

tanks. Although the matches that represent the tanks may not themselves be iconic with respect to the tanks, the spatial attributive structure into which they are fitted is certainly iconic. Referential applications are applied within a structure that is iconically related to the array of particulars that the referential applications function to pick out. For perceptual representation, iconicity is centrally a feature of the attributives—property, kind, and relational attributives.

Since being iconic is not in itself being representational, perceptual representation's being iconic depends on there being non-representational aspects of perceptual attribution. What are the non-representational features that make perception's iconic representation possible? The primary features are geometrical or topographical, temporal, and qualitative.

Iconic Aspects of Perceptual Spatial Representation

Spatial structure is by far the most thoroughly studied non-representational natural feature used in iconic perceptual representation. Many philosophers have ridiculed the idea of a picture in the mind. They base the ridicule partly on the correct point that perceptual state kinds do not literally have spatial extension. Modern perceptual theory does not attribute the literal spatiality of pictures to perception. Representational contents are abstract psychological kinds. They are not laid out in space. Yet perceptual theory does take visual and tactile perception to be spatially iconic.³⁰⁵ Aspects of matrix-like or picture-like format of perceptual content are attributed in models of perceptual representation. Such aspects can be mapped geometrically to spatial structures in the environment. The mapping preserves, in the format of perceptual representational content, analogs of environmental spatial structure. The pure geometry that applies to perceptual representational content derives from the geometry of physical space. Geometrical and topological structures are natural, non-representational aspects of perceptual representation. The structure of normal perceptual representational content is topological, even if not specifically spatial. The structure of both the spatial subject matter and the perceptual representational content can be described in pure geometry or topology. Thus an edge element in a perceptual content represents and can be mapped to an edge in the environment. Parts of the edge element represent parts of the edge in the environment. Directional—say, left-right—relations in the percept correspond to directional relations in the scene.

Such mapping occurs in conscious experience. One can block light from the lower half of one's eye. One thereby blocks representation of the lower part of the scene. Similarly, for the upper, the left, the right, and smaller parts of one's eye. There is a systematic correspondence between spatial aspects of one's receptive apparatus, spatial aspects of the perceived environment, and spatial aspects of one's perceptual representation of the

³⁰⁵ For useful discussions of why postulating iconic representations is not subject to the common ridicule of postulating literal pictures in the head, see S. Kosslyn, S. Pinker, G. Smith, and S. Schwartz, 'On the Demystification of Mental Imagery', *The Behavioral and Brain Sciences* 2 (1979), 535–581; R. Finke, S. Pinker, and M. Farah, 'Reinterpreting Visual Patterns in Mental Imagery', *Cognitive Science* 13 (1987), 73–74; M. Rescorla, 'Cognitive Maps and the Language of Thought', *British Journal of the Philosophy of Science* 60 (2009), 377–407.

environment. No similar mappings occur between words in a non-iconic sentence and spatial subject matters of the words.³⁰⁶

The intuitive point is elaborated in perceptual theory. The abstract topology of perceptual representational content has derivative mathematical association with literal topologies in the brain, and thence to spatial positions of areas of surfaces in the environment. For example, neural activity in the cortical area that connects to retinal receptors that receive light from the upper right corner of the retinal image correlates with aspects of conscious perception that represent the upper right corner of the visual perception of space (and represents entities in the upper right corner of the spatial layout of the scene). Even if consciousness and perceptual content are not literally laid out in space, there is a geometrical or topological structure-preserving mapping between aspects of space and aspects of conscious visual representation of space.

The iconic nature of visual spatial *representation* and *representational content* is grounded in the iconic nature of visual *sensory information registration* and in the spatial layout of aspects of the central brain that correspond to space-mapping areas in visual perception.

Four factors—visual representational content, visual non-representational information registration, cortical central brain areas that underlie spatial perception, and visual receptors—figure in the discussion. All ground either iconic information registration or iconic spatial representation. All are structurally related. The physical layout of the visual receptors renders the registration of information from the retinal image iconic. The iconic registration of the retinal image has mappings into the central brain. These registrational mappings are also iconic. Both mappings help make visual representation in perceptual states (and their representational contents) iconic. The mapping of geometric or topological structures common to physical space, visual receptors, visual information registration by banks of retinal and cortical neurons, and the format of visual representational content lies at the base of the iconic nature of visual spatial perception.

I start with the spatial structure of sensory receptors (at least in vision and touch). Such receptors form a 2-D array in physical space. In vision, each receptor is associated with a certain spatial part of the retinal image—the 2-D array of light that constitutes the proximal stimulus.³⁰⁷

This 2-D layout is preserved in neural layouts in the cortex, layouts specialized for vision. Areas of the primary visual cortex (V1) and other brain areas associated with early stages of visual processing are specialized to respond to corresponding areas of the retinal receptors and retinal image (the proximal stimulus).³⁰⁸ Thus, the *sensory information registration* of proximal stimuli in the early stages of vision has a literal spatial arrangement that corresponds, in vision, to the spatial arrangement of the retinal image. The spatial information registered by the sensors and by the further registrational states in the cortex that derive from them is laid out in spatial matrixes. The matrixes bear literal,

³⁰⁶ For an intuitive rendering of the idea that perceptual representation has a matrix-like format, see Peacocke, *A Study of Concepts*, chapter 3.

³⁰⁷ D. Hubel and T. Wiesel, 'Receptive Fields and Functional Architecture in Two Nonstriate Visual Areas (18 and 19) of the Cat', *Journal of Neurophysiology* 28 (1965), 229–289; S. Engel, G. Glover, and B. Wandell, 'Retinotopic Organization in Human Visual Cortex and the Spatial Precision of Functional MRI', *Cerebral Cortex* 7 (1997), 181–192; B. Wandell, S. Dumoulin, and A. Brewer, 'Visual Field Maps in Human Cortex', *Neuron* 56 (2007), 366–383.

³⁰⁸ Frisby and Stone, *Seeing: The Computational Approach to Biological Vision*, chapters 3, 8.

systematic relations to positions in the retinal image—the area of light hitting the retinae. These non-perceptual registrations are unquestionably iconic.

The notion of a *visual field map* is a technical notion in vision science. It applies to layouts of neural receptors in retinal, sub-cortical, and cortical areas of visual processing. A visual field map must meet three conditions.

First, a region of neural receptors should register, or ground representation of, a substantial portion of the retinal image or an environmental layout. The qualification ‘substantial portion’ is entered to allow for the fact that visual field maps do not register each part of whatever they register with equal surface area. Some visual field maps in V1, the earliest cortical area specialized for visual processing, are oriented primarily to foveated parts of the retinal image.

Second, a visual field map must register a substantial part of what it registers in a way that preserves spatial structure. The map should be roughly continuous. Distance from the center of the map should vary roughly continuously with distance (the eccentricity) from the center of the registered entity—for example, the retinal image. Directions from the center of the map (the angle dimensions) should vary roughly continuously from directions from the center of the registered entity. ‘Roughly’ allows for discontinuities. For example, it allows for discontinuities between the two hemispheres of the human brain that divide registration of the left and right sides of the retinal image. Many discontinuities bear on the border of a map. Some occur within maps.

Third, the basic features of a field map must be roughly consistent across individual subjects—though maps often vary across individuals in size and precise anatomical location.³⁰⁹

There is massive evidence for mapping from the spatial layout of registrational sensors that underlie the early stages of visual processing to areas of the retinal image. The retinal receptors, layouts in the lateral geniculate nucleus (LGN), and many layouts in all the cortical areas (V1–V3) that support early visual processing, all constitute visual field maps.³¹⁰ Since there are hundreds of V1 neurons for every ganglion cell or LGN relay neuron, there is room in V1 for many specialized maps, each mapping the retinal image, each functioning to carry its own task. Numerous species have multiple retinotopic maps in each early processing area, such as V1.³¹¹

³⁰⁹ The conditions are laid out in Wandell, Dumoulin, and Brewer, ‘Visual Field Maps in Human Cortex’, 370. I have generalized their formulations slightly.

³¹⁰ Engel, Glover, and Wandell, ‘Retinotopic Organization in Human Visual Cortex and the Spatial Precision of Functional MRI’; R. Dougherty, V. Koch, A. Brewer, B. Fischer, J. Modersitzki, and B. Wandell, ‘Visual Field Representations and Locations of Visual Areas V1/2/3 in Human Visual Cortex’, *Journal of Vision* 3 (2003), 586–598; Wandell, Dumoulin, and Brewer, ‘Visual Field Maps in Human Cortex’; M. Silver and S. Kastner, ‘Topographic Maps in Human Frontal and Parietal Cortex’, *Trends in Cognitive Sciences* 13 (2009), 488–495; Wandell and Winawer, ‘Imaging Retinotopic Maps in the Human Brain’.

³¹¹ A. Cowey, ‘Projection of the Retina on to Striate and Prestriate Cortex in the Squirrel Monkey, *Saimiri sciureus*’, *Journal of Neurophysiology* 17 (1964), 366–393; A. Cowey, ‘Aspects of Cortical Organization Related to Selective Attention and Selective Impairments of Visual Perception: A Tutorial Review’, in M. Posner and O. Marin eds., *Attention and Performance XI* (Hillsdale, New Jersey: Erlbaum, 1985); R. Gattass, A. Sousa, and M. Rosa, ‘Visual Topography of V1 in the Cebus Monkey’, *Journal of Comparative Neurology* 259 (1987), 529–548; R. Gattass, S. Nascimento-Silva, J. Soares, B. Lima, A. Jansen, A. Diogo, M. Farias, M. Botelho, O. Mariani, J. Azzi, and M. Fiorani, ‘Cortical Visual Areas in Monkeys: Location, Topography, Connections, Columns, Plasticity and Cortical Dynamics’, *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 360 (2005), 709–731; G. Wang and A. Burkhalter, ‘Area Map of Mouse Visual Cortex’, *Journal of Comparative Neurology* 502 (2007), 339–357; W. Geisler, ‘Visual Perception and the Statistical Properties of Natural Scenes’, *American Review of Psychology* 59 (2008), 167–192, 183; B. Wang, H. Yamamoto, J. Wu, and Y. Ejima, ‘Visual Field (cont.)

Until the last 30 years, it was widely thought that visual field maps were located entirely in early visual areas. This view depended partly on inadequate technology for testing the later visual areas, for example, from V4 onward. It also depended on reasoning by psychologists that since the higher areas supported spatial constancies, visual representation was “position invariant”. So, went the reasoning, one should not expect field maps in those areas.

The view also probably depended on not taking into account discoveries in the late 1970s of neural maps in the barn owl that correlate with spatial positions in *distal* environmental space, and that also correlate with the owl’s spatial perceptual competencies.³¹²

Better technology found many maps in the higher visual areas in humans. Many of these maps play a role in mapping the environmental positions of perceptually represented entities, as contrasted with maps that merely register positions in the retinal image.³¹³

The reasoning by psychologists, cited four paragraphs back, was unsound. A given area of a brain map can be active in response to a position in distal environmental space, or can otherwise aid in representation of a position in space. It can support a representation of something in that position via an egocentrically (or even allocentrically) anchored map. The discovery of maps that figure in *perceptually* mapping the distal environment is perhaps most important development in neuroscience’s visual-field mapping in the last 30 or so years.³¹⁴

Sensitivity to *retinal* position is not lost among maps that figure in representing spatial structures in the distal environment. That is, even where a map figures in representing the distal position of a perceived entity, there is evidence that retinal position of the effect of the perceived entity is kept track of, either in that map or in some other map with which that map coordinates.³¹⁵

Maps of the Human Visual Cortex for Central and Peripheral Vision, *Neuroscience and Biomedical Engineering* 1 (2013), 102–110; Wandell and Winawer, ‘Imaging Retinotopic Maps in the Human Brain’.

³¹² E. Knudsen, and M. Konishi, ‘A Neural Map of Auditory Space in the Owl’, *Science* 200 (1978), 795–797; E. Knudsen, ‘Auditory and Visual Maps of Space in the Optic Tectum of the Owl’, *Journal of Neuroscience* 2 (1982), 1177–1194. The owl has auditory and spatial maps of positions in distal environmental space, each of which feeds a further bimodal map.

³¹³ C. Galletti, P. Battaglini, and P. Fattori, ‘Parietal Neurons Recording Spatial Locations in Craniotopic Coordinates’, *Experimental Brain Research* 96 (1993), 221–229, reported an early discovery of neurons that correlate with real positions in space, determined in perceptual spatial constancies. See also N. Logothetis, J. Pauls, and T. Poggio, ‘Shape Representation in the Inferior Temporal Cortex of Monkeys’, *Current Biology* 5 (1995), 552–563; DeAngelis and Newsome, ‘Organization of Disparity-Selective Neurons in Macaque Area MT’; N. Swindale, D. Shoham, A. Grinvald, T. Bonhoeffer, and M. Hübener, ‘Visual Cortex Maps are Optimized for Uniform Coverage’, *Nature Neuroscience* 3 (2000), 750–752; D. Chklovskii and A. Koulakov, ‘Maps in the Brain: What Can We Learn from Them?’, *Annual Review of Neuroscience* 27 (2004), 369–392; S. Murray, H. Boyaci, and D. Kersten, ‘The Representation of Perceived Angular Size in Human Primary Visual Cortex’, *Nature Neuroscience* 9 (2006), 429–434; S. MacEvoy and R. Epstein, ‘Position Selectivity in Scene- and Object-Response Occipitotemporal Regions’, *Journal of Neurophysiology* 98 (2007), 2089–2098; A. McKyton and E. Zohary, ‘Beyond Retinotopic Mapping: The Spatial Representation of Objects in the Human Lateral Occipital Complex’, *Cerebral Cortex* 17 (2007), 1164–1172; Wandell, Dumoulin, and Brewer, ‘Visual Field Maps in Human Cortex’; Silver and Kastner, ‘Topographic Maps in Human Frontal and Parietal Cortex’; T. Carlson, H. Hogendoorn, H. Fonteijn, and F. Verstraten, ‘Spatial Coding and Invariance in Object-Selective Cortex’, *Cortex* 47 (2011), 14–22; Carlson, Hogendoorn, Kanai, Mesik, and Turret, ‘High Temporal Resolution Decoding of Object Position and Category’; B. Barton and A. Brewer, ‘Visual Field Map Clusters in High-Order Visual Processing: Organization of V3A/V3B and a New Cloverleaf Cluster in the Posterior Superior Temporal Sulcus’, *Frontiers in Integrative Neuroscience* 11 (2017), <https://doi.org/10.3389/fnint.2017.00004>.

³¹⁴ Wandell and Winawer, ‘Imaging Retinotopic Maps in the Human Brain’.

³¹⁵ Z. Kourtzi and N. Kanwisher, ‘Representation of Perceived Object Shape by the Human Lateral Occipital Complex’, *Science* 293 (2001), 1506–1509; J. DiCarlo and D. Cox, ‘Untangling Invariant Object Recognition’, *Trends in Cognitive Sciences* 11 (2007), 333–341; MacEvoy and Epstein, ‘Position Selectivity in Scene- and Object-Response Occipitotemporal Regions’; Carlson, Hogendoorn, Fonteijn, and Verstraten, ‘Spatial Coding and

Visual perception is always from a perspective that is marked by the way perceived objects affect our sensors. Retinal position almost inevitably affects mode of presentation.

These points support the double-indexing method that I employed in developing the form of perceptual representational contents. (See Chapter 7, the section *THE FORM OF PERCEPTUAL ATTRIBUTIVES IN LINKAGES*.) An attributive is constitutively as of an attribute. Different attributives can indicate, and attribute, the same attribute. The way in which the attribute is represented, which depends largely on the retinal source of the representation, is constitutive of a representation. Different attributives that indicate the same entity do so through a perspective that is marked by features—prominently spatial features—of the entity's effect on the retina.

Spatial and feature-based attention, both their initiations or commands and their effects—are grounded in visual field maps. Not surprisingly, the mechanisms of visual attention coordinate with the visual field maps that support perceptual processing.³¹⁶

So far, I have discussed visual maps at the neural level. What bases are there for taking neural maps, which are not themselves representational, to bear on the format of visual representational contents—that is, with kinds of perceptual representational competencies? Of course, it is immensely plausible, antecedent to specific evidence, that the functions and causal relations involved in visual perception capitalize upon, or show the marks of, the underlying neural maps. Specific evidence backs this natural expectation.

There are systematic correlations between activity in neural areas and perceptual functions. Such correlations are specific enough to connect features of the visual field maps with corresponding features of perceptual representation.

Stimulation that yields directional change in a neural visual map, or that affects a position in a neural map, corresponds with perceptual representations (and behavioral responses) in the corresponding direction or position.³¹⁷ (I assume here, what I have repeatedly emphasized in earlier chapters, that direction is not *represented* perceptually unless it is combined with ordinal depth or with distance in a 3-D mapping.) Similarly, perception of motion and experience of motion aftereffects correlate with direction of changes in underlying firings across neural visual field maps.³¹⁸ In binocular rivalry, changes in perceptual dominance from one eye to the other commonly correspond to directional waves of firing across a V1 map.³¹⁹

Crowding is a degradation of perceptual representation by nearby distal stimuli. Crowding appears to be determined by spacing between stimuli on visual field maps. So

Invariance in Object-Selective Cortex'; Cichy, Chen, and Haynes, 'Encoding the Identity and Location of Objects in Human LOC.'

³¹⁶ S. Astafiev, G. Shulman, C. Stanley, A. Snyder, D. Van Essen, and M. Corbetta, 'Functional Organization of Human Intraparietal and Frontal Cortex for Attending, Looking, and Pointing', *Journal of Neuroscience* 23 (2003), 4689–4699; J. Maunsell and S. Treue, 'Feature-Based Attention in Visual Cortex', *Trends in Neurosciences* 29 (2006), 317–322.

³¹⁷ T. Albright, 'Direction and Orientation Selectivity of Neurons in Visual Area MT of the Macaque', *Journal of Neurophysiology* 52 (1984), 1106–1130; C. Salzman, K. Britten, and W. Newsome, 'Cortical Microstimulation Influences Perceptual Judgements of Motion Direction', *Nature* 346 (1990), 174–177; C. Salzman, C. Murasugi, K. Britten, and W. Newsome, 'Microstimulation in Visual Area MT: Effects on Direction Discrimination Performance', *Journal of Neuroscience* 12 (1992), 2331–2355.

³¹⁸ A. Ezzati, A. Golzar, and A. Afraz, 'Topography of the Motion After-Effect With and Without Eye Movements', *Journal of Vision* 8 (2008), 1–16.

³¹⁹ S. Lee, R. Blake, and D. Heeger, 'Traveling Waves of Activity in Primary Visual Cortex During Binocular Rivalry', *Nature Neuroscience* 8 (2005), 22–23.

there is a relatively direct correspondence between proximity in the neural maps and perceptual spatial representation of close-by stimuli, retinal and distal.³²⁰

Shifts of attention correlate with such shifts in receptive fields of neurons in visual field maps. These shifts have been shown to have systematic effects on perceptual representation of size, such as an increase of the perceived size of attended stimuli. The shifts in size are of entities in positions that relevant neurons respond to. Such systematic relations between functions of neurons that constitute spatially specific components in map-like neural registration of spatial properties (distal as well as proximal), on one hand, and perceptual representation of spatial properties, on the other, indicates that the format and representational capacities in the visual representation of spatial structures parallel spatial structures in the visual field maps.³²¹

Damage to areas of a neural map produces deficits in spatial representation that correlate with the damaged areas. Given that the brain can produce remappings after such damage and given that there are often many “back up” maps that can compensate for local damage to a map, there is no simple inference from an area of neural map damage to a spatial area for which visual perception shows a deficit. However, allowing for such complexities, there are mappings between areas in a neural map where there is damage and corresponding spatial perceptual deficits. The mappings indicate a topographical format for visual perception.³²²

Psychologists working in these areas assume that these mappings between visual field maps in the brain and perceptual spatial representation are vastly more extensive than the cases that are now known, of which I have cited just a small sample. The fact that there are so many topographically organized neural maps and the limitations of current techniques in identifying and measuring them make investigating these relationships complex and slow-moving.³²³

The role of spatial structure in determining iconic aspects of visual perception goes much further than a natural correspondence between the geometrical or topological structure of perceptual content and the layout of perceptual objects in space. Accounts of perceptual representation of specific spatial attributes in 3-D space use geometrical characteristics of edges and lines that are imprinted, 2-D, in retinal registration.³²⁴ The accounts are explicitly in geometrical or topological form. Patterns of local lengths and orientations of registration of edges in the (literally) spatial layout of the retinal image are used by the visual system in making estimates of larger patterns in physical space. The repeatable, ability-general representational content is taken explicitly, in the science, to have a geometrical or topological structure.

More specifically, neural receptors are sensitive to the directional orientation of bars, edges, and other patterns in the retinal image, at various spatial scales. Recall from

³²⁰ D. Pelli, ‘Crowding: A Cortical Constraint on Object Recognition’, *Current Opinion in Neurobiology* 18 (2008), 445–451.

³²¹ K. Anton-Erxleben, C. Henrich, and S. Trueue, ‘Attention Changes Perceived Size of Moving Visual Patterns’, *Journal of Vision* 7 (2007), 1–9. I discuss philosophical implications of attention’s distorting effects in Chapter 15, the section ATTENTION AND ACCURACY.

³²² J. Kaas, ‘Topographic Maps are Fundamental to Sensory Processing’, *Brain Research Bulletin* 44 (1997), 107–112.

³²³ Wandell and Winawer, ‘Imaging Retinotopic Maps in the Human Brain’, 725.

³²⁴ One can get a sense of the power of conversion from patterns among local surface shapes to representation of 3-D shapes from the op-art pictures of Bridget Riley. See image search results for “Bridget Riley”.

Chapter 3, the section *RETINAL IMAGE CONTOUR REGISTRATION AND SURFACE CONTOUR PERCEPTION*, that an edge in the registration of the retinal image is marked by a line of neurons that fire at a much higher intensity than a line of adjacent neurons. Among central cues to representation of spatial attributes of environmental edges, shadows, and textural features of surfaces—attributes such as slant and tilt—are patterns among lengths and orientations of edges in registrations of the 2-D retinal image.

For example, a pattern of lines in the initial registration of the retinal image that grows progressively smaller at the top of a pattern, in comparison to the bottom, might be a cue to foreshortening that would indicate a backward slant of a surface. Or a pattern of lines that grows progressively shorter in a pattern from left to right might be a cue to surface tilt.

The patterns are present in a perceptual representation. At *perceptual* stages of processing they are given content that represents features of entities in 3-D physical space. For example, the lines might represent textural features on a surface with an orientation. Or they may represent the contours of the facing part of a body. Other cues are relevant—shadows, consistency with occurring within surface boundaries, binocular disparity. Patterns of geometrical characteristics in registrations that come from pre-representational stages of vision (and that can be directly correlated with spatial patterns among neuronal firings) are a *central* cue to computations of perceptual representational content that attributes 3-D volume shapes in the environment.

Roughly, a pattern of lines in a plane takes on 3-D meaning, in something like the way in which the lines in a drawing are used to represent shapes in 3-D space. Again, science takes the percept—hence its representational content—to have a geometrical structure that has systematic, natural, iconic, mappings to structures in physical space.

The science's theory and practice take the structure and these aspects of the content of visual representation to be systematically analogous to structure and content in drawings or other pictures.³²⁵ Again, the representation's being iconic does not hinge on its being in space. It is enough that it have a geometrical or topological structure that has a natural mapping to spatial structures. The idea that visual spatial representation occurs in a map-like format that bears systematic relations to underlying neural visual field maps is well supported. This is the format of spatial and temporal frameworks described in Chapter 7, the section *MINIMALISM AND ICONIC REPRESENTATION IN A SPATIAL COORDINATE SYSTEM* and in Chapter 8, the section *EGOCENTRIC SPATIAL INDEXES IN PERCEPTION*. Work in the psychophysics of vision repeatedly relies on the idea.

So the iconic nature of visual spatial representational content is grounded in the layout of visual receptors and in the layout of the environment. It is also grounded in the iconic nature of visual information registration in the central brain that corresponds to space-mapping areas in visual perception. All five factors—visual spatial representation, visual information registration in brain areas that underlie spatial perception, information

³²⁵ E. Mingolla and J. Todd, 'Perception of Solid Shape from Shading', *Biological Cybernetics* 53 (1986), 137–151; J. Koenderink, A. Van Doorn, and A. Kappers, 'Surface Perception in Pictures', *Perception and Psychophysics* 52 (1992), 487–496; Knill, 'Surface Orientation from Texture: Ideal Observers, Generic Observers, and the Information Content of Texture Cues'; Murray, Boyaci, and Kersten, 'The Representation of Perceived Angular Size in Human Primary Visual Cortex'; Silver and Kastner, 'Topographic Maps in Human Frontal and Parietal Cortex'; R. Fleming, D. Holtzman-Rice, and H. Bülthoff, 'Estimation of 3D Shape from Image Orientations', *Proceedings of the National Academy of Sciences USA* 108 (2011), 20438–20443.

registration in pre-perceptual areas (including visual receptors), the retinal image, and spatial aspects of the distal environment—are structurally related. The physical layout of the visual receptors renders information registration of the retinal image iconic. The registration of the retinal image has mappings into registration states in the central brain. Both bear mapping relations to visual perceptual representation. These natural mappings of geometric or topological structures among levels of information registration and spatial perception are each mappable to spatial structures in the retinal image and the distal environment. These mappings are natural, not representational.

Showing that picture-like or map-like structures correctly model visual states hinges on these structures' providing insight into perceptual competencies. Causal relations among perceptual states and between such states and behavior have been naturally and fruitfully explained by taking these states to have geometrical or topological structures that map to geometrical or topological structures in the environment that are literally spatial. Such models are fruitful because they suggest new hypotheses that a list of the relevant causal relations would never suggest.

For example, suppose that visual perception were represented simply by a set of abstract propositions, with the form of the meanings of ordinary sentences. Then one would expect that size, shape, location, orientation would normally be factored into separate propositions one for each relevant attribute. In iconic, fully formed perceptual representations, such attributes are represented together as a package, although some may be processed in different sequences. This feature is not a consequence of being iconic. It is a prominent feature of iconic *perceptual* representation. It is widely assumed from many sources of evidence that spatial features of a scene are represented together, not separately.³²⁶ Not only perception, but imagery, various types of short-term perceptual memory, and long-term perceptual memory represent in iconic representational structures. All these capacities derive their iconic structure from perception.

Evidence for this fact derives from the way different aspects of a perceptual or perception-derived representation are responded to. Many experiments show the normal interdependence of representation of size, orientation, shape, location. For example, subjects are asked to say whether an arrow points to an imagined dot. The time required to answer is proportional to how far the arrow is from the dot.³²⁷ A view that imagery is stored as non-iconic representations does not naturally predict interlocking representations of different attributes. It must add postulates that purport to express relevant background principles to explain the results. The principles are not motivated by any fruitful

³²⁶ For an almost arbitrary example, see A. Oliva, S. Park, and T. Konkle, 'Representing, Perceiving, and Remembering the Shape of Visual Space', in L. Harris and M. Jenkin eds., *Vision in 3D Environments* (Cambridge: Cambridge University Press, 2011).

³²⁷ S. Pinker, P. Choate, and R. Finke, 'Mental Extrapolation in Patterns Reconstructed from Memory', *Memory and Cognition* 12 (1984), 207–218. The famous rotation experiments by Shepard suggest that orientation and shape are interlocked in mental images as well as in perception. Shepard reported that subjects could not determine whether two depicted 3-D objects had the same shape until they compared one mentally rotated one object into the orientation of the other. The rotations take proportionally more time the greater the difference in their angles of orientation. R. Shepard and J. Metzler, 'Mental Rotation of Three-Dimensional Objects', *Science* 171 (1971), 701–703. There are methodological questions about these experiments. Other explanations of the results are possible. See Chapter 18, the section PERCEPTUAL IMAGINING for more discussion. In any case, the close connection between representation of orientation and representation 3-D volume shape is present in imagery as well as perception.

general view of imagery. The evidence is naturally explained if perceptual imagery is taken to have the geometrical or topological iconic format of perception.³²⁸

Similar evidence supports the widespread view that some aspects of the iconic form of visual perceptual representation are retained in visual working memory and visual anticipation.³²⁹ There is also evidence that iconic form remains in visual perceptual long-term memory.³³⁰ Retention often comes with reduced richness, in something like the way sketches are less rich than realist paintings. In long-term memory, especially in beings with linguistic capacities, there are surely both iconic and non-iconic types of representation.

The fact that perception, perceptual memory, perceptual anticipation, and imagery all share the format and much of the content of visual perception helps suggest, what I will argue in Part IV, that they operate at the same representational level in a single perceptual-level system.

Temporal, Qualitative, and Packaging Iconic Aspects of Visual Perception

Spatial representation is most refined and complex in vision and touch. Temporal representation is most refined in vision and hearing. All three of these systems, and the proprioceptive system, are iconic in temporal representation as well as spatial representation.

The iconic nature of temporal perceptual representation is even more obvious than that of spatial representation. Perceptual states are extended in time. Attributional applications (hence contents) can be temporally extended. Natural correlations between temporal relations in vision and in what is perceived render temporal perceptual attributions in vision iconic.

For example, a temporally extended perception may have a sequence of referential applications that apply attributives to different events that occur sequentially. The temporal order of the referential applications matches the temporal sequence of events. Temporal order is a natural property. Mapping between perception and represented events

³²⁸ See also Shepard and Cooper, *Mental Images and Their Transformations* and Kosslyn, *Image and Mind*. The view that imagery is iconic and non-propositional is disputed in Z. Pylyshyn, 'Return of the Mental Image: Are There Pictures in the Brain?', *Trends in Cognitive Sciences* 7 (2003), 113–118; Pylyshyn, *Seeing and Visualizing: It's Not What You Think*. I believe that Pylyshyn's criticism of some of the proposed neural evidence for an iconic view of mental imagery is correct. However, I think that the most natural explanation of psychophysical evidence is that the formats or structures of the representational content of many instances of perceptual imagery, produced either in short-term memory or endogenously produced on demand, share iconic structure with perceptions. Such imagery is typically less rich and differs from perceptual representation in other ways. I do not go into the issues in depth. Even Pylyshyn does not dispute the standard view that perceptual representational content itself is iconic. I think it fair to say that the mainstream in the science of visual imagery and of relations between perception and imagery has not followed Pylyshyn. Further evidence for relations between visual perceptual imagery and visual perception: L. Cooper and R. Shepard, 'Chronometric Studies of the Rotation of Mental Images', in W. Chase ed., *Visual Information Processing* (New York: Academic Press, 1973); Shepard and Cooper, *Mental Images and Their Transformations*; M. Farah, 'Psychophysical Evidence for a Shared Representational Medium for Visual Images and Percepts', *Journal of Experimental Psychology: General* 114 (1985), 91–103.

³²⁹ For neural and psychophysical evidence that supports taking visual working memory as iconic, see M. Esposito, 'From Cognitive to Neural Models of Working Memory', *Philosophical Transactions of the Royal Society B* 362 (2007), 771–782; N. Rose, F. Craik, and B. Buchsbaum, 'Levels of Processing in Working Memory: Differential Involvement of Fronto-Temporal Networks', *Journal of Cognitive Neuroscience* 27 (2015), 522–532.

³³⁰ M. Schurgin, C. Cunningham, H. Egeth, and T. Brady, 'Visual Long-Term Memory Can Replace Active Maintenance in Visual Working Memory', *BioRxiv* (2018), <https://doi.org/10.1101/381848>.