Continuity Through Revolutions:

A frame-based account of conceptual change during scientific revolutions

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1. Introduction

According to Kuhn's original account of scientific revolutions (Kuhn 1970), a revolutionary change in science is an episode in which one major scientific system replaces another in a discontinuous manner. The disruption begins with a crisis stage that destroys practitioners' faith in the old tradition, followed by a period of confrontation between two incompatible paradigms, leading to partial loss of communication between the communities supporting the paradigms, based on the incommensurability between their conceptual systems. The scientific change initiated by Copernicus in the 16th century has been used as a prototype of this kind of discontinuous scientific change. However, many recent historical studies indicate that this "prototype" did not share the distinctive features of scientific revolutions defined by Kuhn's original account. The changes in astronomy and other sciences during the 16th and the 17th centuries exhibited strong continuity (Barker and Goldstein 1988, Barker 1993).

These historical studies have appeared at a time when historical work by sociologists who are overtly or covertly antagonistic to cognitive studies of science has become increasingly prominent. The difficulty philosophers have found in defending their own approach to the history of science has been created, in part, by the choice -- largely implicit and unexamined -- of cognitive models used in such analysis. With only a few exceptions (Nersessian 1984, 1987, 1995, Thagard 1992), philosophers of science have been handicapped by their continued use of traditional accounts of human concepts, while ignoring important new ideas in fields such as psychology and cognitive science. But it is a philosophical commonplace that choosing the wrong tool can make a particular problem harder, or indeed impossible to solve.

In this paper we offer a theoretical model for the pattern of conceptual change during scientific revolutions using methods from cognitive psychology. We suggest that the discontinuous pattern of scientific change follows from a view that defines concepts through lists of features. In cognitive psychology this “feature list” account corresponds to the traditional philosophical ideal that a concept is definable by means of necessary and sufficient conditions. Both the feature list account of concepts, and the definability of concepts in terms of necessary and sufficient conditions, are now seriously questioned in cognitive psychology (Andersen, Barker and Chen 1996). A more satisfactory account has been developed over the last decade using “frames” as the basic vehicle for representing concepts, and we follow a recent and influential presentation of the frame model by Barsalou (1992, 1993).

We hope to show that if concepts are represented by frames rather than feature lists, the changes characteristic of scientific revolutions, especially taxonomic changes, can occur in a continuous manner. Using the frame model to capture structural relations within concepts and the direct links between concept and taxonomy, we develop a model of conceptual change in science that more adequately reflects current understanding of the historical changes, and especially the insight that episodes like the Copernican revolution are not always abrupt changes. In the following sections, we first introduce the representation of concepts by dynamic frames, and show how concepts understood in this way can provide an account of conceptual change. We then apply these ideas to an important conceptual change that occurred during the Copernican Revolution -- the changes in the concept of “celestial object” from the Aristotelian account to the Newtonian account. In conclusion we suggest that, understood in this way, scientific revolutions show more continuity than discontinuity, while anomalies and the phenomena of incommensurability are no longer liabilities, but play a constructive part in the progress of science.

2. Representation of Concepts by Frames

After the Postscript to The Structure of Scientific Revolutions, Kuhn interpreted paradigms primarily as exemplars rather than worldviews or disciplinary matrices. On the basis of exemplars, he developed a theory of concepts that are learned not through definitions but by ostension. Systems of concepts learned from a process of ostension incorporate a variety of structural knowledge at different abstract levels. At the level of exemplars, this is knowledge of the similarity and dissimilarity relations among individuals. At the level of categories, this is knowledge of the relations between features within a concept. At the level of taxonomy, this is knowledge of the relations among categories belonging to the same contrast set and those between categories that belong to difference taxonomic levels. To describe concepts formed in such a learning process, cognitive scientists have recently recommended that we should represent concepts by frames (Barsalou 1992, Barsalou and Hale 1993, Chen, Barker and Andersen 1998).

Figure 1 is a partial frame representation of the concept of “fowl”. Reading from left to right we see the superordinate concept “fowl”, followed by two vertical arrays giving partial lists of properties of objects falling under the concept. All the objects share the properties in the first list (Attribute), but only some properties from the second list (Value) are typical features. We have chosen to display the subordinate concepts on the extreme right of each frame with diagonal lines linking them to the activated elements in the “Value” list. The reader should bear in mind that all the elements of the “Attribute” list are activated for both concepts. Each pattern of selection constitutes the prototype of a subordinate concept; for example, a typical waterfowl is a fowl whose values for “beak”, “leg”, and “foot” are restricted to “round”, “short”, and “webbed”. Our diagram also emphasizes three very important relations within the concept.

First, the frame captures hierarchical relations between features. Contrary to the assumption that all features within a concept are structurally equal, the frame representation shows that some features are instances of others. For example, both “large” and “body” are features, but the former is a value of the latter. To capture such structural differences, the frame divides features into two different levels: attributes and values; the latter are instances of the former. The distinction between attributes and values reveals the hierarchical relations between features: some values (such as “large” and “small”) are always related to a particular attribute (such as “body”).

Second, the frame captures several stable relations between the attributes; for example, “body” and “neck” are not independent slots in the frame. They are related correlationally, coexisting across contexts. These two attributes are also related conceptually -- their relations reflect people’s understanding that necks are physically carried by bodies, and always attached to bodies in a certain way. Similar relations also exist between “body” and “leg”. Because these relations hold across all typical exemplars of the concept “fowl”, they form relatively invariant structures between the attributes, and are thus called structural invariants.[1]

Last, the frame also captures constraints that produce systematic variability in the values of the attributes. Such constraints exist, for example, between the values of “neck” and “body”: a long neck usually is associated with a large body. This is a physical constraint: a correlation normally exists between the values of these two attributes; otherwise, fowl would find it difficult to achieve balance. Similarly, there is a constraint between the values of “leg” and “body”: long legs usually are associated with a large body. The frame also captures a constraint between the values of “beak” and “foot”: 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”. This is also a physical constraint imposed by nature: webbed feet and round beaks are adapted to the environment in which water birds live, but would be a hindrance on land.

In addition to these structural and constraint relations, the frame model also naturally captures the taxonomic structure. In a frame representation, subordinate concepts are sets of exemplars with particular values constrained by the superordinate frame. In Figure 1, waterfowl are those creatures that have one set of value assignments given by the frame of “fowl”. Similarly, “game bird”, the family including turkeys, chickens, and grouse, is the other subset of “fowl” with different value assignments. In this way, the contrast set that defines the no-overlap principle is specified, and the taxonomy of “fowl” is outlined.

3. Frames and Conceptual Change

The discontinuous pattern of conceptual change appears as an almost inevitable consequence if Kuhn's account of scientific revolutions is combined with an account that describes concepts by a list of unrelated features. Under this representation, an object is classified according to its similarity to existing classes, in terms of the number of shared features. Since, according to Kuhn, concepts are not learned through definitions, there is no single group of standard features, like a list of necessary and sufficient conditions, that can or must be used in classification. Different individuals may select different features as classification standards (Barsalou 1989). Continuing the example with which we began, consider the response of people, trained to identify waterfowl and other kinds of bird in the way Kuhn described, who encounter an unusual waterfowl that has features not previously found together. Such a bird might be a member of the family Anhimidae, a South American waterfowl known by the common name of “Screamer”.[2] They will see a fowl with a pointed beak but webbed feet. Taking the shape of the feet as the most important standard for classification, they may classify it as a waterfowl. If they focus on the shape of the beak, they may find it to be quite similar to game birds. In either case, the anomaly, the inconsistency between duck-like feet and a chicken-like beak, is temporarily resolved. The discovery of this anomaly does not generate any immediate change at the level of taxonomy.

On Kuhn’s original account, taxonomic changes do not occur until the problems of classification caused by anomalies increase beyond a certain limit, or until the accumulation of anomalies finally causes a crisis in the community. If birdwatchers notice more anomalies involving screamers, for example that they have long legs and non-fleshy tongues like most game birds, but have similar palatal structure to waterfowl (the bones of the upper jaw are fused instead of separated), they might develop doubts about the previous classification. The accumulation of anomalies could erode their faith in the existing taxonomy of “fowl”, and cause a crisis. At some point, the community might decide to change the existing taxonomy substantially, and to reconstruct an entirely new taxonomy of “fowl” reflecting the peculiar taxonomic status of screamers. In this way, although changes at the level of empirical observation are continuous, changes at the level of taxonomy are not.

However, the relation between anomalies and taxonomic changes is substantially different if concepts are represented by frames. Because there are relations between attributes, between values, and between attributes and values, the selection of classification standards is not arbitrary, but restricted by the relations within a frame. For example, the constraint relation between “foot” and “beak” in the frame of “fowl” requires that these two attributes be used together in classification. Thus, the discovery of a screamer immediately generates problems, because we do not know how screamers should be classified according to the cluster of standards for “foot” and “beak”. Eventually, this anomaly will force us to alter the frame of “fowl”, because it makes a very important constraint relation between the values of “foot” and “beak” invalid. The anomaly posed by screamers also denies another constraint in the frame: the relation between the values of “leg” and “body” also disappears, because long-legged screamers have only relatively small body size. In this way, a single classification anomaly can directly cause changes in the frame of the superordinate concept.

By changing the superordinate frame, a single anomaly can also alter the taxonomy. The frame of a superordinate concept determines the structure of the conceptual field at the subordinate level by specifying the possible concepts that form the contrast set. Consider the conceptual field determined by the partial frame of “fowl” in Figure 1. This frame has five attributes, each of which has two values. Considering all possible combinations, we have 32 potential concepts (2x2x2x2x2) at the subordinate level. However, many of these potential concepts are theoretically impossible because of the relations between attributes and the relations between values, and some of them are physically nonexistent. The results are only two subordinate concepts -- “waterfowl” and “game bird”. Suppose now the frame experiences substantial changes due to a classification anomaly like the Screamer. The disappearance of some constraints makes several new value combinations possible, and therefore alters the contrast set which had previously been limited to “waterfowl” and “game birds”. Specifically, because there is now no constraint between “foot” and “beak” as well as between “leg” and “body”, a new set of value assignments such as “pointed beak”, “webbed foot”, “long leg”, and “small size” becomes possible. This value combination constitutes a new subordinate concept -- “screamer”, which becomes a new member of the contrast set at the subordinate level.

This taxonomic change, however, can hardly be called revolutionary. By adding a new member to the contrast set, the new taxonomy is different from the old one, but there is no mismatch between them. No concept in the new taxonomy violates the no-overlap principle as applied to concepts from the old taxonomy.

Now, suppose we encounter more classification anomalies: we learn that screamers share some very important anatomical features with waterfowl, for example, a similar palatal structure, which, according to some ornithologists, reveals their common evolutionary origin. Like the previous anomaly, this newly found anomaly first generates further changes in the frame of “fowl”. To accommodate this new discovery, a new attribute (“palate”) and related new values (“fused” and “separated”) are added. More importantly, due to the assumed common evolutionary origin, new structural invariants between “palate” and such external features as “beak” “neck”, “body” “leg”, and “foot” are formed. For the same reason, constraints exist among these value sets, in the form that, say, a fowl with a fused palate is more likely to have a round beak, short legs, and webbed feet.

Similarly, the changes in the frame inevitably alter the taxonomy. The newly added relations in the frame significantly change the structure of the conceptual field at the subordinate level. The strong constraints among the value sets significantly reduce the number of the possible value combinations. For example, such a value assignment set as “fused palate”, “pointed beak”, “webbed foot”, “long leg”, and “small size” that may exemplify “screamer” becomes impossible; “screamer” is no longer a member of the contrast set at the subordinate level. Furthermore, since palatal structure reveals evolutionary origin, it becomes the most important classification criterion. With similar palatal structure, “waterfowl” and “screamer” must be treated as one equivalence class.[3] Thus, a new concept “anseriform” is introduced to denote both waterfowl and screamers, and “anseriform” and “galliform” constitute the new contrast set. To further capture the differences between waterfowl and screamers, a new subordinate level is generated according to the frame of “anseriform”, and “waterfowl” and “screamer” form a new contrast set at the sub-subordinate level.

In contrast to the previous taxonomic change, this one generates mismatches between the two taxonomies. Now the concept “waterfowl” in the old taxonomy refers to referents that overlap those denoted by “anseriform” in the new taxonomy, which refers to both waterfowl and screamers. This overlap may cause communication problems: when people who adopt the new taxonomy call a bird “waterfowl”, they generate one set of expectations regarding the properties of the bird; when those who continue to use the old taxonomy call something a “waterfowl”, they have a different and incompatible set of expectations. Individuals who retain the old taxonomy may categorically deny some applications of concepts proposed by those who adopt the new taxonomy, such as using “anseriform” to refer to both waterfowl and screamers.

Through these two taxonomic changes, a revolutionary change in the concept “fowl” has taken place. But this revolutionary change is achieved in a piecemeal fashion. Every single classification anomaly immediately causes changes in the frame of the superordinate concept and then changes in the taxonomy. Both the changes of frame and those of taxonomy are continuous. New taxonomies naturally arise from revised frames, rather than emerging from the outside. There is no accumulation of anomalies, nor any psychological crisis. At a certain point in this piecemeal evolution, the newly formed taxonomy becomes incompatible with the old one, and then the revolutionary nature of this continuous change becomes recognizable.

4. Frames and the Copernican Revolution

To further illustrate the pattern of revolutionary change in science, let us have a closer look at the Copernican revolution. In particular, let us briefly examine the transition from the dichotomous taxonomy for physical objects (terrestrial vs. celestial), that was dominant at the eve of the revolution, to the new one available around 1700. Figure 2 is a partial frame of the earlier concept. In this frame, there are strong connections between attributes. For example, there was believed to be a causal relation between “constitution” and “stability” -- the composition of an object determined whether it was eternal or changeable. A similar presumptive causal relation also existed between “constitution” and “path” -- terrestrial elements had to move along straight lines to reach their natural places. The strong connections within this frame significantly reduced the number of possible value combinations at the subordinate level. The result was a dichotomous taxonomy, with “terrestrial object” and “celestial object” as the only members of the contrast set.

Compare this with the situation after the publication of Newton's work. We are now obliged to distinguish (at least) stars, planets, moons, and two classes of comet -- returning and non-returning. Comets are now treated as celestial objects. As is well known, the objects falling under the concepts “star”, and “planet” are now embarrassingly different (the sun is now a star not planet; the earth is a planet, when before it was not, and the moon has changed status from planet to satellite). Even more difficult, the features that differentiate these objects are not even present in the Aristotelian account. One important difference between stars, planets and satellites is the location of the center of their orbit (or, to be properly Keplerian, the non-empty focus of their elliptical orbit). But in Aristotle's world, all heavenly motions are either directly or indirectly centered on the earth: there is no possibility of differentiating centers of motion.

If we limit ourselves to an account of concepts that operates from lists of features of the corresponding objects, then we will be hard pressed to regard the change from Aristotle's concept of “celestial object” to Newton's as anything but discontinuous. The lists of features suggested above show major differences in addition and deletion. Most importantly, the feature list approach suggests no mechanism for linking two such lists. It provides a static representation of a particular moment in history. If we have grounds for rejecting a part or all of the characteristic list of a concept, we have to start again from scratch in constructing a new list and thereby a new concept. It is hardly surprising that faced with such a task, we might be tempted to seek new starting points outside science (in social or economic influences) or at least in a part of science uncontaminated by the present failure. When clearly different new ideas replace old ideas, it is tempting to seek their origin outside the conceptual system that has failed us. Taking this view of concepts as our (implicit or explicit) starting point will predispose our historical account to abrupt change.

With a frame representation of concepts, however, we can see that the change from Aristotle’s to Newton’s taxonomy did not occur in an abrupt manner. More important, the frame account illustrates a mechanism for linking the two incompatible taxonomies.

Aristotle’s dichotomous taxonomy had been orthodox until the early 16th century when cometary observations and theories emerged as a pivotal point in the cosmological debate. According to Aristotle, comets were phenomena in the sphere of fire below the moon. Although some comets appeared to share the motions of the heavens, they could not be celestial because they were transitory rather than eternal. But Aristotle's classification of comets was challenged by the discoveries made in the early 16th century. Among these new discoveries, one was particularly important. Observations showed that cometary tails always pointed away from the sun, which was not explained by Aristotle's account. To explain this peculiar phenomenon, an optical theory of comets appeared, which regarded the head of a comet as a spherical lens that focused the rays of the Sun to produce the tail. This optical theory of comets was accepted by many important astronomers in the 16th century.

The optical theory of comets had a profound impact on the dichotomous taxonomy for physical objects and particularly the concept of “celestial object”. Given that comets were not Aristotelian fires, their location became an open question. The dispute over cometary position generated several major changes in the superordinate concept. For those who classified comets as celestial objects, the structural invariant and constraints between “constitution” and “stability” in the Aristotelian frame of “physical object” became invalid, because comets were celestial but not eternal. Changes in the Aristotelian frame of “physical object” provided opportunities to reclassify objects at the subordinate level and then to reorganize the taxonomy. When the strong connections between attributes in the Aristotelian frame had been reduced, some new value combinations, which were prohibited in the old frame, became possible. For example, a combination of ethereal constitution and straight path now became conceivable, and was actually adopted by Kepler in his account of comets. Such new combinations further obscured the Aristotelian demarcation between terrestrial and celestial objects. But cometary observations and theories alone did not completely eliminate the demarcation. It took another hundred years to completely replace the dichotomous Aristotelian taxonomy. In this process, more changes occurred in the frame. For example, two attributes related to ether (“constitution” and “stability”) were dropped from the frame. Without these two attributes, the differences between terrestrial and celestial objects, that is, above or below the Moon, became trivial. At this point, the distinction between terrestrial and celestial objects finally disappeared.

New astronomical discoveries in the 17th century generated more changes in the frame. Before Kepler, planetary motions were understood as the combination of a complex set of circular motions, and astronomical theories were concerned only to predict the angular positions of planets. Distances did not figure in the calculations of positions. Therefore, the Aristotelian frame used purely geometrical attributes, such as “path” and “location”, to capture planetary motions and positions. Kepler was actually the first astronomer to attach physical meaning to planetary paths. By using a single ellipse to represent the continuous path of a planet in space, Kepler was able to calculate positional data with increased accuracy, while at the same time accommodating data on planetary distances for the first time. “Path” then began to have new physical meaning -- it represented the shape of a planetary orbit (Barker and Goldstein 1994). In this way, the attribute "path" in the old frame was redefined and replaced by a new one called "orbit shape".

The discovery of Jupiter's satellites by Galileo also significantly altered the frame. Before this discovery, it was possible for strict Aristotelians to insist that all circular motions were geocentric, and that there were no real epicyclic motions in the heavens. After the discovery of Jupiter's satellites, which perform epicycle motions centered on the planet, it became necessary to admit that there was more than one possible center of circular motions. Thus, a new value set ("geocentric" and "non-geocentric") and a new attribute ("orbit center") were needed to capture this new discovery. Later the value set would change again, allowing stars and planets as orbit centers while other objects move freely and lack a center of motion.[4]

By 1700, the frame of "celestial object" had gradually evolved into a whole new phase with five new attributes and a new set of structural and constraint relations between them (Figure 3). This frame generated a new taxonomy that included such concepts as "star", "planet", "moon", "returning comet", "non-returning comet". At this point, the revolutionary change from Aristotelian/Ptolemaic conceptual structure to a Newtonian system was essentially completed.

5. Conclusion

Our analyses of the changes in ornithological concepts, in our constructed example, and the changes in cosmological taxonomy during the Copernican revolution show that, according to the frame model, taxonomic changes or scientific revolutions can be achieved in a piecemeal manner, through the natural development of new conceptual structures out of predecessors.

If conceptual change is understood as frame revision, the conventional understanding of scientific revolutions requires substantial changes. First, we need to reconsider the role of anomalies. According to the conventional interpretation of Kuhn's theory of scientific revolutions, anomalies are entirely destructive. They deny the legitimacy of an old paradigm, and destroy the faith of its supporters. However, in both the taxonomic changes described above, we see that anomalies also have constructive roles. They not only destroy inappropriate elements from old frames, but also define the content of newly introduced elements. Anomaly-induced changes in frames accordingly produce alterations in taxonomies.

Another virtue of the frame account is that it isolates and identifies the locations within a conceptual structure at which change has occurred, in a way that lends itself to rational debate. Nersessian (1984) and Shapere (1989) have both suggested that scientists offer reasoned arguments for the most important conceptual shifts in science. The frame model shows a precise location for deploying these chain-of-reasoning arguments. They will appear as justifications for changing the attributes and attribute configurations within an existing frame. If these arguments are well known and sound, naturally members of the community that supports the new frame will refuse to revert to the older one. Note that the conceptual structures represented by the new frames in the cases we have considered are incommensurable with the concepts represented by the previous frames. The possibility of justifying frame revisions by chain-of-reasoning arguments thus suggests that we should reconsider the status of incomensurability in scientific revolutions, which has long been equated to irrationality.

The conventional understanding of scientific revolutions highlights the role of irrational elements such as the influences of cultures and paradigms.The frame account however significantly reduces the role of cultural or theoretical stereotypes in the process of taxonomy revision. According to the frame representation, frame revisions are directly induced and guided by anomalies. Although how a concept is represented still has something to do with our cultural and theoretical beliefs (which contribute to some constraints within the frame), many relations within the frame, such as structural invariants and many constraints, are objective. To adopt a new frame is to adapt ourselves to the environment. Thus, it is quite unlikely that individuals will revert back to the old frame after they have accepted a new one, unless there are further significant changes in the environment.

The difficulties in coming back to the old frame after a revolution explain why scientific development, like biological evolution, produces isolated units in the process of growth. In the biological case, these units are reproductively isolated populations with members that cannot breed with members from other populations. In the scientific case, such units are communities of intercommunicating specialists who share the same taxonomy and have problems in communicating with people from other communities (Kuhn 1991, Chen 1997). Because of these isolated units, both scientific development and biological evolution have the same pattern of growth in the form of an evolutionary tree. Kuhn held that the pattern of knowledge growth is "the apparently inexorable (albeit ultimately self-limiting) growth in the number of distinct human practices or specialties over the course of human history" (Kuhn 1992, 15). Proliferation of specialized disciplines is the key feature of scientific progress.

The unidirectional feature of scientific evolution thus gives a whole new meaning to incommensurability. To produce growth in the form of an evolutionary tree, a unidirectional disparity between successive taxonomies or paradigms is necessary. It prevents individuals from going back to the old taxonomy and “forces” them to elaborate the new one. It also reduces the likelihood that the two successive paradigms will produce fertile offspring, and thus enhances the trend of specialization (Kuhn 1992, 1993). By causing translation difficulties and communication obstacles, incommensurability creates unidirectionality. Thus, by means of the frame model of concept representation, we can see that incommensurability is indispensable for the evolution of science. If our account is correct, it may well be that a knowledge system can only evolve unidirectionally if in the process of change it generates incommensurability.

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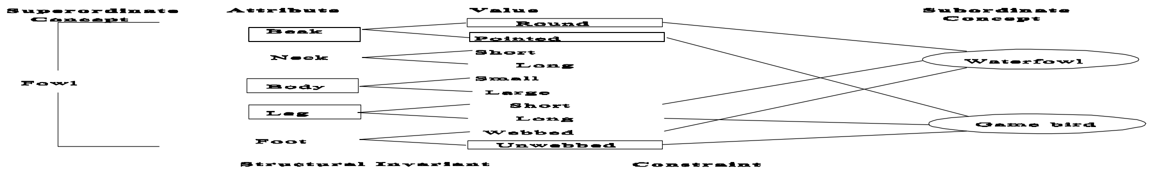
Notes:

1. Note that structural invariants may not exist in atypical exemplars. For instance, there is a structural invariant between “seat” and “back” in the frame for “chair”, which holds across all typical and even moderately typical exemplars of “chair”, but not in barstools. Similarly a waterfowl may lose or lack a beak, a foot, or even a leg, but it would no longer be a typical exemplar.

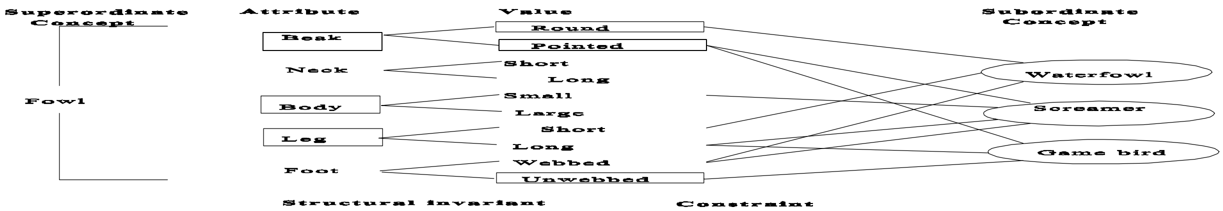
2. The discovery of screamers actually caused a heated debate in the 19th century among ornithologists over the classification of birds, which can be captured by a sequence of frame revisions. We do not give the actual historical sequence here, but present a simplified version of the taxonomic change. For a brief survey of the debate, see Sibley and Ahlquist (1990, 184-224; 302-305).

3. Note that concepts are defined by examples rather than by definitions. Thus, a bird with a fused palate, round beak, short legs, and webbed feet (swan) is a good example of “Anseriform”, and a bird with a fused palate, pointed beak, long legs, and webbed feet (screamer) can still be a moderately good example of “Anseriform”.

4. Other significant changes included the replacement of the attribute “location” by “distance” because of the progress in measuring absolute (not just relative) distance, and the introduction of a new attribute “size” due to Newton's discovery of gravitation.



Superordinate Concept
Attribute
Value
Subordinate Concept
Fowl
Beak
Neck
Body
Leg
Foot
Round
Pointed
Short
Long
Small
Large
Short
Long
Webbed
Unwebbed
Waterfowl
Game bird
Structural Invariant
Constraint


Superordinate Concept
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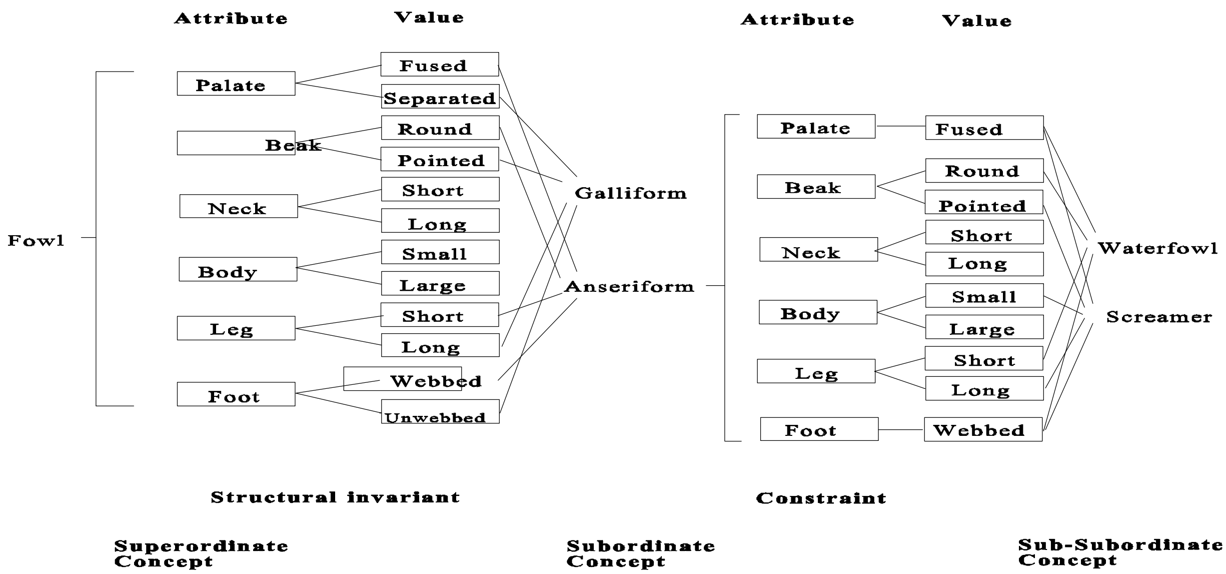
Attribute
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Fowl
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Galliform
Anseriform
Palate
Beak
Neck
Body
Leg
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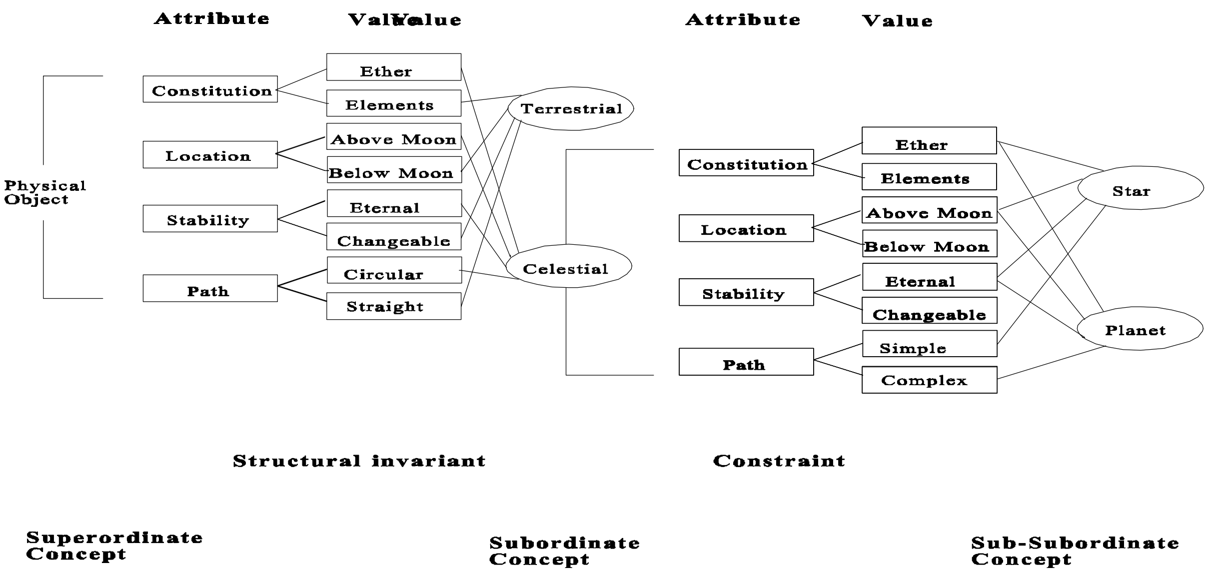
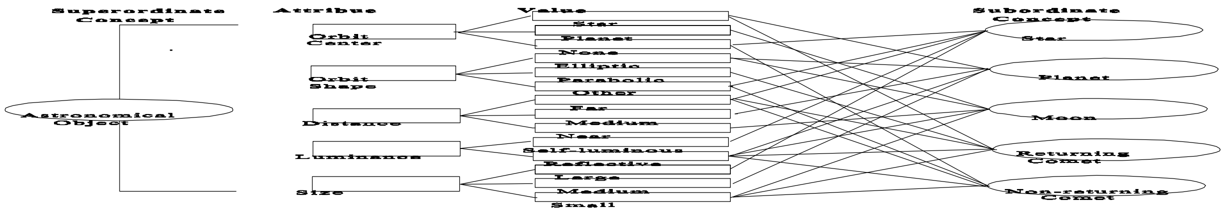
Fused
Round
Pointed
Short
Long
Small
Large
Short
Long
Webbed
Waterfowl
Screamer
Structural invariant
Constraint
Superordinate Concept
Subordinate Concept
Sub-Subordinate Concept


Attribute
Value
Attribute
Value
Physical Object
Constitution
Location
Stability
Path
Ether
Elements
Above Moon
Below Moon
Eternal
Changeable
Circular
Straight
Terrestrial
Celestial
Constitution
Location
Stability
Path
Ether
Elements
Above Moon
Below Moon
Eternal
Changeable
Simple
Complex
Star
Planet
Structural invariant
Constraint
Superordinate Concept
Subordinate Concept
Sub-Subordinate Concept


Superordinate Concept
Attribue
Value
Subordinate Concept
Astronomical Object
Orbit Center
Orbit Shape
Distance
Luminance
Size
Star
Planet
None
Elliptic
Parabolic
Other
Far
Medium
Near
Self-luminous
Reflective
Large
Medium
Small
Star
Planet
Moon
Returning Comet
Non-returning Comet