# Shaping up: The Phenotypic Quality Ontology and Cross Sections

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**Abstract.** The Phenotypic Quality Ontology (PATO) uses the notion of a cross section to relate two- and three-dimensional shapes and to describe the shape of biological entities. What is a cross-section? What is a truthful ontological account of cross sections? In this communication I explore potential answers to these questions, approaching the task from philosophical and ontological perspectives, and provide a preliminary examination of the PATO shape hierarchy. Some critical observations, questions, and suggestions for the shape portion of PATO are presented.

**Keywords.** Shape, ontology, applied ontology, philosophical ontology, biomedical ontology, artifacts, cross section, philosophy of mathematics, Phenotypic Quality Ontology, PATO, ontology of shape

## Introduction

A preliminary examination of the shape hierarchy in the Phenotypic Quality Ontology (PATO) [1] was conducted. Herein I present some critical observations, questions and suggestions for the ontology. The developers of PATO employ the notion of a cross section in order to describe the shapes of biological entities. What is a cross section, and what is an ontological description of them? Potential answers to these questions are explored in the discussion on the ontology of cross sections.

During my analysis of the shape taxonomy, I organized all PATO shape classes in a spreadsheet document, using temporary identifiers for each, and devised a simple comment-code system. Sibling classes were grouped according to the level they are subsumed under the root shape class, 'shape', with the groupings being called the subsumption or nesting level. That is, all siblings classes subsumed once by 'shape' (subsumption level 1) I labeled 'Level 1 terms' and so forth for all the sibling terms subsumed twice (or once under Level 1 terms).

In what follows, key terms and phrases are italicized. Potential ontological categories are also emphasized in boldface, and PATO classes are enclosed in single quotes. Occasionally the latter are emphasized and prefixed with the name of the respective ontology as in: PATO:**shape**. "Category", "class" and "universal" are considered interchangeable, each essentially reflecting general(izable) entities. Similarly for "particular", "instance" and "individual". In section 1 I introduce PATO, the has_cross_section relation, and present some critical observations thereof. In section 2 I provide an ontological discussion of cross sections.

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## 1. PATO: The Phenotypic Quality Ontology

PATO is an applied ontology[2] primarily intended to describe the phenotypic qualities (traits, more specifically) of organisms. Qualities are most commonly and broadly understood in their normal sense as properties, characteristics or attributes of things. For PATO, qualities are more formally understood in the sense of BFO:**quality** of the Basic Formal Ontology in [2] (version 1.1) or [3] (version 2.0). As such, they are a type of dependent entity[3]. Qualities can also be formally described in the sense of DOLCE:**quality** of the Descriptive Ontology for Linguistic and Cognitive Engineering [4], which interestingly differentiates qualities from properties by making them particulars and universals, respectively.

PATO is designed to be used with ontologies of quality-bearing entities [5]. By explicitly mentioning this (type of entity) PATO can be seen as taking a particular stance on what and how things exist, that is, a metaphysical stance on the world. Since the ontology commonly uses [2] as its top-level ontology[4], one can argue that the former essentially adopts the metaphysical assumptions and theory of the latter. If true, this is an important point to remember for any implicit or explicit, contested or controversial, ontological assertions in the top-level. It is significant for persons and theories that hold the ontology of the world to be different. This point would appear to apply to any ontology using an upper-level with a thoroughly worked-out metaphysical, ontological or philosophical theory.

PATO is included in the Open Biological and Biomedical Ontologies Foundry (OBO Foundry) [6]. It is intended to be used with other biomedical ontologies, such as the Gene Ontology [7], and is used for phenotype annotation. According to [8], the Neuroscience Information Framework [9] and the Influenza Ontology [10], among others, use PATO. Examples of PATO classes include ‘shape’, ‘size’, ‘texture’, ‘structure’, ‘physical object quality’, ‘cellular quality’, ‘functionality’, ‘process quality’, and ‘intensity’ to name a few. PATO encompasses a broad range of so-called qualities from the highly general to the more domain-specific, and is ambitious in that respect.[5] Figure 1 displays a sample of the shape taxonomy in PATO as it was structured at the time of this examination. Indentation indicates subsumption (the is_a relation). The first two shape classes, for example, can be read as “aliform is a type of 2-D shape”.

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[2] An applied ontology is an ontology used in or for a field of inquiry or domain science, such as biology or physics. It has a computer-readable format to foster, among other things, automated reasoning, and semantic annotation and interoperability. A (scientific) ontology is ideally a philosophically well-founded theory of the kinds of entities and relationships in the world. Domain ontologies reflect an aspect or portion of the world that is the focus of study for a domain science. For more see [2], [4] and [22].

[3] A dependent entity is an entity that depends on others for its existence. Qualities/properties, being commonly-held examples, are described as being existentially dependent on their material bearer.

[4] A top-level ontology is one whose ontological categories are of the highest generality possible to accurately describe the world or some field of inquiry. Each lower-level category of a lower-level or domain-ontology that uses a top- or upper-level has some upper-level category subsuming it.

[5] With classes such as ‘physical object quality’ and ‘process quality’, both highly general and applicable to different types of entities, the subject matter of PATO is clearly broader than the domain of biology. The abiotic is represented in the ontology as well.

2-D shape
    aliform
3-D shape
    convex 3-D shape
    concave 3-D shape
angular
arrow-shaped
auriculate
bent
branchiness

**Figure 1.** A portion of PATO's shape taxonomy.

Shapes are generally held to be examples of qualities of things. This is intuitively accepted when considering the shape of material objects, but not so obvious when considering the abstract or ideal shapes of geometry. The shapes of material objects (***physical/material shapes***) do not typically exhibit the flawless symmetry of ***geometric shapes***. The distinction between the two, discussed in [11], may help (I) specialize a shape category for applied ontologies such as PATO, and (II) form a correct ontology of shape. PATO shape qualities, at least in the sense of [2, 3], are essentially equivalent to the former: the shape of material entities in the world.

### *1.1. Some Initial Observations*

An initial observation of PATO's shape hierarchy is that of a largely flat one that could benefit from more structuring and category assessment. This includes determining whether the categories are representative of shapes (qualities). For example, two superclasses of PATO:**shape** are 'Morphology' and 'physical object quality', a classification that is not entirely correct. Strictly speaking, morphology is a field or subject of study, not the shape quality of a physical object. The intended reading and meaning is likely "Morphological quality". If so, then an appropriate change in the class name or definition to reflect this would better afford semantic transparency. That is, grasping the meaning of the class from its name will be more apparent.

Although there are similar concerns with other PATO classes and definitions, including those that do not appear to denote shapes (PATO:**robust** for example), I will focus on observations and implications related PATO:**has_cross_section**. Before discussing this relation, I will briefly present two potential strategies for organizing the shape categories.

There are a number of classes whose names end with "-shaped" or "-like", as in PATO:**hourglass-shaped**, 'snowman-shaped', 'spoon-shaped' and 'brush-like shape'. Some of them can undoubtedly be removed, renamed or substituted. If two things are accomplished—a distinction between artifactual and non-artifactual shapes, and an unproblematic general account of artifactuality—then these classes can arguably be grouped accordingly under (Non-)Artifactual shape classes.

PATO does not have a class for spheres, and perhaps justly so. Spheres are geometric shapes and seemingly outside the scope of an ontology whose primary domain is that of phenotypic qualities of biological entities. A *Sphere* class would not fit because (a) geometric shapes are purportedly abstract in nature, (b) their instances are not exhibited by material objects, and (c) the shape qualities of PATO require a material bearer.

Spheres are mentioned, however, in the definitions of PATO:**spheroid**, the parent class (the immediate superclass) of PATO:**spherical**. Now if it were possible for some material entity to exhibit a perfectly spherical shape—giving credence to the idea of perfect material instances of geometric shape universals—then these classes are general enough to encompass those shape qualities in addition to approximate spheres or sphere-like shapes, such as the oblate spheroidal shape quality of the Earth.

Proceeding with the understanding that any given physical object does not, in fact, have a perfect geometric shape quality, we have the following. Assuming the distinction between geometric and physical shapes is both ontologically correct and viable for an applied ontology, differentiating between *Sphere* and *Spherical* categories would reflect the distinction and may prove useful. Instances of a *Sphere* class have the precise geometric properties of a geometric sphere while allowing for variation in scale. For PATO, instances are physical shapes, shape qualities approximating a geometric sphere. A spherical biological cell can be formally related to the geometric sphere via some two-place approximation or resemblance relation.

In noun-based adjectives[6] [12], such as "spheroidal" and "rectangular", the suffixes "-oidal" (or "-oid"), "-ical", and "-ar" indicate resemblance (and thus deviation from the ideal). The definition of PATO:**spherical** is in line with, stating "…the bearer's resembling a ball"[7] (italics added). In terms of class names, those with the above suffixes can be defined as indicating this similarity or approximation. They mark imperfect physical object shape qualities, rather than ideal geometric shapes. This approach would require geometric shape categories in a separate ontology, however.

### *1.2. The PATO cross section relation*

To better structure the shape hierarchy, the developers of PATO utilize the notion of a cross section to relate three- and two-dimensional (3-D and 2-D for short) shapes [13]. More specifically, the has_cross_section relation, a binary predicate, was introduced to relate 2-D and 3-D shape classes. A description of the 3-D shape of a biological cell, for example, would have a 2-D counterpart marking the cross section of that 3-D cell shape. This ontologically commits PATO to cross sections, yet there is no class or corresponding definiton. Below is the definition of PATO:**has_cross_section** with an arbitrary label to the left. I have emphasized the likely unique entity- and category-referring words.

| | |
|---|---|
| (HCS-Def) | **s3** has_cross_section s3 if and only if : there exists some **2d plane** that intersects **the bearer of s3**, and the **impression** of s3 upon that plane has **shape quality s2**. |
| Example: | a spherical object has the quality of being spherical, and the spherical quality has_cross_section round [13] |

According to both the definition and the example, the domain and range are 3-D and 2-D shape qualities, respectively, each a subtype of top-level class BFO:**quality**. Table 1 displays the form and a sample subject-predicate-object expression (the row in grey). Based on the phrasing of the relation the range is cross sections, more

[6] Personal communication with Dr. John Corcoran, University at Buffalo,State University of New York.

[7] The use of the word "ball" is ambiguous, but seems to connote material objects, e.g., a soccer ball, rather than a geometric shape. The definition says that a ball *is a* sphere, but it is the soccer ball that resembles a sphere, not vice versa.

specifically. The implication is that there is some equivalency between cross sections and 2-D shapes. For PATO, it would appear that 2-D shapes are cross-sections. The definition of PATO:**2-D shape** classifies cross-sections as 2-D entities, more generally. For both geometric and physical shapes we can ask, Q1: Are cross sections 2-D shapes (or vice versa)?

**Table 1.** The PATO has_cross_section relation with domain, range, and working example (grey row)

| Domain | Binary Relation | Range |
|---|---|---|
| 3-D shape quality | has_cross_section | 2-D shape quality |
| Spherical | has_cross_section | Round |

Observe that translating HCS-Def completely into first-order predicate logic may require an intersection relation, as well as some relation reflecting the usage of "upon". In the next subsection I present three critical observations of HCS-Def, while attempting to address them. Each is labeled with the prefix "HCS-O" and a number.

### *1.3. The has_cross_section definition – Observations and Questions*

(HCS-O1) Assuming there is no typographic error, the definition may be better served if the second instance of "s3", located on the left side of the bi-conditional, is substituted with "s2". "S2" is also found at the end of the definition, and likely stands for "2-D shape". Using the corresponding full PATO class name in the definition is arguably preferable. There are at least two reasons for the substitution, reiterating a point made in subsection 1.1.

The first is that since the range is 2-D shape qualities, the substitution will more easily reflect this, making for a more readable and transparent definition to ontology editors and users. Similar minor changes will make formal definitions more consistent with any informal natural language description, and perhaps encourage the promotion of standards and best practices for applied ontology development and curation.

The second reason is that if both instances of "s3" signify distinct entities of the same type—either 3-D or 2-D shapes—then the relation cannot apply to geometric shapes, nor to the bearer of the shape, mind-external 3-D material objects. A sphere does not have a 3-D cross section, nor does, say, a particular orange. A cross section is commonly, if not always, of a lower-dimensionality than the cross-sectioned entity.

(HCS-O2) 2-D planes are mentioned in HCS-Def, signaling an ontological commitment to planes. In what sense do 2-D planes exist and what kind of entity are they? Do they interact with the bearer of the shape quality, as the definition suggests, and if so, how? The two are clearly of different types.

The 2-D plane is a geometric or mathematical entity, entities not explicitly represented in PATO's top-level, [2], and thus beyond the scope of PATO. Depending on the nature of geometric/mathematical entities, planes may be a type abstract entity, more generally, or a cognitive entity. [4], and much philosophical literature, supports geometric shapes and mathematical entities as abstract. By contrast, and according to PATO, the bearer of a shape quality is a BFO:**material entity**.

Assuming planes are mathematical entities, how exactly do they interact with material objects? With these questions we find ourselves in the sphere of the philosophy of mathematics in which a central concern is the ontological status of mathematical entities. Are they mind-internal constructions, mind-external spatio-temporal entities, abstract (non-spatio-temporal and non-mental), or otherwise? Is a

***mathematical entity*** class to be introduced to subsume a ***2-D plane*** class? If so, then in what ontology are they to be a part (a mathematical entity ontology, perhaps)? How would this ontology be used with PATO and its top-level?

Consider the following approach. If planes interact with 3-D material bearers, or if cross sections are only created by an intersection (a form of interaction) of distinct entities, then introduce an ***intersection*** relation, a binary predicate with 2-D planes and 3-D material objects (or shapes qualities) as domain and range. The problem is that we would be hard-pressed to explain how they interact in this way. We do not literally find 2-D planes in the mind-external world, except perhaps in a representational sense.

Within a computational or mathematical system, a 3-D model of a real-world object can be intersected (in whatever equivalent sense) with a 2-D plane. This would be a *computational representation* of an otherwise abstract geometric entity. It makes more sense to ontologically describe the interaction of these entities in a cognitive, mathematical, or computational setting or context.

I am therefore inclined to suggest that only geometric shapes can be intersected in this sense. That is, a ***geometric intersection*** relation would relate geometric entities. Physical shapes are only subject to intersection with a plane when they are abstracted from the mind-external 3-D material bearer, idealized or represented in a cognitive, mathematical, or computational form. Perhaps the physical shape, so abstracted, can be modeled as a geometric shape.

(HCS-O3) Although we intuitively understand the meaning of "impression" from HCS-Def, it is not described and marks an ontological commitment to impressions. Is an ***impression*** class, and corresponding logical definition, to be added to PATO? Is it a primitive, the meaning of which comes from our natural-language comprehension of its usage in context? Is the impression identical to the cross-section? Let us examine this and the intersection process implied by HSC-Def a bit further.

The intersection of a 2-D plane with a 3-D shape quality results in a 2-D impression of the latter on the former. So how does the impression relate to the 2-D plane? It is not clear whether the impression is on the plane as a book can be on a table, or whether the impression is a quality of the plane. Both appear implausible.

To say either the shape or the cross section is on the plane is to suggest that the cross section is independent of both the plane and sphere, just as a table and a book are independent, but interacting, entities. Ontologically, there is no independent cross section standing in an *on* relation (in this sense) to the plane. The cross section appears to form by the intersection.

A mereological theory can be used to assert that the sphere and plane partially overlap, and define the cross-section as the region of overlap. This would support the idea that the cross section is not an independently existing entity. Provided a theory of location, part of the 2-D plane can also be described as being co-located with part of the 3-D shape. These formal accounts would more accurately apply to cross sections in a geometric context as types of immaterial, abstract or mathematic entities.

If impressions have 2-D shape qualities, then impressions are quality-bearers. Are we to gather that the 3-D material object is the bearer of the 3-D shape quality, the plane a bearer of the impression, and finally the impression a bearer of the 2-D shape quality? This may be problematic.

According to PATO, shape qualities, not the bearer, have cross sections. Yet according to [2], PATO's adopted top-level ontology, qualities do not themselves have qualities. At best, any asserted high-order quality is a quality of the bearer. Given this, and assuming cross sections are 2-D shape qualities, the material bearer would have the cross-section as a quality, not the 3-D shape quality of the bearer as PATO holds (see 1.2 and Table 1). Unless planes and impressions play some role in avoiding this apparent dilemma, a contradiction exists. This is a potential, if not actual, conflict between the ontological theory of the top-level and the lower-level ontology.

From the preceding, we observe that PATO is ontologically committed to cross sections, shape qualities and their bearers, and arguably 2-D planes and impressions upon the planes. We can partially address HCS-O3 by being ontologically parsimonious and avoid commitment to impressions. Rephrasing the definition to avoid use of "impression", or (perhaps) explicitly stating that the word be understood in an informal manner are possible solutions. HCS-O3 introduces the question, Q2: Do/can both shapes and material objects have cross sections? It appears so.

The next section discusses the ontology of cross sections. I identify some of their general properties, labeling them with the prefix "CS-P" and a number as they appear. Potential definitions/descriptions are marked with "CS-D". I also present interpretations of cross sections as types of (a) mind-external artifacts, (b) mind-internal entities, (c) mind-external portions of objects, and (d) spatio-temporal regions.

## 2. The Ontology of Cross Sections

What are cross sections, and what is an accurate ontological description of them? We generally conceive of cross sections as either two-dimensional slices/sections of things, or geometric description of things. The former are purportedly parts or types of material entities, and the latter types of representational artifacts in the sense of [14, 15]. In short, cross-sections are 2-D sections or descriptions of 3-D entities. We also understand the notion of cross-sections by an action or process: cutting/slicing or intersecting an entity to expose some internal structure, surface or shape.

Generally speaking, we can section something mind-internally by imagining the cross section of some entity; mind-externally, by performing actual dissections of biological specimens; or virtually/computationally by producing computational representations and simulations. These are three modes of cross-sectioning, the last two of which involve the first. Relevant definitions from both [16] and [17] reflect the idea that a cross section can be an actual cut/cutting of something, or a representation of it.

In medicine, 3-D sections of biological entities—cells, tissue, organs, organisms—are obtained by actual dissections or other cutting/sectioning processes. By contrast, 2-D slices are virtually obtained or simulated with technology such as Computed Axial Tomography in which X-rays scan a biological subject. This scanning process, in effect, produces 2-D slices in a computational or graphical form in order to visually convey information about the interior of the subject.

Numerous slices taken from varying angles and positions are combined to form a 3-D mosaic: a 3-D computational representation of, say, the human brain. A particular brain is virtually sliced or sectioned based on, or by the gathering of, information that is (i) received and subsequently processed by the scanner and associated software, and (ii) transmitted via X-rays. Ultimately, 2- and 3-D images and simulations representing the subject are produced for the medical practitioner to examine. Thus, medical imaging provides us with an example of (representational) cross sections.

Other fields, such as architecture and engineering, use cross sections (or variations thereof) with the aid of software applications such as AutoCad [18] and Photoshop [19]. These applications permit similar constructions and comparable simulated dimensional (de)compositions to communicate internal and structural information. It is evident that these cross sections have a descriptive power that is highly useful for industry and education. Consider blueprints, floor plans, scientific illustrations, computer simulations, and modeling and manufacturing techniques. Whether in medicine or engineering, from computational cross-sectioning processes—types of artifactual processes—representational artifacts are created.

(**CS-P1**) A cross section is always a cross section of something, just as a physical/material shape as opposed to a geometric shape, is always a shape of the object [11]. Cross sections are always cross sections of some entity. They reflect some aspect of what is sectioned. An individual cross section of a particular brain depends at least on that brain, the persons engaging in the sectioning, and the technology involved. The notion of a cross section presupposes that of something to be sectioned (**CS-P2**).

We consider, cognize, imagine and seek the cross section of an object for a purpose. We consider it to satisfy a particular function. Functions, like qualities, are often ontologically classified as a type of dependent entity. ***Medical Cross Sections***, a potential domain-level subcategory of a ***Cross Section*** category arguably have the function of communicating structural or internal information about the biological subject. These considerations support the idea that (**CS-P3**) cross sections are a type of dependent entity. It remains to be seen precisely what type of dependent entity.

When we imagine the cross section of some real or fictional object we are abstracting from the object. We selectively focus on certain parts, properties or aspects of the object, while ignoring others. This is common to any abstraction process. The mind-internal abstraction yields to our mind's eye a figure—the cross section—whose boundaries are that of the representation of the mind-external object. With no mind-external manifestation of the abstraction—artifacts such as images of the brain—the cross section will remain a mental construction. We can ask Q3: Are cross sections types of artifacts, or do these artifacts represent cross sections?

If we take the position that an image from a medical scan represents a cross section of the brain, rather than being a ***computational cross section*** of the brain, then we ontologically commit to two types of entities. One is the representation and the other is the represented. The images surely represent some physical part, some collection of properties, some snapshot of an ongoing biological process, or some aspect of the brain, more generally. That aspect is of the internal structure (and goings-on) of the scanned portion of the brain (1) viewed two-dimensionally or in a 2-D form, and (2) relative to some axis (of rotation, of symmetry) or some pre-defined coordinate system.

In short, the cross section could be described as **CS-D1**: a 2-D representation/description of the internal structure (and contents) of the subject at a moment of time and relative to a given axis or coordinate system. If cross sections are created by persons to serve the function of conveying this information, then it is obvious that there is an artifactual element to their nature. Similar to representational artifacts, they could be declared as types of *information artifacts*. Accordingly one may wish to categorize cross sections as *information content entities* in the sense of [20]. Whatever the case, a particular cross section is a dependent entity that conveys and reflects some information, some reality, about what is sectioned.

To cross-section or to section something is to divide or cut it into one or more N-dimensional slices/sections. For 3-D material objects, any actual slices are always of the same dimensionality. There are no 2-D material slices of a brain, for example. Therefore, unless understood as 2-D descriptions or representations of (portions of) things, and unless a cross section category is specialized, it may not be appropriate for material entities. For geometric shapes, by contrast, the slices are indeed of a lower dimensionality.

The sectioned entity is either actually of a higher dimensionality, or is conceived in the imagination as an entity having a higher dimensionality (**CS-P4**). Implicit in the notion of a cross section is the distinction between (entities of) differing dimensionality (**CS-P5**). For material objects this entails material extension along those dimensions. CS-P4 implies **CS-P6**: Cross sections are of a lower dimensionality than that which is cross-sectioned. Considerations of dimensions provides an interpretation of cross sections as a 3-D entity viewed from the perspective of a 2-D entity.

### *2.1. Geometry and Cross sections*

There is a distinct geometrical nature to cross-sections. One reason for the dimensional difference between the cross-section(ed) is that a 2-D geometric entity, such as a plane, is used to produce or exhibit the cross section. From the perspective of a plane, 3-D geometric shapes and 3-D material objects are viewed two-dimensionally. They become or are seen as 2-D. Since material objects are not actually cut into 2-D slices, whatever slice is produced is more along the lines of CS-D1, a 2-D view, representation or description of the object. Whether the sectioned entity is geometric or material, there is always a conscious involvement or focus (**CS-P7**).

In geometry, the cross section of a 3-D geometric shape (or figure more generally) is the shape produced by the intersection of the 3-D shape with a 2-D plane. A cross section of a sphere is a circle, for example. From the vantage point of a plane, a sphere appears as a circle. For more complex or irregular figures the cross section varies significantly depending on its position and angle through the figure. The position and angle are identifiable by specifying an axis (or coordinate system) through or relative to the geometric object.

Imagine a 2-D plane intersecting a representation of an aircraft. A plane perpendicular to an axis that runs from nose-to-tail will produce a different cross section if it were perpendicular to an axis running from wing-tip to wing-tip. Each will therefore communicate and represent different properties and information about the aircraft. By specifying a rotational axis or coordinate system for the sectioned entity, the orientation of the 2-D plane and resultant varying cross sections can be precisely identified. With this in mind, perhaps PATO:**has_cross_section** is not simply a binary predicate but ternary such that: X has_cross_section Y at/relative to Z, where Z is some axis, coordinate system or set of coordinates.

The cone and the conic sections are examples of this *cross-sectional variation* for geometric shapes. A plane intersecting a cone at different positions and angles produces different curves: the parabola, the hyperbola and the ellipse (a closed curve), of which the circle is one type. Cross sections would appear to have the same dimensionality as the plane or figure used to geometrically intersect the sectioned shape (**CS-P8**).

One exception to this idea involves planes that are tangential to higher dimensional shapes. Consider the effect on PATO:**has_cross_section**. Assuming cross sections of geometric shapes are themselves shapes, and assuming the point (a 0-D entity) is asserted as a type of shape, the following holds. When a plane tangentially touches or intersects any shape—at the apex of a cone or at the pole of a sphere, for example—the cross section at that region is a point. The intersection yields a shape of lower dimensions than the plane. Therefore, if points are accepted as proper cross sections, then the range of the has_cross_section relation must change to cover not only 2-D shapes, but shapes of lower dimensions as well.

Thus far we have observed that from the perspective of a 2-D plane 3-D shapes often vary depending on the orientation of the plane through the entity. In other words, the cross section depends on certain relationships obtaining between specific entities. With this we now explore cross sections and processes further.

*2.2. Cross-sectioning Processes*

As mentioned in section 1, we can describe cross sections in a processual manner. That is, we can formulate an account of intersecting figures as a process. The ***geometric intersection process*** of a plane with a sphere yields a circular cross section. In an ontology that has *state* as a category, the state of being intersected results from that process. This particular cross section exists when the sphere and the plane stand in one or more specific relations to each other.[8] It exists when shapes are participating or engaging in certain processes manifesting those relations. Although it appears timelessly true that the cross section of a sphere is a circle[9], one may distinguish between particular and universal cross sections, holding that the former only (come to) exist during an intersection process.

If so, then given the discussion in preceding sections the individual cross section is neither a property of the individual sphere nor of the plane. These (**CS-P9**) instances of geometric cross sections can be ontologically described as *relationally-dependent entities*, perhaps more specifically as ***relationally-dependent shapes***. 'Relational quality' from [3] is a class that reflects this idea in certain respects, but diverges from the conception by concerning material, not geometric, objects.

Some plane participates in a geometric intersection process with some sphere, the intersection of which is a circle. We call this the cross section. The individual circle is not an independent entity in this context. It is exhibited by the intersection, reflecting some information or properties about the sphere. The information may include the radius, circumference, chord length or area (the cross-sectional area) of the sphere at, or relative to, certain reference points or axes. In this way, we can understand geometric cross sections as intersections in a sense (**CS-P10**).

Accepting CS-P10, we describe geometric cross sections as, **CS-D2A**: the geometric intersection of some N-dimensional shape, in an N-dimensional space, with a 2-D plane. If one wishes to allow for intersections involving figures other than planes, such as the intersection of a sphere with a hyperbola or a cube, we can more generally hold **CS-D2B**: Geometric cross sections are the intersection, or the figure exhibited by the intersection, of some N-dimensional shape with another. What if we wish to analyze the intersection in terms of points or lines?

Descending to a lower geometric granular level, that which is intersected more discretely than the unities that are the sphere and the plane, is that which they have in common: points or lines. They can be described as sharing or having overlapping points when they intersect. Along these lines, geometric cross sections are **CS-D3**: the set of points shared by a 3-D shape and a 2-D plane when the two intersect. Connecting those points forms a continuous figure that is the cross section in question.

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[8] Some may wish to call this amalgam a geometric context.

[9] Is this equivalent to saying that the cross section, itself, has a circular quality? Is it a property of spheres that they have circular cross sections?

Finally, observe that a plane continuously moving through a sphere and perpendicular to one of the spheres axes results in a geometrical cross section changing through time. The circle continuously changes its size, diameter and area while essentially preserving its identity as a (relationally-dependent) circle. Imagine the same continuous motion for the aircraft example. At each temporal moment, or at each point along the axis, one can identify either a changing cross section or distinct cross sections. We can therefore describe a cross section at a single moment of time and diachronically.

### *2.3. Cross sections as Spatio-Temporal Entities*

Some applied ontologies, such as [2], include two-dimensional spatial regions as an ontological category. With [2] as it's top-level, one can easily hold that PATO implicitly accepts these types of entities as well. Using a *spatial region* category we can form an alternative characterization of a cross section. A cross section is the 2-D portion of space-time, or the 2-D spatial region, whose boundaries are defined by the spatial or material extent of some part of the 3-D material object.

In short, we may be tempted to assert **CS-D4**: cross sections are 2-D portions of space occupied by the sectioned entity. Similarly one may equate cross sections with 2-D material portions/sections of things (**CS-D5**). These would imply that any portion of 2-D space or of the 3-D material object is a cross section. Both CS-D4 and CS-D5 are most likely incorrect characterizations of cross sections.

Cross sections are not literally 2-D material slices of things because, again, 2-D material slices of 3-D material objects are never created. Matter being 3-D, there is always some depth to a material slice. If cross sections are 2-D slices of 3-D material objects, and space(-time) is at least 3- or 4-D, then 2-D material slices or spatial regions will not be found in the ontology of the world: they do not (and cannot?) exist.[10]

At best, an actual ***physical/material cross-section*** (as with a dissected brain) could be construed as the *surface* of the section. In this case, if surfaces of material objects are included in an ontology as types of 2-D entities, then perhaps these 2-D material surfaces can be equated to 2-D material cross sections. One may propose **CS-D6**: A cross section of a material object is the surface of an internal section (part) of the object, a surface that is orthogonal to a predefined axis or coordinate system, and that is exposed by some sectioning process. This conception is in line with [21], which defines a cross section as the surface or shape that is or would be exposed by cutting something orthogonal to an axis.

We do not observe cross sections of things outside of, and unrelated to human cognition or activity, and thus outside of some artifactual context. They appear to be, in large part, our creations, but creations intentionally reflecting some aspects of other entities. They are often born as mental artifacts that are mind-externally concretized using information about, or acquired from, the entities that are cross-sectioned.

## 3. Closing Remarks

The Phenotypic Quality Ontology uses shape quality categories and the notion of a cross section to describe the shape of biological entities. Drawing from a preliminary

[10] If the universe is at least 3-D, then it may be true that all 2-D entities—2-D shapes, 2-D spatial regions, etc.—are all dependent entities, perhaps mental constructions or mathematical tools.

analysis of the shape hierarchy of PATO, I first presented some critical observations, questions and suggestions, focusing on the has_cross_section relation. Second, I discussed the ontology of cross sections, identifying general properties, and presenting potential definitions and interpretations of cross sections.

Finer distinctions and greater clarity is needed, specifically with regard to (1) the ontology of geometric/mathematical entities, how they relate to artifacts and material objects, and (2) the relationship between the universal-particular and geometric-physical shape distinctions. With these in place a more accurate ontology of shape may better structure and organize existing applied ontologies that use shape categories.

A point worth reiterating concerning theoretical/philosophical and applied ontology development in general is the comparison of the top- and lower-level ontological theories. For any domain-ontology using a philosophically rigorous top-level it is beneficial for the developers of the former to assess whether they agree with the ontological/metaphysical account of the latter, or whether theirs is consistent with it.

Cross sections have a descriptive power in that they convey information about an entity of a greater dimensionality. They simultaneously reflect properties of the sectioned entity, and have artifactual and relationally-dependent aspects.

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