BILINGUAL PUBLISHING GROUP

Forum for Linguistic Studies

https://journals.bilpubgroup.com/index.php/fls

ARTICLE

Sensory Schema: From Sensation to Knowledge

Wes Raykowski

Arts, Education and Law, Griffith University, Nathan, QLD 4111, Australia

ABSTRACT

How do we know we used the right word in a sentence? The standard answer invokes grammatical rules, context, usage, and logic—but this article argues that the process of reasoning is guided by sensations. Human individuals experience sensations—not the molecular or neural mechanisms that produce them. Therefore, meaning arises from the sensations that words prompt, not from words themselves. Thinking operates through patterns of sensations, most below conscious awareness, while those that rise to consciousness guide the process by signaling alignment or conflict with patterns from past experiences. To explain this process, the article proposes the sensory schema framework, which investigates how sensations are organized at a more fundamental level than image schemas and conceptual metaphors in cognitive linguistics. Analysis across diverse domains—language, mathematics, science, art, and everyday behavior—reveals that sensory experience is inherently structured as products of intensity and extent, the core mechanism by which embodiment shapes conceptual knowledge. This cross-domain consistency demonstrates that patterns cognitive linguistics identifies within language reflect universal organizational principles of sensory experience. The article synthesizes core ideas from previously published works and demonstrates how the framework generates testable predictions for empirical research while offering applications in language acquisition, computational linguistics, and clinical assessment.

Keywords: Sensory Schema; Sensory Products; Intensity; Extent; Embodied Cognition; Experiential Grounding; Sensory Simulation

*CORRESPONDING AUTHOR:

Wes Raykowski, Arts, Education and Law, Griffith University, Nathan, QLD 4111, Australia; Email: wes.rajkowski@alumni.griffithuni.edu.au

ARTICLE INFO

Received: 18 November 2025 | Revised: 8 December 2025 | Accepted: 9 December 2025 | Published Online: 6 January 2026

DOI: https://doi.org/10.30564/fls.v8i1.12785

CITATION

Raykowski, W., 2026. Sensory Schema: From Sensation to Knowledge. Forum for Linguistic Studies. 8(1): 18–44.

DOI: https://doi.org/10.30564/fls.v8i1.12785

1. Introduction

Human cognition comprehends a wide spectrum of experiences, from direct sensations like pain and color to abstract notions such as price, confidence, or mathematical ideas. These sensations and their patterns manifest across diverse forms of human expression—language, music, visual art, mathematics, scientific models, and everyday behavior—offering insights into the organization of the mind itself.

To uncover these insights, the investigation employs an approach analogous to archaeology: just as archaeologists reconstruct past societies by analyzing artifacts from multiple sites, cognitive structures can be reconstructed by analyzing diverse forms of human expression. Rather than following the traditional route from neural networks to social cognition, the investigation examines expressions—linguistic and non-linguistic alike—treating them as windows into underlying cognitive architecture.

A key principle underpins this investigation: cognition operates through sensory simulation [1]. Thinking unfolds as patterns of sensation—most operating below conscious awareness yet continuously shaping cognition—while those rising to consciousness guide reasoning explicitly by signaling alignment or conflict with prior patterns. Consequently, expressions across domains do not arise from arbitrary symbolic manipulation but from systematic patterns grounded in how humans directly experience and simulate sensations.

Central to the investigation is the sensory schema framework, which posits that experiences—from immediate sensations to abstract concepts—share a common organizing structure. Cross-domain analysis reveals a recurring pattern: the interplay between nested intensity (e.g., the brightness of red) and concatenated extent (the area of a red surface). This intensity × extent pattern operates across representational systems through universal cognitive mechanisms: addition, averaging, and product. These operations—though resembling mathematical terms—function as fundamental processes for understanding experiences across disciplines.

Relationship to Cognitive Linguistics:

The framework seeks to advance cognitive linguistics, particularly embodied cognition theory [2–4]. While cognitive linguistics has primarily analyzed linguistic evidence—documenting how bodily experience structures language through conceptual metaphors and image schemas—its theoretical claims extend beyond language. Lakoff and Johnson [3] explicitly argue that conceptual metaphor is a cognitive phenomenon with linguistic manifestations, not merely a linguistic feature. The sensory schema takes this claim seriously by investigating how experiential patterns manifest across all forms of human expression: mathematical notation, scientific models, visual representation, musical structure, and everyday behavior.

This cross-domain analysis strengthens cognitive linguistics' core thesis: when the same organizational patterns appear in linguistic expressions ("in love"), mathematical notation (set membership $\in$), and visual composition (figure/ground relationships), this provides evidence that cognitive linguistics has identified genuine features of cognition rather than linguistic conventions. Readers interested specifically in the linguistic aspects of sensory schema theory may refer to Raykowski [5–7] in Cognitive Semantics journal. This article builds on that methodological foundation to explore fundamental patterns of human cognition as evidenced across multiple domains of expression.

1.1. Words and Meaning

Most people intuitively believe that words carry inherent, "correct" meanings—a belief arising from the apparent ease of everyday communication. When we say "chair," we expect others to understand a piece of furniture for sitting, as if the word itself contains this meaning. Sensory schema theory challenges this view, arguing that meaning arises not from words themselves but from sensory experiences shaped by the physical body's interaction with the environment [5–8]. Words, as symbolic prompts, lack inherent meaning [9]; instead, they trigger context-dependent simulations [1]—partial reactivations of sensory experiences, such as the tactile sensation of sitting or the visual form of a chair.

Consider learning to ride a bicycle. Initially, a rider consciously attends to balance, pedaling, and steering, but with practice these actions become automatic, much like reflexes such as blinking. Similarly, understanding words like "chair" starts with conscious associations to sensory experience (e.g., the pressure and contact area when sitting—concepts formalized later as intensity × extent). With repetition, these links become automatic. Because automatic processes operate below conscious awareness, the word's meaning feels inherent—a learned "reflex" that obscures its experiential origins. This article challenges that assumption by exploring the embodied origins of meaning and the crucial role sensations play in its formation. The following section develops this experiential approach.

1.2. Shifting Perspective: From Objects to Experience

Understanding sensory schema theory requires a shift in perspective from the familiar, object-centered framework to one that is rooted in experience and sensation. One area where this perspective shift is essential is in understanding terms like "product". For most, these immediately bring to mind numbers and arithmetic (such as 2 × 8 = 16). However, these words had broader meanings well before their mathematical use: a "product" is anything that results from combining influences—bread is the product of flour and baking, knowledge is the product of education. Sensory schema theory returns to this original sense. Here, a product like "intensity × extent" refers to the total effect or magnitude of a sensation, not just a calculated number but an experiential outcome.

Just as "product" must be reinterpreted in the sensory schema framework, so too must "property." In realism, properties are features attached to objects. In the experiential view, a property is not a static attribute of an object, but a pattern structured by sensory modality, defined by intensity (how strong or vivid) and extent (how much space, time, or context is involved). For instance, color is not an inherent property of a surface, but a visual quality experienced in gradations of hue, brightness, and saturation—themselves determined by patterns of activation within the sensory system. Thus, experiential properties serve not merely as one instance of meaning, but as organizing templates for subsequent, more complex or abstract concepts and expressions.

Building on the need to rethink "product" and "property" in cognitive and sensory terms, it is equally important to reconceptualize sensation itself—not as mere data or abstract information about external objects, but as the immediate conscious qualities constituting human awareness. Sensations are the foundational units of perception: concrete, qualitative "what-it-is-like" aspects of awareness. To fully appreciate sensory schema theory, readers are encouraged to step beyond the confines of objects as containers of properties, or products as mere numbers, and instead consider how experience itself is built from patterns of sensation.

This experiential reorientation is central to sensory schema theory and becomes especially important for understanding how everyday expressions combine fundamentally different types of sensation—a challenge addressed in the next section.

2. Linguistic Indications of the Intensity-Extent Pattern

The sensory schema framework emerged from systematic observation of how humans structure expressions across different sensory domains. The theory proposes that human expressions share a common structure combining intensity of sensation with extent, and that this pattern provides the cognitive foundation for expression across many disciplines—an aspect developed throughout this article. Understanding this pattern requires examining how we actually talk about intensity. If intensity and extent are fundamentally united in experience, we should expect language to reflect this unity. Indeed, speakers consistently use extensive language—terms describing publicly observable phenomena such as countable objects, measurable distances, and spatial relations—to express private experiences of intensity. This pattern, observable across all sensory modalities and abstract domains, provides evidence that intensity and extent are not merely associated but deeply intertwined in human cognition and expression [2,3].

- **We Cannot Show Intensity Directly**

Consider how you communicate about intensity. When you experience strong sensations—pain, heat, loudness, brightness—you cannot point to intensity itself. You need something visible, something measurable, something others can observe.

Take a thermometer. You feel hot—that's private, locked inside your experience. The mercury rises in a spatial column—that's public, everyone can see it. You read "38.5 °C" or say "I have a fever"—now others understand your intensity through extent, through measurable distance in space.

Or consider a pain scale at the doctor's office. You hurt—that's yours alone. You point to a number on a line—that's shared space. The doctor understands "severe pain"—your private intensity communicated through spatial position on a public scale. Or a volume meter. Sound feels loud to you—private experience. The needle moves across a dial—public movement. Someone reads "80 dB"—your sensation translated into calibrated distance.

The pattern repeats everywhere. Private intensive experience must be translated into public extensive representation to be communicated. We cannot show intensity directly. We can only show its correlation with extent—with space, distance, quantity, things we can measure and share.

- **All Our Intensity Words Come from Extent**

  Look closely at how we describe intensity, and you'll find something remarkable: virtually every term borrows from extent. Every category of intensity vocabulary originates in publicly observable, concrete phenomena.

  We use vertical and spatial language to describe intensity: "high pressure," "low volume," "rise in temperature," "elevated mood," "deep depression." Size language maps onto intensity: "big problem," "small improvement," "enormous talent." Quantity language expresses intensity: "more intense," "less painful," "much brighter."

  We describe intensification as if it were material accumulation: "pain grows," "anger increases," "tension builds," "pressure accumulates," "anxiety mounts." We borrow from physical force: "strong emotion," "weak argument," "powerful idea." We extend temperature experience: "heated debate," "cold reception," "warm feelings." We apply light vocabulary: "bright student," "brilliant idea," "dim understanding." We map spatial depth onto qualitative richness: "deep thought," "profound insight," "shallow understanding."

  Even our most abstract intensity vocabulary—degree, level, grade, extent, scale [10]—refers to ranked positions or measured quantities in space. Each term originates in concrete, extensive, publicly observable phenomena. We describe invisible, private intensity exclusively through visible, public extent.

- **The Language Flows One Way**

  This creates a striking asymmetry. All intensity vocabulary borrows from extent. We say "high intensity" using vertical space. We say "strong feeling" using physical force. We say "deep emotion" using spatial depth. We say "great pain" using physical size. But the borrowing never goes the other direction. Extent vocabulary never borrows from pure intensity. We never describe spatial extent using purely intensive terms. You don't say a road is "very red-long." You don't say a duration is "loudly extended." Extent keeps its own vocabulary. Intensity must borrow from extent.

  Why this one-way street? Language privileges extent because extent is public—observable, measurable, shareable. Intensity is private—felt, experienced, locked inside. To talk about intensity, we must map it onto the publicly observable framework of extent.

- **Why We Talk This Way**

  Three factors explain this pattern. First, you can demonstrate extent. Point to it. Measure it. Multiple people can verify it. But intensity? That's locked in private experience. You can't hand someone your headache. You can't show them your anger. To communicate intensity, you must map it onto something public—onto extent.

  Second, experience itself intertwines intensity and extent. You never experience pure intensity without some extent, never experience pure extent without some level of intensity. When you hear loudness, you hear sound-over-duration. When you see brightness, you see light-across-area. Language reflects this experiential unity. What's united in experience gets united in expression.

  Third, children learn extensive vocabulary first—objects, spatial relations, countable things. By the time they develop refined intensity discrimination, the extensive framework is already established. Intensive experience gets mapped onto existing extensive language.

- **What This Means for Understanding Experience**

  This linguistic situation creates real challenges. When we say "increase," do we mean intensity deepens or extent expands? When we say "more," do we mean greater intensity or greater extent? When we say "build up," are we describing intensification or accumulation? The sensory schema framework addresses these challenges through systematic distinctions. Throughout this work, we'll distinguish: levels intensify (intensity deepens within units) from layers accumulate (more units added). This allows us to analyze what everyday language intertwines, revealing the dual structure underlying simple expressions like "increase volume" or "build tension."

The intertwining isn't a flaw in language. It's evidence of how human cognition structures experience—through patterns that fundamentally unite intensive and extensive aspects. Understanding this helps us see what's been hiding in plain sight: the architecture of experience itself.

The following section examines specific challenges that arise when attempting to represent both intensity and extent simultaneously.

3. The Challenge of Representing Intensity and Extent

The sensory schema began with a simple observation: everyday expressions like "dark red apple" combine two fundamentally distinct aspects of experience: sense of intensity and extent. What makes these two aspects distinct?

3.1. Structure of Experience

Consider seeing a red apple. Two distinct aspects organize this experience, each feeling fundamentally different:

- Intensity feels concentrated in a single moment of sensing—one experience of "how red" the color appears at a point. This is the degree or vividness of sensation. When you focus on one spot, you experience a specific level of redness—perhaps pale pink or deep burgundy. You cannot point to this intensity. There is nothing in the world for others to touch or measure that corresponds to "how vivid" the red feels to you. This intensity exists in private space—your sensations, accessible only to you.
- Extent feels distributed across multiple locations—spread over the apple's surface. This is the spatial scope of sensation. Unlike intensity, extent corresponds to things in public space—the apple's surface, the distribution of pigment, the area occupied by the object. Others can access these by being in the same space with them: touching the apple, measuring its surface, observing the spatial distribution.

These aspects structure experience differently: intensity operates as degree (how much of the property at one location), while extent operates as distribution (how many locations possess the property). Intensity is non-spatial; extent is inherently spatial.

3.2. The Two Spaces

Everything we know comes through sensation. Yet sensations differ fundamentally in whether they correspond to things others can access by being in the same space with them.

Private space contains sensations accessible only to you. Intensity, vividness, and degree are genuine experiences, but there is nothing in public space to point to. When you experience "how dark the red feels," you cannot show it to another person. Others cannot be in the same space with your experience of vividness—they cannot touch it, measure it, or observe it directly.

Public space contains objects, surfaces, and boundaries in the shared world. The apple and red pigment exist here. Others can access these by being in the same space with them—touching the apple, observing the pigment, measuring the surface. When you point to the apple, others can direct their attention to the same object.

The crucial insight: both intensity and extent are sensations (experiences in private space), but extent corresponds to things in public space while intensity does not. When we say "extent is public," we mean it corresponds to objects others can access by being in the same space—not that your experience of extent is public. The apple's surface exists in public space; your experience of seeing that surface remains in your private space. Yet we experience both as unified. When you look at the apple, you don't experience intensity and extent as separate. You experience an integrated whole: "red apple."

3.3. Beyond Abstract and Concrete

The crucial distinction isn't between abstract versus concrete, mental versus physical, or internal versus external. Rather, it concerns whether experiences correspond to things in public space—objects you can point to, touch, and share by being in the same space—or that exist only in private space.

Consider two people embracing. You can point to the two people (they exist in public space) and observe their behavior. But you cannot point to "their relationship"—the affection or trust they feel exists in their private spaces. The relationship is genuine experience, but it lacks independent presence in public space beyond the people themselves.

3.4. Levels, Layers, and Containers

To communicate about sensations in private space (like intensity), we use conceptual tools that leverage things in public space. The sensory schema employs three core elements:

Levels (intensity) represent private experiences, the qualitative states of "how intense" a sensation feels—a degree or magnitude. Levels are non-spatial and non-additive: experiencing "vivid red" twice doesn't produce "more vivid red." Levels are nested hierarchically, where higher levels subsume all levels below them (cf. on spatial primitives[11]; on nested profiling[12]). They exist as private experiences of degree with nothing corresponding to them in public space.

Containers represent things in public space. A container is any structure that spatially bounds substance—a glass holding water, a body region containing receptors, the apple's surface. Containers occupy measurable space, enabling spatial relationships. Crucially, containers exist in public space where others can access them by being in the same space—touching them, measuring them, pointing to them.

Content (layers of substance) represent things in public space that are used metaphorically to indicate experiences in private space. Layers are accumulated substance within containers—water filling a glass, pigment covering a surface. Layers are spatial, additive, and countable. Like containers, layers exist in public space—you can observe water accumulating or measure pigment thickness by being in the same space with them.

3.5. Metaphorical Role of Layers

Layers serve a dual function: they exist as things in public space while indicating experiences in private space. When we say "the glass is half full," we point to layers of water (public) to indicate levels (private). Similarly, "dark red apple" points to the apple's red surface (public) while indicating intensity in private space. These objects serve as prompts or triggers for simulation in private space. The mapping is metaphorical: physical correlates preserve the structure of intensity (ordering from low to high) without reproducing what the private experience feels like.

3.6. From Communication to Conflation

This necessity creates conflation—treating experiences in private space as properties of objects in public space. When we say "the apple is red," we treat redness (private intensity) as if it were a property belonging to the apple (object in public space). This linguistic structure obscures the fact that redness is a relational experience between observer, object, and light conditions—something that happens in your private space when you're in the same space with the apple.

Conflation is both necessary and limited. It is necessary because we cannot communicate about private experiences without using public objects as prompts. When we say "dark red apple," we conflate private intensity (experienced vividness) with public extent (spatial distribution of pigment), treating both as if they were the same type of thing—properties of objects—when they fundamentally differ in their relationship to space. Conflation enables communication but systematically obscures the distinction between what exists in private space and what exists in public space. The sensory schema addresses this challenge by explicitly preserving the distinction these linguistic shortcuts obscure.

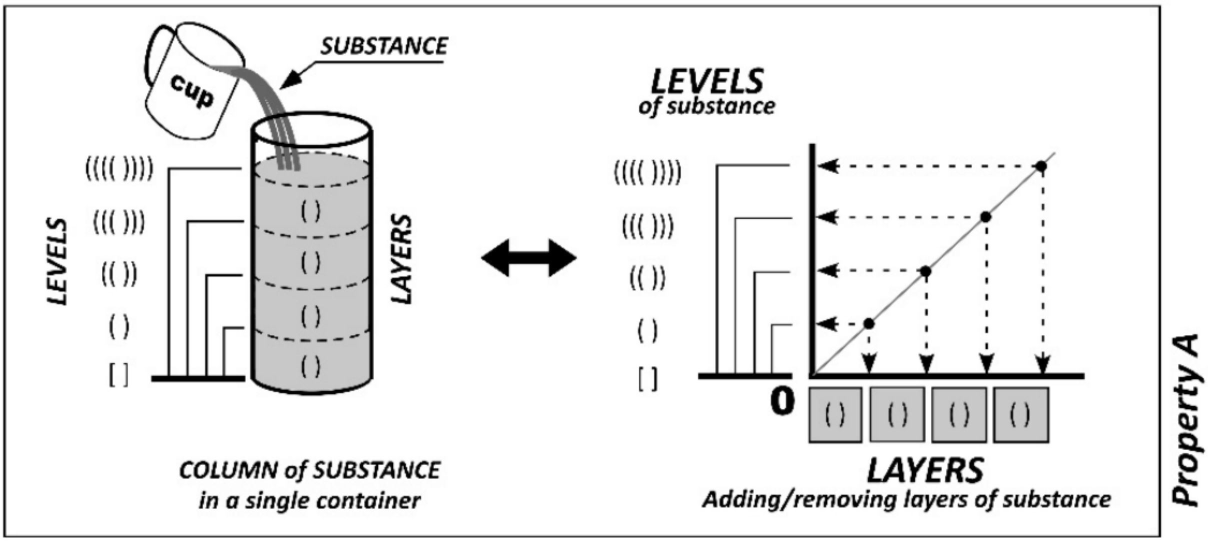
3.7. The Sensory Schema as Solution

The sensory schema distinguishes private sensation from public extent while showing how they combine in experience. The framework does not capture subjective quality—no diagram can reproduce "what it's like" to see vivid red—but rather reveals how intensity (private) and extent (public) are organized and how they systematically relate. Section 4 develops this schema in detail.

4. The Sensory Schema

In contemporary research, cognition is commonly approached from two perspectives: the molecular basis of cognition and the social construction of meaning. These perspectives address different levels of explanation—biological and social/cultural. Sensory schema theory bridges these levels by grounding all forms of thinking—language, mathematics, science, art, human behavior—in patterns of sensory experience[13,14]. A key challenge this framework addresses is how we communicate about private experience using public 'objects'.

Its central tenet is that all perceived or conceived phenomena arise from the interplay of intensity (levels) and extent (spatial/temporal scope) of sensations. This interplay is illustrated by a conceptual metaphor of substance (e.g., water or meaning) in a container (e.g., a glass or a mind), as depicted in **Figure 1**.



(**a**) (**b**)

Figure 1. The sensory schema metaphor: (**a**) folded—layers stacked to form levels; (**b**) unfolded—layers and levels separated.
Note: Nested brackets (((( )))) show intensity levels; horizontal sequences ( )( )( )( ) show layers.

Figure 1a depicts a single container with four levels of intensity, while **Figure 1b** separates layers of substance from abstract levels of intensity to highlight their distinct roles. The metaphor represents an individual (the container) holding sensory or conceptual experience, with levels indicating its intensity.

These concepts and their combinations are described in Sections 4.1–4.3.

4.1. Interpreting Schema

As a metaphor, the sensory schema is not an absolute or rigid framework but a relative one, with its meaning shaped by context. Metaphors are not literal truths but tools for mapping one domain of experience (e.g., physical layers of sediment) onto another (e.g., abstract concepts like trust or anxiety). Their meaning shifts depending on the context and scale of their application.

One key aspect of the sensory schema concerns the private/public relationship introduced in Section 3. The distinction between private and public is central to this framework. Private refers to direct sensory experience—the immediate, first-person sensation that occurs within an individual. Public refers to bodily expressions (e.g., movements) or environmental modifications (sound, objects) that can be shared with others who occupy the same space (though not necessarily at the same time). For example, the sensation of sitting in a chair is private: it is the direct sensory experience of pressure, support, and comfort felt by one person. To prompt comparable sensations in others, one must construct a chair—a material object that acts as a mold, deforming another person's body and thereby activating their sensory receptors in a comparable way. The chair thus serves as a public medium through which private sensations can be indirectly transferred.

At the neural level, processes such as neurotransmitter release and receptor activation occur within the body (public space) but generate experiences in private space. While these processes could theoretically be observed with instruments, the experiences they generate—the intensity of activation—remain private, directly accessible only to the individual. Understanding how private experiences become publicly expressed through material forms is essential for applying the metaphor appropriately across different contexts.

The sensory schema is a complex and rich metaphor. It is not a binary system (e.g., true–false, one–zero, open–closed) but an intricate interplay among levels, substance, layers, containers, and their combinations. While these components can be analytically isolated for specific purposes—examining hierarchy alone, focusing on layers or containers independently, or even reducing relationships to binary terms—they remain fundamentally interconnected within the complete schema. The following subsections discuss levels first, followed by substance, layers, and then containers, exploring their roles in single containers and arrays of multiple containers within the sensory schema.

4.2. The Intensive Aspect of Sensations: Levels

At the foundation of individual sensory experience lie two key dimensions: intensity and extent. Intensity refers to the qualitative levels of a sensory property—such as degrees of brightness, taste, or pain. These levels form a nested organization, meaning every higher level contains all lower levels, creating a hierarchy. Importantly, levels are inherently non-spatial: they resemble abstract thresholds, much like points or planes in geometry, and do not possess measurable substance or extension (cf. on force-dynamic schemas[15]).

Extent, by contrast, involves layers, which are substantive and spatial. Layers are formed by the accumulation of substance (e.g., water in a glass) and are always additive. Adding layers increases extent—a spatial, measurable property that exists in public space and can be used to indicate levels (which exist in private space).

Despite this conceptual separation, we habitually express and interpret sensations in spatial terms. To make private qualitative experiences accessible, we map non-spatial intensity (levels) onto spatial, physical representations (layers).

However, this process creates conflation (see Section 3.6). This conflation obscures the non-additive, abstract logic of nested levels, blending it with the additive, spatial logic of concatenated layers.

Conflation is entrenched by the metaphors we use—saying layers form "the distance between levels," treat intensity as if it can literally be stacked or accumulated like physical matter.

The following properties define levels as the intensive aspect of the schema:

- **Representation**: The intensive aspect of sensation is depicted by brackets, where (( )) symbolizes two nested levels and ((((( ))))) five, representing abstract thresholds, similar to mathematical points or geometric planes, not tangible layers or boundaries.
- **Idempotency**: Levels are non-additive; combining identical levels (e.g., level (a) + level (a) = level (a)) does not increase intensity. For example, adding red paint of the same intensity does not alter the intensity of the paint.
- **Nested Structure**: Levels of properties form a hierarchy, where a higher level subsumes the potential of all levels below it, down to the zero level (empty container). Unlike layers of substance, which are tangible, levels are abstract. **Figure 1a** illustrates higher levels encompassing lower ones, with layers providing the palpable separation between these abstract thresholds.
- **Unconstrained Nesting**: Without the constraint of identical layers—for example, ( )( )( )( )—the abstract, non-spatial nature of levels allows countless possible arrangements of equivalent forms. For example, (( )) = (( )) = (( )) shows that all three, and more, two-level nested expressions are equivalent[5]. Layers provide measurable separations between levels, creating the illusion of regular spacing. This regularity is illusory because levels and layers are orthogonal (independent), operating on distinct scales (e.g., color intensity vs. area, pitch vs. duration, pain intensity vs. area).
- **Sense of Unity**: As shown in **Figure 1**, nested levels of a property coexist simultaneously, forming a unified whole that is continuous internally but discrete externally. The unit cannot be divided without its destruction.
- **Privacy of Levels**: Levels, as abstract states, are private and harder to communicate compared to tangible layers in public space.
- **Vertical Orientation**: In the sensory schema metaphor (**Figure 1a**), each level corresponds to a specific "height" representing qualitative intensity (e.g., degree of pain, rate of speed), while layers constitute the substance-like material that accumulates to reach that threshold.

This section has explored the concept of levels in sensory experience. The following section will examine the notion of extent.

4.3. The Extensive Aspect of Sensations: Layers and Containers

In the context of the sensory schema (**Figure 1**), there are two types of extent, which differ in their conceptualization and scale: one associated with layers and the other with containers. Both layers and containers are related to nested levels, but each relates in a different way. Layers of substance accumulate inside each container, indicating the level of intensity within that container. Containers, with their contents, form arrays capable of expressing spatial relations by varying levels.

Note that when using the sensory schema, levels, layers, substance, and containers should all pertain to the same property or sensory modality. For example, in the sensory schema, painful experience involves substance (pain sensation), a container (body region), extent (scope of pain's distribution—e.g., some or all of the body affected), and intensity (felt magnitude—e.g., mild or severe pain). Layers in public space (activated body regions) indicate levels in private space (experienced intensity).

The next section examines the notion of substance.

4.3.1. Substances

In everyday language, a substance is a tangible material that occupies space and has independent existence. Water is a familiar example—a liquid that flows, can be poured, and takes the shape of its container. Similar properties are displayed by powders, dry sand, and paint. These tangible substances serve as source domains for metaphors about abstract concepts. Sentences like "Building trust over time" or "Trust eroded away" describe trust as if it were a concrete substance that accumulates or diminishes. Just as dust on a table or paint on a canvas accumulates physically, abstract concepts such as trust, anger, or joy can be conceptualized as metaphorical substances that accumulate experientially.

In the sensory schema metaphor, substance is any property that accumulates within a container—whether tangible material (water, paint) or abstract experience (trust, redness-as-sensation). Tangible substances like water serve as metaphors for abstract substances like trust, enabling us to conceptualize abstract properties as quantifiable entities. The redness example below illustrates how physical paint (tangible) serves as a metaphor for the experience of redness (abstract) in the context of the sensory schema:

- **Situation**: Red and white paints mix on a palette before application to canvas. This tangible process represents how redness varies in intensity.
- **Substance**: Paint is tangible; experienced redness is abstract. Redness as experience is conceptualized like a pigment whose intensity varies with mixing proportions.
- **Container**: Canvas (tangible) holding paint serves as a metaphor for the sensory system processing (color) experience.
- **Layers of substance**: Substance accumulates in layers to create extent and support intensity. In physical terms, layers might be brushstrokes of paint; in experiential terms, they represent sensory units corresponding to redness.

It is important to understand what the sensory schema metaphor represents and what it does not.

The metaphor captures structural relationships at multiple levels. Compositionally, containers hold substance organized into layers that indicate levels. In terms of dependency, representing levels requires accumulated layers, which require substance organized into separate units, which in turn require spatial containment. In terms of conceptualization, layers of accumulated substance provide a tangible means to indicate abstract levels—creating public representations of private intensity. Together, these relationships reveal the orthogonality of intensity and extent, and how elements interact to enable representation. However, the metaphor does not represent literal physical processes (paint is not neural tissue), causal mechanisms (it doesn't explain how neurons generate consciousness), or functional dynamics (real sensory systems actively process, unlike passive containers). The metaphor is a structural template for understanding cognitive organization, not a literal description of biological implementation.

4.3.2. Layers of Substance

Artists typically mix paints on a palette rather than directly on the canvas. Only when satisfied with the tint or shade do they transfer the paint, layer by layer, to the canvas using a brush. In the painting analogy, each brushstroke can be thought of as delivering one 'cupful' of paint. This process illustrates how layers function in the sensory schema: layers are created by transferring substance in discrete units (cupfuls) from a source to a container. The source of this substance remains unspecified in the framework. This deliberate abstraction allows the schema to apply across different implementations without committing to specific mechanisms or material substrates. The capacity to add or subtract substance, regardless of source, accounts for the external regulation of processes in the container (amplification through adding substance, attenuation through removing substance, sensitivity adjustment through varying layer thickness, and qualitative aspects like mixing properties). Because the cup is usually small, multiple cupfuls are needed to reach the desired amount. Assuming the cup is always full, the volume of substance per cupful, together with the shape and size of the container, determines the thickness of all layers. The thickness can be varied by using differently sized cups, but there is a fundamental constraint: layers must have non-zero thickness to accumulate and create extent.

The metaphorical conceptualization in **Figure 1a** is highly flexible. It encourages the reader to think of layers as volume (in the case of water) or as accumulation (dust on a table), but also as abstract substances like beauty ('beauty blossoming with age'), joy ('joy overflowing'), sadness ('sadness weighing heavily'), and similar qualities. This contributes to the richness of the sensory schema metaphor. The following points summarize the metaphorical use of substance and layers:

- **Representation**: Layers can be represented by concatenated round brackets: ( )( ) stands for two and ( )( )( )( )( ) for five discrete layers. Layers can be material (layers of cream, dust, paint, or sediment) or abstract (layers of meaning, power, knowledge, beauty, joy, and trust).
- **Creating and Removing Layers**: In the sensory schema metaphor, layers are created by adding substance (located outside the container) to the container using a cup. Removing a layer means scooping the substance from the container using the same cup and returning it to the source.
- **Layers as Units**: Layers are indivisible units; their volume is defined by the size of the cup (**Figure 1a**). Layers must possess non-zero thickness to function as accumulative units that create extent.
- **Adding and Removing Layers**: For simplicity, the sensory schema assumes containers with regular shapes (consistent horizontal cross-sections), ensuring all layers have constant thickness. This allows layers to be treated as identical, indivisible units. For example, layer b + layer b = two layers of b, or layer b − layer b = empty container.
- **Relation to Levels**: Adding layers indicates higher levels; removing them indicates lower levels. Layers (public) correspond to levels (private) but do not produce them—they serve as tangible indicators of abstract intensity (see Section 3.6 regarding conflation).
- **Concatenated Structure**: In the context of the metaphor, the layers in a column are concatenated, meaning there are no gaps between them. Violating concatenation would result in the loss of the column's continuity. Concatenation encompasses more than continuity; it includes repetition of a unit (layer in this case), the extent of that repetition, temporal progression, and direction of progression—aspects discussed in detail in Section 5.4 on orthogonality of product factors.
- **Extent of Property**: In the sensory schema, extent is the total number of accumulated layers within the container. The extent depends on the unit used in the schema. For example, if the metaphor is applied to money, an extent of $10 may be ten one-dollar coins, five two-dollar coins, or one ten-dollar note.
- **Horizontal Orientation**: In **Figure 1a**, the orientation resulting from accumulation is vertical. However, in the unfolded version of the schema (**Figure 1b**), discrete layers are plotted along the horizontal axis to indicate their substance-like nature.
- **Public Aspect of Layers**: The substance is supplied from an external source, as represented in **Figure 1a** by a cup used to transfer substance into the container. In this context, layers are public, while levels are private.

The next section examines the role containers play in the schema metaphor.

4.3.3. Containers: Properties and Conceptualization

In the schema metaphor, a container is a conceptual structure that bounds and organizes layers—material (e.g., water) or abstract (e.g., beauty or importance). Containers embody both spatial and representational dimensions: they occupy physical space (enabling spatial relationships) and hold accumulated substance organized into layers. Crucially, containers do not hold intensity itself—levels of intensity exist in a different ontological space (private, experiential). Rather, the accumulated layers within containers serve as the material substrate that represents or corresponds to those private levels, making intensity conceptualizable in public, spatial terms.

Beyond merely holding layers, containers facilitate the accumulation of substance through various processes—for example, pouring, absorbing, or condensing for water, and learning or transferring for abstract substances like knowledge. Theoretically, any object or structure that can hold a substance can serve as a container in the sensory schema metaphor. For example, water can be contained in a vessel (e.g., a glass full of water), absorbed (e.g., a towel, wet or dry), or accumulated on a surface (e.g., morning dew on a leaf). These interactions produce both a public extent—including spatial distribution (e.g., some, all, or most of the towel)—and a private intensity, reflecting the magnitude of the property at any given location (e.g., slightly or very wet or dry).

Note the many ways in which a substance like water is delivered from external sources to various containers. For example, it is poured from a vessel (e.g., a jug filling a glass), falls as rain (e.g., rainwater filling a bucket), or comes from the surroundings as humidity (e.g., moisture in clammy air). Note also the rich selection of possible containers (e.g., glass, bucket, leaf, or towel), water states or forms (e.g., liquid, vapor, or moisture), modes of delivery (e.g., rain, droplets, or moisture), and processes involved (e.g., accumulation, condensation, or absorption). Physical and abstract substances behave similarly. Consider the concept of 'knowledge' as an example:

- Container: A student as an individual learner.
- Substance Interaction: Knowledge (abstract substance) is absorbed through lessons or discussions, forming layers of understanding in the student's mind.
- Extent (Public Expression): Demonstrated understanding—test scores, articulated explanations, or ability to apply concepts.
- Intensity (Private Magnitude): The depth of comprehension at each point—slightly understood, moderately understood, well understood, or profoundly understood.
- Example: Knowledge, like water, can be accumulated, poured into the mind, transferred, drained, lost, or passed on to others. It can have depth and can overflow and spread.

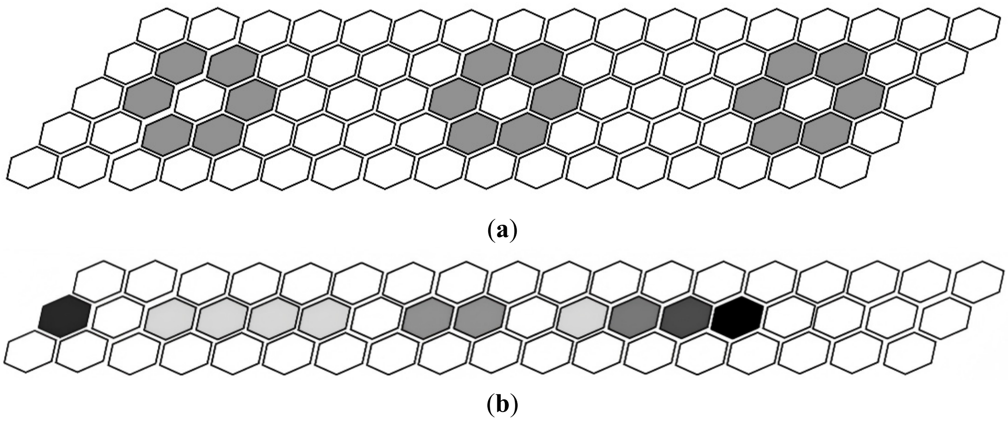
These container properties apply fundamentally at the level of individual units—a single sensor, receptor, or person. A single container can hold varying amounts of substance, representing different intensity levels. Spatial patterns and relationships (such as images, edges, gradients, or relative positions like "next to" or "between") can be represented only when multiple containers form arrays, where the position of each container and the variation in levels across containers together encode spatial information. Section 4.3.4 explores how spatial arrays enable the sensory schema to represent complex spatial relationships.

4.3.4. Arrays of Containers: Representing Spatial Patterns

When we think of patterns, we typically visualize them spatially: a flower's arrangement of petals, a face's configuration of features, a checkerboard's alternating squares. These patterns exist as two-dimensional arrays where each location has a particular intensity—bright or dark, saturated or pale. **Figure 2** shows such a pattern—recognizable shapes formed by different shades of gray. These patterns appear to exist "out there" in public space, as distinct areas where shades seem to be properties of the surfaces themselves. Yet Section 3.6 reminded us that shades of color are not properties of objects. Hue is a relational experience between observer, object, and light conditions—something that happens in private space. The question then arises: how do we come to perceive color and its shades as located "out there"?

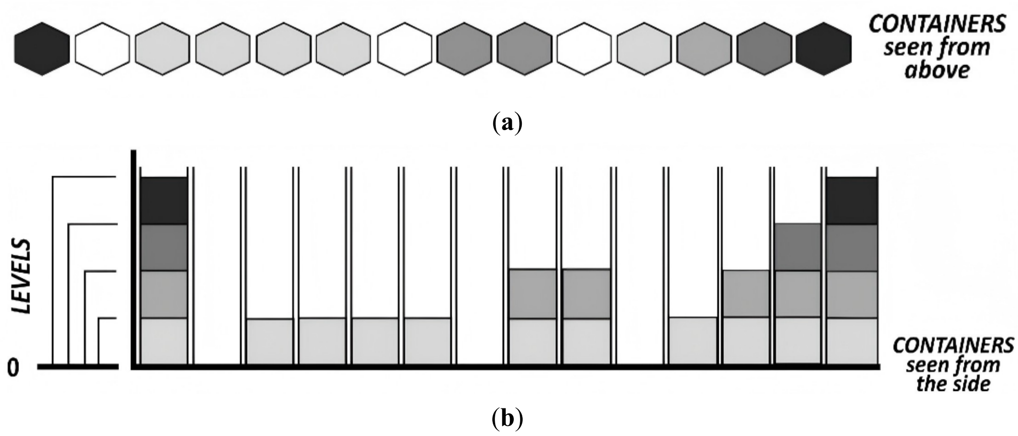
The sensory schema reveals what everyday experience conceals: the distinction between private intensity and public extent. Consider the linear pattern in **Figure 2b**—a sequence of fourteen unit areas displaying different shades of gray created by mixing varying proportions of white and black paint. For this example, assume the pattern was created by applying a single layer of paint to each location on the canvas. This stipulation is critical: it allows us to differentiate between literal layers of paint in public expressions and the metaphorical use of layers in the sensory schema to represent nested intensity.

This linear pattern is analyzed in **Figure 3**.



(**a**) (**b**)

Figure 2. Large array of containers created by varying intensity of gray, as seen from above. (**a**) shows three symbolic flower heads; (**b**) shows a linear pattern of shades of gray.



(**a**) (**b**)

Figure 3. The linear pattern from **Figure 2b**. (**a**) Top-down view of the pattern; (**b**) Side view: sensory schema—metaphorical layers represent nesting of intensity, independent of physical paint. Patterns in (**a**) and (**b**) are aligned to show correspondence.

Two Ways of Looking at Patterns

- **Figure 3a**: Looking down at the pattern, we see what appears in **Figure 2b** and **Figure 3a**—a sequence of distinct shades distributed across space. This is how we naturally experience patterns: intensities (shades) seem to be properties located on surfaces in public space, where individuals encounter each other and objects, and where all expressions are made. Each unit appears to have a particular shade as its property.
- **Figure 3b**: The side view presents the sensory schema interpretation of the same pattern. Here, we shift from observing colored surfaces to examining the underlying structure: how intensity (private, nested) relates to extent (public, spatial).

The schema employs two orthogonal axes: vertical (nested levels) and horizontal (fourteen concatenated containers). Critically, the vertical columns of layers in **Figure 3b** do not represent the actual paint layers on the canvas—we stipulated only one physical layer per unit. Instead, the layered structure reveals what the single-layer view conceals: intensity itself has nested structure.

Each shade we experience—from white (no intensity) through progressively darker grays to black (maximum intensity)—corresponds to a different depth of nesting. An empty container appears white [ ]; one level of nesting produces light gray [( )]; two nested levels produce darker gray [(( ))]; three levels darker still [((( )))]; maximum nesting shown as black [(((( ))))]. This correspondence is shown explicitly by the nested bracket notation on the left vertical axis.

The layers in **Figure 3b** are not paint layers but representational layers—a visual device to make nested structure explicit. Because intensity is structured through nesting (levels within levels), and because nesting is private and non-spatial, we use spatial layering (extensive, publicly visible) to represent intensive structure (private, nested). The progression from white through grays to black doesn't represent adding paint; it represents deepening nesting. This is why we need both views: **Figure 3a** shows the public appearance (distributed shades on surfaces); **Figure 3b** reveals the private structure (nested levels within each location).

Without this dual representation, we cannot explain how private intensity (which has no spatial location) comes to appear as properties distributed across public space. The schema shows that what appears "out there" as different shades at different locations is actually the same capacity for nesting at each location, but activated to different degrees. The spatial distribution we see from above reflects different degrees of nesting revealed from the side.

Sensory Schemas as Graphs

The sensory schema lends itself to visualization as a bar graph in its discrete form, where each bar represents a unit (container) displaying the maximum intensity level for that unit. Concatenated containers are symbolized as sequential brackets: [ ][ ] … [ ]. Layers within containers are indicated by stacked brackets such as ( )( )( )( ), where the number of layers indicates the presence of corresponding levels (((( )))) — four identical layers indicate four uniformly spaced levels. While an observer in public space perceives only the maximum (outermost) intensity, the full nested structure of levels is represented in private cognitive space. A large number of these metaphoric containers makes expressing numerous patterns possible, differing in terms of extent, location, and intensity. The schema arrangement enables depiction of spatial relations (e.g., **Figure 2**) and changes such as motion. As the granularity of these units approaches the infinitesimal—with bars becoming infinitely thin and numerous—the discrete representation converges toward a continuous Cartesian graph.

Relation to Cartesian Coordinates

Figure 3b may resemble a Cartesian coordinate system (graphs), but this resemblance is misleading. In Cartesian coordinates, both axes represent spatial dimensions within a single homogeneous space that can be combined mathematically (3 m east + 4 m north = 5 m northeast). In other words, they exist in the same space. In the sensory schema, the horizontal axis represents extent (spatial, public, additive) while the vertical axis represents intensity (non-spatial, private, non-additive). These are incommensurable—they cannot be directly integrated. They can only be depicted together through conflation.

4.3.5. Linguistic Evidence for Sensory Schema in Graphs

The language we use to describe Cartesian graphs reveals an unconscious mapping between mathematical representations and embodied sensory experiences. We consistently employ vertical terminology for intensity relationships and horizontal terminology for sequential relationships [2,15]. For example, we naturally say "the function rises to a peak" and describe "higher values" on the y-axis, using spatial metaphors that mirror how we experience intensity as layered sensation. Similarly, we describe "moving across the data points" and refer to the "next measurement" on the x-axis, employing sequential language that reflects the concatenated nature of extent.

A simple linguistic test reveals how fundamental these mappings are. When we attempt to swap the terminology—saying "the function crosses to a peak" instead of "rises," or "moving up the data points" instead of "across"—the language becomes immediately unnatural and unclear. This cognitive resistance arises because we are tapping into deeply embodied spatial metaphors where the vertical dimension corresponds to nested intensity and the horizontal dimension corresponds to concatenated extent. This linguistic evidence strongly supports the sensory schema theory's claim that mathematical representations are grounded in the same 'intensity × extent' structure that underlies all sensory cognition. Even abstract mathematical thinking relies on fundamental sensory schema, with the vertical axis being intuitively understood as nested relationships and the horizontal axis as concatenated units.

5. Products Are More Than Aggregation

Among concepts critical to cognition, few are more fundamental than the notion of sensory products. Every experience, every sensation, every expression of perception exists as a product—there is no sensation that is not a product. This is not merely a theoretical claim but a fundamental constraint: for any experience to exist or be expressed, it must be formatted as a product of nesting (e.g., intensity) and concatenation (extent, unit repetition). The absence of either aspect renders sensory experience or its expression impossible.

Products are often intuitively understood as simple totals—the sum or aggregate of individual measurements across space or time. However, this view captures only part of the picture. The key insight is that every sensory product—whether the brightness and size of a colored patch, the pitch and duration of a sound, or the sweetness and volume of a taste—represents a structured combination of two orthogonal concepts: nesting and concatenation. We have already encountered a few examples of this principle in preceding sections. Each demonstrates that sensation cannot exist as pure intensity without spatial or temporal extent, nor as pure extent without some level of intensity.

The universality of this product structure—the fact that all experiences and their expressions are "formatted" as products of intensive and extensive aspects—reveals why the sensory schema metaphor is so powerful: it captures not just one type of sensation but the fundamental architecture of all sensory cognition.

5.1. Sensory Products

This section examines the nature of products within the sensory schema metaphor in greater detail. Sensory products are conflations of orthogonal concepts: nesting (e.g., intensity or speed) and concatenated units (sensory cells or various metaphorical containers). Understanding products as conflations helps explain both their ubiquity and their cognitive utility. Informally, a product of a modality or property can be viewed as a collection of metaphorical containers sharing an identical level of the property. This uniformity of levels across containers forms spatial patterns that, through their contrast with neighboring patterns or backgrounds, make shapes and forms easier to perceive. Sensory products, therefore, are a cognitive mechanism for simplifying noisy experiences by determining a common level of sensory activation. Together with adjacent contrasting patterns, a simplified impression of the object is created for further processing.

Products display the following characteristics:

- **Formal definition**: A product is a structured whole composed of unique associations between levels of a property (e.g., intensity of activation) and corresponding extents (e.g., spatial area or duration).
- **Multiplicative Relationship**: Product = Intensity × Extent for a given property and object.
- **Representation**: Products can be represented by brackets combining square brackets for empty containers and round brackets for levels of content. For example, 2 levels in 3 containers can be expressed as: [(( ))][(( ))][(( ))]. This corresponds to 2 × 3 = 6.
- **Equivalent Forms**: Different combinations of intensity and extent can yield the same value (e.g., 1 × 10 = 2 × 5 = 5 × 2 = 10 × 1 = 10). These equivalent forms represent the same overall magnitude in formal terms, highlighting the invariant nature of sensory products.
- **Sensory Idempotence in Products**: When products are added, the intensive aspect remains constant while the extent accumulates. For example, if a product is represented as 'ab', where 'a' denotes the intensity and 'b' the extent, then adding two identical products yields: ab + ab = a(b + b) = 2ab.

This shows that the overall magnitude of the product increases by accumulating the extent (such as containers), while the intensity remains unchanged. Expressions with different intensities, like $2 + $10, cannot be directly added unless cognitively restructured to share a common intensity ($2 × 1 + $2 × 5 = $2 × 6). These constraints on addition and division ensure coherence in the structure of products.

- **Conjunctive condition**: Products exist only when both their factors are present, experienced, and operational at the same time—the absence of either factor means no sensory product can form.
- **Conceptual duality**: In the context of conflation, intensive and extensive aspects of products continuously modify each other. For example, in the experience of redness, imposing concatenation (e.g., applying paint layers) onto nesting (color intensity) introduces repetition and progression, while nesting imposes confinement and discreteness onto concatenation's potentially endless repetition (see **Figure 1b**).

The interplay between intensive and extensive factors explains why sensory products feel both natural and constructed, both stable and dynamic—they embody the fundamental tension between nested order and concatenated flow that characterizes sensory experience. One special case deserves particular attention: the zero product.

5.2. The Zero Product

The sensory schema metaphor emphasizes that a "zero level" of intensity (e.g., silence, no motion, no importance) is not an absence of a property, but a meaningful experience with an inherent extent.

- **Sensor Presence**: To perceive "zero intensity" (nothingness), a sensor of some type must be present and active. It is represented by an empty container. For three empty containers, it can be depicted with brackets as [ ][ ][ ].
- **"Nothing" as a Product**: Nothing is a product of zero intensity and some extent of a property.
- **Sensory Idempotence**: Adding zero product to zero product does not increase the nested value, but does increase its extent, thus increasing the total value.
- **Experience with Extent**: A "zero product" (e.g., 0 × extent) is an experience that persists over a certain duration or scope (extent), distinguishing it from true non-existence. In sensory experience,

$0 \times 1 \neq 0 \times 100 \neq 0 \times 1000$, even though these expressions are mathematically equivalent. The experiential difference lies in the extent.

- **Musical Example**: In music, silence is not the absence of sound but a meaningful zero-level auditory experience with temporal extent. A ten-second silence in a musical composition creates a different experience than a one-second silence, even though both have zero intensity. The auditory system remains active during silence, processing the zero level of sound across the specified duration. This distinguishes musical silence (zero intensity × temporal extent = meaningful pause) from the complete absence of auditory experience (no auditory capacity or temporal extent). Composers utilize silence as an expressive element precisely because it maintains the 'intensive × extensive' product structure while operating at zero intensity level. The same explanation applies to empty space and other similar properties.
- **Mathematical and Logical Zero**: In mathematics and formal logic, 0 is treated as the absence of quantity or property—an exception that behaves differently from other numbers. Mathematics defines 0 as the additive identity ($n + 0 = n$) but leaves division by 0 undefined, while formal logic treats zero as the absence of a property or the negation of existence. Neither framework captures the sensory experience of a zero level, such as silence (a perceptible zero intensity of sound with duration) or black (a perceptible zero intensity of color over space). Sensory schema theory unifies zero with other numbers by representing it as a product ($0 \times n$), where 0 is a minimal intensity level, not an absence of experience.

The musical example demonstrates that zero-level experiences are rich, structured phenomena, not mere gaps or absences. The next section examines applications of sensory products across different domains.

5.3. Applications of Sensory Products

Sensory products represent the simplest form of experience. They combine state (nested intensity) with change (concatenated units) into an experience that appears as a steady state. In 1-D, these products resemble rectangles with constant intensity (height) and extent (base).

5.3.1. Basic Properties of Sensory Products

Sensory products help us understand processes that happen too quickly (or too slow), or at scales beyond human experience. As an example, recall the act of hitting a ball, which happens extremely quickly. To make it easy to grasp, we convert the highly irregular impulse curve into a product resembling a rectangle—one with constant force (intensity) and sufficiently long duration (extent) to experience it. Similarly, sensory products provide a framework for experiencing spatial relations when we view microscopic images of cellular structures or macroscopic images of astronomical phenomena.

The key aspect of all these examples is the process of averaging levels. Imagine perceiving an apple by means of tiny sensory receptors, like the photoreceptors in your eyes. At first, these receptors detect different intensities, creating a jumbled mix of sensations. This complexity becomes organized by averaging the intensity of nearby receptors with similar responses. Distributing intensity over a larger area forms distinct regions, making features like the apple's shape or color easier to notice and recognize. **Figure 4** shows effects of this process, with four shades of gray representing different regions, simplifying the image of an apple. Each area of uniform shade is a sensory product, combining intensity (like a shade) and extent (like an area).

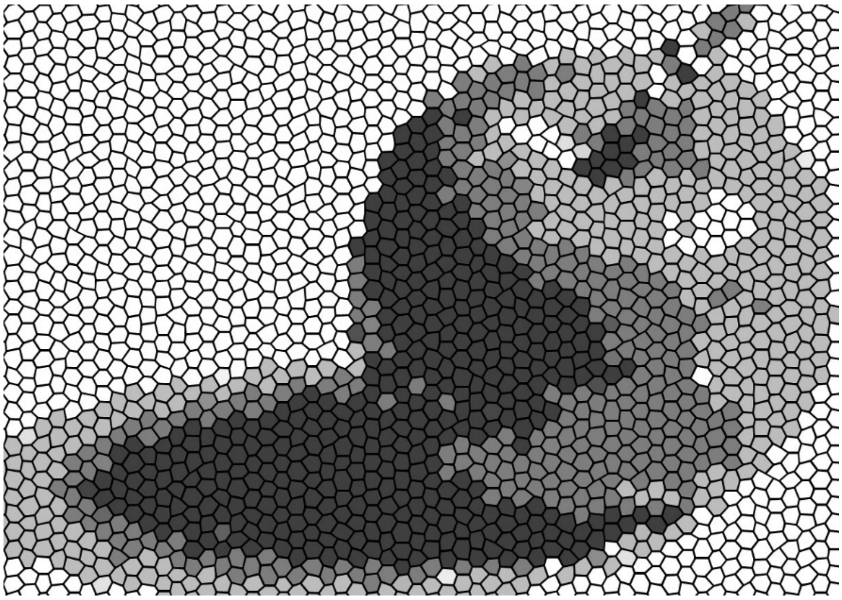


Figure 4. Example of averaging a continuously varied image, reducing infinite gradations to four discrete levels of gray.

5.3.2. Product Representations and Conversions

Because they are defined by intensity and extent, which are orthogonal (independent of each other), sensory products can have multiple forms, such as intensive representations (high intensity, small extent) and extensive representations (low intensity, large extent). **Figure 5** illustrates three key forms of sensory products with descriptive names:

- **Intensive representation** has extent one, with high intensity, like (7 × 1) for 7. This is used in comparisons and multiplication, as single units are easier to multiply.
- **Extensive representation** has intensity one and large extent, like (1 × 7) for 7. It is used in conceptualizing addition and division, as it emphasizes countable units.
- **Square representation** has equal intensity and extent, like (3 × 3) for 9. It provides a template for squaring operations.

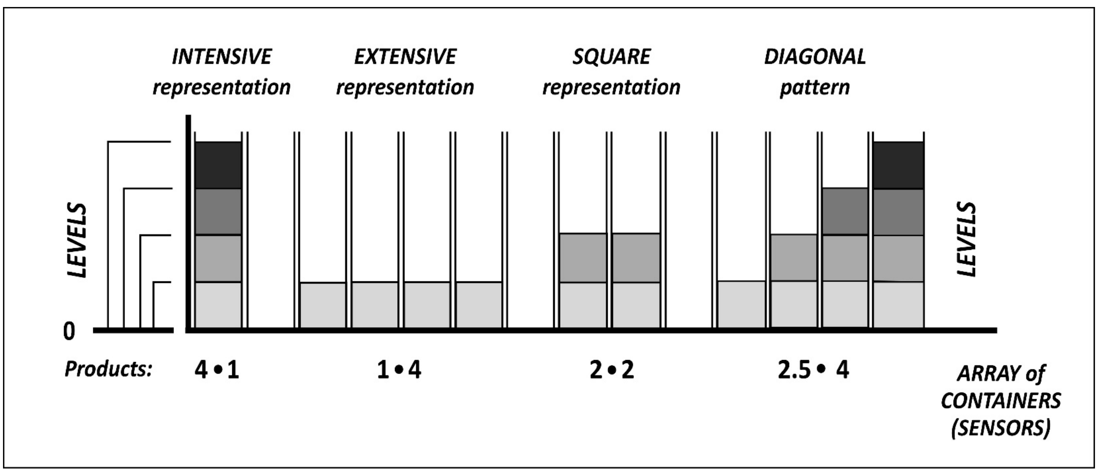


Figure 5. Sensory product interpretation of sensory schema metaphor. The diagram shows four typical representations of products: intensive, extensive, square and diagonal.

The sensory schema theory enables conversion between these different product representations. Transforming an extensive representation (e.g., (1 × 3): 1 intensity, 3 extent) to an intensive one (e.g., (3 × 1): 3 intensity, 1 extent) involves increasing intensity and reducing extent to one, and the reverse for intensive to extensive. However, not all numbers can form square representations. Some numbers like 4 or 9 can easily form square representations (2 × 2, 3 × 3), but others like 3, 5, or 7 cannot—their square roots are irrational, making square visualization impossible in the discrete container system.

Importantly, this type of conversion should not be confused with swapping roles in context-dependent expressions like "red apple," where redness (intensity) and apple surface (extent) have fixed roles that cannot be reversed. Numbers, however, are context-free and can occupy either position in the product notation. This flexibility stems from the positional notation system used in sensory products: intensity first, extent second. While this fixed order cannot be changed without revising the theory, numbers themselves—being context-free—can function as intensity in one expression and as extent in another.

For example, the number 3 serves as intensity in (3 × 4) but as extent in (4 × 3). This distinguishes numerical products from linguistic expressions like "red apple," where redness must always function as intensity (the qualitative property) and apple surface must always function as extent (the measurable dimension). Sensory products require both intensity and extent to be present (absence of either negates the product), maintaining this positional structure regardless of whether the factors are context-free numbers or context-dependent concepts.

5.3.3. Mathematical Applications

Note the difference between the sensory schema and mathematical notation. In the sensory schema, numbers are products of intensive and extensive factors, so they can have more than one expression. For example,

$$(1 \times 12) = (2 \times 6) = (4 \times 3) = (3 \times 4) = (6 \times 2) = 12$$

represents what in mathematics is the number 12. Each expression represents a different intensive-extensive structure, yet all equal 12 because numbers are context-free.

In mathematics, addition like 4 + 3 is simple but becomes complex in the sensory schema:

$$(2 \times 3) + (2 \times 4) = 2 \times (3 + 4) = (2 \times 7).$$

This follows the principle of sensory idempotence described earlier, where products with the same intensity can be added by accumulating their extents.

Multiplication like 4 × 3 follows the positional rule 'intensity × extent', becoming a product of products. For example, to multiply (1 × 3) and (1 × 4), first convert the extensive representation (1 × 3) into an intensive unit (3 × 1)—three levels in one container [((( )))]. This unit can then be multiplied by (1 × 4), meaning: take this 3-level unit and place it in 4 containers. The result is (3 × 1) × (1 × 4) = (3 × 4), interpreted as 4 containers of 3 levels each: [((( )))] [((( )))] [((( )))] [((( )))]. This can be reformatted extensively as 12 units of 1 level each: [( )] [( )] ... [( )].

Standard mathematics uses a simplified, conflated notation for numbers, which may obscure critical insights about numbers and their operations, emphasizing algorithmic manipulation over structural insight (cf. Ch. 18 on the embodied basis of arithmetic [3]). One such insight concerns prime numbers, like 7, which can be expressed as (1 × 7) or (7 × 1) in sensory schema notation, revealing that primes have only two product forms (intensive and extensive representations), unlike composite numbers which have multiple intermediate forms. For example, the expressions (1 × 6) = (2 × 3) = (3 × 2) = (6 × 1) represent the number 6 in mathematics, demonstrating that composite numbers offer greater representational flexibility.

5.3.4. Products Beyond Mathematics

The product structure is evident in language and other forms of expression like fine art, music, and everyday behavior, where intensity (qualitative properties, like redness or comfort) combines with extent (measurable objects or dimensions, like an apple's surface or a chair). For example, in language, "red apple" combines redness (its intensity) with the apple's surface (extent), and "comfortable chair" combines comfort (intensity) with the chair (extent). In fine art, "vivid painting" pairs the vividness of color (intensity) with the canvas area (extent), and in music, "loud symphony" links sound volume (intensity) with the duration of performance (extent). In everyday behavior, "confident stride" combines confidence (intensity) with the physical movement of walking (extent). All these examples are orthogonal pairs, combining intensity and extent, for example: redness/surface, comfort/chair, vividness/canvas, volume/duration, and confidence/movement.

This raises a question: Why do we so naturally combine color intensity with surface, comfort with objects, or sound with duration? The next section examines the cognitive origins of this product structure.

5.4. Orthogonality of Product Factors

Where do the notions of intensity and extent come from? At the level of the individual, this pattern is grounded in conscious sensations. Every moment of awareness reveals distinct aspects of sensation—such as brightness versus area, or loudness versus duration. These aspects, though fundamentally independent, are linked through sensory modalities: brightness and area in vision; loudness and duration in hearing. Importantly, this linkage occurs even though intensity and extent have different underlying experiential structures: intensity corresponds to nesting (as described in Section 4.2), while extent corresponds to concatenation (discussed in Section 4.3.2). Across all my articles, I use intensity and extent as more accessible examples of the underlying concepts of nesting and concatenation. The relationship between these two factors—intensity and extent, hence nesting and concatenation—was described as orthogonal [6], in a sense that goes beyond simple geometric perpendicularity: it involves different scales of sensation, with intensity referring to the magnitude within a single unit (a "lower scale"), and extent expressing aggregation across multiple units (a "higher scale"), together yielding a product of uniform intensity. This is distinct from other types of relationships, such as the "southeast" direction, where both elements operate on the same scale, or from simple opposition or alignment. Understanding this orthogonality is essential because sensory products are more than just aggregates. The following subsection explores how this orthogonal relationship manifests in different varieties of experience.

Varieties of Orthogonal Relationships

All sensory experience involves temporal progression (concatenation), but we experience it differently depending on whether intensity remains constant or varies during that progression. The orthogonal structure of nesting and concatenation manifests in both static and dynamic forms.

- **Static variants** (such as intensity × extent) capture experiences where intensity remains constant across the progression—like the steady pressure of sitting in a chair or walking at a constant pace. These create the sensation of a steady state despite the underlying temporal flow.
- **Dynamic variants** (such as tension → extension) capture experiences where intensity varies across the progression—like the changing forces when getting up from a chair or accelerating while walking. These create the sensation of transformation or change.

This distinction reflects an inherent directionality in the nesting-concatenation relationship: nesting creates a kind of potential or tension that finds release through extended action. This directional character of the orthogonal structure may provide the cognitive foundation for causal reasoning itself—concepts like cause and effect, potential and action, or charge and discharge appear to derive from this fundamental pattern of nested intensity finding expression through concatenated extent. Understanding this temporal nature of all products is crucial for grasping the full structure of sensory experience: even "static" experiences involve ongoing temporal progression. What we experience as stability or constancy is actually the repetition of identical intensity across successive moments. Thus, the interplay between nesting and concatenation not only generates quantitative measures but also gives rise to qualitative phenomena such as potential, force, balance, causation, thresholds, gradients, and hierarchical structures.

It is important to recognize that products formed from nesting and concatenation can take many different forms, such as pairs like (tension → extension) or (force × distance). Some of these variants are elaborated below, starting with the intensity-extent pair:

- **Intensity × Extent**: This variant highlights experiences where intensity remains constant across the progression, creating what we experience as a static relationship between intensity and extent (e.g., of an apple) such as color, taste, and other properties, as well as more abstract ones. Some examples include (Brightness of color × its area), (Sound volume × duration), and (Temperature × affected region). Additional examples include sitting in a chair (constant pressure intensity repeated moment by moment) or walking at constant pace (steady speed repeated across distance and time). In each case, the repetition of identical intensity creates the sensation of stability or steady state, despite the underlying temporal progression.
- **Tension → Extension**: This variant captures dynamic experiences where intensity varies across the progression, creating what we experience as change or transformation. These are often causal relationships where the initial state of strain, potential, or readiness (tension—

represented as accumulation) leads to a spatial or temporal release, change, or realization in the form of manifestation or movement (extension—expressed as concatenated repetition). The arrow (→) denotes this inherent directionality: represented intensity naturally seeks expression through spatial-temporal extension. Examples include (Force → Displacement), (Tension → Release), (Charged → Discharge), (Pressure → Flow), and (Potential → Action). In human experience of one's own body, tension is experienced as "accumulated" intensity and extending (as a verb) means spatial repetition unfolding in time. The conventional language of "cause and effect" maps onto this more fundamental pattern of represented intensity finding expression through extended manifestation.

- **Per unit × Number of units**: This variant describes situations where a per-unit value or rate (intensive factor) is combined with the number, duration, volume, or extent of units (extensive factor) to produce a total value (extensive product). Rate itself is an intensive aspect because extent equals 1 (e.g., $/1 item). When multiplied by number of units (extent), it yields the total, following the same 'nesting × concatenation' structure. Examples include: (Price per unit × Number of units = Total cost), (Speed × Duration = Distance traveled), (Power per device × Number of devices = Total power consumption), (Calories per bite × Number of bites = Total calorie intake), (Flow rate × Time = Total volume), and (Work output per hour × Hours worked = Total work done).
- **Force × Distance (Work)**: The product of force (which feels intensive, like tension in action—representing "accumulated potential" or nesting) and distance (an extensive displacement—representing concatenation) defines energy and work, both of which are fundamental concepts in mechanics, biological motion, thermodynamics, and engineered systems. These are examples rather than abstract conceptualizations, illustrating how the 'nesting × concatenation' pattern manifests in physical experience. Similarly, the product of force and moment arm (the lever distance) yields torque, also called the moment, which relates to balance and rotational equilibrium. Examples include the human arm, wrench-turning bolts, door hinges, bicycle pedals, and steering wheels, as well as statics and dynamics in fields such as bridge design.

The examples above illustrate possible interpretations of orthogonyms (orthogonal pairs) across varying levels of abstraction. These orthogonal pairs can be identified in all forms of expression—from language and mathematics to science and art. Cultural and mathematical elaborations (such as price per unit, torque, or work) build upon this foundational sensory template, extending the basic 'intensity × extent' structure into increasingly abstract domains. This elaboration proceeds in two directions simultaneously: intensive direction (up—including more complexity, depth, and nested levels) and extensive direction (forward—extending through time and space via concatenated progression). It is crucial to note that this framework describes the structure of sensory experience and expression, not ontological claims about external reality.

- **A Note on Conflation in Language**
  In everyday language, we commonly say "levels accumulate" or "accumulating intensity"—expressions that conflate what are analytically distinct operations. Levels intensify (nested, intensive), while layers accumulate (concatenated, extensive). However, this conflated usage accurately reflects how sensory products present these categorically different phenomena as unified in experience. Throughout this work, I maintain analytical precision when needed while acknowledging that conflated expressions naturally arise from the structure of sensory experience itself.

The next few sections describe how levels are used in cognitive operations.

6. Cognitive Operations Through Intensity Variation

One of the most fundamental aspects of cognitive processes is the variation of levels (e.g., intensity), a process used in many sensory operations, only some of which are discussed. The processes described below involve changes in intensity across parts of the array, and multiple intensity changes can take place simultaneously, which simplifies procedures.

6.1. Fundamental Operations

In the following illustrations, dark rectangles (█) represent an intensity, and underscores (_) indicate background level (zero intensity).

Division, Partition, and Separation:

This operation divides a well-defined product into two parts through selective change of intensity.

(_████████_ _ _) array A → (_███_ _███ ██_) array A

By reducing intensity in selected containers of the array, the originally continuous area is divided into two separate regions, with one shifted to the right by two spaces. Importantly, the space separating the two regions is not merely a thin boundary or an indistinct "space" but a distinct product consisting of two containers with zero intensity.

Addition and (Re)Combination:

This operation is the reverse of division (partition and separation) as it merges two or more regions of equal intensity to form a single, contiguous area.

(_███_ _█████_) array A → (_████████ _ _ _) array A

Here, the gap between the two blocks is filled by increasing intensity, while the intensity at the distant end is reduced to zero (background), maintaining the original extent. While sensory products with differing intensities cannot be directly added through simple accumulation (as noted earlier), they can be combined through weighted averaging, which yields a new product with intermediate intensity (cf. on simulation blending[14]).

Movement and Transformation:

Creating a sense of movement in an array of sensors involves increasing intensity at the leading edge of a pattern and decreasing it at the trailing edge. In the example below, an eight-unit pattern appears to shift to the right as these intensity changes occur.

(_████████_ _ _) array A ↔ (_ _███████ █_ _) array A

This process not only produces the experience of relative motion, but also engages the cognitive mechanisms underlying spatial reasoning, temporal processing, and dynamic visualization.

Enlargement/Expansion and Diminution/Contraction:

Both enlargement and diminution involve changes in extent. Enlargement occurs when new containers are added and their intensity levels are matched to those of an existing product. Diminution is the reverse process.

Averaging Properties of Different Intensity Levels:

Consider combining batches of different juice concentration conceptualized as sensory products of intensive and extensive factors:

Product A: 80% × 2 cups = 1.6 cups of pure juice

Product B: 40% × 3 cups = 1.2 cups of pure juice

Mixing/averaging:

Total pure juice: 1.6 + 1.2 = 2.8 cups of pure juice

Total mixture volume: 2 + 3 = 5 cups

Resulting concentration: (2.8 cups juice ÷ 5 cups) × 100% = 56%

In mixing, we add the products (intensity × extent). The mixture concentration reflects a weighted combination, not a raw sum.

(80% × 2 cups) + (40% × 3 cups) = (56% × 5 cups)

This process demonstrates how, cognitively and mathematically, addition of two products with different concentrations yields a product with a weighted average concentration that reflects both the quantity and quality of the components.

Mixing Different Properties:

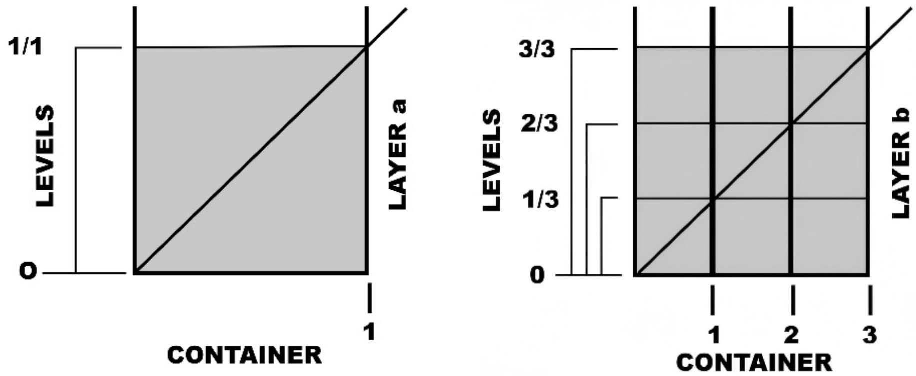
In this framework, mixing different sensory properties is not possible, as it violates the requirement for congruence—different properties (e.g., color and sound) cannot share the same intensive scale or be measured in common units. The sensory schema describes processes that vary only in intensity and extent along one property or dimension.

The Nature of Cognitive Operations

The framework reveals something profound: diverse operations—moving objects, adding quantities, dividing wholes—involve changes of intensity within a static framework. One operation, however, works in the opposite direction: differentiation increases the number of levels rather than changing their intensity, creating finer distinctions within the same extent.

6.2. The Operation of Level Differentiation

How does this paradoxical inward subdivision actually work? Differentiation involves generating finer levels uniformly distributed within a unit (for example, a cell or container). To maintain the same total extent of the unit while introducing finer levels, each new layer must be proportionally thinner. The procedure is illustrated in **Figure 6**, which shows the original single-level unit (**Figure 6a**) differentiated into three levels (**Figure 6b**).



(**a**) (**b**)

Figure 6. Differentiating levels within the unit. (**a**) depicts a container with one level. (**b**) shows how differentiating new levels affects layers and containers [5].

To ensure equal distances between these new levels, accumulated layers must be proportionally thinner relative to the height of the original unit. This in turn requires proportional subdivision of the container base so that the total sums to 1. Critically, differentiation as described here concerns logical or representational reasoning about sensory structure rather than alterations to the fixed physical array. This is a cognitive operation, not a physical transformation.

The cognitive process of differentiation generates fractional structure. Consider the differentiation to create three levels in **Figure 6b**. This process creates three nested levels ($0 < 1/3 < 2/3 < 3/3$), then three identical layers ($1/3 + 1/3 + 1/3 = 3/3$), and finally, the container base is proportionally divided ($1/3 + 1/3 + 1/3 = 1$ unit). In the process of adding layers to create new levels, we progress from containers to accumulated layers to resulting levels. In differentiation, we reverse this: starting with a desired level structure, we determine the necessary layer proportions, which then determine container subdivisions.

Both processes follow identical logic, but adding layers creates the sense of increase, while differentiation creates the impression of diminution, as each fractional level represents less than the whole.

Limits of Differentiation in Sensory Products

Unlike pure mathematical constructs, sensory-based cognition operates within biological constraints. Sensory products possess a dual structure consisting of levels and extents of a property, tied to biological structures such as receptive fields and cortical columns.

Levels can be differentiated arbitrarily finely through purely sensory operations (discrimination and simulation), approaching infinitesimally small differences between consecutive levels. As differentiation progresses, layers must subdivide accordingly to preserve the product structure—the 'intensity × extent' relationship that defines sensory experience. However, because layers are extensive structures with positive magnitude, their thickness cannot be reduced to zero—positive quantities cannot sum to zero, creating a logical contradiction. Consequently, layer extent imposes a fundamental limit on level differentiation.

A parallel constraint applies to containers: their spatial extent cannot be divided infinitely without individual units approaching zero, which would contradict the requirement for positive extent. Because intensity and extent are conflated in sensory products, these extensive limits on layers and containers impose limits on how finely we can differentiate intensity levels. This intuition parallels the mathematical concept of limits, where variables approach zero arbitrarily closely. However, unlike pure mathematics, sensory products must maintain positive extensive magnitude, creating a hard constraint rather than an asymptotic approach.

Finer level discrimination enables the extraction of more refined activation patterns through averaging—a process of combining multiple sensory inputs, discussed in the next section on integration.

7. Sensory Integration

The human sensory system confronts a fundamental constraint: unlimited incoming detail meets strictly limited memory resources. Every moment, millions of photoreceptors fire, thousands of mechanoreceptors respond to touch, and countless molecules trigger olfactory neurons. If the brain attempted to preserve each sensory signal as a distinct memory trace, storage capacity would be exhausted within seconds. Yet we navigate the world with apparent ease, recognizing faces, understanding speech, and recalling complex scenes. This paradox resolves through a universal cognitive process: the creation of sensory patterns.

Consider drawing a dollar bill from memory. Most people produce a rectangle with a crude portrait, "$1", and perhaps 5–10 symbolic elements total. Now consider artist Stephen Wiltshire (https://www.stephenwiltshire.co.uk/biography), who reproduces architectural cityscapes in extraordinary detail after a single helicopter flyover—perhaps 5000–10,000 symbolic elements. Yet examining his drawings closely reveals that his windows become schematic, his architectural details turn into symbolic shortcuts. Like our dollar bill, Wiltshire's images are fundamentally symbolic—just operating at vastly different granularity.

This reveals something crucial: the difference between ordinary and apparently "photographic" memory is one of degree, not kind. Both operate through pattern products at task-appropriate resolution. Wiltshire hasn't escaped pattern formation; he has developed extraordinarily fine-grained symbolic vocabulary and learned which patterns to preserve. Memory limitations don't determine whether we use patterns—pattern formation is universal—but rather what resolution we deploy.

Pattern formation thus enables both recognition and understanding. Without pattern products, matching current input to stored representations would demand comparing millions of intensity values—a computational impossibility. The child who learns "dog" extracts pattern products capturing commonalities while discarding intensity differences between Dalmatians and Dachshunds.

Sensory integration, then, is the set of processes by which the brain creates these essential patterns—bringing together multiple elements while managing their intensity relationships. The cognitive system employs three distinct integration processes managing intensity relationships along a spectrum: concatenation maintains separate intensities, averaging blends different intensities to an intermediate level, and summation preserves identical intensities while accumulating extent. I will now examine each process in detail.

7.1. Concatenation: The Foundation of Pattern Formation

Concatenation describes the foundational structure of sensory arrays, applying to both layers within containers and to containers themselves: there are no gaps between successive layers, and no gaps (discontinuities) between adjacent containers. Concatenated layers define continuous levels on the intensive scale. Concatenated containers define continuous space, creating the array within which products form. This gapless arrangement serves two complementary functions: Independence—content in each container is independent, ensuring variety and detailed representation; Interaction—despite independence, containers can affect adjacent units through averaging or summation, enabling pattern formation. Independence enables initial detail expression; then integration creates larger-scale patterns from local variations.

Concatenation is the most general form of integration: products maintain distinct intensities while occupying adjacent positions. I denote this as: $(a_1 \times b_1) \oplus (a_2 \times b_2) = (a_1 \times b_1, a_2 \times b_2)$, where $\oplus$ indicates concatenation.

Examples Across Domains:

Concatenation operates across representational systems with the same structural principle: products maintain distinct intensities while occupying adjacent positions.

- **Numbers**: $(100 \times 4) \oplus (10 \times 3) \oplus (1 \times 8)$ represents the numeral "438"—a concatenated structure with different intensities (100, 10, 1), not a sum. Mathematical algorithms interpret this positional structure as 438.
- **Speech**: Phonemes concatenate temporally: $(/k/ \times 1) \oplus (/æ/ \times 1) \oplus (/t/ \times 1)$ = "cat", each maintaining distinct acoustic identity.
- **Typography**: Letters concatenate spatially: $(c \times 1) \oplus (a \times 1) \oplus (t \times 1)$ = "cat", each maintaining distinct visual

shape.

- **Language**: Words concatenate semantically: (car × 1) ⊕ (park × 1) = "carpark", each maintaining distinct conceptual identity.
- **Music**: Notes concatenate melodically: (C × quarter) ⊕ (E × quarter) ⊕ (G × half), each maintaining distinct pitch and duration.

7.2. Averaging: Blending to Common Intensity

Averaging integrates products with different intensities by creating a weighted intermediate level. Unlike concatenation, which preserves distinct intensities, averaging produces uniform intensity across the combined extent. When products are averaged, we: (1) calculate the total contribution from each product (intensity × extent), (2) sum these contributions, (3) divide by the total extent to find the weighted average.

Consider combining juice batches: (80% × 2 cups) averaged with (40% × 3 cups) results in (56% × 5 cups). This demonstrates how averaging yields intermediate intensity reflecting both quantity and quality of components (see Section 6.1 Fundamental Operations). The resulting product has uniform intensity (56%) across the total extent (5 cups).

This cognitive simplification through averaging is illustrated in **Figure 4**, which shows an image of an apple represented as a mosaic of units: four areas of contrasting intensity (shades of gray) instead of a nearly infinite number of elements with different intensities. This dramatic reduction in complexity results from averaging local intensity variations into uniform regions, transforming detailed sensory input into manageable pattern products. Averaging can be applied sequentially (in pairs) or globally by removing internal walls and leaving external walls of the container group.

7.3. Summation: Accumulating Extent with Identical Intensity

True addition means accumulating extent while maintaining constant intensity—only possible when all products share the same intensity level: (5 × 4) + (5 × 2) = (5 × 6).

Intensity 5 is preserved while extents 4 and 2 accumulate to 6. This follows the principle of sensory idempotence: when products with the same intensity are added, the intensive aspect remains constant while extent accumulates.

Confusing Addition with Concatenation: Products with different intensities cannot be directly summed. Consider (100 × 4) ⊕ (10 × 3) ⊕ (1 × 8). These have different levels of intensities (100, 10, 1) — this is therefore concatenation, not summation. The expression "400 + 30 + 8=438" represents an algorithmic procedure applied to the concatenated structure, not a direct sensory sum. To achieve true summation, we must first convert all products to the same intensity level (e.g., the tally mark 'I' repeated 438 times. Each instance is a prompt, not a number, and all instances are concatenated).

Higher-Order Pattern Properties: Whether through averaging or summation, the patterns created through integration possess higher-order properties: they interlock with other patterns to form larger compositional structures, suggest functions and affordances for action, facilitate categorical recognition and classification, and enable inference of occluded or incomplete patterns. These issues are not explored in this article.

7.4. Sensory Integration

Analysis of human expressions reveals a fundamental pattern: experience is structured as products of intensity and extent. The sensory schema framework provides an interpretation of how these products combine, suggesting processes that differ markedly from mathematical algorithms yet arrive at equivalent results. Understanding this distinction illuminates the relationship between experiential structure and mathematical formalization.

7.4.1. Integration in the Sensory Schema: Simultaneous Averaging

The sensory schema theory interprets integration as simultaneous averaging of levels across arrays of units. Consider the container metaphor extended to multiple units. When two containers with different intensities combine, imagine removing the partition between them while preserving external walls—the contents blend instantly to produce uniform intensity across the combined extent.

Extending this to entire arrays: integration involves simultaneously "removing internal partitions" between all integrated units while maintaining the array's external boundaries. All intensities average together at once, weighted by their respective extents. This is not sequential computation building up piece by piece—it is simultaneous chemicallike interaction where total extent is preserved while the resulting intensity represents each unit's contribution. This total has direct experiential meaning: (Brightness × area) = total visual stimulation; (Loudness × duration) = total auditory experience; (Pressure × region) = total tactile sensation. The integrated result is not abstract calculation but lived magnitude—the "how much" of an entire experiential pattern captured in a single measure.

7.4.2. From Mathematical Formalization to Linguistic Simulation

Integration operates across a spectrum—from the highly formalized procedures of calculus to the implicit, simulation-based processes of language comprehension. Understanding this spectrum reveals how the intensity × extent pattern manifests in fundamentally different ways depending on the representational system.

Mathematical Integration: Explicit Sequential Procedure

Mathematical integration represents one extreme: a fully explicit, algorithmic procedure.

The Riemann sum approach exemplifies this: divide the domain into intervals (Δx), sample function values at points ($f(x_i)$), form products ($f(x_i)\times\Delta x_i$), sum these products, and refine through limits:

$$\int f(x)dx = \lim_{(\Delta x\to 0)} \Sigma\, f(x_i)\cdot\Delta x_i$$

This procedure is sequential—each step builds upon the previous, following precise rules. Every element is explicitly specified: interval boundaries, function values, multiplicative operations, summation procedures. Nothing is left implicit. The intensity × extent product structure (f(x) representing intensity, Δx representing extent) is preserved throughout, but rendered as formal algorithmic steps that must be executed in order.

Language: Triggering of Implicit Simulation

Language operates at the opposite extreme. Rather than explicit algorithmic procedures, linguistic expressions trigger automatic sensory simulations that unfold sequentially as the utterance progresses[16–18]. Consider hearing "The bright red surface":

- "bright red" → triggers visual simulation (color intensity, saturation)
- "surface" → extends simulation (spatial extent)

These simulations are not conscious constructions but automatic reactivations of sensory patterns. Each word provides minimal cues that guide simulation as it unfolds word-by-word, temporally sequential but not algorithmically procedural.

The sequential nature of linguistic simulation is crucial: simulation begins immediately with the first word and dynamically updates as each subsequent word arrives. Critically, each word triggers a complete intensity × extent product—the brain cannot simulate intensity alone without some extent, nor extent without some intensity level. When you hear "bright," you simulate brightness-of-something-extended, drawing on past experiences to supply the unspecified extent; conversely, hearing "surface" prompts extent-with-some-intensity, with brightness drawn from memory. Linguistic input may underspecify either factor, but simulation supplies both from prior experience—typical instances, salient examples, or memorable encounters—all formatted as intensity × extent products. Subsequent words refine and constrain the simulation, but each stage maintains the intensity × extent unity. This incremental simulation process has been documented extensively in embodied cognition research[14,16,17]. Eye movement studies demonstrate that sensory-semantic processing occurs rapidly during word recognition: fixation durations increase when words mismatch contextual expectations[19,20], and somatotopic activation patterns appear during action word processing[21,22]. These temporal dynamics support the claim that sensory simulations are triggered immediately and updated incrementally as linguistic input unfolds. Word selection research similarly shows that accessing semantically richer or more sensory-specific terms requires additional processing time[23,24], consistent with the proposal that intensity × extent simulations vary in specificity and must align with context.

Radical Underspecification and Simulation

The sequential triggering of simulation enables—indeed requires—radical underspecification in linguistic expression. Words don't encode sensory details; they cue simulations that listeners' sensory systems complete automatically.

"Bright red surface" provides minimal specification: No exact wavelength, saturation, or luminance values; No specific surface area, shape, or texture; No viewing angle, lighting conditions, or spatial context. Yet listeners effortlessly simulate a rich sensory experience. How? Because sensory systems automatically fill in unspecified details based on prior experience. Language exploits this capacity: rather than encoding everything explicitly (as mathematical notation does), language provides strategic cues that trigger simulation, relying on listeners' sensory systems to supply the rest.

This underspecification isn't a limitation—it's what makes language efficient. If language had to specify every sensory detail explicitly (as calculus specifies every computational step), communication would become impossibly cumbersome. Instead, language leverages the listener's ability to simulate, providing just enough information to guide simulation while leaving specific sensory qualities to be filled in automatically.

The intensity × extent pattern operates in both systems but manifests differently:

- **Mathematics**: explicitly specifies intensity functions and extent measures, requiring sequential algorithmic computation
- **Language**: provides minimal cues to intensity and extent, triggering sequential simulation that implicitly integrates sensory patterns

Both are sequential, but mathematics achieves integration through explicit procedure while language achieves it through implicit simulation. This contrast reveals that the sensory schema—the fundamental intensity × extent pattern—can be realized through radically different mechanisms depending on whether the system prioritizes formal explicitness (mathematics) or efficient communication (language).

Understanding language as sensory simulation rather than symbolic computation helps explain phenomena that otherwise seem puzzling: why language seems so imprecise yet communication succeeds, why context matters so profoundly, why the same words trigger different simulations for different listeners. Language doesn't encode meaning—it triggers the simulation of sensory experiences, and those simulations automatically integrate intensity and extent patterns even when language leaves them radically underspecified.

7.5. Empirical Predictions and Applications

The sensory schema framework generates testable predictions for empirical research. If word selection is guided by sensory simulations structured as intensity × extent products, several patterns should emerge in behavioral and eye movement studies:

- **Response time predictions**: Selecting words with high sensory specificity (e.g., "scarlet" vs. "red") should take longer when the prompted simulation conflicts with sentential context, as the intensity × extent pattern must be adjusted. Word selection research has demonstrated that semantically richer terms require additional processing[23,25], consistent with the simulation-updating process proposed here.
- **Eye movement predictions**: Fixation durations should increase when intensity or extent mismatches occur between words and context. Research on contextual effects during reading[19,20] shows that semantic violations produce longer fixations and regressions, supporting the view that readers continuously update sensory simulations to maintain coherence.

Beyond word processing, the framework has broader implications. In language acquisition, understanding that meaning arises from sensory simulations rather than symbolic definitions suggests pedagogical approaches emphasizing experiential grounding. In computational linguistics, modeling semantic representation as intensity × extent products could improve word embeddings and generation systems. Clinically, the framework offers insights into language disorders where sensory-semantic connections are disrupted, potentially informing assessment and intervention strategies. Cross-linguistically, examining how different languages encode intensity and extent patterns could reveal universal constraints on semantic structure.

These applications demonstrate that while the sensory schema is a theoretical framework, it connects systematically to empirical phenomena and practical concerns across multiple domains.

8. Conclusion: From Sensation to Knowledge

Building on previously published work[5–8,26], this article presents a unified sensory schema framework. Like archaeologists reconstructing past societies from artifacts, this study reconstructs cognitive structures by analyzing diverse forms of human expression across multiple domains.

It begins with a fundamental premise: human individuals experience sensations—not the molecular or neural mechanisms that produce them. By analyzing consistent patterns across diverse expressions—language, mathematics, science, art, and everyday behavior—a recurring structure emerges: the interplay between nested intensity (the qualitative "how much" within units) and concatenated extent (the quantitative "how many" across units). This orthogonal relationship—intensity × extent—structures experience from immediate sensations to abstract concepts.

8.1. Implications for Cognitive Linguistics

The cross-domain consistency documented here provides empirical support for cognitive linguistics' core claim that embodied experience structures conceptual knowledge[3,13]. When the same intensity × extent pattern appears in linguistic expressions ("bright red surface"), mathematical notation (∫f(x)dx), visual composition, and musical structure, this demonstrates that cognitive linguistics has identified genuine features of cognition rather than linguistic conventions. The patterns cognitive linguistics documents within language manifest across representational systems because all draw on common cognitive foundations rooted in sensory experience.

Perhaps most significantly, the sensory schema addresses a fundamental gap in embodied cognition theory: it proposes the mechanism by which embodiment and experientialism might actually operate. While cognitive linguistics has documented conceptual metaphors and image schemas extensively, the field has not fully explained how bodily experience structures conceptual knowledge—what organizational principles in experience itself make certain patterns productive for cognition. The sensory schema proposes a specific answer: sensory experience is inherently structured as 'intensity × extent' products, and this structure provides the template for organizing knowledge across domains. This moves beyond cataloging embodied patterns to understanding why embodiment works as it does.

The framework thus validates and extends cognitive linguistics' insights, showing that image schemas and conceptual metaphors reflect how sensory experience itself is organized. Language makes these patterns explicit and accessible for analysis, but they operate across all domains where humans structure knowledge.

8.2. Future Directions

Further research could address: cross-cultural validation of these patterns, developmental patterns showing how product structure emerges in children acquiring different symbolic systems, neural correlates of simultaneous integration processes, computational implementations based on product architecture, and psycholinguistic testing of whether processing abstract concepts activates sensory systems as the intensity-extent structure predicts. The framework also generates specific predictions for word selection research: if choosing words is guided by sensory simulations, response time and eye movement studies should reveal processing delays when intensity × extent patterns mismatch sentential context[19,23,25]. Beyond empirical investigation, the framework offers applications in language pedagogy (emphasizing experiential grounding in vocabulary instruction), computational linguistics (modeling semantic representations as intensity × extent products), and clinical assessment (understanding language disorders involving disrupted sensory-semantic connections).

Understanding how sensation structures knowledge through the intensity-extent product reveals not just what patterns exist, but why these particular patterns prove so fundamental to human cognition. The sensory schema thus offers cognitive linguistics what embodiment theory has long promised but not fully delivered: an account of the cognitive architecture that makes embodied meaning possible.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Conflicts of Interest

The author declares no conflict of interest.

References

[1] Barsalou, L.W., 1999. Perceptual symbol systems. Behavioral and Brain Sciences. 22(4), 577–660.
[2] Lakoff, G., Johnson, M., 1980. Metaphors We Live By. University of Chicago Press: Chicago, IL, USA.
[3] Lakoff, G., Johnson, M., 1999. Philosophy in the Flesh: The Embodied Mind and Its Challenge to Western Thought. Basic Books: New York, NY, USA.
[4] Johnson, M., 1987. The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason. University of Chicago Press: Chicago, IL, USA.
[5] Raykowski, W., 2018. Layers and levels: What a column of water tells us about human cognition. Cognitive Semantics. 4(1), 104–133. DOI: https://doi.org/10.1163/23526416-00401005
[6] Raykowski, W., 2019. Is there such a thing as orthogonyms? Cognitive Semantics. 5(2), 201–226. DOI: https://doi.org/10.1163/23526416-00502002
[7] Raykowski, W., 2022. Sensory schema: From sensory contrasts to antonyms. Cognitive Semantics. 8(2), 240–274. DOI: https://doi.org/10.1163/23526416-bja10027
[8] Raykowski, W., 2014. Conceptual Understructure of Human Experience: Volume 1 – Thesis. CreateSpace: North Charleston, SC, USA.
[9] Evans, V., Green, M., 2006. Cognitive Linguistics: An Introduction. Lawrence Erlbaum Associates: London, UK; Edinburgh University Press: Edinburgh, UK.
[10] Paradis, C., 2008. Configurations, construals and change: Expressions of degree. English Language and Linguistics. 12(2), 317–343.
[11] Mandler, J.M., 2004. The Foundations of Mind: Origins of Conceptual Thought. Oxford University Press: Oxford, UK.
[12] Langacker, R.W., 1987. Foundations of Cognitive Grammar, Vol. 1: Theoretical Prerequisites. Stanford University Press: Stanford, CA, USA.
[13] Gibbs, R.W., 2006. Embodiment and Cognitive Science. Cambridge University Press: Cambridge, UK.
[14] Bergen, B.K., 2012. Louder Than Words: The New Science of How the Mind Makes Meaning. Basic Books: New York, NY, USA.
[15] Talmy, L., 2000. Toward a Cognitive Semantics, Volume II. MIT Press: Cambridge, MA, USA.
[16] Zwaan, R.A., Taylor, L.J., 2006. Seeing, acting, understanding: Motor resonance in language comprehension. Journal of Experimental Psychology: General. 135(1), 1–11.
[17] Kaschak, M.P., Glenberg, A.M., 2000. Constructing meaning: The role of affordances and grammatical constructions in sentence comprehension. Journal of Memory and Language. 43(3), 508–529.
[18] Gallese, V., Lakoff, G., 2005. The brain's concepts: The role of the sensory-motor system. Cognitive Neuropsychology. 22(3–4), 455–479.
[19] Kambe, G., Rayner, K., Duffy, S.A., 2001. Global context effects on processing lexically ambiguous words: Evidence from eye fixations. Memory & Cognition. 29(2), 363–372. DOI: https://doi.org/10.3758/BF03194931
[20] Rayner, K., 1998. Eye movements in reading and information processing: 20 years of research. Psychological Bulletin. 124(3), 372–422. DOI: https://doi.org/10.1037/0033-2909.124.3.372
[21] Hauk, O., Johnsrude, I., Pulvermüller, F., 2004. Somatotopic representation of action words in human motor and premotor cortex. Neuron. 41(2), 301–307. DOI: https://doi.org/10.1016/S0896-6273(03)00838-9
[22] Pulvermüller, F., 2005. Brain mechanisms linking language and action. Nature Reviews Neuroscience. 6(7), 576–582. DOI: https://doi.org/10.1038/nrn1706
[23] Altarriba, J., Bauer, L.M., 2004. The distinctiveness of emotion concepts: A comparison between emotion, abstract, and concrete words. American Journal of Psychology. 117(3), 389–410.
[24] Vigliocco, G., Vinson, D.P., Lewis, W., et al., 2004. Representing the meanings of object and action words: The featural and unitary semantic space hypothesis. Cognitive Psychology. 48(4), 422–488. DOI: https://doi.org/10.1016/j.cogpsych.2003.09.001
[25] Levelt, W.J.M., Roelofs, A., Meyer, A.S., 1999. A theory of lexical access in speech production. Behavioral and Brain Sciences. 22(1), 1–38. DOI: https://doi.org/10.1017/S0140525X99001776
[26] Raykowski, W., 2024. From sensations to contrast, opposition and numbers. Forum for Linguistic Studies. 6(4), 231–253. DOI: https://doi.org/10.59400/fls.v6i4.6780