Perceptual Symbols and Taxonomy Comparison

Xiang Chen
California Lutheran University

Abstract. Many recent cognitive studies reveal that human cognition is inherently perceptual, sharing systems with perception at both the conceptual and the neural levels. This paper introduces Barsalou's theory of perceptual symbols and explores its implications to philosophy of science. If perceptual symbols lie in the heart of conceptual processing, the process of attribute selection during concept representation, which is critical for defining similarity and thus for comparing taxonomies, would no longer be determined solely by background beliefs. The analogous nature of perceptual symbols and the spacial nature of intraconceptual relations impose new constraints to attribute selection. These constraints help people with different background beliefs select compatible attributes, which constitute a common "platform" for taxonomy comparison.

1. Introduction. Most cognitive scientists and philosophers in the 20th century believed that perceptual and conceptual are two fundamentally different cognitive stages and concepts are inherently abstract. Cognitive process starts with perceptual states that arise in sensory-motor systems and correspond to the referents. In the next step, however, subsets of perceptual states are transduced into abstract, amodal conceptual symbols that bear no correspondence to the perceptual states. This is the so-called amodal approach to concept representation.

Recently, more and more cognitive studies reveal that perceptual elements exist in conceptual processing. Some cognitive scientists thus suggest a very different approach to concept representation. They propose that human cognition is inherently perceptual, sharing systems with perception at both the conceptual and the neural levels. Since concepts are used in all higher cognitive activities, the radical change in concept representation could considerably alter our understanding of many issues in philosophy of science.

In this article I will first introduce Barsalou's theory of perceptual symbols and the related empirical evidence. I will further explore the implications of Barsalou's theory to taxonomy comparison. If perceptual symbols lie in the heart of conceptual processing as suggested by Barsalou, rival taxonomies can be rationally compared on a "platform" rooted in our common preference in conceptual processing. This account of taxonomy comparison is supported by evidence from both cognitive and historical studies.

2. Barsalou's theory of perceptual symbols. Although the amodal approach provides a convenient formal language to account for some cognitive phenomena, it encounters numerous difficulties. First, no one has ever provided direct evidence that abstract symbols lie at the heart of conceptual processing. There have been attempts to test the amodal assumption by using picture and word processing tasks, but the results seem to be negative (Seifert 1997). Second, the amodal approach does not explain how the transduction process maps perceptual states to abstract symbols. Neither biological nor information processing mechanisms have been identified for such transformation. Without a satisfactory account of the transduction process, confusion also arises in the symbol grounding process. As pointed out by Searle in his analysis of the so-called Chinese room problem, because abstract symbols bear no similarity to their referents, relations between these symbols and their referents are entirely arbitrary (Searle 1980).

In light of many empirical findings, Barsalou recently proposes a theory of perceptual symbols, claiming that knowledge is essentially perceptual (Barsalou 1999a; Barsalou 1999b). According to Barsalou, perceptual states are not conscious, subjective images but neural records of the brain that arise during perception. In the second stage of human cognition, these perceptual states are not transduced into a completely different kind of representational symbols. Instead, subsets of perceptual states are extracted via selective attention and stored permanently in long-term memory. These subsets, called perceptual symbols, are schematic, containing only small fragments of perceptual states. For example, only the shape of a physical object remains in the perceptual symbol, while information of its other features such as color and position is filtered out. On later retrievals, these subsets can function symbolically, standing for referents in the world. With an appropriate level of skills, we can integrate perceptual symbols into systems to simulate objects and events.

Fundamentally different from such abstract symbols as propositions, perceptual symbols are structurally related to their referents. Perceptual symbols are represented by the same system as the original perceptual states – the neural systems that represent color in perception, for example, continue to represent the color of objects in perceptual symbols. Since perceptual states structurally correspond to the referents, perceptual symbols are also analogical to the referents. The perceptual symbols for blue and green are necessarily more alike to each other than the symbols for blue and red.

Barsalou's theory of perceptual symbols is supported by many empirical studies. Findings from neuroscience have proved, for example, that some categorical knowledge is grounded in the sensory-motor region of the brain, and damage to a particular sensory-motor region can disrupt the process of categorization that uses this region to perceive physical exemplars. Damage to the bilateral temporo-limbic structures and inferior temporal lobes, for example, could disrupt the visual process and convergence of sensory information. As the result, the patients have difficulties in processing categories of living beings, such as *bird* and *frog*, whose exemplars are processed visually. Similarly, damage to the left fronto-parietal areas could disrupt motor-kinaesthesic integration (handling of objects) so that the patients cannot process categories of man-made articles such as *tool*. These findings strongly suggest that categorical knowledge contains perceptual elements (Gainotti, *et al.* 1995).

More direct evidence for the perceptual approach comes from a series of experiments performed by Barsalou and his collaborators (Barsalou, *et al.* 1999). In one of these experiments, they had subjects to perform a standard conceptual task of feature listing -- subjects were asked to list the properties typically true of various concepts. Subjects were divided into three groups, each of which was given imagery, neutral, or word association instruction respectively. The imagery group was asked to "construct an image for the concept and describe it," and the word association group was asked to "produce associated words that come to mind for a concept." The neutral group was simply asked to "list the characteristics typically true of a concept." In this setting, the two rival approaches to concept representation have opposite predictions. The perceptual approach predicts that neutral and imagery subjects should produce the same distributions of features because both groups use perceptual symbols to generate features, while word association subjects should differ from the others because they use a lexical network to produce features. However, the amodal approach predicts that neutral and word association subjects should have the same performance because both use abstract symbols to generate features, and imagery subjects should differ from the others because they are the only ones who access features via perceptual simulation. The experimental results showed very high correlations between the features generated by imagery and neutral subjects. In contrast, the correlations between neutral and word association subjects were much lower. These results suggest that subjects naturally use perceptual simulations to produce properties. Barsalou and his collaborators also had subjects to perform other conceptual tasks such as property verification, in which subjects were asked to verify whether a concept has a specific property. The results also indicated that neutral subjects had the same performance as imagery subjects. All these experiments support the core assumption of the perceptual approach, namely, that perceptual simulation lies at the heart of conceptual processing.

3. Perceptual symbols and spacial relations. Because perceptual symbols are structurally related to their referents, concepts cannot be represented as "flat" entities by lists of independent features, nor by groups of necessary and sufficient conditions. These representation vehicles can only describe relational information implicitly (Barsalou & Hale 1993). To capture the structure of a concept, we must highlight the interconnections among its elements, or the intraconceptual relations. The perceptual approach thus suggests that concepts should be represented by such apparatus as frames, which are most effective in illustrating relational information. Although the traditional amodal approach has used frames to represent concepts, it treats them merely as convenient tools to reconstruct concepts. The perceptual approach believes, however, that concepts must be represented by frames, because we actually use frame-like structures in conceptual processing.

A frames is a set of multivalued attributes integrated by structural connections. Figure 1 is a partial frame representation of the concept *bird*. The frame divides features into two groups, attributes and values. Attributes such as *beak*, *neck*, *body*, *leg* and *foot* constitute the core of the frame, and each attribute can adopt different values when it represents different exemplars. The frame emphasizes three very important intraconceptual relations. First, it captures hierarchical relations between attributes and values -- some values (*large* and *small*) are always related to a particular attribute (*body*). Second, it captures several structural relations between the attributes. *Neck* is physically carried by *body* and always attached to *body* in a certain way. Lastly, it captures constraints that produce systematic variability in the values. If the value of *foot* is *webbed*, then the value of *beak* is more likely *round*, or if *foot* is *unwebbed*, then *beak* is more likely *pointed*.

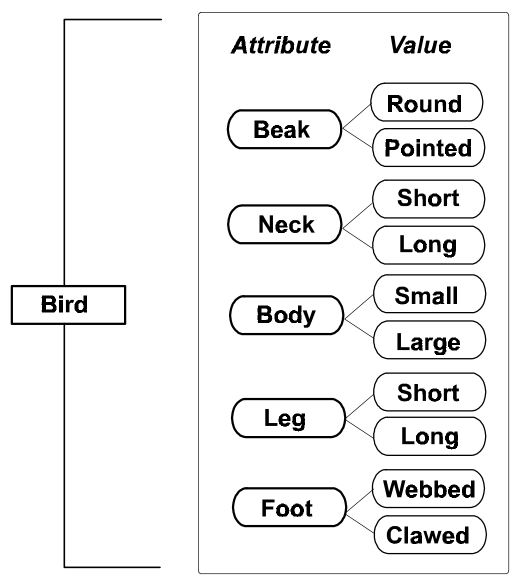

Figure 1. A partial frame of *bird*

Although both the amodal and the perceptual approaches use frames to represent concepts, they interpret this apparatus in very different ways. The amodal approach uses linguistic forms to describe frames. Both attributes and values of a frame are stated in words, and structural relations and constraints are stated in statements. Although words do not literally constitute the contents of these representations, it is assumed that conceptual states are analogous in many important ways to language, such as having the same combinatorial syntactic and semantic structure. Just as language processing involves the sequential processing of words in a sentence, conceptual processing is assumed to involve the sequential processing of amodal symbols in sentence-like structure (Fodor & Pylyshyn 1988).

According to the perceptual approach, however, both attributes and values of a frame are perceptual symbols that bear analogous relations to both the perceptual/neural states from which they derive and to the referents that they represent. Barsalou, for example, believes that attributes of an entity concept are schematic symbols that specifically outline subregions of the referent (Barsalou 1999a). In the frame of *bird*, each attribute (*beak*, *neck*, *body*, *leg* and *foot*) represents a specific subregion of the referent, and they together determine the overall shape of birds. Similarly, values are perceptual symbols that specify the contents of these subregions by fleshing out the details (e.g., *pointed beak* and *long neck*). Since attributes are analogous symbols that represent subregions, the structural relations among them are in essence spacial. For example, the structural relation between *neck* and *body* is that the former is above and carried by the latter. Similar spacial relations also exist between *neck* and *beak*, *body* and *leg*, as well as *leg* and *foot*, but we usually do not describe them linguistically.[1]

If intraconceptual relations in entity concepts are in essence spacial, then it is logical to expect that we do not treat all entity concepts equally. Some entity concepts contain more spacial information and thus offer more diagnostic cues than others, and consequently we should be able to process and analyze these concepts more effectively and efficiently than others. Thus, the perceptual approach implies that we should develop preference to concepts that contain rich spacial information in various cognitive tasks. Such an implication has been confirmed by the discovery of the so-called basic-level concepts in categorization.

In a series of experiments in the late 1970s, Rosch and her collaborators discovered that we prefer to classify objects at a certain abstract level. Although a seat-like object with four legs and a back can be categorized at a very abstract level as *furniture*, or at a less abstract one as *chair*, or at a very concrete level as *kitchen chair*, we usually choose to start classification at the middle level. In their experiments, Rosch and her collaborators used several methods to determine the procedures of classification. They gave subjects a series of pictures in rapid succession and then asked subjects to classify them. They found that subjects used middle-level concepts such as *chair* more frequently than the more abstract ones such as *furniture* or the more concrete ones such as *kitchen chair*. They also provided subjects a list of concepts at all three different levels, and asked subjects to describe the attributes of these concepts. They found that subjects consistently generated more attributes for concepts at the middle level than those from other levels. Rosch called this preferred level of classification the basic level (Rosch, *et al.* 1976: 383-435).

Studies of anthropological linguistics further showed that the preference to basic-level concepts is universal, across all cultures. For example, Berlin and his co-workers discovered that Tzeltal speakers in Mexico always started their classification with concepts at a particular abstract level: the level of genus. Berlin and his co-workers found this preference by naming experiments. They went out into the jungle with native speakers, and asked the subjects to name the plants they saw. Tzeltal speakers in these experiments consistently named them at the level of the genus (*oak*, *maple*) instead of the level of the species (*sugar maple*, *live oak*) nor the level of the life form (*tree*), even though they could distinguish the species or know the name of the life form (Berlin, *et al.* 1974: 30-37).

To explain the special status of basic-level concepts, Rosch referred to the fact that the referents of basic-level concepts often share common shapes, that is, have similar spacial characters. For example, the referents of such a basic-level concept as *chair* often have overwhelming similarities in their shape. In contrast, it is hard to see any similarity in shape among the referents of the superordinate concept *furniture*.[2] Because they have a high level of similarity in spacial characters, basic-level concepts contain more diagnostic cues for classification. Thus, our preference to the basic-level concepts in classification supports the perceptual approach's implication that intraconceptual relations in entity concepts are essentially spacial.

4. Perceptual symbols and taxonomy comparison. The perceptual approach to conceptual representation can also shed light on many issues that has interested philosophers of science for a long time, for example, the issue of taxonomy comparison. A taxonomy is a classification system that organizes concepts into different groups according their similarity relations. In a frame representation, similarity between two concepts is described in terms of the matches in the values of relevant attributes. But what should be counted as relevant attributes? According to the amodal representation, the frame itself does not offer answers to this question because it is abstract and bears no analogous relations to the referents. We need background beliefs or intuitive theories to decide which attributes are relevant. If two persons do not have compatible background beliefs, they could disagree with each other in their selections of relevant attributes and consequently their judgments of similarity.

To further understand the difficulties in taxonomy comparison, let us take a close look of a historical case: the comparison of the taxonomies of birds during the Darwinian revolution. In the 17th century when the first ornithological taxonomy was developed, birds were simply divided into two classes, *water-bird* and *land-bird*, according their *beak shape* and *foot structure*. Typical examples of *water-bird* were those with a round beak and webbed feet like ducks, and typical examples of *land-bird* were those with a pointed beak and clawed feet like chickens. By the mid 19th century, however, many newly found birds could not be fitted into the dichotomous system. For example, a South American bird called "screamer" was found to have webbed feet like ducks but a pointed beak like chickens. To accommodate these anomalies, a popular taxonomy proposed by Sundavell in 1830s adopted more attributes, including *plumage pattern*, *wing-feather arrangement* and *lag form* were adopted, as classification standards. It put *screamer* under a new category *grallatores,* independent of *water-bird* and *land-bird* (Figure 2).[3]

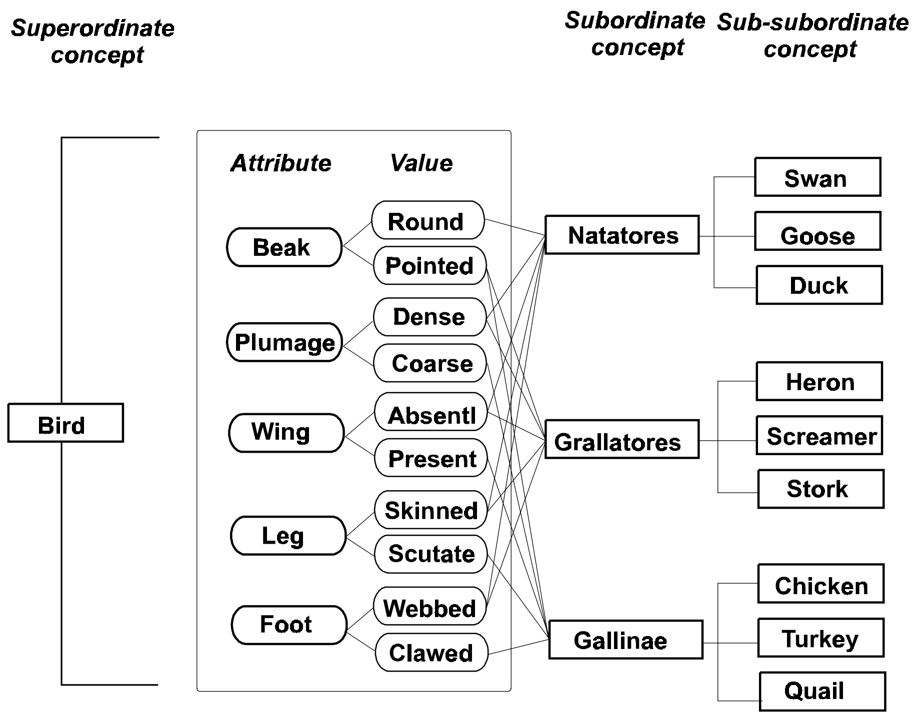

Figure 2. A frame representation of the Sundevall taxonomy (only three related subordinate concepts are listed)

The Darwinian revolution caused radical changes in bird classification. Influenced by Darwin's beliefs that species are not constant and therefore affinity among species must be founded on their common origin, ornithologists realized that many morphological features used as classification standards in pre-Darwinian taxonomies were arbitrary and irrelevant. They began to search for features that could review the origin of birds. In a popular post-Darwinian taxonomy proposed by Gadow in 1893, a different set of attributes were adopted, which included *palatal structure*, *pelvic muscula-ture form*, *tendon type*, *intestinal convolution type*, *carotid artery form*, and *wing-feather arrangement*. As the result, *screamer* and *anseres* (equivalent to *water-bird*) were no longer independent of each other. They were together put under a new category *anseriform* (Figure 3).

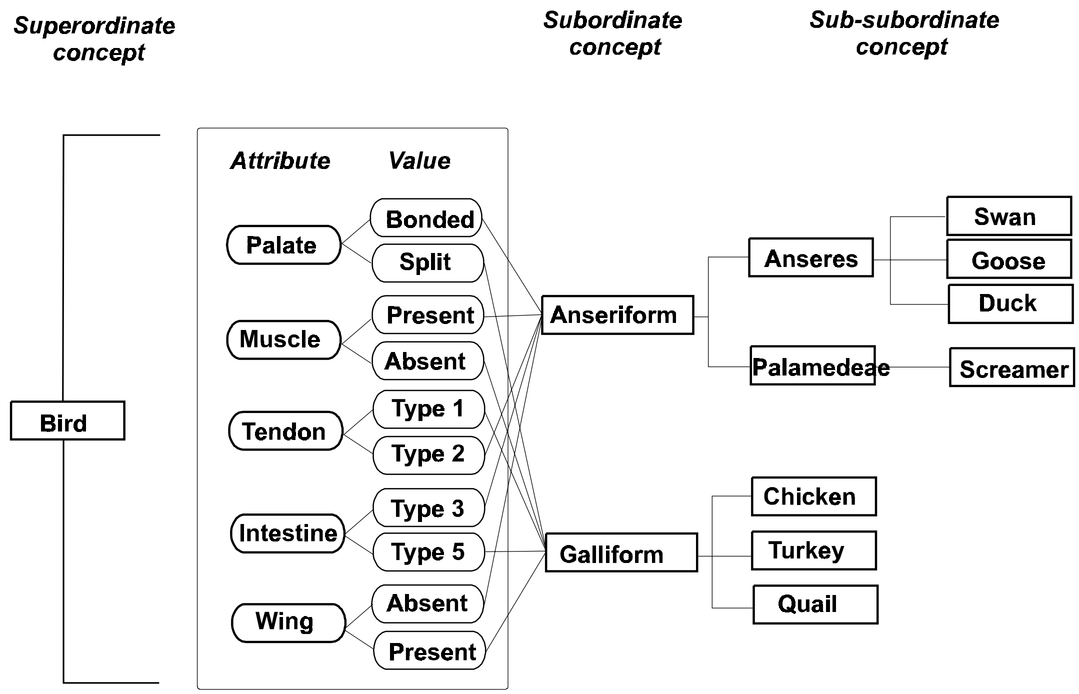

Figure 3. A frame representation of the Gadow taxonomy (only two related subordinate concepts are listed)

These two taxonomies of birds made different predictions of similarity and dissimilarity relations. The pre-Darwinian taxonomy put *screamer* and the equivalent of *water-bird* under two contrastive covering terms and emphasized their dissimilarity, while the post-Darwinian taxonomy put them under the same covering term and emphasized their similarity. But observations of similarity or dissimilarity relations could not be used directly to test these two rival taxonomies. Given the fact that the taxonomic change occurred during the Darwinian revolution, ornithologists from either side shared very little in their understandings of the objects. With different standards in attribute selection, they could have incompatible judgements regard-ing whether an observation of similarity was relevant. Thus, according to the amodal representation, it is very difficult to see how these two taxonomies built upon radically different background beliefs could be com-pared in a rational way.

The perceptual approach however understands the process of taxonomy comparison quite differently. Perceptual symbols are schematic fragments extracted from perceptual states via selective attention. Which perceptual symbols can be used as attributes in concept representation depend upon what the perceptual states can offer, and we can only select attributes from a list of candidates decided by the perceptual states. Al-though background beliefs and intuitive theories continue to influence our selections of attributes, these factors cannot create attributes that do not exist in the perceptual states. If two taxonomies are built upon similar observations, similarity in perceptual states can become a common ground for communication between people who adopt different taxonomies. They may select different attributes in concept representation, but they can understand each other's selection and may not necessarily regard others' choices as incompatible. Furthermore, we have seen in the last section that, because intraconceptual relations are in essence spacial, people develop preference to use concepts that contain rich spacial information in various cognitive tasks. The preference to basic-level concepts exists in categorization, because they have overwhelming similarities in such spacial character as shape. There is reason to believe that such a preference should also exist in attribute selection, because people can process spacial information more effectively and efficiently. To represent the concept *bird*, people could prefer to choose those attributes that reveal spacial characters such as the shape. If this is the case, the preference to spacial concepts could further reduce the list of possible attributes, and help people who adopt rival taxonomies make compatible selections.

Findings from cognitive psychology support the above implications of the perceptual approach. In an experiment, Rosch and her collaborators asked subjects to write down all the attributes of various concepts. Although these subjects shared very little in their background beliefs, many attributes that they wrote down were in common. The consensus was even more evident when the subjects were asked to write down attributes for biological concepts, such as *bird*, *fish* and *tree* (Rosch, *et al.* 1976: 387-393). More researches have been done to study the process of attribute selection for biological concepts. In a series of experiments, Tversky and Hemenway asked subjects to list attributes of various biological concepts. They divided the attributes selected by the subjects into two kinds according to whether they are body parts of the creatures. The results were very interesting: more than 70% of the attributes selected by the subjects for representing basic-level biological concepts such as *bird*, *fish* and *tree* are body parts (Tversky & Hemenway 1984: 173-78). This consensus indicates that people indeed prefer attributes that contain rich spacial information, because body parts of biological objects are perceptually salient: they are identifiable by their shapes and can be extracted and processed more effectively and efficiently than other kind of information.

The preference to attributes with rich spacial information, particularly, to body parts also existed in our historical case. At first glance, the attribute list embedded in the post-Darwinian taxonomy is considerable different from the one in the pre-Darwinian taxonomy. They had only one common attribute (*wing-feathering arrangement*). But it is important to note that these two lists of attributes are compatible: none of the listed attributes in one taxonomy overlaps those in the other. A closer examination of these attributes further shows that the two lists of attributes share a common feature -- all of them are anatomical parts of birds. In light of cognitive studies, there is reason to believe that such a preference was not accidental, but reflected a general feature of human cognition.

The different but compatible lists of attributes embedded in the pre-Darwinian and post-Darwinian taxonomies of birds could provide a common "platform" for rational comparison. Because of the compatible attribute lists, people from both sides would agree with each other on what attributes should count as relevant in judgments of similarity and dissimilarity. When observations showed more and more similarities between *screamer* and *water-foul* in skull character (bonded palate), skeleton (sternums with only one pair of incisions), wing pattern (11 primary feathers), muscular system (type 2 tendon) and digestive system (type 3 intestinal convolution), supporters of the pre-Darwinian taxonomy would have to agree that all these similarities were relevant and accept them as legitimate evidence for testing their taxonomy. When observations of the similarities between *screamer* and *water-foul* became overwhelming, they would have no choice but admit that their taxonomy was in trouble.

Historical evidence indicates that the two rival taxonomies were indeed compared and evaluated in a rational manner. Although there were debates regarding the merits of the two rival systems, criticisms from either side were mainly based upon observations of similarity and dissimilarity relations between birds. The main objection to the pre-Darwinian taxonomy was, for example, that it grouped many dissimilar birds together. As pointed out by a supporter of the Gadow taxonomy, "many of the alliances [in the pre-Darwinian taxonomy], such, for instance, as that of Pitta with the true Thruches, are indefensible on any rational grounds" (Newton 1893). Due to the compelling evidence regarding similarity and dissimilarity relations, the community quickly formed a consensus. Before the end of the 19th century, the Gadow taxonomy was accepted by the ornithological community, and, through the work of Wetmore in 1930, became the principal basis for the classification of birds in use until the 1950s (Sibley & Ahlquist 1990: 202-215). The transformation from the Sundevall taxonomy to the Gadow taxonomy was fundamental -- in fact it was a part of the Darwinian revolution. The revolutionary nature of this taxonomic change makes the quick and smooth acceptance of the Gadow taxonomy unusual. Apparently, Gadow's success resulted from the overwhelming evidence that he presented. However, without a common platform for defining the relevance of these attributes, it would have been impossible for the community to develop a consensus on Gadow's empirical evidence. Thus, the compatible attribute lists could have functioned as a cognitive platform for the rational evaluations of the pre-Darwinian and the post-Darwinian system and resulted in the quick and smooth taxonomic change.

5. Conclusion. To explain how different taxonomies can be compared, philosophers have offered many accounts. Some appealed to shared reference (Putnam 1975) or shared background beliefs (Shapere 1989), and some others introduced such non-empirical criteria as simplicity and consistency (Kuhn 1970). Now cognitive studies offer a different account. If concepts are inherently perceptual, the process of attribute selection, which is critical for defining similarity and thus for comparing taxonomies, would no longer be determined solely by background beliefs. The analogous nature of perceptual symbols and the spacial nature of intraconceptual relations impose new constraints to attribute selection. These constraints help people with different background beliefs select compatible attributes, which constitute a common "platform" for taxonomy comparison. Thus, rival taxonomies can be compared rationally, partly because we have common preference in our conceptual processing.

Thus far empirical studies have only tested and supported the core assumption of Barsalou's theory of perceptual symbols, namely, that perceptual simulation lies at the heart of conceptual processing. There are different interpretations among cognitive scientists on whether perceptual simulation alone can represent human knowledge. But the impact of this new concept representation on philosophy of science is profound. In addition to taxonomy comparison, the perceptual approach also sheds light on such issues as scientific models, concept learning and scientific change.[4] Thus, the recent development in concept representation deserves attention from philosophers, and much more research is needed to explore the implications.

Notes:

[1.] In action concepts such as *bite*, some structural relations among attributes are temporal -- an *open mouth* is followed by a *closed mouth*.

[2] Although the referents of subordinate concepts also share common shapes, the gain in similarity in shape is small and the cost in handling a dramatic increase of information is huge. Moving to this level of abstraction, according to Rosch, is not worth the cost.

[3] Note that both attributes and values are perceptual symbols. But for simplicity reason, I continue to use linguistic forms to describe them in the figures.

[4] By defining perceptual symbols as neural states, Barsalou's approach may overcome a difficulty of the received account that interprets models as images and has trouble in accounting for their explanatory power. For implications of the frame representation to concept learning, see (Andersen, *et al.* 1996). For implications of the frame model to scientific change, see (Chen, *et al.* 1998; Chen & Barker 2000).

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