Springer

---

http://www.jstor.org

THE 'PLATFORMS' FOR COMPARING INCOMMENSURABLE TAXONOMIES: A COGNITIVE-HISTORICAL ANALYSIS

XIANG CHEN

SUMMARY. This paper examines taxonomy comparison from a cognitive perspective. Arguments are developed by drawing on the results of cognitive psychology, which reveal the cognitive mechanisms behind the practice of taxonomy comparison. The taxonomic change in 19th-century ornithology is also used to uncover the historical practice that ornithologists employed in the revision of the classification of birds. On the basis of cognitive and historical analyses, I argue that incommensurable taxonomies can be compared rationally. Using a frame model to represent taxonomy, I show how rational comparisons were achieved in the historical case through compatible contrast sets and attribute lists. Through analyzing the cognitive processes of classification and concept representation, I further explain how rival taxonomies in the historical case could be rationally compared on 'platforms' rooted in such cognitive mechanisms as relational assumptions and preferences for body parts in conceptual processing.

Key words: Kuhn, incommensurability, taxonomy, theory choice

1. INTRODUCTION

One of the most controversial themes in Kuhn's philosophy of science is his incommensurability thesis, which, in its original version, claims that rival paradigms are incomparable due to full-scale meaning change in their vocabulary. Many critics however pointed out that even full-scale meaning change does not necessary lead to incomparability. For example, by proposing a causal theory of reference, Putnam argued that the referents of many terms remain the same during a paradigm shift, because reference is established at an initial naming ceremony and thus independent of descriptive content (Putnam, 1975).

To counter Putnam's objection, Kuhn in his later writings offered a new version of the incommensurability thesis, which limits meaning change to a restricted class of kind terms. These kind terms, together with their interconnections, form the taxonomy that classifies the subjects in the domain.

During a taxonomic change, many kind terms from the old taxonomy are preserved; at the same time, some new kind terms are added, some old ones are deleted, and many others are rearranged in different ways. To make sure that no two kind terms 'may overlap in their referents unless they are related as species to genus,' systematic redistribution of the referents to which the kind terms refer becomes necessary (Kuhn, 1991, p. 4).[1] Sometimes referents previously regarded as quite unlike need to be grouped together, while referents of some single term in the old taxonomy have to be divided between different ones. These changes in reference 'affect not just the referents of an individual term but of an interrelated set of terms between which the preexisting population is redistributed' (Kuhn, 1989, p. 31). Since such redistribution always involves more than one kind term and since kind terms are always interdefined, taxonomic change is necessarily holistic. After a taxonomic change, there is no longer a 'shared metric' or a common platform on which individuals from different communities can obtain neutral evidence – the same observation could be classified differently in the completing taxonomies. Kuhn thus maintained that rival taxonomies cannot be evaluated by means of observations and so cannot be compared rationally.[2]

What interests us here is not Kuhn's conclusion of incomparability, but his attempt, though incomplete, to explore the cognitive processes behind taxonomic change. Kuhn did not limit his analysis of taxonomic incommensurability at the semantic level. 'Though I'll continue to talk of [taxonomy] as containing primarily words and their meanings, I think of it as a more general sort of categorizing module' (Kuhn, 1990, p. 5). Our understanding of kind terms is rooted in our capacity of recognizing kinds, which, 'between their origin and demise, trace a lifeline through space and time'(Kuhn, 1993, p. 315). To construct a taxonomy, we need a 'mental module' or a 'neural mechanism' that enables us to recognize and reidentify kinds through their evolution. Kuhn thus implied that taxonomic change requires various modifications in our cognitive apparatus, and taxonomic comparison must involve some kind of cognitive processes or mechanisms. Kuhn did not offer any detail of the cognitive processes or mechanisms behind taxonomic change, but his suggestion to analyze taxonomic change from a cognitive perspective represents a significant departure from the traditional position in philosophy of science that treated rational comparison of rival theories as a semantic issue, merely in terms of the relations between terms (theories) and referents (observations).

In this paper I am to examine taxonomy comparison from a cognitive perspective, that is, by focusing on the cognitive mechanisms behind taxonomic change instead of phenomena at the linguistic level. For this reason,

taxonomies in this paper are defined not merely as systems of terms, but also as systems of concepts, which are temporary constructions in working memory. I develop my arguments by drawing on the results of cognitive psychology, which reveal the cognitive mechanisms behind the practice of taxonomy comparison. I also use the taxonomic changes in 19th-century ornithology to uncover the historical practice that ornithologists employed in the revisions of the classification of birds. The cognitive and historical analyses indicate that incommensurable taxonomies can be compared rationally. Using a frame model to represent taxonomy, I show how rational comparisons were achieved in the historical case through compatible contrast sets and attribute lists. Through analyzing the cognitive processes of classification and concept representation, I further explain how rival taxonomies in the historical case could be rationally compared on 'platforms' rooted in such cognitive mechanisms as relational assumptions and preference for body parts in conceptual processing.

2. A FRAME-BASED REPRESENTATION OF TAXONOMY

Although attempts to classify birds can be found in the writings of Aristotle, the first avian taxonomy did not appear until the 17th century. It was John Ray who in 1676 constructed a systematic classification that covered all birds known at the time and arranged them in a hierarchical system.[3] To many, Ray's taxonomy formed the foundation of modern ornithology (Newton, 1893, p. 7).

In the 17th century, classifications of birds were mainly used for organizing specimens in public museums or private 'cabinets of birds'. Since making durable preserved specimens of birds was still a difficult art at that time (for large birds, only parts of the bodies such as heads, legs and wings could be preserved), Ray had to rely upon externally visible parts of birds as the classification standards. He chose beak shape and foot structure as the key standards, and divided all birds into two main categories: *water-bird* and *land-bird* (Ray, 1678, p. 20).[4] Typical examples of *water-bird* are those with a round beak but webbed feet like ducks, and typical examples of *land-bird* are those with a pointed beak and clawed feet like chickens.

A traditional method to represent the Ray taxonomy or any taxonomic system is to outline the relations among the concepts in terms of their extensions (Kay, 1971, pp. 868–872). Figure 1 is a partial representation of the Ray taxonomy according to this method.[5] It indicates that there is an inclusive relation between the superordinate term 'bird' and the subordinate terms 'water-bird' and 'land-bird,' because the latter are subsets of the former. The extensional representation also implies that there are
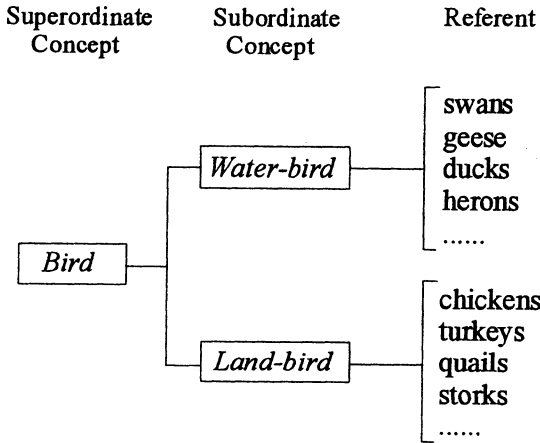
| Superordinate | Subordinate | Referent |
| Concept | Concept | |

Figure 1. The Ray taxonomy.

contrastive relations among terms within the same subordinate group, be-cause such terms as 'water-bird' and 'land-bird' should never be applied to the same object. It is acceptable to call a water-bird a 'bird' because of their inclusive relations, but not to call it a 'land-bird'. In other words, terms belonging to the same subordinate group cannot overlap in their referents, and so no object is both a 'water-bird' and a 'land-bird'. This is the non-overlap principle for taxonomic or kind terms.

Although the extensional method successfully represents the end product of classification, it does not reveal the process, particularly, it fails to cap-ture how standards for classification are formed. In the Ray taxonomy, birds were classified according to externally visible features such as beak shape and foot structure, all of which are body parts of birds. The selec-tion of these features as the classification standards reflected Ray's un-derstanding of birds, particularly their anatomy. Cognitively speaking, the Ray taxonomy derives directly from the superordinate concept *bird*, which defines the relevant body parts as well as their relations, and functions as a cognitive mechanism generating the whole taxonomy. But the extensional representation does not illustrate the internal structure of the superordinate concept. Keeping the internal structure of the superordinate concept in a black box, the extensional representation fails to reveal the cognitive pro-cess that generates the taxonomy. Without the classification standards, we simply do not know how to make a new classification when a new bird is found.

To capture the cognitive mechanisms that generate rich structural rela-tions within a taxonomy, we need a representation that outlines not only the interconceptual relations among concepts, but, more important, the
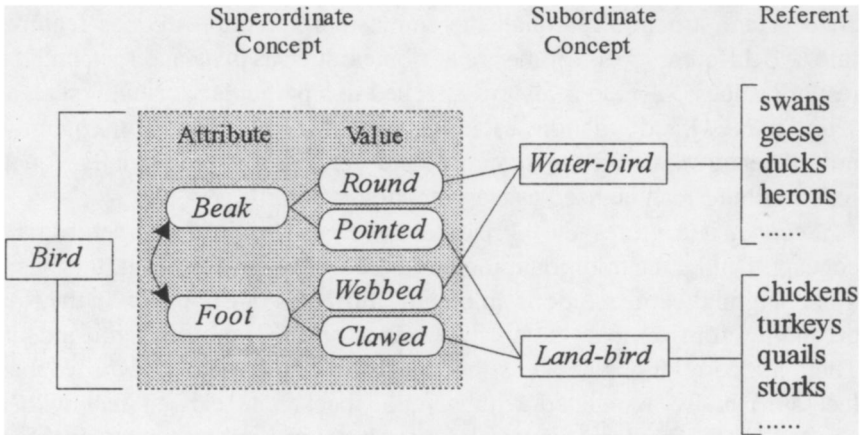
Figure 2. A frame representation of the Ray taxonomy.

intraconceptual relations within concepts, particularly the superordinate one. One solution is to bring the superordinate concept out of the black box by detailing its internal structure. In other words, we need an intensional model that can capture the contents of the superordinate concept in a taxonomy by outlining its internal structure. The traditional model for concept representation, which represents concepts through a list of unrelated features or a set of necessary and sufficient conditions, is obviously inadequate. Cognitive scientists such as Larry Barsalou recently recommend that we should represent the internal relationships of concepts by frames, that is, sets of multivalued attributes integrated by structural connections.[6]

Figure 2 is a partial frame representation of the Ray taxonomy, which reveals the internal structure of the superordinate concept *bird*. Similar to the extensional model, the frame representation outlines the structure of a taxonomy in terms of different abstract levels, from superordinate to subordinate. The key difference here is that we introduce a frame to illustrate the superordinate concept.[7] The frame of the superordinate concept contains two lists of properties: an attribute list and a value list, and outlines several kinds of connection between these properties. Next to the frame is a list of subordinates (*water-bird* and *land-bird*), which share all the properties in the attribute list, but only some from the value list. Each pattern of selection constitutes the prototype of a subordinate concept. By introducing a frame, our new intensional representation captures several important intraconceptual relations missed by the extensional model.

First, it captures the hierarchical relations within the superordinate concept. Contrary to the conventional assumption that all features within a

concept are structurally equal, the frame representation divides features into two different levels. Some are attributes, such as *beak* and *foot*, and the rest are values. A value is always attached to a particular attribute (such as *round* to *beak*) and functions as an instance of the attribute. Consequently, not all features within the superordinate concept are functionally equal: only attributes can be used as classification standards.

Second, it captures the horizontal relations within the superordinate concept. Unlike the traditional model for concept representation, the frame model highlights the relations among the attributes of a concept. In the Ray taxonomy, for example, the attributes *beak* and *foot* are not independent. There are correlations between the value of *beak* and that of *foot*: webbed feet are usually associated with a round beak, and clawed feet with a pointed beak. These are physical constraints imposed by nature: webbed feet and round beaks are adapted to the environment in which water-birds live, but clawed feet and pointed beaks would be a hindrance in water.[8] Because of these constraint relations, the attributes *beak* and *foot* must be used together as a cluster in classification.

Third, it also reveals the cognitive mechanisms behind the contrast-ive relations among subordinate concepts. The frame of a superordinate concept directly determines the possible concepts at the subordinate level. For example, since the frame of *bird* in the Ray taxonomy has two at-tributes and each of them has two possible values, there are four possible property combinations (2x2) and thereby four possible concepts at the sub-ordinate level. But due to the constraints between the value sets, some of these property combinations are conceptually impossible, such as *round beak* with *clawed foot* and *point beak* with *webbed foot*. The results are only two property combinations (*round beak* with *webbed foot* and *pointed beak* with *clawed foot*), which form two subordinate concepts – *water-bird* and *land-bird*. In this way, the frame specifies the contrastive relations between the two subordinate concepts. They contrast each other in re-spect to *beak* and *foot*. These two mutually exclusive but jointly exhaustive subordinate concepts constitute the contrast set under the superordinate one.

3. CONTRAST SETS AND RELATIONAL ASSUMPTIONS

The Ray taxonomy dominated ornithology in the 17th and the 18th cen-turies. Many ornithologists during this period, including Linnaeus (1735), Brisson (1756), and Latham (1781), continued to use the characters of beak and foot as the main classification standards to construct new taxonomies of birds (Stresemann, 1975, pp. 49–57). However, ornithology was fun-
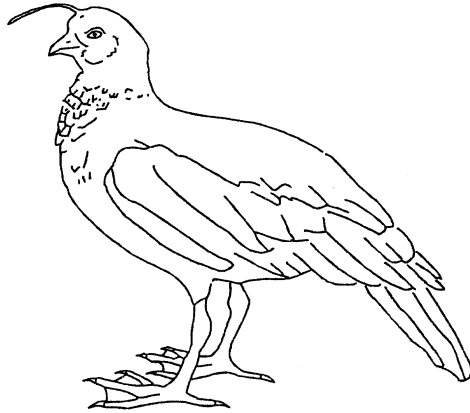
Figure 3. Horned screamer *Anhima cornuta.*

damentally altered by the social and economic revolution beginning at
the end of the 18th century. Because of the enormous colonial and com-
mercial expansion, numerous ships were sent to almost every continent of
the world, and several government-sponsored scientific expeditions were
launched between 1815 and 1830. Consequently, the number of specimens
of birds increased exponentially during this period (Farber, 1997, pp. 92–
98). Ornithologists began to realize that the existing Ray system failed to
cover many newly discovered species of birds, and they thus developed
doubts over the existing taxonomy, particularly its use of beak shape and
foot structure as the sole standards in classification.

For the sake of simplicity, let us concentrate on the impact of one
particular discovery. In the late 18th century, ornithologists discovered a
strange creature from South America by the common name of 'screamer'
(Figure 3). A peculiar feature of screamers is that they have webbed feet
like ducks but a pointed beak like chickens. The combination of these
two features, which were supposed to be incompatible according to the
Ray taxonomy, caused confusion. The constraint between *foot* and *beak*
in the Ray taxonomy required that these two attributes be used together
in classification. Thus, the discovery of screamers immediately generated
problems, because ornithologists did not know how screamers should be
classified according to the cluster of *foot* and *beak*. Eventually, this an-
omaly forced them to alter the frame of *bird* and the associated taxonomy,
because it made a very important constraint relation between *foot* and *beak*
invalid.

In the early 19th century, many ornithologists, including Sundevall (1835),
Keyserling and Blasius (1839), Nitzsch (1840), Muller (1845) and Lillje-
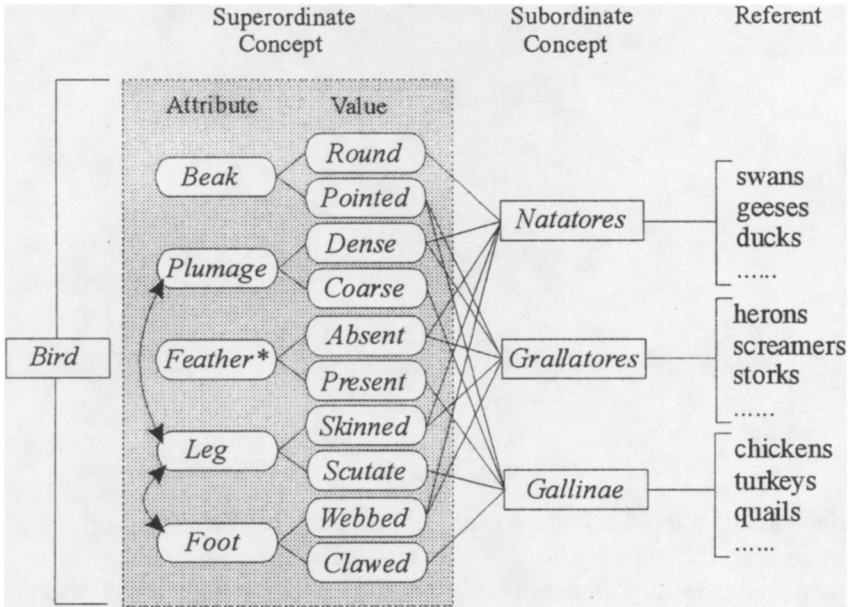borg (1866), presented new classifications of birds to replace the failing

Figure 4.   A frame representation of the Sundevall taxonomy.
* The attribute *Feather* refers to the fifth secondary.

Ray system. All of these new systems replaced beak shape and foot struc-
ture with comprehensive sets of classification standards that included many
external, morphological features. An example of these new taxonomies is
the one presented by the Swedish ornithologist Carl Sundevall in 1835.
This is a taxonomy that employs many external features of birds, such
as beak shape (round or pointed), plumage pattern (refined or coarse),
feathering arrangement in the wings (with or without the fifth secondary
feather), leg covering (skinned or scutate) and foot structure (webbed or
clawed) (Sundevall, 1889, pp. 197–207, 223–42). Figure 4 is a partial
frame representation of the Sundevall taxonomy.[9]

Embedded in the Sundevall taxonomy is a whole new concept of *bird*.
First, unlike Ray's notion, Sundevall's *bird* includes many new attributes
in addition to *beak* and *foot*. Second, Sundevall's *bird* no longer entails
a constraint relation between *beak* and *foot*; instead, new constraint re-
lations are formed between *foot* and *plumage*, as well as between *foot*
and *leg covering*. Again, these are physical constraints imposed by nature,
resulting from the adaptation to the environment. The new superordinate
concept inevitably alters the taxonomy by expanding the conceptual field
at the subordinate level. The five attributes generate more possible property
combinations, and thereby more possible concepts. The Sundevall tax-

onomy thus was more flexible than Ray's dichotomous system to cover various anomalies. Specifically, because the attribute *beak* and *foot* are no long related in the Sundevall system, it becomes possible to have a property combination that includes both *point beak* and *webbed feet*, the key features of screamers. In this way, Sundevall effectively eliminated the anomaly caused by the newly founded screamers.

The newly introduced Sundevall taxonomy exemplifies the Kuhnian taxonomic change – holistic redistribution of referents due to addition, deletion and rearrangement of kind terms. Because of the referent redistribution, many terms in the new taxonomy cannot be translated to the old ones, nor the other way around. Consequently, communication obstacles were bound to occur between the followers of the two systems. The followers of the Ray taxonomy, for example, would regard 'grallatores' from the Sundevall taxonomy as incommensurable, because they could not find an equivalent native term with referents that do not overlap those of the foreign one. Both 'water-bird' and 'land-bird' from the old taxonomy overlap 'grallatores,' which includes water-birds like herons as well as land-birds like storks. On the other hand, the followers of the Sundevall taxonomy would regard 'water-bird' from the Ray taxonomy as confusing, because they could not find an equivalent native term without violating the non-overlap principle. Sundevall's 'natatores' overlaps Ray's 'water-bird'; specifically, the former is included by the latter, but they are not in species-genus relations.

But the redistribution of referents did not wipe out the possibility of rational comparison. If we consider the intraconceptual relations within the superordinate concept that determines the process of classification, we would see that the Ray and the Sundevall taxonomies are still compatible in many aspects. Let us concentrate on the contrast set at the subordinate level. In the Ray taxonomy, this is the set with 'water-bird' and 'land-bird,' and in the Sundevall taxonomy, this is the set with 'natatores,' 'grallatores' and 'gallinae'. In terms of their extensional relations, the two contrast sets have little similarity. But as pointed out by many recent cognitive studies, extensional definitions alone do not reveal the linguistic necessities relating the members of contrast sets. Such linguistic necessities are rooted in the common beliefs about the contrasts and inclusions shared by the competent speakers from a speech community (Grandy, 1992). These common beliefs usually exhibit themselves in the form of relational assumptions. For example, to construct a taxonomy, we need a specific inclusive assumption that puts all subordinate concepts under the covering one. We also need a set of contrastive assumptions, each of which defines a specific aspect in which two subordinate concepts contrast. In our frame repres-

entation, all of these relational assumptions are embedded in the internal structure of the superordinate concept. The inclusive assumption derives from the attribute list: all subordinate concepts belong to the superordinate one because they all share the properties of the attributes. The contrastive assumptions derive from the pattern of the activated values: two concepts contrast if they have different values in the same attribute.

In terms of their relational assumptions, the Ray taxonomy and the Sundevall taxonomy are compatible. The compatibility first consists in their contrastive assumptions: many contrastive assumptions in the old taxonomy are preserved after the taxonomic change. For example, the contrastive assumption regarding the relations between *water-bird* and *land-bird* in the old contrast set are preserved in the new one, where *natatores* and *gallinae* continue to be in contrast by having opposite values in the same pair of attributes. More important, the newly added contrastive assumptions do not interfere or contradict with the preserved ones. The new contrastive assumptions regarding the relations between *natatores* and *grallatores*, deriving from the opposite value assignments in the attributes of *plumage, feather* and *leg covering*, do not alter the contrastive assumptions inherited from the old contrast set.

The compatibility also consists in the relations between the inclusive assumptions of the two contrast sets: there is no fundamental disagreement between the two taxonomies regarding the inclusive relations between the superordinate and the subordinate concepts. Those who adopted the Sundevall taxonomy should agree that both *water-bird* and *land-bird* in the old taxonomy are *bird*, although they might have different ideas about some features of *water-bird* and *land-bird* and about their relations. Similarly, those who retained the Ray taxonomy should agree that both *natatores* and *gallinae* from the new taxonomy are *bird*, and they should also agree that the newly founded screamers are birds too, although they might conceptualize these birds differently in some other aspects.

Because the relational assumptions adopted in the process of classification are compatible, it is possible that the Ray and the Sundevall taxonomies can be compared according to shared evidence, despite that they are incommensurable due to the mismatches in the referents of their terms. For example, the Ray taxonomy predicts that there are no birds with a pointed beak and webbed feet, because of the constraint relation between *beak* and *foot* in the superordinate frame and the exhaustive assumption associated with the contrast set. However, the Sundevall taxonomy predicts that it is possible to have birds with a pointed beak and webbed feet, because there is no constraint relation between *beak* and *foot* in the superordinate frame. These two predictions are contradictory and can be compared with

empirical evidence. If the supporters of the Sundevall taxonomy found some birds, say screamers, with a pointed beak but webbed feet, they could use these creatures as the evidence to challenge the Ray taxonomy, on the base of the inclusive assumption that screamers are *bird*. Because they shared the same inclusive assumption, those who retained the Ray taxonomy would have to agree that screamers belonged to *bird*, and thus were legitimate evidence for testing their taxonomy. Consequently, they would have no choice but admit that their taxonomy was in trouble.

In this way, the compatible relational assumptions function like a platform that offers shared standards to define the classification scheme used to identify the evidence. With such a platform, it became possible for the followers of the Ray taxonomy and those of the Sundevall taxonomy to agree with each other on the legitimacy of the evidence and then to achieve rational judgments of these two rival taxonomies. The compatibility between the relational assumptions embedded in the Ray and the Sundevall taxonomies offers an explanation for the consensus among ornithologists when they evaluated the two rival taxonomies. By the mid-19th century, most ornithologists either adopted the Sundevall taxonomy or advocated systems that employed similar morphological characters as classification standards and thus were in essence identical to the Sundevall system. As observed by the American ornithologists Spencer Baird, 'the classification of bird ... has engaged the attention of a large number of naturalists, although until within a comparatively short time there has not been any very great difference in the systems adopted by the leading writers on general ornithology. The more commonly received basis has been the character of the bill and the shape and general structure of the feet ... Within a few years, however, a great change has taken placed in the methods of ornithological classification, and most continental authorities have abandoned the old arrangement ..., as based on the shape and character of the bill, and substituted a much more natural system' (Baird, 1858, pp. 1–2). The quick and smooth replacement of the Ray taxonomy by the Sundevall taxonomy thus indicates that the two incommensurable taxonomies could have been evaluated on a common ground. If there was no overwhelming evidence shared by both sides, it would have been almost impossible for the community to achieve consensus regarding the rival taxonomies in such a speedy and decisive manner.

4. ATTRIBUTE LISTS AND THE PREFERENCE FOR BODY PARTS

The taxonomic change caused by the replacement of the Ray system with the Sundevall system in the first half of the 19th century can hardly be
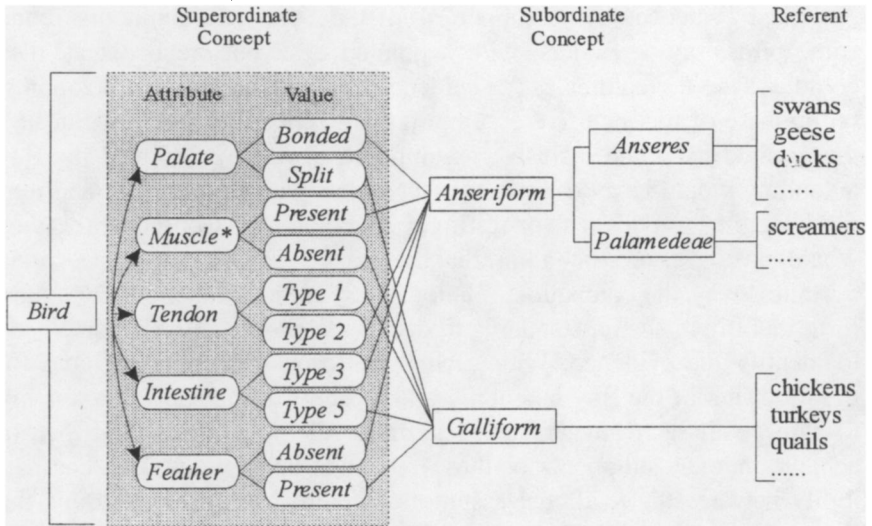
Figure 5. A frame representation of the Gadow taxonomy.
* The attribute *Muscle* refers to the pelvic musculature.

called revolutionary. Although the Sundevall taxonomy classified birds in a different way, it shared the same metaphysical foundation with the Ray taxonomy. Sundevall continued to believe that species are constant and therefore 'species and genera *ought to be arranged according to their resemblance in form*' (Sundevall, 1889, p. 17; original emphasis). A much more profound taxonomic change in ornithology occurred during the second half of the 19th century, when Darwin discovered that species are not constant, and therefore affinity among species must be founded on their common origin. Influenced by Darwin's evolutionary theory, ornithologists realized that many morphological characters used as classification standards in previous taxonomies were arbitrary, and they began to search for new classification criteria that could display the origins of birds.

Meanwhile, the screamer caused more troubles, because ornithologists found many new anatomical similarities between screamers and waterfowl (Parker, 1863). For example, it was found that both screamers and waterfowl (swans, ducks and geese) have similar skull characters (bonded palate), similar skeletons (sternums with only one pair of incisions), similar wing patterns (with 11 primary feathers) and similar feather structure (a small aftershaft). These observations exposed the problems of the Sundevall taxonomy, which emphasized the dissimilarities between screamers and waterfowl.[10]

To replace the problematic Sundevall system, Hans Gadow in 1893 introduced a new classification of birds. This is a taxonomy built upon

both genealogical and morphological similarities, with an assumption that greater phenotypical similarity implies greater genetical similarity and hence closer relationship. Using about forty characters from various anatomical systems, Gadow advocated a whole new taxonomy supported by overwhelming evidence. Among these classification characters, there are six that represented the major anatomical systems. They are palatal structure (bonded or split palate) for the skeleton, pelvic musculature (present or absent) and the tendon in the legs (several different types) for the muscular system, intestinal convolution (several different types) for the digestive system, carotid arteries (two different arrangements) for the circulatory system, and feathering arrangement in the wings (with or without the fifth secondary) for the morphology (Gadow, 1892, pp. 230–256). Figure 5 is a partial frame representation of the Gadow taxonomy.[11]

Embedded in the Gadow taxonomy is a new concept of *bird*, which includes a new list of attributes and a whole new set of constraint relations. The strong constraint relations among all attributes reflect the assumption that similarities in these anatomical features reveal a common origin and therefore the values of these attributes ought to be correlated. Gadow's new understanding of the superordinate concept again alters the taxonomy. The strong constraints among the attributes significantly reduce the number of the possible property combinations. For example, such a combination as *bonded palate, type 4 tendon, presented fifth secondary in the wings* that may exemplify screamers becomes impossible, and Sundevall's *grallatores* that refers to screamers cannot be included in the contrast set at the subordinate level. At the same time, the similarities between waterfowl and screamers in skull character, skeleton, wing pattern and feather structure suggested that they should be put under the same covering concept.[12] Thus, Gadow introduced a new subordinate concept *anseriform* to denote both waterfowl and screamers, and put *anseriform* and *galliform* (the equivalent of Sundevall's *gallinae*) together in a contrast set. To further capture the differences between waterfowl and screamers, he constructed a new subordinate level where *anseres* and *palamedeae* form a new contrast set.

According to Kuhn, the Gadow taxonomy is incommensurable with the Sundevall taxonomy. Because the referent redistribution occurred in an interrelated set of concepts, communication between the two systems became extremely difficult. For example, the followers of the Sundevall taxonomy would regard Gadow's 'anseriform' as confusing because they could not find an equivalent native term without violating the non-overlap principle. The referents of Gadow's 'anseriform' overlap those of Sundevall's 'natatores' – the former includes the latter as a subset but they are not in species-genus relations. The followers of the Gadow taxonomy, on

the other hand, would regard Sundevall's 'grallatores' as incommensurable because of its overlap with 'anseriform'.

The differences between the Sundevall and the Gadow taxonomies are much deeper. The relational assumptions that define the contrast sets of the two taxonomies are no longer compatible. The Gadow taxonomy is built upon many new relational assumptions in conflict with those embedded in the Sundevall taxonomy. For example, *anseres* and *palamedeae* are in contrast in the Gadow taxonomy, but not so in the Sundevall taxonomy, where the equivalents of these concepts (*natatores* and *screamer*) belong to different categories and thus are not in contrast. Furthermore, *natatores* and *gallinae* are in contrast in the Sundevall taxonomy, but not so in the Gadow taxonomy, where their equivalents (*anseres* and *galliform*) are located at different abstract levels. Even worse, the inclusive assumptions in these two taxonomies are also incompatible, and there are fundamental disagreements regarding the inclusive relations between the two taxonomies. Those who adopted the Gadow taxonomy would insist that *palamedeae* should be included in the contrast set under *anseriform*, but those who retained the Sundevall taxonomy would categorically disagree and put the equivalent of *palamedeae*, i.e., *screamer*, underneath *grallatores*.

Because they do not share compatible contrast sets, the Sundevall taxonomy and the Gadow taxonomy cannot be compared in terms of their predictions regarding individual species. For example, the Sundevall taxonomy predicted that there were birds called 'grallatores' with a pointed beak and webbed feet. If the supporters of this taxonomy found creatures like screamers with a pointed beak but webbed feet, they could claim that the prediction was confirmed. But this judgment was not consensual unless people from the other side agreed with the legitimacy of the evidence, that is, that screamers belong to *grallatores*. In the eye of Gadow's supporters, screamers were not *grallatores* and should not be used to support the prediction. On the other hand, the Gadow taxonomy predicted that there were birds called 'anseriform' with a pointed beak and webbed feet, and the supporters of this taxonomy would cite the observations of screamers as positive evidence. But those from the other side would categorically deny the legitimacy of this kind of empirical evidence. To them, screamers were not the referents of *anseriform* and should not be used to verify the prediction of the Gadow taxonomy. With incompatible relational assumptions, there was no platform shared by both sides for defining empirical evidence.

Obviously, point-by-point comparison is not the only form of evaluating theories. A taxonomy not only defines the properties of the included kind terms, but also describes the similarity and dissimilarity relations

among the terms. Thus, the Sundevall and the Gadow taxonomies can be evaluated in a holistic way, by means of the similarity and dissimilarity relations that they entailed. For example, by putting screamers and waterfowl under two contrastive concepts (*natatores* and *grallatores*), the Sundevall taxonomy emphasizes their dissimilarity relations. Observations of the dissimilarities between screamers and waterfowl can then be used as evidence to support this taxonomy, and observations of the similarities between the two are negative evidence. In contrast, by putting screamers and waterfowl under the same superordinate concept *anseriform*, the Gadow taxonomy emphasizes the similarity relations between the two, and can be supported by observations of the similarities between screamers and waterfowl.

But similarity and dissimilarity relations cannot be observed directly, because they are not defined merely in terms of the number of matches or mismatches between certain features. It is our knowledge of the objects and their interrelations that determines what features count as relevant in judgments of similarity and dissimilarity. Without constraints on what is to be counted as a relevant feature, any two things could be said to be similar or dissimilar to any degree. In a frame representation, the constraints on similarity and dissimilarity relations exist in the frame of the superordinate concept. Similarity and dissimilarity relations are first described in terms of the matches or mismatches in the values of the attributes. The assumption here is that all attributes listed in the frame are relevant features that define similarity and dissimilarity relations. Thus, two compatible frames, more specifically, two compatible lists of attributes, are necessary for comparing similarity and dissimilarity relations.

When we construct a frame to represent a concept, our selection of the attributes is not arbitrary. Attribute selection is usually influenced by our own experience, goals and intuitive theories (Barsalou, 1992, p. 34). So, it is not surprised that the selected attributes in the Sundevall and the Gadow frames are considerably different – only one (*feather arrangement in the wings*) remains unchanged. But it is important to note that these two lists of attributes are not incompatible. None of the selected attributes in one frame overlaps those in the other – the newly activated attributes in the Gadow frame (*palate, muscle, tendon* and *intestine*) do not overlap any attributes in the old frame, nor do those unique Sundevall attributes (*beak, plumage, leg* and *foot*). 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. This common feature suggests that there might be a consensus between the two taxonomic systems regarding the range of possible attributes. Because of this consensus, there was no disagreement between the followers of the two rival taxonomies about the

legitimacy of the selected attributes, although they might disagree on their significance or importance.

The compatibility between the selected attributes of the Sundevall and the Gadow frames is not accidental. Many cognitive studies find that people often agree with each other on selected attributes in the process of frame construction, although they eventually adopt totally different frames. For example, Rosch and her collaborators in a series of experiments asked subjects to write down 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 such biological concepts as *bird*, *fish* and *tree* (Rosch *et al.*, 1976). Later, more research has 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 or not 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 and Hemenway, 1984).

The preference for body parts in attribute selection is probably rooted in the cognitive process of concept representation. Barsalou recently suggests that human cognition is inherently perceptual, sharing systems with perception at both the conceptual and the neural levels (Barsalou, 1999a). Unlike the traditional approach that regarded perceptual and conceptual as two fundamentally different cognitive stages, Barsalou believes that perceptual elements lie in the heart of conceptual processing. According to Barsalou, a cognitive process starts with perceptual states that arise in sensory-motor systems. Perceptual states are records of the neural activation and are structurally analogous to the referents. In the second stage of cognition, 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 are called perceptual symbols, which, on later retrievals, can function symbolically, standing for referents in the world. With an appropriate level of skill, we can integrate perceptual symbols into systems to simulate objects and events. Thus far Barsalou and his cooperators have conducted a series of empirical studies to support the perceptual approach of concept representation, although there are still different opinions among cognitive scientists on whether perceptual simulation alone can represent human knowledge (Barsalou *et al.*, 1999a,b).

Barsalou's theory of perceptual symbols can shed light to the cognitive process of attribute selection. If concepts are inherently perceptual, then a frame should be understood as an integrated system of perceptual symbols that bear analogous relations to both the perceptual states from which they derive and to the referents that they represent. Specifically, for entity concepts (such as biological concepts), attributes listed in frames are spatial symbols that outline subregions of the referents (or the typical examples of the referents). In the frame of *bird*, for example, each attribute (say, *beak, plumage, feather, leg* and *foot* in the Sundevall frame) represents a specific subregion of the referents, 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 *dense plumage*).

The spatial nature of attributes implies that not all features of an object are treated equally in the process of attribute selection. Some features contain more spacial information and offer more diagnostic cues than others, and consequently they are used more frequently during concept representation. This explains the preference for selecting features that contain rich spacial information as attributes.[13] For biological objects, body parts are such preferable features – they are spatially salient because they are identifiable by their shape and because they collectively outline the overall shape of the referents. Thus, body parts are frequently selected as attributes in constructing frames for biological concepts.[14]

The preference for body parts in attribute selection could provide a common platform for rational comparison of the Sundevall and the Gadow taxonomies. Because of the compatible attribute lists, people from both sides would agree with each other on what features should count as relevant in judgments of similarity and dissimilarity. When observations showed more and more similarities between screamers and waterfowl in skull character, skeleton, feathering pattern, muscular system and digestive system, the supporters of the Sundevall taxonomy would have to agree that all these similarities were relevant and accept them as legitimate evidence for testing their taxonomy. Consequently, when the observations of the similarities between screamers and waterfowl became overwhelming, they would have no choice but admit that their taxonomy was in trouble.

Rooted in the common preference in conceptual processing, the compatible attribute lists between the two taxonomies offer an explanation for the success of the Gadow system. 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 different birds. The main objection to the Sundevall 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 Sundevall 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 and Ahlquist, 1990, pp. 202–215). Unlike the replacement of the Ray taxonomy by the Sundevall taxonomy, 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, which was organized around more than forty classification criteria, or more than forty attributes for the concept *bird*. Without a common platform for defining the meaning and relevance of these attributes, however, it would have been impossible for the community to develop a consensus on Gadow's empirical evidence. Thus, the compatible attribute lists, rooted in the preference for body parts, or more general, the preference for spatial features in attribute selection, could have functioned as a cognitive platform for the rational comparison of the Sundevall and the Gadow systems and resulted in the quick and smooth taxonomic change.

5. CONCLUSION

Both the historical and cognitive analyses indicate that there are different kinds of taxonomic change. We have seen taxonomic change like the one from the Ray system to the Sundevall system, where the two taxonomies were incommensurable, but some local lexical structures remained compatible. We have also seen taxonomic change like the one from the Sundevall system to the Gadow system, where the two taxonomies were incommensurable and no compatible lexical structures existed. But with the help of frame representations that expose the internal structures of the superordinate concepts involved in the taxonomic change, we find that the attribute lists embedded in these two incommensurable taxonomies remained compatible. Indeed, there are reasons to believe that the two distinct formats of taxonomic change revealed by our historical and cognitive analyses are only examples in a continuous spectrum. Both taxonomic

change and the associated notion of incommensurability should be treated as a matter of degree.

Our historical and cognitive analyses thus show that common platforms for rational comparison exist between incommensurable taxonomies. These platforms need not be global, nor must lexical structures that constitute the platform be identical. Compatible local lexical structures such as contrast sets can nurture rational comparison. Furthermore, the platform for rational evaluation need not be linguistic. Common preferences we develop in the process of classification and concept representation, such as the preference for body parts in attribute selection, can also offer a basis for rational comparison. Thus, we must realize that there are a variety of cognitive platforms for rational comparison during taxonomic change, including both linguistic elements (identical taxonomies and compatible contrast sets) and cognitive mechanisms (preferences in conceptual processing), and we must admit that we have not yet exhausted the list of the possible cognitive platforms for rational comparison.

Finally, our historical and cognitive analyses reveal an important aspect of taxonomic change that may have been overlooked by previous studies. Most previous philosophical analyses of taxonomy change focused upon the semantic aspect. Although Kuhn did suggest that taxonomic change have a cognitive perspective, he in his later writings continued to focus on the linguistic aspect by emphasizing the non-overlap principle of kind terms and using referent redistribution as the key indicator of revolutionary change. But taxonomic change is rooted deeply in the cognitive mechanisms behind the processes of classification and concept representation. These cognitive mechanisms determine the process of mutual understanding and rational comparison during taxonomic change. In fact, the cognitive platforms for rational comparison identified in our historical cases, that is, compatible contrast sets and attribute lists, were the products of such cognitive mechanisms as the relational assumptions adopted in classification and the preference for body parts developed in concept representation. Without an appropriate cognitive model for concept representation, however, all of these cognitive mechanisms would remain hidden. Thus, to fully understand the nature of taxonomic change, it is necessary that we first reflexively examine the cognitive model used to represent taxonomy. In this regard, the cognitive sciences should offer us fresh materials and invaluable suggestions.

NOTES

[1] This is the so-called non-overlap principle for kind terms, which plays a very important role in Kuhn's taxonomic incommensurability thesis. For more analysis of the non-overlap principle and its relations to Kuhn's latest incommensurability thesis, see (Chen, 1997).

[2] Kuhn thus argued that progress in science is similar to biological evolution, that is, science has progressed from primitive beginnings but not toward any particular goal such as truth. For a more sophisticated evolutionary account of science, see (Hull, 1988).

[3] Ray's classification was based upon the research of Francis Willughby, who died in 1672 and left Ray his notes of ornithology. Ray published the three-volume work, in Latin in 1676, and an English translation, *The ornithology of Francis Willughby* in 1678.

[4] In this paper, italics signify concepts and double quotes signify words.

[5] The Ray taxonomy further subdivided *water-bird* and *land-bird* according to similar classification standards. For the sake of simplicity, Figure 1 focuses on the demarcation at the immediate subordinate level, and lists only a few typical examples (referents) of the subordinate concepts.

[6] For more about the defects and limits of the traditional concept representation, see (Andersen *et al.*, 1996). For general discussions of frame representations, see Barsalou, 1992, pp. 174 and Barsalou and Hale, 1993, pp. 124–137. For applications of frame representations in the philosophy of science, see Chen *et al*, 1998, and Chen and Barker, 2000.

[7] We can introduce frames to capture the internal relations within the subordinate concepts. For the sake of simplicity, we limit our discussion to the internal structure of the superordinate one.

[8] Constraint relations among attributes can result also from intentional limitations initiated by human agents. An example of intentional limitations is the process of optimization, in which human agents select desirable values of attributes according to their goals (Barsalou, 1992, 39). This implies that significant communication difficulties or incommensurability would occur between agents with different goals. For more discussion of incommensurability of this kind see Chen, 1994.

[9] Sundevall divided birds into seven orders according to more than a dozen standards. Among the seven orders, only three, *gallinae*, *grallatores* and *natatores*, are relevant to our discussion. For the sake of simplicity, Figure 4 lists only the three related subordinate concepts and the five attributes used in distinguishing between them. For the same reason, Figure 4 lists only a few examples (referents) of these subordinate concepts.

[10] The Sundevall taxonomy encountered many other problems, which however are beyond the subject of our discussion.

[11] Gadow divided birds into 13 orders, but only two, *anseriform* and *galliform*, are relevant to our discussion. For the sake of simplicity, Figure 5 lists only these two subordinate concepts and only those attributes used in distinguishing between them. The partial frame does not include *carotid arteries* as an attribute, because it is irrelevant to the distinction between *anseriform* and *galliform*.

[12] Note that concepts are defined by examples rather than by definitions. Thus, a bird with a bonded palate, type 2 tendon, absent fifth secondary in the wings (say, a swan) is a typical example of *anseriform*, while a bird with a bonded palate but type 4 tendon and present fifth secondary in the wings (a screamer) is still a moderately good example of *anseriform*.

[13] The preference for spatial features also exists in other cognitive processes. For example, to explain the special status of basic level concepts in classification, Rosch referred to the fact that the referents of basic-level concepts often share common shapes, that is, they have similar spatial characters. Because they have a high level of similarity in spatial characters, basic-level concepts contain more diagnostic cues for classification (Rosch *et al.*, 1976).

[14] The preference for body parts indicates the important role of partonomy in taxonomy comparison. Unlike taxonomy that focuses on 'kind of' relations, partonomy outlines 'part of' relations. For more on the differences between taxonomy and partonomy, as well as a variety of partonomic relations, see (Winston *et al.*, 1987).

REFERENCES

Andersen, H., Barker, P. and Chen, X.: 1996, 'Kuhn's Mature Philosophy of Science and Cognitive Psychology', *Philosophical Psychology* **9**, 347−363.

Baird, S.: 1858, *Birds. Reports of Explorations and Surveys, to Ascertain the Most Practicable and Economic Route for a Railroad from the Mississippi River to the Pacific Ocean*, Vol. 9, Part 2, B. Tucker, Washington, D.C.

Barsalou, L.: 1992, 'Frames, Concepts, and Conceptual Fields', in A. Lehrer and E. Kittay (eds), *Frames, Fields and Contrasts: New Essays in Semantical and Lexical Organization*, Erlbaum, Hillsdale, NJ, pp. 21−74.

Barsalou, L.: 1999a, 'Perceptual Symbol Systems', *Behavioral and Brain Sciences* **22**, 577−609.

Barsalou, L.: 1999b, 'Perceptions of Perceptual Symbols', *Behavioral and Brain Sciences* **22**, 637−660.

Barsalou, L. and Hale, C.: 1993, 'Components of Conceptual Representation: From Featurelists to Recursive Frames', in I. Mechelen, J. Hampton, R. Michalski and P. Theuns (eds), *Categories and Concepts: Theoretical Views and Inductive Data Analysis*, Academic Press, New York, pp. 97−144.

Barsalou, L., Solomon, K. and Wu, L.: 1999, 'Perceptual Simulation in Conceptual Tasks', in M. Hiraga, C. Sinha and S. Wilcox (eds), *Cultural, Typological, and Psychological Perspectives in Cognitive Linguistics: the Proceedings of the 4th Conference of the International Cognitive Linguistics Association, Vol. 3*, John Benjamins, Amsterdam, pp. 209−228.

Brown, C.: 1976, 'General Principles of Human Anatomical Partonomy and Speculations on the Growth of Partonomic Nomenclature', *American Ethnologist* **3**, 400−424.

Chen, X.: 1994, 'Why Do Scientists Have Disagreements about Experiment?: Incommensurability in the Use of Goalderived Categories', *Perspectives on Science* **2**, 275−301.

Chen, X.: 1997, 'Thomas Kuhn's Latest Notion of Incommensurability', *Journal for General Philosophy of Science* **28**, 257−273.

Chen, X., Andersen, H. and Barker, P.: 1998, 'Kuhn's Theory of Scientific Revolutions and Cognitive Psychology', *Philosophical Psychology* **11**, 528.

Chen, X. and Barker, P.: 2000, 'Continuity Through Revolutions: A Framebased Account of Conceptual Change During Scientific Revolutions', *Philosophy of Science* **67**, 208−223.

Farber, P.: 1997, *The Emergence of Ornithology as a Scientific Discipline: 1760–1850,* D. Reidel, Boston.

Gadow, H.: 1892, 'On the Classification of Birds', *Proceedings of the Zoological Society of London* **1892**, 229–256.

Grandy, R.: 1992, 'Semantic Fields, Prototypes, and the Lexicon', in A. Lehrer and E. Kittay (eds), *Frames, Fields, and Contrast: New Essays in Semantic and Lexical Organization*, Erlbaum, Hillsdale, pp. 103–122.

Hull, D.: 1988, *Science as a Process: An Evolutionary Account of the Social and Conceptual Development of Science*, The University of Chicago Press, Chicago.

Kay, P.: 1971, 'Taxonomy and Semantic Contrast', *Language* **47**, 866–887.

Kuhn, T.: 1989, 'Possible Worlds in History of Science', in S. Allen (ed.), *Possible Worlds in Humanities, Arts and Sciences*, Walter de Gruyter, New York, pp. 9–32.

Kuhn, T.: 1990, 'An Historian's Theory of Meaning', Talk to cognitive science colloquium, UCLA. Unpublished manuscript.

Kuhn, T.: 1991, 'The Road since Structure', in A. Fine, M. Forbes and L. Wessels (eds), *PSA 1990*, Vol. 2, Philosophy of Science Association, East Lansing, pp. 3–13.

Kuhn, T.: 1993, 'Afterwords', in P. Horwich (ed.), *World Changes*, The MIT Press, Cambridge, MA, pp. 311–341.

Newton, A.: 1893, *A Dictionary of Birds*, Adam and Charles Black, London.

Parker, W. K.: 1863, 'On the Systematic Position of the Crested Screamers (Palamedea Chavaria)', *Proceedings of the Zoological Society of London* **4**, 511–518.

Putnam, H.: 1975, 'The Meaning of 'Meaning' ', in K. Gunderson (ed.), *Language, Mind and Knowledge, Minnesota Studies in the Philosophy of Science, Vol. 7*, University of Minnesota Press, Minneapolis, pp. 215–271.

Ray, J.: 1678, *The Ornithology of Francis Willughby*, John Martyn, London.

Rosch, E., Mervis, C., Gray, W., Johnson, D. and Boyes-Braem, P.: 1976, 'Basic Objects in Natural Categories', *Cognitive Psychology* **8**, 382–439.

Sibley, C. and Ahlquist, J.: 1990, *Phylogeny and Classification of Birds: A Study in Molecular Evolution*, Yale University Press, New Haven.

Stresemann, E.: 1975, *Ornithology: From Aristotle to the Present*, Harvard University Press, Cambridge, MA.

Sundevall, C.: 1889, *Sundevall's Tentamen*, Porter, London.

Tversky, B. and Hemenway, K.: 1984, Objects, Parts, and Categories, *Journal of Experimental Psychology: General* **113**, 169–193.

Winston, M., Chaffin, R. and Herrmann, D.: 1987, 'A Taxonomy of Partwhole Relations', *Cognitive Science* **11**, 417–444.

Department of Philosophy
California Lutheran University
60 West Olsen Road
Thousand Oaks, CA 91360–2787
USA