnitudes. The fact that we are dealing with two different *analog* concepts helps to bring out the non-triviality of the thesis that perception has analog content in virtue of having analog vehicles.<sup>5</sup>

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