Reasoning by multiple analogies

by

Cameron Shelley

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Abstract

If you were Monica Lewinski's mother, how would you describe Linda Tripp? Remember that Linda Tripp is the woman who tapped her own phone conversations with Monica and then used them to incriminate President Clinton. Marcia Lewis, Monica's actual mother, chose the following expression: "She is like a meddlesome witch, a praying mantis." This expression conveys a *multiple analogy*, a comparison in which several sources are likened to a target. In this case, the first source tells us that Marcia thinks of Linda as a disagreeable woman who entices youngsters into her confidence in order to ensnare them for her own purposes, much like the witch who trapped Hansel and Gretel. The second source tells us that Marcia thinks of Linda as a creature that ambushes others out of an inhuman lust for prey.

This example shows the usefulness of multiple analogies in satisfying certain cognitive goals, such as constructing an adequate explanation of Linda Tripp and her behavior. Multiple analogies have also proven to be very useful in satisfying other kinds of cognitive goals, such as those of philosophers and scientists. However, no cognitive model of multiple analogies has yet been proposed or explored. This dissertation presents an exploration of multiple analogies as found in the literature of evolutionary biology, archaeology, and philosophy with the aim of proposing a cognitive model of this interesting mode of reasoning. This model is based upon the *Multiconstraint theory* of analogies, which is extended for the purpose, and also contrasted with previous theories of analogy.

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Contents

1 Multiple analogies past and present **1**

1.1 Introduction 1

1.2 Plato 8

1.3 Aristotle 12

1.4 Bacon 17

1.5 Mill 21

1.6 Shared-structure theory 26

1.7 Summary 33

2 Multiple analogies in Coelacanth biology **35**

2.1 Analogies in science 35

2.2 Single analogies in the *Multiconstraint theory* 39

2.3 Analogies in evolutionary biology 47

2.4 Coelacanth: The living fossil 49

2.5 Implications for multiple analogies 55

2.5.1 Structural consistency 57

2.5.2 Corroboration 59

2.5.3 Abstraction and exemplification 60
2.5.4 Supplementation 61
2.5.5 Disanalogy and extension 63
2.6 Summary 64

3 Multiple analogies from the Mesozoic 67
3.1 Analogies and evolutionary theory 67
3.2 Ceratopsians: The horned dinosaurs 69
3.3 *Archaeopteryx*: The first bird 77
3.4 Implications for multiple analogies 88
3.4.1 Visual representations 89
3.4.2 Evolutionary scenarios 98
3.4.3 Multi-stage analogies 107
3.4.4 Fecundity 108
3.5 Summary 111

4 Multiple analogies in archaeology 114
4.1 Analogies in archaeology 114
4.2 Peruvian pots 120
4.3 Greek figurine legs 125
4.4 Clovis mammoth harvesting 129
4.5 Implications for multiple analogies 135
4.5.1 Visual imagery 135
4.5.2 Specificity 139
4.5.3 Supplementation 141

4.6 Analogies in archaeological theory 142
4.7 Summary 148

5 Multiple analogies in Plato's *Republic* **150**
5.1 Analogies in Plato's philosophy 150
5.2 The function of the soul 154
5.3 Health and justice 159
5.4 Plato's condemnation of the poet 164
5.5 Implications for multiple analogies 170
5.5.1 Complementation and narrative representation 171
5.5.2 Specificity 176
5.5.3 Supplementation 178
5.6 Plato on multiple analogies 181
5.7 Summary 183

6 The very model of a multiple analogy **187**
6.1 Multiple analogies in perspective 188
6.2 Breaking multiple analogies into parcels 191
6.3 Purpose and planning 196
6.4 Representations 201
6.4.1 Verbal 202
6.4.2 Visual 202
6.4.3 Narrative 205
6.5 Processes 208
6.5.1 Abstraction and exemplification 209

6.5.2 Supplementation 211
6.5.3 Specificity 213
6.6 Philosophy of science 215
6.6.1 Disanalogy and extension 216
6.6.2 Fecundity and theory change 217
6.6.3 Evolutionary scenarios 219
6.6.4 Archaeological scenarios 220
6.6.5 Discovery versus justification 221
6.7 Normative aspects of multiple analogies 222
6.8 Concluding remarks 229

List of Figures

2.1 A rough phylogeny of Coelacanth species. The solid arrows indicate the homological explanation of *Latimeria* reproductive biology as inheritance (and conservation) of reproductive strategy from a hypothetical common ancestor labeled "Ur-Coelacanth." The analogy with the shark *Hexanchus* is indicated by the dashed arrow. 53

3.1 *Triceratops* squares off against two *Tyrannosaurus rex*, from a mural by Charles R. Knight for the Field Museum of Natural History, Chicago (Photo CK9T). 70

3.2 Sample modern and fossil organisms grouped in rows according to similarities of horn shape and structure (Farlow and Dodson, 1975, p. 357). Combat behavior (Type 1, 2, or 3) of the fossil ceratopsian may then be inferred by analogy. A, chameleon; B, rhino; C, steer; D, North American mountain goat; E, *Monoclonius*; F, *Torosaurus*; G, *Protoceratops andrewsi*. Not drawn to scale. 71

3.3 *Proavis*, the hypothetical ancestor of *Archaeopteryx*, reconstructed by Heilmann (1927, p. 200) with patagia like the frilled gecko. This creature also appears in the *Rite of spring* sequence of the Disney film *Fantasia* in 1940. 80

3.4 Terminal phalanges (without horny claws) from the feet of selected bird types compared with those of four specimens of *Archaeopteryx* (Ostrom, 1974, p. 37). The columns display the middle "toe" (III) and the hallux (I) of each bird. The four *Archaeopteryx* feet are most like those of ground birds and unlike those of all the other birds, ground predators in particular. The horizontal lines equal 5 cm on the scale of each claw. 84

3.5 A visual analogy taken from the front leaf of a Christmas card. The scene juxtaposes similar events from two analogous sequences representing the causes and outcomes of transportation difficulties. . . . 93

3.6 Rough phylogeny of ceratopsian dinosaurs from the Judithian, Edmontonian, and Lancian periods of the Upper Cretaceous (Farlow and Dodson, 1975, p. 354). The phylogeny distinguishes three groups of ceratopsians: a "primitive" group, labeled A through C in the central column; a "long-frilled" group D through H in the left-hand area; a "short-frilled" group I through M in the right-hand area. Lines displaying phylogenetic relationships were deliberately omitted by Farlow and Dodson to express uncertainty on details of inheritance. 102

3.7 The reconstruction by Ostrom (1979, p. 55) of the evolution of flight in *Archaeopteryx*. The top half of the figure depicts a proto-*Archaeopteryx* using its feathers as aids to catching insects. The bottom half of the figure shows *Archaeopteryx* in a similar pose for the purposes of comparison, although *Archaeopteryx* was likely capable of flying after its prey. 103

6.1 An outline cognitive model of multiple analogies. 195

List of Tables

2.1 A representation of the proportional analogy "Just as those seeds are unmelted by fire, so these men are unmelted by strong laws" (*Laws*, 9.853c–d). 41

2.2 A representation of Darwin's analogy between domestic selection and natural selection. Subscripts distinguish different instantiations of identical predicates. 43

2.3 A multiple analogy of *Centroscymnus* and *Ruvettus* with *Latimeria* regarding eye pigmentation as an adaptation to seeing in deep ocean water. 51

2.4 A multiple analogy of *Triturus* and *Hexanchus* with *Latimeria*. *Triturus* is used only to repair disanalogous mappings between *Hexanchus* and *Latimeria*. 56

3.1 The chameleon/steer/*Torosaurus* component of the multiple analogy as given in the middle row of figure 3.2. This table represents the outcome of step 3 of Farlow and Dodson's procedure of functional comparisons. 75

3.2 Heilmann's gecko+Hoatzin/*Archaeopteryx* analogy. Note the use of selected features of the frilled gecko to partially overcome disanalogous mappings between the Hoatzin hatchling and *Archaeopteryx* domains. Ostrom attacks this analogy on the basis that two locomotory functions, clambering and flying, cannot generally be subserved by adaptations of the same organ, *i.e.*, the wing. The fact that wings count as adaptations for catching food and fleeing predators is omitted from the table. 82

4.1 A representation of the Quihuay+Taricá/Moche analogy given by Donnan (1971). The analogy imputes to the Moche a similar plan to that employed in Quihuay and Taricá for sharing production facilities while distinguishing pots. 122

4.2 A representation of the analogy constructed by Talalay (1987) to the target of Neolithic clay legs found in the Peleponnese. 128

4.3 A representation of the analogy between wolves and elephant cullers with Clovis hunters from Haynes (1991). Note that the *elephant cull* domain is left deliberately incomplete. 133

5.1 A representation of the analogy from eyes, ears and pruning knives to the soul (*Republic*, 1.352e–3e). 157

5.2 A representation of the analogy between health in the body and justice in the soul as given in the *Republic* (4.444c–e). 161

5.3 Another representation of the analogy between health in the body and justice in the soul as given in the *Republic* (4.444c–e). 163

5.4 A representation of the analogy from the painter and tragedian to the poet (*Republic*, 10.605a–b). 168

5.5 A representation of the analogy between mythical history and present social structure among the Trobriand islanders (Malinowski, 1926). See Shelley and Thagard (1996, p. 172). 175

Chapter 1

Multiple analogies past and present

But it is not possible that two things alone should be conjoined without a third; for there must needs be some intermediary bond to connect the two. And the fairest of bonds is that which most perfectly unites into one both itself and the things which it binds together; and to effect this in the fairest manner is the natural property of proportion [*analogia*].

Timaeus, in Plato's *Timaeus*, 31b–c.

1.1 Introduction

An analogy is a kind of comparison that may occur in many contexts, serve many purposes, and take on may forms. Consider, for example, the remarks made by Prince Philip, the Duke of Edinburgh, on the demand for a law banning handguns

in Britain following the shooting of 28 schoolchildren (16 fatally) in Dunblane, Scotland in March 1996. The Prince argued against the ban by comparing handguns to golf clubs and cricket bats:[1]

> If a cricketer, for instance, suddenly decided to go into a school and batter a lot of people to death with a cricket bat, which he could do very easily, are you going to ban cricket bats?

The Prince's comparison displays a number of features of central importance in analogical reasoning. First, the comparison is constructed with a specific purpose in mind, namely to weigh against proposals to ban handguns. Such a ban in the case of cricket bats would be absurd, the Prince maintains, therefore it would also be absurd in the case of small arms. Second, the Prince bases the argument not on any obvious similarity between handguns and cricket bats, which look nothing alike, but on their (potential) similarity of use. Both, the Prince claims, can easily be used to kill people. Third, the Prince's choice of cricket bats for comparison was made within a particular context. In fact, he was being interviewed by a BBC radio sports reporter when he made the remarks. Thus, sports, especially ones such as golf and cricket that are familiar to the Prince, were primed by the circumstances of the interview. Fourth, the leisurely and rule-bound air associated with golf and cricket contrasts highly with the frantic and unnatural feelings associated with a mass shooting. Finally, the Prince mentions cricket for comparison not simply for its own sake, but also on behalf of other sports and sporting equipment, such as golf and golf clubs, which might serve the argument just as well.

[1] From the Toronto Star, 5 February 1997.

These sorts of issues arise in the consideration of any analogy. Analogies generally serve some purpose, of which persuasion is only one. They are based on deep connections between things rather than some simple surface similarities such as physical resemblance. The choice of things to compare is not necessarily optimal, but is often suggested by arbitrary features of the context in which the analogy is constructed. The things compared in analogies may carry emotional values that make the analogy stronger or weaker. And analogies may involve the comparison of more than two items, if sometimes implicitly. All of these factors weigh in the acceptance or rejection of an analogy with respect to its purpose. In the case of the Prince's analogy, there are some obvious problems. For example, the Prince's argument relies on the similarity of use of handguns and cricket bats. As Alison Crozier, whose daughter was killed in the Dunblane shootings, points out

> Golf clubs are made for sport, for enjoyment. Guns are made to kill. There is no comparison between the two things.

An analogy premised on the ease with which someone might use a golf club or cricket bat in place of a handgun to kill people must be counted as a weak analogy. Additional appeals to tennis racquets, croquet mallets and the like would not make much difference.

More plausible applications of analogy to the problems posed by firearms have been proposed. Consider the suggestion made by Davidoff (1998) that physicians should counsel their patients regarding the potential consequences of firearm possession. The American College of Physicians surveyed their members on the issue of treating firearms violence as an epidemic like, *e.g.*, AIDS or tobacco addiction

(Cassel et al., 1998), and issued a position paper on the subject (Ginsburg, 1998). Davidoff (1998, p. 235) urges medical practitioners to play a similar role in reducing firearms-related injuries as they have done in reducing injuries from other human activities with medical consequences:

> But if the only change that comes from reframing gun violence as a medical issue is that internists and surgeons begin actively counseling their patients regularly on gun safety, the effect on firearm violence could be substantial. Our patients looked at us strangely in the 1970s when we began asking them whether they used seat belts. "What's that got to do with my medical condition?" But clinicians kept at it, and seat-belt counseling, along with improved seat-belt technology and mandatory seat-belt laws, is now seen as part of good preventive practice. The story is much the same with smoking, sexually transmitted diseases, and other difficult behavior-related health issues.

In other words, doctors could begin talking to patients about the risks they expose themselves to by keeping firearms around them, just as they do in connection with other medically risky practices such as ignoring seat belts, smoking, having unprotected sex, and so on.

Davidoff's analogy or "reframing" (as he calls it) may be judged in the same manner as the analogy offered by Prince Charles. First, it has a specific purpose, namely to advocate that medical practitioners counsel their patients about risks to their health as a result of having firearms. Such counseling has had positive effects in the cases of seat belts, smoking and AIDS, so why not treat firearms possession

the same way? More than that, Davidoff's analogy invites us to reconceptualize, or "reframe", the whole issue of firearms possession. As with seat belt usage in the 1970s, the idea of treating firearms as a medical issue appears strange at first. Thus, the analogy also serves to give the firearms issue a new conceptual structure which includes counseling as a potential mitigator. Second, the argument is not based on simple resemblances of firearms to seat belts, viruses or cigarettes. Rather, it is the adverse effect of these things on health that makes them comparable. This analogy does not hold in virtue of superficial features, but in virtue of similarities of cause and effect. Third, of course, Davidoff has selected only medical analogs for comparison. As a physician and editor of the *Annals of Internal Medicine*, he is an authority on medical practices and the epidemiological side of firearms use, and may therefore expect his opinion to carry some persuasive force. Fourth, the seat belt, smoking, and AIDS analogs are emotionally coherent with the issue of firearms use. All are taken quite seriously from a medical standpoint, and the air of gravity associated with counseling for various, medically risky behaviors transfers appropriately to the subject of firearms and the injuries resulting from the use of firearms. And finally, Davidoff cites not one, but three analogs to make his point. This sort of multiple comparison makes his plea for medical counseling all the more effective and convincing.

All of these aspects of analogy are important in understanding and evaluating analogical thinking. Of course, some aspects have received more attention than others in the time since analogies became a subject of philosophical inquiry in classical Greece. Currently, much of the research on analogy has been taking place in the

field of Cognitive Science, where comprehensive theories and models of analogical thinking have begun to emerge. The purpose of this dissertation is to apply some of that research to a better understanding of one aspect of analogy mentioned above that has not been fully explored, namely *multiple analogies*. In a single analogy, only one source analog is used to support a comparison. So, for example, when Bierce (1958) defines *wit* as "the salt with which the American humorist spoils his intellectual cookery by leaving it out," he is comparing the activity of writing humor (unfavorably) with the activity of cooking and nothing else. In a multiple analogy, several sources are used. Thus, Prince Philip compares handguns to cricket bats *and* golf clubs, and Davidoff compares firearms to seat belts, cigarettes, *and* AIDS. The aim of this dissertation is to inquire into the nature of multiple analogies and show in what respects they are of philosophical and cognitive interest.

Before embarking on this inquiry, it is helpful, and intrinsically interesting, to examine what philosophers have said on this subject before. The aim of the remainder of this chapter is to present a brief review of theories of analogy from Plato to Mill; it is Mill's theory that holds sway in philosophical circles today. This review is *not* intended to be a comprehensive history of the subject, but a résumé of the highlights, pointing out what influential philosophers have had to say that is relevant to the subject at hand. Specifically, this review shows that although sophisticated thinkers since the time of Plato have demonstrated some awareness of multiple analogies, they have done little to include multiple analogies in their explicit characterizations of analogy. This odd disparity between theory and practice indicates both that multiple analogies are 'natural' cognitive entities,

i.e., they are commonplace, *and* that they have tended to escape careful scrutiny. So, this review satisfies historical curiosity and also motivates the work presented in the rest of this dissertation.

Section 1.2 examines Plato's view of analogy largely from evidence in the *Republic*, and characterizes that view as a *shared-abstraction* theory of analogy;

Section 1.3 presents Aristotle's still-influential *proportional* theory of analogy, and shows that it is also a *shared-abstraction* theory;

Section 1.4 reviews Bacon's remarks on analogy, specifically his break with the Aristotlean theory and his proposal of a *shared-attribute* theory of analogy;

Section 1.5 examines Mill's treatment of analogy, which is similar to Bacon's, and his assimilation of analogy to inductive inference by another version of the *shared-attribute* theory;

Section 1.6 outlines the origin of the *shared-structure* theory in the twentieth century, concentrating on the work of Keynes, Hesse, Polya, Evans, Winston, and Gentner.

The sections indicate that these researchers concentrated only on *some* of the properties of analogy discussed above, *e.g.*, the nature of the connection between analogs and the suitability of these connections for the purpose of argument. Also, except of Polya, these researchers considered only single analogies in proposing their theories, although many have used multiple analogies in their practise. This disparity between theory and practice illustrates the need for a theory of multiple analogy.

1.2 Plato

Plato was a prolific user of analogies, at least for the first two-thirds of his career, and had clearly thought about what analogies are and what they could be used to do. But he does not present us with any extended, theoretical treatment of the subject. The statements he did record in his dialogs present a slightly fuzzy picture of what analogies are, and a contradictory picture of whether they could be recommended for philosophical use. On some occasions, Plato condemns comparisons as inherently misleading; on other occasions he presents them as a useful and commendable tool in the philosopher's dialectical bag of tricks.

The task of this section is not to sort out Plato's entire view of analogy; further inquiry on this subject may be found below in chapter 5 and in (Robinson, 1953, pp. 202–22) and (Lloyd, 1966). For present purposes, an indication of Plato's view(s) of analogy, especially multiple analogy, will suffice.

Plato provides some very colorful and insightful characterizations of analogical reasoning. One of his most interesting treatments of analogy comes in the *Republic*, a dialog replete with analogical arguments, where Plato elucidates the nature of analogy by a comparison (2.368d):[2]

> [Socrates:] "If someone had, for example, ordered men who don't see very sharply to read little letters from afar and then someone had the thought that the same letters are somewhere else also, but bigger and in a bigger place, I suppose it would look like a godsend to be able to

[2]All translations of Plato's *Republic* in this chapter are from Bloom (1968), unless otherwise indicated.

> consider the littler ones after having read these first, if, of course, they do happen to be the same."

Socrates convinces his companions to tackle the difficult topic of justice in the character of an individual human being by analogy with justice in the character of a whole city. He says that the form [idea] of justice is easier to apprehend in the case of the city; therefore, he and his friends should begin by considering what makes a city just and then proceed, by comparison, to considering what makes an individual just (2.369a).

Here, Plato presents a version of what may be called the ***shared-abstraction*** theory of analogy. In other words, Plato says that an analogy may be drawn between an individual and a city because they both share in a third thing, namely the *idea* of justice. This *idea* is an abstract property that applies to both the individual and the soul. Were there no shared idea (or *eidos*, the more common term Plato uses to mean the same thing; see *Republic*, 3.402c–d), there would be no basis for concluding anything from an analogy. Also, the fact that Plato grounds his model of analogy in his theory of forms (or true ideas) means that analogies, so construed, hold strictly for *essential* properties of their analogs. For Plato, each form has an unchanging existence which is realized only fleetingly and imperfectly in the everyday world. Thus, a form captures the properties of things that always hold true. Since analogies hold solely in virtue of two things sharing in one unchanging form, those things cannot be analogous due to accidents or coincidences. So, for example, the fact that two stones happen to be the same distance from the sea is mere happenstance and does not make them analogous.

Of course, there is the practical difficulty of determining what the forms are and how they may be reliably accessed for the purpose of analogical reasoning. Socrates states that young philosophers should only be introduced to the forms, by education in dialectical thought, starting at age thirty-five (7.539e). That is a long time to wait to start using analogies!

Besides examining the epistemological legitimacy of analogical reasoning, Plato also offers a motivation for it, or perhaps two. First, the letter comparison discussed above seems to imply that reasoning about justice by analogy may simply be easier than reasoning about it by some other means. In other words, analogy may act as a cognitive facilitator. Second, the letter analogy also seems to imply that Socrates and his friends may enjoy some confidence in their analogical conclusions because those conclusions are based on premises that they can apprehend clearly. In other words, since the big letters are easily legible, Socrates and the others may feel confident that they understand what those letters are, and may therefore feel confident that they understand what the little letters are, despite their difficulties in making out the little letters *per se*. It is not entirely clear whether Plato intended to support only one of these motivations or both, but both are consistent with his explicit comments on the subject.

In any case, when Socrates inquires into the nature of justice in the soul, he uses an analogy which involves *two* sources, namely the organization of the city and the organization of a flock of sheep. First, Socrates notes that the human soul, which is where human character resides, must be divided into three parts by analogy with the city, which has three classes of citizens, namely the rulers, the guardians, and

the many (4.435b). He argues that the human soul must likewise be divided into three corresponding parts, namely the calculating part, the spirited part, and the appetetive or ordinary part (4.435b–6b). Each of these parts attempts to direct the whole soul according to their individual natures (4.437b–41d). Since justice in the city consists in each class minding its own business, justice in the soul also likely consists in each part of the soul minding *its* own business (4.437d–e).

In the case of the city, the business of the ruling class is to direct the other classes, and the business of the guardian class is to obey the rulers and keep the many in line. Socrates supports this assignment by raising an analogy between the city and a flock of sheep. He states that the spirited part of the soul pursues victory at all costs, unless it is overruled by the calculating part, just as a herd dog herds a flock of sheep unless its master calls it in (4.440d). In this analogy, the shepherds are analogous to the city's rulers, the dog to the guardians, and the sheep to the many. By this analogy, Socrates clarifies what he means by each class in the city minding its own business. Then, he asserts that the parts of the soul mind their own business when, by analogy with the city, the calculating part rules, the spirited part obeys and marshals the ordinary part to obey the rulers also (4.441e).

Thus, the analogical argument that justice in the soul means a particular pattern of ruling and obedience among its three parts depends on two source analogs, the city and the flock. The city analog provides the tripartite division and suggests a pattern of political organization. The flock analog makes the pattern more specific and concrete. Also, the flock analog adds confidence in the conclusion, since the pattern of flock organization had already been discussed by Socrates and accepted

by the others (3.415d–6c). In its use of common pattern and established sources for confidence, this multiple analogy appears to have all the properties that Plato claimed for single analogies.

In his explicit comments on analogy, Plato set out a version of the shared-abstraction theory. On Plato's theory, an analogy consists in an idea or pattern that is shared by two things. Plato did not comment explicitly on the possibility or nature of multiple analogies. The example of the analogy from the city and flock to the individual soul indicates that Plato was sophisticated in the use of multiple analogies. But, the example does not tell us whether Plato felt that they would be subsumed under his concept of single analogies, or whether he simply failed to consider the issue at all. Whatever the case, Plato set the precedent for theories of analogy and the omission of multiple analogies from those theories.

1.3 Aristotle

Aristotle was the first philosopher to provide an explicit analysis of analogy along with its applications in areas such as poetry, rhetoric, logic, and science. The fundamental aspects of Aristotle's theory may be covered by attending to the meaning of two terms that he used which correspond to what we call 'analogy', namely *proportion* [analogia] and *example* [paradeigmata]. Fuller reviews of Aristotle's treatment of analogy may be found in (Hurlbutt, 1985, pp. 102–7), (Hesse, 1966, pp. 130–56), and (Lloyd, 1966).

Aristotle formalized and generalized the notion of identical, numerical ratios into the following general, and probably very familiar, formula: $A : B :: C : D$ or

"A is to B as C is to D" in plain English. This expression is the formula for the so-called 'proportional analogy'. Plato, among may other pre-Aristotlean Greek philosophers, implicitly used this notion when thinking about analogies, but restricted it to numerical ratios such as $2 : 4 :: 4 : 8$ or "two is to four as four is to eight". In other words, four is twice two and eight is twice four. The quotation from Timeaus given at the beginning of this chapter clearly takes analogy in this way, as the identity of numerical ratios. But Aristotle generalized this expression to cover the case of identical relations holding between *any* two pairs of objects. This generalization is stated in the *Topics* (1.17.108a6–11), where Aristotle gives illustrations such as "knowledge is to the thing known as sensation is to the thing sensed". In other words, just as knowledge is about facts, sensation is about material objects. The relationship of 'aboutness' is identical in each case. Really, this analogy is simply a version of the age-old metaphor between sight and intellect, as in the expressions "seeing is believing" or "I see what you mean" (Lakoff and Johnson, 1980, p. 48).

Aristotle applied his theory of proportional analogy in many areas. For instance, he noted that many good metaphors seem to *be* good in virtue of an underlying analogical relationship. For example, Aristotle states that since a cup is to Dionysus (the god of wine) as a shield is to Ares (the god of war), a cup may be metaphorically described as 'the shield of Dionysus' and a shield may be metaphorically described as 'the cup of Ares' (*Poetics*, 21.1457b21–23). The identical relation shared by both analogs in this case could be described as *x is the implement most appropriate to y*.

Plato ensures that analogies are non-trivial by insisting that they are legitimate solely in virtue of a shared form. Thus, no accidental similarities may form the basis of an analogy, properly speaking (section 1.2). Aristotle ensures the non-triviality of analogies under his account in a different way, via two restrictions. First, Aristotle distinguishes analogy from identity. He claims that some things are completely identical in all essential properties, such as the celestial bodies (*Parts of Animals*, 1.5.644b22–7). Because of this, it would be trivial to assert, for example, that celestial bodies are analogous to one another because they are imperishable. Thus, it would be trivial to note that imperishability is to the planet Venus as it is to the planet Mars. Conversely, Aristotle maintains that some things are different in all essential properties and that it is proper to construct analogies between only such things. For example, birds and fish are analogous insofar as feathers are to birds what scales are to fish (*History of Animals*, 1.4.644a10–b17), *i.e.*, feathers:birds::scales:fish. By restricting analogies to non-identical relations between non-essential properties, Aristotle excludes trivial comparisons from his theory of analogy.

This first restriction still leaves open the possibility that analogies could hold between purely accidental properties of things. Aristotle resolves this issue by relating analogy to induction. In this sense, Aristotle typically speaks of 'example' [paradeigmata] rather than 'analogy'. Induction is a form of reasoning that proceeds from particular cases to a generalization that is true of all cases. Consider, Aristotle says (*Prior Analytics*, 2.23.68b19–22), those animals that are long-lived, *e.g.*, men, horses, and mules. Upon inspection, we notice that each of these animals is bileless.

We may conclude, therefore, that *all* long-lived animals are bileless. Thus we have reasoned from an inspection of each case of long-lived animal to a generalization true of all of them; this process is induction.[3] Aristotle claims that reasoning by example is similar to induction, except that we reason from one particular case to another particular case, leaving the inductive generalization unstated (*Prior Analytics*, 2.24). So, for instance, we might reason that for the Athenians to attack the Thebans is evil, since Thebes is the neighbor of Athens and the example of the attack of the Thebans on the Phocians shows that it is evil for a city to attack its neighbor. In Aristotle's view, we first reasoned from one case, the attack of the Thebans on the Phocians via a non-exhaustive induction to the implicit generalization that all attacks by one city on its neighbors are evil. It follows deductively that an attack by Athens on its neighbor Thebes would be evil as well. In this way, Aristotle claims that all analogies make an implicit appeal to some unstated generalization. By this second restriction of analogies to comparisons covered by a generalization, Aristotle includes only inductively plausible comparisons in his theory of analogy.

In the *Rhetoric* (2.20), Aristotle indicates two things about the use of examples, namely that reasoning by example (1) depends on proportional analogies, and (2) may involve multiple analogs. Consider the following illustration about the need for the Greeks to prevent the Persians from taking over Egypt (1393a31–b3, translation from McKeon, 1941):

> We must prepare for war against the king of Persia and not let him

[3]In fact, we have not examined *every* long-lived animal, and most actual inductions are not exhaustive in this way. Aristotle ignores this problem, however.

> subdue Egypt. For Darius of old did not cross the Aegean until he had seized Egypt; but once he had seized it, he did cross. And Xerxes, again, did not attack us until he had seized Egypt; but once he seized it, he did cross. If therefore, the present king seizes Egypt, he also will cross, and therefore we must not let him.

The analogy appears to be cast in the proportional mold: Egypt is to the present king of Persia as it was to Darius and as it was to Xerxes. Here, Aristotle uses two sources. Many of the other cases of 'example' discussed by Aristotle in this section also appeal to multiple sources, each cast (or thrust) into the proportional form. Aristotle does comment on the ways in which multiple examples affect the rhetorical appearance of an argument, but does not alter his proportional theory to accomodate the use of extra material. Perhaps he thought of multiple sources as simply a case of more of the same.

Aristotle's treatment of analogy represents a significant advance on Plato's treatment. Aristotle provided a general representation of analogy, the proportional representation, and distinguished analogy from identity on the one hand and coincidence on the other. He applied his theory to account for analogies in many different areas. Like Plato, Aristotle gave a version of the *shared-abstraction* theory of analogy, by stating that analogies are legitimated by an inductive generalization.[4] Also like Plato, Aristotle appears to admit multiple analogies into his account, but never

[4]In the *Topics* (1.18.108b10–2), Aristotle states that inductions are constructed from things known to be similar by analogy. This claim introduces a circularity into Aristotle's theory of induction in the sense that, having made analogy dependant on induction, he makes induction dependant on analogy. Perhaps he means to say only that analogies serve as heuristics in guiding us to proper, logical inductions.

incorporates them into his theory.

1.4 Bacon

Following Aristotle, many philosophers of the classical and medieval periods examined analogy and analogical reasoning. The Stoic philosophers, for example, combined Aristotle's *analogy* and *example* under the rubric of analogy, thus giving that term roughly the connotation it has to this day (Hurlbutt, 1985, pp. 107–12). Medieval philosophers such as Aquinas made analogy a central issue in examining the relation between God and his creation (Hurlbutt, 1985, pp. 118–22; Ashworth, 1992). But the current view of analogy in philosophy may be more directly traced to Bacon (1620). Bacon treated analogy largely for its contribution to scientific induction, and took a view contrary to that recommended by Aristotle. See (Keynes, 1921, pp. 265–73) and (Leatherdale, 1974, pp. 4–8) for overviews of Bacon's theory of analogy.

Bacon viewed the construction of general theories or 'axioms' as the ultimate goal of science. He proposed a specific method for fulfilling this goal. Axioms result from a careful process in which the natural philosopher collects all instances of some phenomenon into specific tables. The first table receives all the known instances that share a particular attribute; this table is known as the *table of essence and presence* (2.11, *Novum Organum*). The second table receives all the known instances that are identical to each instance in the first table except that they *lack* the attribute in question; this table is known as the *table of deviation or*

absence in proximity (2.12, *Novum Organum*).[5] When the tables are complete, the philosopher examines the first table to see what attributes distinguish its entries from those in the second table and infers as an axiom that these attributes are the cause of the difference.

Of course, this procedure begs the question of how the philosopher may recognize that attributes are shared among instances in the first place in order to collect instances together correctly. Bacon claims that analogy is the basis or "first step" of this recognition of resemblance (2.27, *Novum Organum*):[6]

> [Such analogies] are those which represent the resemblances and conjugations of things, not in lesser forms but merely in the concrete. Hence they may be called the first and lowest steps toward the union of nature.
>
> ...
>
> Men's labor therefore should be turned to the investigation and observation of the resemblances and analogies of things, as well in wholes as in parts. For these it is that detect the unity of nature, and lay the foundation for the constitution of sciences.

In other words, the recognition of resemblances or shared attributes follows from the construction of analogies, in Bacon's view. Once constructed, analogies become a basis for inductive inference in science. Bacon does not state exactly what he means

[5]Bacon also describes a *table of degrees or comparison* that receives all instances in which a attribute appears only to a certain degree (2.13, *Novum Organum*), but this may be omitted for present purposes.

[6]All translations of the *Novum Organum* in this chapter are taken from Spedding et al. (1863), unless otherwise indicated

by analogy, but his illustrations indicate that he has something like proportional analogies in mind.

Bacon does address the issue of the legitimacy of analogies. He urges caution in using analogies and maintains that good analogies are those based on "physical resemblances, that is, real and substantial resemblances; resemblances grounded in nature, not accidental or merely apparent" (2.27, *Novum Organum*). As examples he includes the similar shapes of Africa and South America, which are identical in the arrangement of wide and narrow parts, and the similarity of mathematical transitivity and the deductive syllogism, which are identical in having a middle term:

$a = b$	All p are q
$\underline{b = c}$	$\underline{\text{All } q \text{ are } r}$
$a = c$	So, all p are r

Bacon's reference to "real and substantial resemblances" hardly clears up the issue of distinguishing good analogies from trivial ones since he does not state what "real and substantial" means in precise terms. He seems to hold that a well-educated person will simply know a good analogy when he or she sees one. Nevertheless, his statement shows, at least, that Bacon was concerned about the subject and recognized that analogies do not concern superficial similarities.

Bacon provides no discussion of multiple analogies, but some do appear among the many colorful and thought-provoking comparisons that he presents in explaining his philosophical views. For example, Bacon uses a multiple analogy with light,

the letters of the alphabet, and plant seeds to address a potential objection to his program of painstaking experimentation in the pursuit of knowledge (1.121, *Novum Organum*):

> To suppose, therefore, that things like these [many, careful experiments] are of no use is the same as to suppose that light is of no use, because it is not a thing solid or material. And the truth is that the knowledge of simple natures well examined and defined is as light: it gives entrance to all the secrets of nature's workshop, and virtually includes and draws after it whole bands and troops of works, and opens to us the sources of the noblest axioms; and yet in itself it is of no great use. So also the letters of the alphabet in themselves and apart have no use or meaning, yet they are the subject matter for the composition and apparatus of all discourse. So again the seeds of things are of much latent virtue, and yet of no use except in their development. And the scattered rays of light itself, until they are made to converge, can impart none of their benefits.

Bacon argues that, when taken together, detailed and painstaking experiments can be expected to yield weighty and fruitful results, just as light rays yield illumination when focussed, as letters form words when combined correctly, and as seeds become plants when combined with nutrients.

Bacon's treatment of analogy represents a break with the tradition set by Plato and Aristotle. Indeed, Bacon saw Aristotle's logic as a baneful influence on natural philosophy (1.54, 63, 96, *Novum Organum*) and set out himself to undo the

damage. He sought to redefine the concept of scientific induction and made analogy a fundamental constituent of inductive inference. Specifically, Bacon insisted that analogy consists in two things sharing a particular, direct and non-accidental attribute, *without* reference to an inductive generalization. Thus, Bacon proposes what may be called a *shared-attribute* theory of analogy, one in which analogies are formed by direct comparison of the attributes of two things unmediated by a third item such as a form or an inductive generalization. Bacon does offer a solution to the problem of distinguishing good analogies from bad ones, but it seems to rely entirely on the observant character of the analogizer rather than any characteristic of the analogy in question. There is no indication that Bacon ever contemplated multiple analogies and the appeal to obviousness in his theory of single analogies hardly allows for extrapolation to the multiple case. But, like Plato and Aristotle, he certainly made use of them.

1.5 Mill

Mill is the pivotal figure in the history of analogy in philosophy in the sense that it is Mill who transmitted a Baconian account of analogy to the modern tradition. North (1981, p. 123) states the situation very aptly:

> Mill was to the nineteenth century what Bacon had been to the seventeenth, namely empiricist philosopher and self-appointed arbiter of scientific method. ... Both Bacon and Mill paid attention to analogy, in their account of induction, and Mill's passage on the subject was especially influential in philosophical circles.

Mill's theory is so similar to Bacon's that Keynes (1921, pp. 265–73) treats both of them in the same passage. Although Mill does not mention Bacon in his treatment of analogy *per se*, he does praise Bacon's theory of induction elsewhere (Mill, 1872, 3.3 §2), so it is likely that he was influenced by Bacon's inductive account of analogy. Like Bacon, Mill rejects the Aristotlean theory of proportional analogy and instead assimilated analogy to induction. See North (1981, pp. 132–4) for a review of Mill's theory from the perspective of modern logic.

Mill's treatment of analogy is given in book 3, chapter 20 of his *System of logic* (Mill, 1872). He begins by rejecting the proportional analogy apparently because he thinks that to point out that two things share one relation in common is merely peculiar and inconsequential (Mill, 1872, 3.20 §1). He proposes instead that analogy be based on the number of attributes or features that two things share in common (Mill, 1872, 3.20 §2):

> Two things resemble each other in one or more respects; a certain proposition is true of either one, therefore it is true of the other.

In other words, Mill takes analogy to be the inference that some proposition m (as he calls it) is true of item B because items A and B both have features f, and m is true of A. Mill's formula could be expressed as follows (see also North, 1981, p. 132):

$$\frac{\begin{array}{l} has(A,f), has(B,f) \\ m(A) \end{array}}{\text{So, probably } m(B)}$$

As Mill points out, this formula covers induction, or "complete induction" when the features f are invariably found in both A and B. Analogy is thus simply a special case of induction when such an invariable association is not known to hold.

In this account, Mill conflates analogical comparison with analogical inference, perhaps a necessary move since he eliminated strictly relational comparison from the start. In place of relational comparison as a means of legitimating analogical reasoning, Mill gives an analysis of what restrictions, when added to the above formula, might make an analogical inference more or less likely. First, Mill stipulates that there must be no known connection between f and m. If it is known that the presence of features f implies the truth of m, then we have an "invariable connection" and therefore a "complete induction" but not an analogy, by definition. If it is known that the presence of features f does *not* imply m, then the truth of $m(A)$ must be considered a coincidence with respect to $f(A)$. So the truth of $m(B)$ would also most likely be a coincidence with respect to features $f(B)$. Analogies based on known coincidences would hardly be convincing.

Second, assuming the first condition is met, Mill holds that the probability that an analogy is robust is increased in proportion with the number of features f shared by A and B. Conversely, this probability is decreased in proportion with the number of features f' *not* shared by A and B. Mill supports this idea by noting that features tend to be present in groups, so that the presence of one feature usually implies the presence of others in both A and B. Mill (1872, 3.20 §3) adds that the similarity or dissimilarity of *circumstances* in which A and B display features f weighs similarly into the probability of an analogical inference.

Mill does consider the possibility that we may have specific reasons (less certain than $has(A, f) \rightarrow m(A)$) to weight certain features more or less heavily in considering the plausibility of an analogy. In his example concerning the likelihood of life on the moon and planets based on analogy with the Earth, Mill says that the differences between Earth and the other orbs consist "chiefly" in their different amounts of light, heat, rotational velocity, density, and gravity; other dissimilarities are "secondary". Unfortunately, it is not clear how this primary/secondary distinction is to be made, nor how it fits into the rest of his theory. Mill's theory also implies that confidence in an analogy may be bolstered simply by adding to the list of shared features f, although this policy of indiscriminant addition hardly seems to be sound methodological advice for a practicing scientist. Of course, Mill (1872, 3.20 §3) states that analogy should serve as a "mere guidepost" so that there may be no point in trying to bolster an analogy in the first place. But if analogical reasoning is worth doing at all, it is worth inquiring into how it may be done well and efficiently.

Although Mill does note that analogies may suggest conflicting conclusions, he does not consider any case in which analogies might *support* each other's conclusions. But there is at least one example of a multiple analogy in his writings. Consider the following passage in which Mill (1893, 1.1 §3) argues that it is nonsensical to say that some products are more the result of labor than nature, or *vice versa*:

> Some writers have raised the question, whether nature gives more assistance to labour in one kind of industry or in another; and have said that

> in some occupations labour does most, in others nature most. ... It is impossible to decide that in any one thing nature does more than in any other. ... When two conditions are equally necessary for producing the effect at all, it is unmeaning to say that so much of it is produced by one and so much by the other; it is like attempting to decide which half of a pair of scissors has most to do in the act of cutting; or which of the factors, five and six, contributes most to the production of thirty.

In other words, no sort of priority can reasonably be assigned between two necessary and jointly sufficient conditions, such as the contribution of nature and labor to manufacture, just as no such priority can be assigned to the work of each blade of a pair of scissors or each factor of an integer. It is not clear how Mill's theory of single analogies should be extended to cover this case. The same features f, two necessary and jointly sufficient factors, appear in both scissor and numeric source analogs. Should we simply count the features f twice and double the assurance we draw from the sources of Mill's analogy? If the same features appear in two analogs then, by Mill's logic, they probably appear in many more, which should increase the probability of the analogy. But this procedure does nothing to increase the number of distinct features in f, which was the measure of increased probability in the single-analogy case; it simply allows us to count f several times.

Like Bacon, Mill broke with the traditional, proportional analogy and instead treated analogy as a special case of inductive, scientific inference. Unlike Bacon, Mill gave analogy a strictly heuristic function and did not see it as an important contributor to inductive inference. Mill proposed a version of the ***shared-attribute***

theory of analogy by defining analogy as an inference licensed by a direct comparison of shared features. He set restrictions on analogy to help distinguish good ones from poor ones, but these involve only counting the number of similarities and dissimilarities, a crude and not always practical procedure. Mill did not consider multiple analogies in his theory, nor is it clear how his theory should be extended to cover this case. But, like the other philosophers reviewed in this chapter, he did make use of multiple analogies on occasion.

1.6 Shared-structure theory

Two streams of thought on analogy are apparent in the twentieth century. The first stream is the continuation of Mill's shared-attribute theory. Mill's theory remains popular with many philosophers, particularly logicians and philosophers of science who take formal logic as the appropriate model of scientific inquiry. The theory of analogy given by Salmon (1984, p. 105), for example, is essentially identical to Mill's, *i.e.*,

> Objects of type X have properties G, H, *etc.*
>
> Objects of type Y have properties G, H, *etc.*
>
> <u>Objects of type X have property F.</u>
>
> So, objects of type Y have property F.

Obviously, this statement is very similar to that given by Mill as described in section 1.5.

The second stream of thought on analogy also derives from Mill's theory but combines it with concepts taken from mathematics, science, and artificial intelligence. The theory resulting from this stream of thought may be called the *shared-structure* theory. Shared-struture theories come in several varieties including the *Multiconstraint theory*, which is treated in some detail in section 2.2. On the shared-structure theory, an analogy consists in two analogs that share not attributes (or not *merely* attributes) but also relations and relations among relations. The nature of this theory may be clarified by selectively reviewing how thinking on analogy has been influenced by ideas from mathematics, science, and artificial intelligence over the course of this century.

Keynes (1921) gave a treatment of analogy which may be treated as a clarification of Mill's. Keynes (1921, p. 223) states that two objects are analogous insofar as the same proposition concerning their attributes is true of both of them. Keynes makes two innovations important to the later development of shared-structure theory. First, he introduces a mathematical notation, $g(\phi, f)$, to represent the proposition that holds true of both objects, where g is a relation between attributes ϕ and f that both objects possess. Second, Keynes (1921, pp. 257–60) discusses the importance of cause and effect relations in justifying the conclusion of a *material* analogy—that is, an analogy between physical objects or states of affairs. In the material world, a small number of causal laws suffice to relate a large number diverse attributes. Thus, analogies based on a shared causal relation may be asserted with some confidence because there are so few alternative causal relations that might be present, and these may be eliminated by other considerations. For example, Keynes

(1921, pp. 257–8) claims that we may confidently believe the proposition that the overt acts of other people are caused by mental states that belong to them by analogy with our observation that our own overt acts are caused by nothing other than mental states that belong to us. In other words, we infer that other people must have mental states like ours because we cannot imagine what else would cause them to act so much like we do.

Keynes was primarily interested in estimating the likelihood of conclusions derived by analogy. Thus he introduced causality not because of its importance for organizing other concepts but because its mere presence serves to increase likelihood. Hesse (1966) takes up and improves Keynes theory of material analogy by revising his treatment of causality in two ways. First, she allows for analogies between objects that share *several* distinct causal relations and not just one. Second, Hesse (1966, pp. 77–86) argues that causal relations are important because of their predictive power, not because of their small number. If we know that a causes b in one domain and that c exists in another domain, then we may be lead to predict and look for d such that c causes d (Hesse, 1966, pp. 72–4). In effect, causal relations play a special role in prompting us to fill out analogies completely, especially in scientific research. Hesse notes that in some cases, the presence of shared causal relations is sufficient to warrant an analogy—that is, similarity of attributes is not necessary.

Polya (1954, 1957) gives the first clear statement of a shared-structure theory of analogy (Polya, 1954, p. 13): "two systems are analogous, if they agree in clearly definable relations of their respective parts." There are two important points to

note about this definition. First, analogy here depends on the sharing of *several* relations rather than a single relation as in Keynes's theory. Second, on this view, analogy consists entirely in similarity or agreement of relations and *not* on similarity of parts of relations, meaning attributes, as on Mill's view. Overall, Polya's theory appears to be a mathematical adaptation of the Aristotelean proportional analogy, which Polya (1954, p. 14) also discusses. The influence of the proportional theory is also evident in Polya's (1957, p. 37) description of what it means for two relations to "agree" with each other: "we may contract the two ... statements into one that applies equally to both [systems]." Thus, the sharing of relations is seen as *equivalent to* having both systems governed by the same generalization, as in Aristotle's theory (section 1.3). However, Polya also appears to have been influenced, perhaps indirectly, by Mill. This influence can be seen in his characterization of analogical inference concerning two geometrical figures (Polya, 1957, p. 43): "Knowing that the triangle and the tetrahedron are alike in many respects, we conjecture that they are alike in one more respect."

Polya's theory is of interest here largely because it was an important influence on Evans's ANALOGY program, the first computational model of analogy (see Hall, 1989). Evans (1968) applied Polya's ideas about analogy to the construction of a computer program that solved geometric analogy problems of the kind commonly found in IQ tests. ANALOGY was given eight geometric figures, A, B, C, and 1 through 5, and required to determine which of 1 through 5 best completed the proportional analogy $A : B :: C :?$. The program would generate a representation of each figure in terms of spatial relations, *e.g.*, *inside(P1,P2)* to signify that object

P1 sits inside object *P2*. Then, it would generate several rules that would transform figure *A* into *B* and *C* into each of 1 through 5. Finally, it calculated the length of each rule and picked the figure contained within the *longest* rule as the best answer. The longest rule is favored because it tends to be the most specific rule applicable to the problem at hand, and because this preference best matches human performance on similar problems. Evans's work is important because it was the first attempt to apply artificial intelligence techniques to the problem of analogical thinking. These techniques include a rich and concise set of relational representations, *i.e.*, spatial representations, and the notion that some rules, *i.e.*, the longest ones, may be more important than others in constructing good analogies.

Winston (1980) applies artificial intelligence techniques to linguistic forms of analogical reasoning and learning. He emphasized the importance of matching concepts together and of abstract information, especially causal information, in analogy construction and evaluation. Matching means that the components from each of two analogs should merely be aligned into pairs, and *not* that they should be subsumed or subsumable under a single generalization. This constraint is a basic tenet of any shared-structure theory. Winston also emphasized the contribution of causal relations in the following two ways. First, Winston's program awarded points to analogies in proportion to the number of shared relations. Since he was interested in constructing analogies between story plots, and since causal relations occur frequently in story plots, shared causal relations contributed to the score of an analogy by sheer weight of numbers. In this sense, Winston's program behaved much like Evans's ANALOGY program in prefering structurally rich analogies to

structurally poor ones. Second, Winston (1980, pp. 695, 700) states that causal relations are instrinsically important and that knowledge of causal relations in one analog can guide the process of matching its components with those of another analog. His program therefore gave analogies containing matching causal relations an extra, bonus score for each such relation. Winston's point here is similar to that made by Hesse concerning the utility of causal relations in guiding analogy construction, although Winston was apparently unaware of Hesse's work.

Gentner (1981, 1983), following up on the work of Polya, Hesse, and Winston, proposed the *structure mapping* theory, which may be fairly described as the first, clearly stated version of a shared-structure theory of analogy. The theory states that an analogy between A and B is a set of mappings between the two sets of predicates that represent A and B (Gentner, 1983, pp. 157–8). Mappings correspond to the matchings described by Winston, but are subject to the following three rules:

1. Mappings between attributes are largely or completely ignored;
2. Mappings between relations, *e.g.*, $R(a_0, a_1)$ to $R(b_0, b_1)$, are emphasized where
3. they enter into *systems* of relations, *e.g.*, $R'(R_{a0}, R_{a1})$ to $R'(R_{b0}, R_{b1})$.

The third rule is called the *systematicity principle* and stipulates that analogies are good analogies insofar as they contain mappings between richly structured, higher-order relations. Higher-order relations are often, though not invariably, causal ones. Psychological experiments indicate that people find such analogies more apt or convincing than analogies which lack mappings between higher-order predicates (Gentner, 1983, pp. 165–6). The systematicity principle embodies the use

of predicate-and-argument syntax in representing the structure of analogical mappings. Some version of the systematicity principle figures in all shared-structure theories, including the *Multiconstraint theory*.

Polya (1957, pp. 43–4), alone among the above authors, discusses multiple analogies. Polya states that multiple analogs may be used to strengthen a comparison or to generalize it. Generalization, which Polya holds to be the more important of these two uses, amounts to assembling source analogs that are fairly different from each other and therefore agree, when they do agree, in broader or more abstract relations than would apply to the single analogy case. Such abstract relations may then suggest general theorems about the objects to which they apply. It is interesting to contrast this view with that of Evans, who followed Polya's ideas on analogy, at least regarding single analogies. According to Evans, constructing the best single analogy depends upon finding the most *specific* relation that holds between the analogs. But, according to Polya (1957), constructing the best multiple analogy depends upon finding the most *general* relation that holds among the analogs. This apparent difference in objectives between single and multiple analogies suggests either that the two kinds of analogy are really very different, or that these notions of the purpose of analogies, single and multiple, are oversimplified. One of the major aims of this dissertation is to examine the influence of purpose on the nature of multiple analogies in the context of a shared-structure theory.

1.7 Summary

Of the many aspects of analogical reasoning that might be addressed, philosophers and other researchers have focussed largely upon single analogies and epistemic aspects of single analogies that legitimate analogical inferences. Three sorts of solutions are proposed. First was the *shared-abstraction* theory, elaborated by Plato and Aristotle, in which a comparison is licensed not directly by the analogs involved but by an idea or generalization that is true of both of them. Second was the *shared-attribute* theory, developed by Bacon and Mill, in which a comparison is licensed directly by consideration of the two analogs in question. Third is the *shared-structure* theory which has emerged from the consideration of analogies in the empirical and formal sciences.

Several of the issues connected with analogical reasoning that were raised in section 1.1 are not addressed in the theories discussed above. One of these issues is the nature of multiple analogies, analogies involving several source analogs. There is little indication that the philosophers and researchers whose work has been outlined above considered this issue, although many of them did use multiple analogies on occasion. We can only speculate about the reason for this omission, but we can do something about it. The remainder of this dissertation constitutes an inquiry into multiple analogies from a philosophical and cognitive standpoint. The purpose of this exercise is to give a reasonably comprehensive account of multiple analogies by adapting a current theory of analogy, the *Multiconstraint theory*, to the needs inferred from an examination of many instances of multiple analogies drawn from the history of biology, archaeology, and philosophy. The result is, at last, a

philosophical theory of analogy in which the use of multiple analogies is given due consideration.

The remaining chapters of this dissertation provide the following material:

Chapter 2 gives a description of the *Multiconstraint theory* in the case of single analogies and extends it to a multiple analogy concerning Coelacanths taken from the biological literature;

Chapter 3 follows up this material with an examination of multiple analogies in theories of the evolution of horned dinosaurs and birds, and gives a discussion of what this work shows about the place of analogy in evolutionary biology;

Chapter 4 provides an examination of several multiple analogies from the archaeological literature, along with a discussion of the implications of this work for archaeologists concerned with the role of analogy in their field;

Chapter 5 presents an account of multiple analogies from Plato's *Republic*, in which multiple analogies figure prominently, and further explore's Plato's attitude towards them;

Chapter 6 unifies the cognitive aspects of this research in the form of a cognitive model of multiple analogies, and summarizes the insights gained into the philosophy of evolutionary biology and archaeology, and into Plato's philosophy as well.

Chapter 2

Multiple analogies in Coelacanth biology

All our reasonings concerning matter of fact are founded on a species of analogy, which leads us to expect from any cause the same events, which we have observed to result from similar causes. ... The anatomical observations, formed upon one animal, are, by this species of reasoning, extended to all animals; and it is certain, that when the circulation of the blood, for instance, is clearly proved to have place in one creature, as a frog, or fish, it forms a strong presumption, that the same principle has place in all.

Hume, *Enquiry concerning the human understanding*, § 9.

2.1 Analogies in science

Analogies play a vital role in many sciences. The importance of analogy to scientific discovery and explanation in particular has been the subject of extensive

philosophical and historical research. For example, consider the discovery of the circulation of the blood by Harvey (1628). Prior to Harvey's work, it was thought, following Galen, that the blood distributed through the arteries was consumed by the body and that the blood collected in the veins was produced by the liver from fluids taken into the body by eating and drinking (Pagel, 1967, pp. 127–8). Harvey argued, based on his observations of the heart and blood vessals in action, that the blood found in the veins was exactly the blood found in the arteries, only depleted of nutrients. Harvey describes his discovery as follows (translation from Whitteridge, 1976, p. 75):

> I began to bethink myself whether it [the blood] might not have a kind of movement as it were in a circle. And this I afterwards found to be true....
>
> We may call this motion circular in the same way in which Aristotle says that the air and the rain imitate the circular motion of the heavens. For the earth being wet evaporates by the heat of the sun; the vapours being drawn upwards condense and being condensed descend again in raindrops and wet the earth.

Harvey continues on to compare the circulation of the blood with the circular movement of the sun around the earth. From this statement, it appears that the analogy between the circulation of the two fluids, namely blood in the body and water in the atmosphere, helped Harvey to construct and pursue his new hypothesis (see Pagel, 1967, pp. 82–6). Harvey's theory was successful, despite the fact that the capillaries connecting the arteries to the veins were not described until 1661 by

Marcello Malpighi.

In archaeology, ethnographic analogies played an important role as evidence for the human origin of prehistoric artifacts. Until the late seventeenth century, prehistoric stone tools were typically classified as fossils and thought to be the result of natural processes in the earth, or to have fallen from the sky just as meteorites were known to do (Grayson, 1983, p. 5). But, as scholars began to question the accepted view of fossils, they began to compare these stone tools with those that they found in use among contemporary natives of the Americas. Many scholars concluded that Europe had once been populated by peoples who had little or no knowledge of metallurgy and made their tools from stone just as the Indians did. For example, in 1686 the British antiquarian Robert Plot noted that theories about the stone tools manufactured by ancient Britons could be constructed through comparison with the stone tools then manufactured by the North American Indians (Trigger, 1989, pp. 52–3). The realization that stone could be the basis of a whole technology eventually lead to the concept of a stone age, in distinction to a bronze age and an iron age, for example (Trigger, 1989, pp. 54–5).

Around 1838, Darwin derived the basic concept of the struggle for existence from reading Malthus's book *An essay on the principles of population* (1816). Malthus noted that human populations grow at an exponential rate, whereas their food and other resources grow at only an arithmetic rate, implying that many more humans are born than could possibly survive to reproduce. Thus, humans must struggle for resources in order to live long enough to have and raise children. Similarly, Darwin realized, many more plants and animals are born than their environment

can support, so that they must also be engaged in a struggle for resources in order to live long enough to produce offspring (see Gould, 1993, pp. 301–2). From this analogy, Darwin obtained his idea of the struggle for existence in the biological world.

The importance of single analogies in science demands careful scrutiny and a precise and comprehensive form of representation, one which may then be extended to the representation of multiple analogies. The purpose of this chapter is to introduce the *Multiconstraint theory* as the representation of single analogies and to begin applying and extending it to multiple analogies, specifically multiple analogies occurring in the biological literature on the "living fossil" Coelacanth. To this end, the remainder of this chapter presents the following material:

Section 2.2 introduces the *Multiconstraint theory* and its account of single analogies in terms of constraints on the analogical-mapping process;

Section 2.3 discusses the use of *analogy* as a technical term in evolutionary biology;

Section 2.4 examines multiple analogies used by biologists in constructing and debating theories about the Coelacanth, a rare and inaccessible fish once thought to be extinct, and shows how the *Multiconstraint theory* may be used to represent these analogies;

Section 2.5 reviews the issues that arise from this examination for the *Multiconstraint theory*, *i.e.*, the cognitive processes through which multiple analogies are constructed and used.

The sections indicate the importance of multiple analogies to the practise of biology, and also indicate how the *Multiconstraint theory* must be reconsidered in the light of this practise.

2.2 Single analogies in the *Multiconstraint theory*

A single analogy is a structured comparison between a target and exactly one source. Single analogies are the subject of most theories of analogy (see chapter 1), including the familiar theory of proportional analogy as described by Aristotle (section 1.3). A proportional analogy consists of four parts, divided into a source and a target, which share an identical relation. The proportional analogy may be summarized in the form A:B::C:D, where A and B are the source objects, C and D are the target objects, the ":" represents the relation between each pair, and the "::" represents the distinction between the source on the left and the target on the right.

Consider, for example, an analogy given in Plato's dialog *The Laws* (9.853c–d) by the Athenian Stranger. The Athenian feels compelled to apologize for proposing to legislate harsh punishments in his hypothetical city, since he holds that the citizens of a truly well-governed city would not need the correction of punishment to act properly. But, as the Athenian sagely points out, any collection of mere mortals will contain some who will require punishment in order to keep them in line (translation from Pangle, 1980):

> We're humans, and legislating now for the seed of humans. Therefore, there is no blame incurred by our fearing lest one of our citizens become, as it were, "hornstruck" [*kerasbolos*]—so tough by nature that he

> wouldn't melt. Just as those seeds are unmelted by fire, so these men are unmelted by strong laws.

As Pangle (1980, p. 245n3) notes, the term *kerasbolos* is applied to beans that are so dried out and hard that they would not soften (or "melt") even when boiled over a fire. The Athenian stranger is comparing some recalcitrant man among the citizens of the hypothetical city with such a bean. In proportional notation, the analogy could be represented as follows: hard-bean:boiling-water::some-man:strong-laws. The analogy does its work by transferring the relation *unmelted-by* (represented by the ":") from the bean domain to the civic domain. The result, if we understand *unmelted-by* as *undeterred-by* when applied to humans, is support for the proposition that some men will be undeterred by strong laws, *i.e.*, the mere threat of legal sanction. This proposition then serves as justification for carrying out harsh penalties, in order to teach those men that lawbreaking does not pay.

But analogies may be more sophisticated, containing more structure and nuance than those easily represented in proportional notation. Analogies are not restricted to four objects A, B, C, and D. Neither do the relations present in an analogy, represented by the ":", need to be identical. In the bean/man example, Plato pretends that the relation *unmelted-by* is identical in both plant and human domains, even though *unmelted-by* cannot literally be applied to the human target. What he really means, as noted above, is the relation *undeterred-by*. The relation in the source is instead a *metaphor* for the relation in the target. Also, analogies may include not only the relations among basic objects, but also the *reasons* why those relations hold true. In the *Republic* (6.491d–2a), for example, Socrates gives

Source	Target
hard-bean boiling-water	some-man strong-laws
unmelted-by(hard-bean,boiling-water)	undeterred-by(some-man,strong-laws)

Table 2.1: A representation of the proportional analogy "Just as those seeds are unmelted by fire, so these men are unmelted by strong laws" (*Laws*, 9.853c–d).

a similar plant/human analogy, saying that a poor education may stunt the ethical development of a citizen just as poor gardening may stunt the growth of a plant. In fact, he explains that poor gardening is the *cause* of poor growth in plants since the needs of the plants are not met, implying that a similar causal relation between lack of education and inadequate ethical development holds in citizens. Thus, Socrates tells us not only *that* a relation holds in both domains, but also *why* that relation holds in both domains. There is no way of representing both lower- and higher-level relations in one analogy using the proportional notation. The *Multiconstraint theory* (MT) of Holyoak and Thagard (1995) addresses these and other issues based on studies and computational models of human cognition. In the MT, there is no restriction on the number of items involved in analogical comparisons, nor on the relations among them. In fact, the inclusion of higher-level relations is of central importance to the theory.

In the MT, an analogy may be thought of as an alignment of two conceptual structures in a table of predicates of increasing abstractness. Consider for a moment the MT representation of the proportional, bean/man analogy as given in table 2.1. Each row in the table represents a *mapping* between the source and the target. The rows in the uppermost box (underneath the titles) identify the *attribute* mappings—that is, mappings between the basic features of source and target. So the *hard-bean*

in the source domain corresponds to *some-man* in the target. The row in the next box underneath identifies the *relational* mapping—that is, the mapping between relations that hold true under each domain. So the predicate *unmelted-by* in the source domain, which may be read as "a hard-bean is unmelted by boiling water", corresponds to the predicate *undeterred-by*, "some man is undeterred by strong laws", in the target domain.

For a more sophisticated example, consider the analogy that Darwin (1859) constructed between natural selection on the one hand and domestic selection on the other hand (Darden, 1983, pp. 152–6, Millman and Smith, 1997). Darwin considered the similarities between the breeding of domestic animals and plants and the speciation of wild animals and plants and used the comparison to help construct the concept of natural selection. The pigeon breeder, for instance, takes advantage of the inherent variability in his birds to choose and promote desirable features. Nature, Darwin claimed, distinguishes variations in wild animals similarly in terms of their competitive fitness with the result that the best ones are selected (Gould, 1993, pp. 355–9). Just as the choosiness of the breeder would lead to new breeds, the selectiveness of nature would lead to new species. To a first approximation, this analogy may be captured as in table 2.2 (see Holyoak and Thagard, 1995, p. 191).

In addition to having attribute and relational mappings of the type discussed above, this analogy provides a third set of mappings given in the rows of the lowest box of table 2.2. These rows identify the *system* mappings—that is, mappings between the systemic properties in each conceptual structure. The system predicates in each domain give an explanation of how their respective relational predicates fit

Domestic choice	Natural selection
breeder old-breeds new-breeds	nature old-species new-species
choose(breeder,old-breeds) descend-from$_d$(new-breeds,old-breeds) improve-upon(new-breeds,old-breeds)	select(nature,old-species) descend-from$_n$(new-species,old-species) fitter-than(new-species,old-species)
cause$_d$(choose,descend-from$_d$) in-order-that(choose,improve-upon)	cause$_n$(select,descend-from$_n$) because(fitter-than,select)

Table 2.2: A representation of Darwin's analogy between domestic selection and natural selection. Subscripts distinguish different instantiations of identical predicates.

together. The system predicates in the source domain, for example, tell us that the cause of the descent of new breeds from old ones is the action of choosing imposed on the old breeds by the breeder (*cause$_d$*), and that the breeder does this choosing in order that the new breeds represent an improvement upon the old ones (*in-order-that*). In other words, the system predicates outline the plan of action that the breeder carries out (consciously or not) in the course of animal husbandry.

The system predicates in the target domain tell a similar story. The cause of the descent of new species from old ones is the action of selection imposed on the old species by nature (*cause$_n$*). The new species are also fitter than the old ones as a result of this selection process (*because*). These predicates do not describe a *plan*, as in the domestic choice domain, but rather an *explanation* of how new and fit species replace their predecessors. In other words, although *nature* is mapped to *breeder*, no volition or intention is ascribed to it; *nature* is similar to *breeder* as a metaphor only.[1]

[1]At least, this distinction between intentional choice exercised by breeders and unintentional

Although it is not perfect, Darwin's analogy is quite reasonable. On the MT, the coherence of an analogy is measured in accord with the following three criteria (Holyoak and Thagard, 1995, pp. 22–38):

1. Structural consistency: The extent to which the analogy constitutes an isomorphism;

2. Semantic similarity: The extent to which mappings connect elements that are perceptually or semantically similar to each other;

3. Purpose: The extent to which information built up in the target conceptual structure contributes to the solution of the problem at hand.

The constraint of structural consistency derives from Gentner's systematicity principle (see section 1.6) and concerns the syntax of the predicates in the analogical mappings. It means that, ideally, (i) each predicate in the source is mapped to a unique predicate in the target and *vice versa*, and that (ii) when two predicates are mapped, their respective arguments, if any, are also mapped. These constraints are treated as *soft* constraints—that is, their satisfaction is encouraged but not absolutely required. When both criteria are completely satisfied, the analogy is a structural isomorphism.

Darwin's analogy obeys this criterion reasonably well; (i) each predicate is mapped to exactly one other predicate. The final mapping in table 2.2, however, violates condition (ii). Neither the pair of first arguments, namely *choose* and

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selection exercised by nature appears to have been a fundamental step in Darwin's development of his theory of evolution (Millman and Smith, 1997, p. 183). As Randy Harris points out (pers. comm.), Darwin increasingly encouraged an intentional interpretation of natural selection in revisions of the *Origins*, apparently to court a Natural Theological interpretation of evolution.

fitter-than, nor the pair of second arguments, namely *improve-upon* and *select*, are themselves given as mappings elsewhere in the analogy. Rather, *choose* is mapped to *select* and *fitter-than* is mapped to *improve-upon* at the relational level. In the MT, this violation counts against the coherence of the analogy as a whole, but the problem belongs more with the MT than with Darwin's analogy. The predicates *in-order-that* and *because* both relate an antecedent condition to a consequent one, but simply arrange those arguments in the opposite order from each other. In the case of *in-order-that*, the antecedent is the first argument and the consequent is the second argument. The order is reversed in the case of *because*. Part ii of this constraint could be generalized as follows: When two predicates are mapped, their arguments *which occupy corresponding roles* are also mapped. With this more general statement of structural consistency, this final mapping in Darwin's analogy would be completely acceptable since the antecedent and consequent conditions of each predicate *do* correspond appropriately. Darwin's analogy, as represented in table 2.2, meets this extended version of the constraint of structural consistency.

Like structural similarity, the constraint of similarity is a soft one, meaning that dissimilar elements may be mapped together if necessary, especially if structural consistency is strong. Darwin's analogy meets the constraint of semantic similarity reasonably well. Each mapping pairs predicates of identical or similar meaning. The predicates *choose* and *select* are very close semantically, although Darwin was fairly careful to distinguish the artificial (source) and natural (target) domains by restricting the word "choice" to the former and "selection" to the latter. Later, Darwin (1871, p. 916) noted that *sexual* selection, especially sexual selection

resulting from struggles between individuals of the same sex to be chosen as mates by individuals of the opposite sex, is even more closely analogous to artificial selection, apparently because both of these cases involve the actual exercise of *choice* (see also Millman and Smith, 1997, p. 176). In other words, sexual and artificial selection are more strongly analogous than natural and artificial selection because the former two domains involve a mapping between predicates of greater semantic similarity.

The analogy also fulfills its purpose since the target conceptual structure provides a powerful explanatory device for evolutionary theory. With the concepts of descent and fitness as supported by the analogy, the theory of natural selection can explain the similarities and differences among species in terms of descent with modification, where particular modifications are imposed by selection pressures originating with the struggle for existence. The explanation primarily consists in the system mappings of Darwin's analogy, which clarify *why* new species might evolve. The fulfillment of the purpose of an analogy typically depends on the predicates contained in its system mappings (Holyoak and Thagard, 1995, pp. 34–7). Once constructed, the target conceptual structure concerning natural selection can be explored and refined on its own, as Darwin and subsequent evolutionists proceeded to do.

The MT may be called a *shared-structure* theory since it takes analogy to consist in a direct comparison of two conceptual structures, and the coherence of the analogy depends upon the properties of the structure shared by each analog (see section 1.6). Also, the constraints of structural consistency, semantic similarity,

and purpose are soft constraints, that is, analogies need not satisfy all of these constraints perfectly, especially if relaxing the satisfaction of one constraint to a certain degree permits the analogy to better satisfy another constraint. However, the coherence of an analogy is *also* a holistic property of the context in which the analogy occurs (Thagard and Shelley, ip). In other words, analogies are judged good or bad not only by the structure shared by the analogical mappings themselves but also by how well they fit with other things that are known or believed by the analogizer. This connectedness of analogies and their contexts is especially apparent in the constraint of purpose, which covers the contribution that analogies might make to someone's overall cognitive or epistemic goals. Thus, in the MT, the legitimacy of an analogy depends on both its intrinsic properties and how well it relates to extrinsic information.

To date, the MT has been applied to single analogies because it has generally been applied to problems whose purpose may be satisfied by use of a single source analog. However, some situations call for the use of several source analogs to meet the purposes of the analogizer. These multiple analogies and the purposes they serve need to be considered. Section 2.4 moves us in that direction, by an examination of multiple analogies concerning the Coelacanth.

2.3 Analogies in evolutionary biology

Before embarking on an inquiry into multiple analogies in Coelacanth biology, it is necessary for the sake of clarity to make some remarks on the standing use of *analogy* as a technical term in evolutionary biology itself. Similar characteristics

in two given organisms are said to be *analogous* where they are the result only of similar selection pressures. For example, the aquiline shape of fish and whales are analogous characteristics because they are similar in form and are both the result only of similar forces of natural selection—that is, natural selection for locomotion through water. The emergence of analogous characteristics is often referred to as *convergent evolution.*

However, organisms may also share similar characteristics due to inheritance from a common ancestor. Such characteristics are said to be *homologous.* For example, the opposable thumbs of humans and apes are homologous characteristics because humans and apes retained them from a common ancestor that had opposable thumbs. Homologous characteristics are often referred to as examples of *parallel evolution.* For present purposes, homology may be taken simply to designate characteristics shared by common descent, whereas analogy designates non-homologous characteristics shared by response to similar selection pressures.[2]

In this technical sense, analogies in evolutionary biology generally indicate similar adaptations. Constructing analogies among living organisms is not so important since evidence concerning their adaptations is obtainable through observation *in vivo.* In the case of organisms that are extinct or otherwise difficult to observe at first hand, analogy construction becomes very important. Indeed, analogies are often the primary source of insight into the lives and adaptations of such species. Explanations of the adaptations of rare or extinct organisms, therefore, provide ex-

[2]On the history of the *analogy/homology* distinction, see (Kitcher, 1993, pp. 14–5) and (Bowler, 1996, pp. 46ff). Although the distinction is conceptually useful, it is often difficult in practice to distinguish the relative contributions of inheritance and convergence to the similarity of any two characteristics (Lauder, 1986; Zuckerkandl, 1994). But this difficulty may be ignored here.

cellent examples of analogical reasoning in *both* the biological and cognitive senses. The Coelacanth is an instance of just such a rare organism whose attributes scientists have explained using multiple analogies.

2.4 Coelacanth: The living fossil

First described by Agassiz in 1836, species of the order Coelacanth (technically *Coelacanthini*) flourished from roughly 375 million years ago until 80 million years ago, and were thought to have gone extinct with the dinosaurs (Thomson, 1991, p. 75). The discovery of a modern Coelacanth, *Latimeria chalumnae*, off South Africa in 1938 and then a population off the Comores Islands in 1952 created a worldwide sensation in "the fish that time forgot" (Smith, 1957).[3] The close relationship of the Coelacanth to primitive land vertebrates makes it important for evolutionary studies (Gorr and Kleinschmidt, 1993). The rarity and obscurity of *Latimeria* poses many biological questions, including *where does it live?* and *how does it reproduce?* The uses of multiple analogies to answer these questions is discussed in this section.

The first question concerns the home range of *Latimeria*, *i.e.*, the depth at which it lives. The Coelacanths caught off the Comores have all been taken by native fishermen using long lines dropped from drifting canoes. It is difficult to know exactly how deep the lines drop (Smith, 1957, p. 242) and the lines are of a uniform length and therefore sample only *one* stratum of ocean water. So the

[3]In 1998, a population of Coelacanths were found in Indonesia (Erdmann et al., 1998), but that population has yet to be studied closely.

fact that all Coelacanths are caught at that stratum does not answer the question (Thomson, 1991, p. 136). Comparative studies of Coelacanth eyes and body oils do, however, provide an answer. Analysis of the pigment in the rod cells of *Latimeria* eyes shows that they best absorb light at a wavelength of 473nm (Locket, 1980, p. 289). This wavelength is very close to that best absorbed by the eyes of the deep sea shark *Centroscymnus* (472nm) and the "oil fish" *Ruvettus* (474nm). These wavelengths correspond to the light that furthest penetrates oceanic water (470–476nm), which indicates that all three fish are adapted to see in the same deep stratum. Since *Centroscymnus* and *Ruvettus* both live roughly 200 to 300m deep, then *Latimeria* mostly likely does as well. This analogy may be represented as in table 2.3.

Note that the mere similarity among wavelengths does not warrant the conclusion that Coelacanths live in deep ocean water. Without the system mapping $adapt_c$ & $adapt_r$ to $adapt_C$, the relational mapping $inhabit_c$ & $inhabit_r$ to $inhabit_C$ would not fulfill its purpose. That is, if pigment absorbency were *randomly* distributed over depths of habitation rather than being an *adaptation* in accordance with evolutionary theory, then no conclusion about depth of habitation of the Coelacanth could be supported by this evidence.

This multiple analogy is corroborated by another one, involving the bodily oils and fats in *Latimeria*'s body. In their study of Coelacanth biochemistry, Nevenzel et al. (1966) show how the concentration of oils and fats in this fish is analogous to that of other fish which live in deep ocean water (200 to 300m). This concentration of oils and fats constitutes an adaptation for *neutral buoyancy* at those depths.

Centroscymnus	Ruvettus	Coelacanth
Centroscymnus rod-pigment$_c$ deep-ocean-water$_c$ 472nm-light	*Ruvettus* rod-pigment$_r$ deep-ocean-water$_r$ 474nm-light	Coelacanth rod-pigment$_C$ deep-ocean-water$_C$ 473nm-light
have$_c$(*Centroscymnus*,r-p$_c$) absorb$_c$(r-p$_c$,472nm-l) penetrate$_c$(472nm-1,d-o-w$_c$) see-in$_c$(*Centroscymnus*,d-o-w$_c$) inhabit$_c$(*Centroscymnus*,d-o-w$_c$)	have$_r$(*Ruvettus*,r-p$_r$) absorb$_r$(r-p$_r$,474nm-l) penetrate$_r$(474nm-1,d-o-w$_r$) see-in$_r$(*Ruvettus*,d-o-w$_r$) inhabit$_r$(*Ruvettus*,d-o-w$_r$)	have$_C$(Coelacanth,r-p$_C$) absorb$_C$(r-p$_C$,473nm-l) penetrate$_C$(473nm-1,d-o-w$_C$) see-in$_C$(Coelacanth,d-o-w$_C$) inhabit$_C$(Coelacanth,d-o-w$_C$)
enable$_c$(have$_c$,see-in$_c$) because$_c$(absorb$_c$,penetrate$_c$) adapt$_c$(see-in$_c$,inhabit$_c$)	enable$_r$(have$_r$,see-in$_r$) because$_r$(absorb$_r$,penetrate$_r$) adapt$_r$(see-in$_r$,inhabit$_r$)	enable$_C$(have$_C$,see-in$_C$) because$_C$(absorb$_C$,penetrate$_C$) adapt$_C$(see-in$_C$,inhabit$_C$)

Table 2.3: A multiple analogy of *Centroscymnus* and *Ruvettus* with *Latimeria* regarding eye pigmentation as an adaptation to seeing in deep ocean water.

Neutral buoyancy for some depth means that the fish can float freely there without having to expend energy to avoid sinking deeper or rising upwards (Thomson, 1991, p. 140). Both *Centroscymnus* and *Ruvettus* have oils and fats that adapt them for deep ocean water, so another multiple analogy holds between these fish and *Latimeria*, and could be represented much as in table 2.3 with *oils-and-fats* and *neutrally-buoyant-in* substituted for *rod-pigment* and *see-in*, respectively. The hypothesis supported by these two analogies has recently been confirmed by direct observation of living Coelacanths from submersibles (Fricke and Hissman, 1994); they do indeed spend their time at roughly 250m depth.

The second question regarding Coelacanth reproductive biology has also been addressed by multiple analogies. This case is of special interest because evidence from multiple analogies has conflicted with evidence derived from *homology*. As noted above (section 2.3), homology concerns the pattern of descent of an organism, its "family tree" as it were, and how an organism possesses characteristics by virtue of its genetic inheritance. Given that one organism possesses a particular characteristic, and in the absence of contradictory information, a biologist may conclude that other organisms sharing a common ancestor with it will also possess that characteristic.

Watson (1927) described a fossil of the extinct Coelacanth *Undina* that contained two immature *Undina* in the rear of its abdominal cavity. Given the position, good condition, and similar orientation of the two immature fish, Watson argued that they were *not* prey located in the stomach but rather young Coelacanths maturing in their mother's reproductive tract. He concluded that Coelacanths are

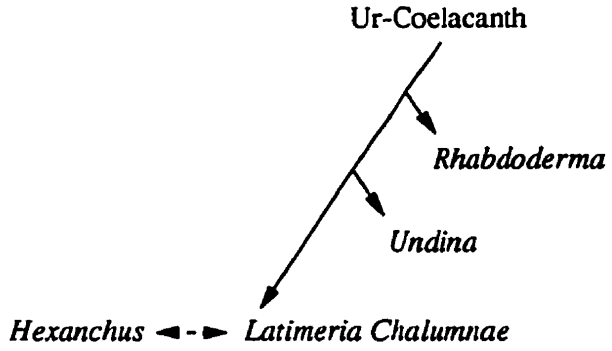

Figure 2.1: A rough phylogeny of Coelacanth species. The solid arrows indicate the homological explanation of *Latimeria* reproductive biology as inheritance (and conservation) of reproductive strategy from a hypothetical common ancestor labeled "Ur-Coelacanth." The analogy with the shark *Hexanchus* is indicated by the dashed arrow.

viviparous, giving birth to live young. By homology (see figure 2.1), *Latimeria* should also be viviparous. But viviparity generally implies internal fertilization—that is, penetration of the female by the male sex organ—and *Latimeria* males do not appear to possess the proper equipment.

Schultze (1972) described fossils of two immature specimens of the extinct Coelacanth *Rhabdoderma* with clear traces of yolk sacs attached to them. Since these specimens were not found in the body cavity of a mature fish, it seemed likely that they were free-swimming. Free-swimming hatchlings with yolk-sacs imply that *Rhabdoderma* was *oviparous*, laying eggs that later hatch into fry and enjoy parental protection until they consume their yolk-sacs and eat on their own (Thomson, 1991, p. 196). Schultze postulated oviparity for *Latimeria* by homology. This hypothesis is consistent with the lack of internal fertilization in *Latimeria*, since laid eggs may be fertilized by the male simply by shedding his sperm onto them, as lungfish do (Thomson, 1991, p. 194). Schultze explained away Watson's homol-

ogy with *Undina* by claiming that the immature *Undina* were prey after all, *i.e.*, *Undina* was a cannibal!

Griffith and Thomson (1973) disputed Schultze's homological argument on the basis of analogy with deep ocean fish of which the shark *Hexanchus* is exemplary. This shark, which lives at the same depths as *Latimeria*, is *ovoviviparous*, having eggs that are fertilized and hatched *within* the reproductive tract so that the young are effectively born alive. The reason *Hexanchus* reproduces in this way is that it is *ureotelic*—that is, it has a high level of urea in its bloodstream as an adaptation to maintain osmotic equilibrium with the surrounding ocean water. Without such a mechanism, the fish would dehydrate and die, just as humans do if they drink enough seawater. For various reasons, the ureotelic mechanism does not operate until late in fetal development, so immature sharks must be kept inside the mother's reproductive tract to avoid direct exposure to the ocean. Like *Hexanchus*, *Latimeria* is ureotelic, so by analogy it should share that shark's ovoviviparity as well.[4] The analogy may also explain Schultze's free-swimming *Rhabdoderma* hatchlings: Thomson (1991, pp. 199–200) recalls seeing gravid (pregnant) female *Hexanchus* sharks shed their immature embryos onto the deck of a ship after being caught, a reaction caused by extreme stress. The *Rhabdoderma* hatchlings may have been shed similarly by a stressed mother, rather than being born ovoparously as Schultze claimed. Griffith and Thomson's hypothesis was "abundantly confirmed" (Locket, 1980, p. 284) shortly afterwards when a gravid female *Latimeria* was dissected and shown to have five immature embryos, with yolk-sacs attached, lodged in her

[4]Other possible reproductive strategies, such as laying hard-shelled eggs, or maintaining embryos internally by a placenta were ruled out in the case of *Latimeria* based on previous research.

reproductive tract (Smith et al., 1975).

Griffith and Thomson's analogy *does* suffer a major difficulty, however. As with viviparity, ovoviviparity requires internal fertilization, but male Coelacanths do not appear to possess the right equipment, such as the claspers and penetrative (or "intromittent") organ of *Hexanchus*. Thomson (1991, p. 197) seeks to repair this disanalogy by reference to a *further* source analog, a newt that achieves internal fertilization without a penetrative organ:

> In the common European newt *Triturus*, for example, the male courts the female with elaborate wriggling movements and pheromone secretions, and she positions herself next to him. He deposits his sperm in a gelatinous package, and she slides alongside, places her cloaca over the package, and picks it up. The gelatinous material dissolves, and the sperm swim up into the oviduct.

In short, Thomson suggests that pheromones, ritual, and gelatin may substitute for the male *Latimeria*'s lack of claspers and a penetrative organ. This repair may be represented as in table 2.4. This issue of how Coelacanths achieve internal fertilization remains unresolved.

2.5 Implications for multiple analogies

A number of issues concerning multiple analogies arise from a consideration of the above examples of Coelacanth biology. These issues may be conveniently stated in terms of the *processes* of inference in which multiple analogies participate. These

Triturus	Hexanchus	Coelacanth
Triturus	*Hexanchus*	Coelacanth
	ovoviviparity$_h$	ovoviviparity$_c$
internal-fertilization$_t$	internal-fertilization$_h$	internal-fertilization$_c$
ritual+gelatin$_t$	claspers+organ	ritual+gelatin$_c$
have$_t$(*Triturus*,r+g$_t$)	have$_{h0}$(*Hexanchus*,c+o)	have$_{c0}$(Coelacanth,r+g$_c$)
	have$_{h1}$(*Hexanchus*,ovoviviparity$_h$)	have$_{c1}$(Coelacanth,ovoviviparity$_c$)
perform$_t$(*Triturus*,i-f$_t$)	perform$_h$(*Hexanchus*,i-f$_h$)	perform$_c$(Coelacanth,i-f$_c$)
	require$_h$(ovoviviparity$_h$,i-f$_h$)	require$_c$(ovoviviparity$_c$,i-f$_c$)
adapt$_t$(have$_t$,perform$_t$)	adapt$_h$(have$_{h0}$,perform$_h$)	adapt$_c$(have$_{c0}$,perform$_c$)
	because$_{h0}$(perform$_h$,require$_h$)	because$_{c0}$(perform$_c$,require$_c$)
	because$_{h1}$(perform$_h$,have$_{h1}$)	because$_{c1}$(perform$_c$,have$_{c1}$)

Table 2.4: A multiple analogy of *Triturus* and *Hexanchus* with *Latimeria*. *Triturus* is used only to repair disanalogous mappings between *Hexanchus* and *Latimeria*.

processes include establishing structural consistency in the presence of multiple mappings, corroboration of multiple analogies from other sources including other multiple analogies, the use of abstraction and exemplification to select and construct multiple source analogs, supplementation of one source analog by another, and disanalogy and extension as motives for the introduction of further source analogs.

2.5.1 Structural consistency

Consider first the process of analogical mapping evident in connection with the Coelacanth's depth of habitation (see table 2.3). In this multiple analogy, each predicate in the target conceptual structure is mapped to *two* predicates in the source. For example, the predicate $inhabit_C$ is mapped to both predicates $inhabit_c$ and $inhabit_r$. By the principle of structural consistency condition i (section 2.2), this fact should *weaken* the overall analogy rather than strengthen it. Yet this predicted result contradicts the actual result that the analogy is strengthened by the multiple mapping.

There are a number of options available to redress the situation. The principle of structural consistency could be maintained intact by creating two target predicates $inhabit_{C0}$ and $inhabit_{C1}$, one corresponding to each source predicate. The two predicates would only be differentiated for the purpose of constructing separate mappings with each source analog. This option is merely *ad hoc* and without any other merit to recommend it. Structural consistency could also be maintained intact by handling the two mappings separately in a serial manner. In other words, the constraint could be revised to read: Each predicate is mapped to exactly one

other predicate *at a time*. This solution, although more plausible, presents a cognitive oddity much like a person trying to use visual parallax to judge the distance to an object by alternately closing one eye and then the other. Other things being equal, the tendency of the brain to process information in parallel rather than serial fashion implies that explanations of cognitive phenomena should favor parallel models over serial ones. It would seem preferable, then, to revise the principle of structural consistency to accommodate processing of multiple mappings in a parallel manner. This revision could be conditioned on the evidential independence of the multiple source predicates, as is the case for the evidence provided by each of the *Centroscymnus* and *Ruvettus* conceptual structures. In other words, the condition could be changed to allow for any number of analogs provided those analogs are not simply versions of the same thing. For someone to do otherwise, as Wittgenstein (1967, §265) observes of a similar situation, it would be "as if [he] were to buy several copies of the morning paper to assure himself that what it said was true". Clearly, no multiple analogy constructed simply with multiple copies of the same source analog would be any better than the corresponding single analogy. Thus, the parallel principle would stipulate a constraint like the following: Each predicate is mapped to exactly one other predicate *in each independent source analog*.

The difference between the serial and parallel statements of the structural consistency constraint also depends on how one regards the relation between single and multiple analogies. The serial statement works by *reducing* multiple analogies to a series of single ones. The parallel statement works by treating single analogies as a *special case* of multiple ones. (One source analog alone may be considered

trivially independent for the purposes of the parallel statement.) It is not yet clear which view of the consistency constraint is the best description of how people actually process multiple analogies. It is tempting to accept the serial view because it takes single analogies to be more fundamental, and single analogies are more familiar. But the parallel view is more in keeping with the parallel-processing nature of the MT, and it may appear more acceptable as multiple analogies become better understood. Furthermore, the parallel statement is more parsimonious, since the serial verison should also restrict its one-at-a-time mappings to independent source analogs. Thus, the serial version of the structural consistency constraint is merely the addition of a timing condition to the parallel version. Of course, human cognition does not always follow the most parsimonious design, so psychological evidence obtained in any future experiments on multiple analogies may require this position to be retracted.

2.5.2 Corroboration

This whole situation is repeated at another level where the corroboration of the rod-pigment analogy by the oils-and-fats analogy is concerned. In other words, the conclusion that *Latimeria* inhabits deep ocean water is supported by *two* multiple analogies. Again, this situation raises the prospect of having two identical predicates to represent one conclusion, or to find some way of interleaving both multiple analogies into one representational structure. Fortunately, none of these steps appears to be necessary. Unlike multiple mapping, corroboration is an extra-analogical cognitive process whereby inferences made *by any means* are brought to

bear in support of some conclusion. In other words, corroboration is a process by which analogies (in this case) are used in the service of an overarching *explanation* (Thagard, 1989). Corroboration, then, falls outside the scope of this dissertation.

2.5.3 Abstraction and exemplification

Two further and coordinate processes involved in multiple analogies are *abstraction* and *exemplification*. Abstraction is a process whereby a large number of potential source analogs is reduced to a more manageable quantity. Abstraction of this kind is evident in both Coelacanth analogies discussed in section 2.4. In the case of rod-pigments *and* reproductive strategies, there are a great number of fish with which *Latimeria* might be compared, but the task of constructing so many analogies is presumably too onerous and redundant to be useful. In both analogies, the biologists take advantage of the fact that fish fall into natural, evolutionary groups in order to reduce the full set of source analogs to two,[5] one for each group. In this way, analogical inference can benefit economically from the quantity of source analogs without requiring burdensome or confusing cognitive costs.

But abstraction itself does not account for the examples discussed above. Exemplification is also used in the sense that specific fish, rather than averaged or idealized ones, are chosen to exemplify each group of source analogs. In the case of rod-pigments, *Centroscymnus* exemplifies the group of deep ocean sharks and *Ruvettus* exemplifies the group of deep ocean teleosts. Mappings to the target Coelacanth are then made with each of these exemplary sources on behalf of their entire

[5]These two groups are sharks and teleosts in the pigment analogy, and newts and sharks in the reproductive strategy analogy.

groups. By means of abstraction and exemplification, then, analogical mappings may be constructed that efficiently serve the purpose of maximizing confidence in the inference that results from the analogy.

2.5.4 Supplementation

There are instances, of course, where abstraction and exemplification alone fail to provide a fully satisfactory analogy. Such an instance is provided by the analogy of reproductive strategies between *Hexanchus* and *Latimeria*. This analogy implies that *Latimeria* should have claspers and a penetrative organ, which it is known to lack. The use of mating ritual and gelatin by *Triturus* in place of such equipment is brought in as an additional source analog in an attempt to replace these errant mappings (see table 2.4). This process of repairing one source with another may be called *supplementation* (Spiro et al., 1989).

It is difficult to assess the exact extent to which supplementation repairs an analogy. Biologists who use it seem to prefer it do doing nothing about problematical mappings. However, supplementation appears to create a sort of chimaera, a fictitious creature possessing a mixture of the properties of known animals. The supplementation given in table 2.4, for example, seems to involve a comparison between the Coelacanth and a part-newt, part-shark creature. Viewed this way, supplementation seems like an insubstantial form of epistemological support for an inference based on such an analogy. Perhaps the best response to this dilemma is that of Padian (1991, p. 151), who defends supplementation as a means of overcoming arbitrary, historical limitations encountered in constructing some evolutionary

analogies:

> Not all possible structures or adaptive forms that ever existed are still extant, including transitional evolutionary forms. The living world provides us with only a limited range of organisms for comparison, and this range is essentially a random historical artifact. ... Therefore the choice of suitable analogies, and the recognition of their constraints and limitations, is to me one of the most salient problems in the application of biomechanical analyses to extinct organisms.

In other words, the problems encountered in constructing an analogy between, say, Coelacanths and *Hexanchus*, may be ameliorated by noting that the natural world, by unhappy accident, simply does not provide any better source analogs. Biologists presumably cannot be blamed for finding themselves in this circumstance, and may therefore be permitted to repair problematic analogies by adding extra source analogs and thereby creating chimaeras, provided they can do so without going beyond the realm of biological possibility. In other words, nature happens not to have created the right analog, so this task falls to the biologist.[6] The constraints that circumscribe biological possibility are up to biologists to determine and are therefore not addressed here.

[6]There is a curious parallel here with the argument made by Darwin (1859) regarding the poverty of the fossil record. Darwin argued that we do not find many fossils of "intermediate links" between modern species because geologic, fossil-forming processes preserve a very small sample of the organisms alive in any particular era. Similarly, Padian argues that the living species which *have* evolved represent only a very small sample of the organisms that *might* have evolved under other circumstances.

2.5.5 Disanalogy and extension

Finally, reasoning with multiple analogies exhibits an interesting social dimension, which may be described in terms of the processes of *disanalogy* and *extension*. As a form of socially distributed cognition, analogy seems to lend itself to the ancient ethical dictum "help your friends and hurt your enemies". This dictum is the epitome of ethical conduct offered by Polemarchus in Plato's *Republic* (1.334b). Disanalogy figures in the "hurt your enemies" half, meaning that it is often used as a means of disputing the claims of one's professional competitors. Bonner (1963, pp. 276–7) speaks of evolutionary biologists offering analogies and "cringing" at the thought that adversaries will soon counter with many disanalogies. Bonner notes that offering strong analogies should prevent this reaction. Griffith and Thomson provide an instance of this process when they argue against Schultze's attribution of oviparity to Coelacanths on the basis of the resulting disanalogy with otherwise similar fish like *Hexanchus* which, in turn, motivates their development of this comparison in its own right. Despite their ubiquity and importance, there are currently no theories that address the nature or uses of disanalogies. Unfortunately, detailed consideration of this topic lies outside the scope of this dissertation.

Extension figures in the "help your friends" half of the social dictum. The fact that one biologist offers an analogy encourages his professional supporters to find further analogies along the same lines. Thomson, for example, extends Griffith's original *Hexanchus*/Coelacanth analogy in two ways. First, Thomson extends it to explain away the free-swimming *Rhabdoderma* hatchlings described by Schultze. He notes that gravid female *Hexanchus* are known to shed embryos under stress,

and that gravid female Coelacanth might therefore also do this (Thomson, 1991, pp. 196–200). Thomson also attempted to supplement the *Hexanchus*/Coelacanth analogy by bringing the newt *Triturus* into consideration. In this sense, extension appears not to be a specific cognitive process, but a general professional, social goal to which multiple analogies are particularly suitable.

There appears to be nothing *inherently* social about disanalogy or extension; a biologist might well posit disanalogies or extensions of his own analogies. But these processes lend themselves naturally to social distribution for two reasons: (1) They fulfill the social goals enjoined by the ethical dictum "help your friends and hurt your enemies", and (2) they reflect the fact that there are simply too many potential source analogs for any one person to keep in mind. On the second point, the distribution of knowledge in the scientific community implies that analogical sources should come from all quarters, and therefore that multiple analogical reasoning *should* be, in some respects, socially distributed.

2.6 Summary

Analogies have long been recognized as important to the process of scientific discovery and explanation. Biologists such as Darwin have used analogies to construct their theories of evolution. Modern biologists continue to use analogies when developing and debating theories concerning the evolution of particular organisms such as the Coelacanth. Moreover, the Coelacanth debate shows the importance of multiple analogies to scientific discourse, and reveals different ways in which multiple analogies may serve cognitive goals.

Multiple analogies give rise to epistemological issues that are simply not evident from a consideration of single analogies. These issues may be discussed in terms of the cognitive processes involved in the construction and use of multiple analogies. The processes of abstraction and exemplification show how scientists may make profitable use of multiple source analogs in order to construct more convincing analogies without going into redundant or confusing detail. In other words, these processes fulfil the purpose of utilizing all the supportive analogs available to biologists by referring to certain organisms that may be thought of as representative of the entire biological groups to which they belong. The process of supplementation enables biologists to compare organisms to one another in the face of any accidental inadequacies with the use of any one, particular analog. Supplementation, then, is a method of fulfilling the purpose of a single analogy where no suitable single analogy can be constructed.

The relationship between multiple analogies and disanalogies brings attention to the problem of disanalogies and the lack of any theory concerning them. It also points to the socially distributed nature of science, since the pattern of multiple analogies and disanalogies in the Coelacanth literature suggests that scientists, as a group, act in accord with the dictum "help your friends and hurt your enemies". Multiple analogies may arise through a process of extension for the purpose of satisfying the "help your friends" half of this mode of conduct.

The nature of the multiple analogies explored in this chapter also raises technical issues for theories of analogy such as the MT. In particular, multiple analogies call for clarification of the constraint of structural consistency. The structural

consistency condition, specifically the requirement for one-to-one mappings, may be restated to allow for the processing of several source analogs in serial or parallel fashion. The question of which revision to accept first requires that the relationship between single and multiple analogies to be re-evaluated. In an inherently parallel theory such as the MT, the parallel revision is the most natural one to adopt.

The MT is a *shared-structure* theory of analogy which may be extended to account for the issues raised in this chapter. Predicates from multiple source analogs may simply be placed into many-to-one mappings with the target analog where those sources are independent of each other. In cases where all the source analogs are similar, this situation simply increases confidence that the target conceptual structure is well-founded. In cases where some source analogs are dissimilar, this situation may be described as an attempt to repair the dissimilarity by supplementation. These situations may be accounted for in the MT by allowing multiple mappings to be put in place in the appropriate way. This apparently simple extension enables the MT to capture the important processes through which multiple analogies fulfil the purposes that cannot be met by single analogies. In other words, this extension enables the MT to describe those aspects of scientific epistemology that are important in scientific fields such as evolutionary biology but that are not evident when only single analogies are considered.

Chapter 3

Multiple analogies from the Mesozoic

All flesh is grass, and all its beauty is like the flower of the field.

The grass withers, the flower fades, when the breath of the Lord blows upon it.

Isaiah 40.6–7

3.1 Analogies and evolutionary theory

The Coelacanth is a classic example of what Darwin (1859, p. 151) called a "living fossil". Living fossils are scarce in both senses of that term: They are rare and they live in out-of-the-way places. For these reasons, biologists must often resort to analogies when reasoning about the lives and adaptations of Coelacanths. As might be expected, the problems are even more acute in the case of reasoning about dead fossils, organisms that are truly extinct. But the lives and adaptations

of extinct organisms may be just as interesting as those of living ones. Also, the study of extinct organisms offers special insights into the course of evolution and the demands to be met by evolutionary theory. Therefore, any consideration of multiple analogies in biology should include studies of extinct organisms.

Famous among extinct organisms are the Mesozoic ceratopsians or "horned dinosaurs" and the *Archaeopteryx* or the first bird. *Archaeopteryx lithographica* was first discovered in a limestone quarry at Solnhoffn, Germany in 1861, only two years after the publication of Darwin's *On the origin of species.* It immediately became an important case study for the new theory of evolution as applied to the fossil record (Bowler, 1996, pp. 261–80). It still remains the oldest and most primitive fossil bird known. *Triceratops*, the first ceratopsian dinosaur ever identified as such, was first described in 1889 by O. C. Marsh who originally mistook it for a bison (Dodson, 1996, pp. 6–7). Its large neck frill and formidable facial horns make it one of the most easily recognized of dinosaurs. The frill and horns, which look so out of place on what should be a docile herbivore, remain the focus of public admiration and professional attention.

Chapter 2 presented the MT as an account of single analogies, and proceeded to extend it as an account of multiple analogies based on examples of multiple analogies concerning the Coelacanth. This chapter builds upon the results of chapter 2 based on examples of multiple analogies concerning ceratopsians and *Archaeopteryx*. This new material reinforces the points made in chapter 2 but also adds new ones as they arise.

Section 3.2 discusses multiple analogies and their role in the development of the-

ories about ceratopsians;

Section 3.3 examines the nature and role of multiple analogies in the debate over *Archaeopteryx* and its relation to modern birds;

Section 3.4 reviews the implications proceeding from the previous two sections for the nature of multiple analogies, especially the use of visual representations in multiple analogies, the contribution of multiple analogies to evolutionary biology, especially to the building of evolutionary scenarios, and the fecundity of multiple-analogy construction as a research strategy.

These sections complete the picture of multiple analogies in evolutionary biology sketched in chapter 2.

3.2 Ceratopsians: The horned dinosaurs

The ceratopsian or "horned" dinosaurs possess some very characteristic and striking cranial accoutrements, namely the large bony frills projecting upward from the back of their skulls, and the horns and knobs growing from a variety of locations on the frill and the face. A different configuration of frill, horns and knobs characterizes each species of ceratopsian. The *Triceratops* as rendered by Charles R. Knight remains the classic image of a ceratopsian, using its bony frill and horns to ward off two marauding *Tyrannosaurus rex* (see Czerkas and Glut, 1982, pp. 80–1). This image, shown in figure 3.1, clearly illustrates the original explanation of the frill and horns functioning as a means of defense against predators.

Figure 3.1: *Triceratops* squares off against two *Tyrannosaurus rex*, from a mural by Charles R. Knight for the Field Museum of Natural History, Chicago (Photo CK9T).

But, as Farlow and Dodson (1975, p. 353) note, this explanation is incoherent with the explanation of similar cranial equipment in many modern organisms (see also Molnar, 1977, p. 176). In many large, modern mammals, horns are used for intraspecific combat—that is, dominance contests among males within a species—and sexual display—that is, to impress potential mates. In fact, the theory of sexual selection suggests that new species may arise simply because the males (typically) in each of them possesses a variation on the sexual ornamentation of their common ancestor. Females of different groups may come to prefer different variations in their mates, thus causing the groups to diverge into species. This process may act rapidly and upon many variations at once and can therefore result in many different species which are distinguished largely by their external appearance alone. This fact would explain why there are so many funny-looking varieties of ceratopsians in the fossil record (Sampson, 1995, p. 40). These comparisons suggest a different picture of ceratopsians than that drawn by Knight.

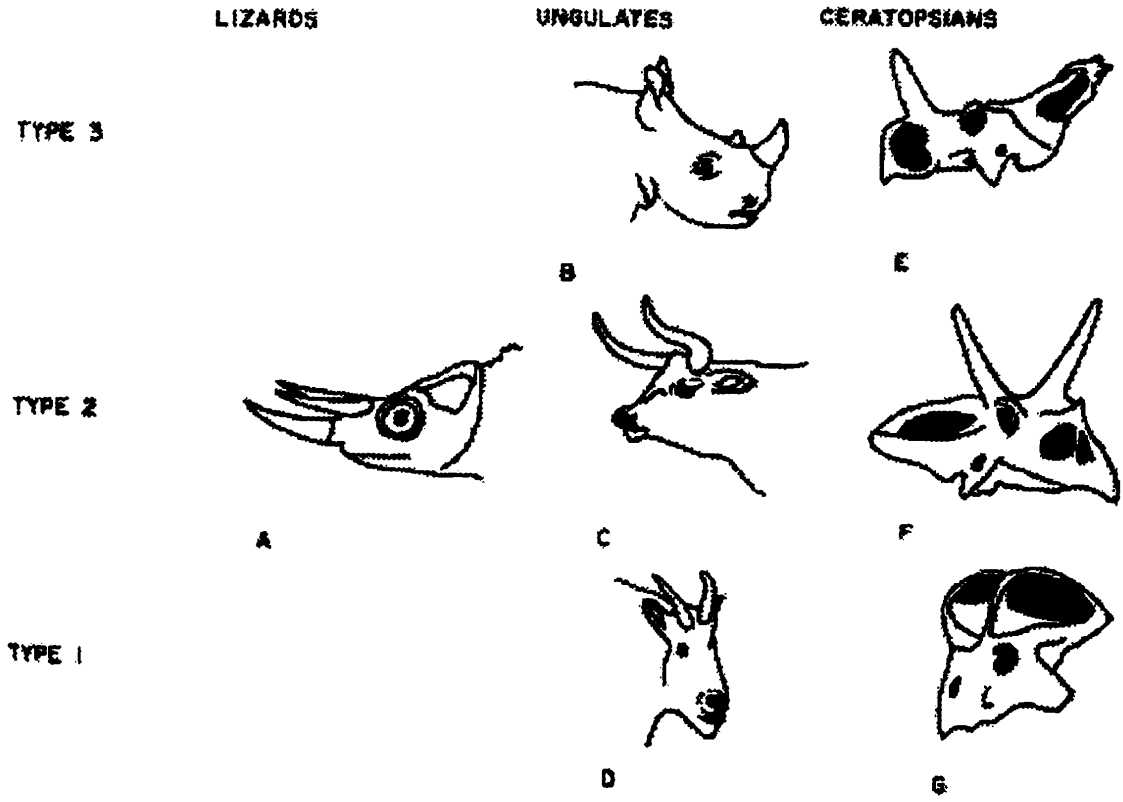

Figure 3.2: Sample modern and fossil organisms grouped in rows according to similarities of horn shape and structure (Farlow and Dodson, 1975, p. 357). Combat behavior (Type 1, 2, or 3) of the fossil ceratopsian may then be inferred by analogy. A, chameleon; B, rhino; C, steer; D, North American mountain goat; E, *Monoclonius*; F, *Torosaurus*; G, *Protoceratops andrewsi*. Not drawn to scale.

Farlow and Dodson challenge the original interpretation of ceratopsian headgear as a defense against predators by noting the disanalogy of that interpretation with the behavioral significance of the headgear of modern ungulates (hoofed mammals). The obvious way to reduce this disanalogy is to pursue the potential analogy between the two types of organisms. Farlow and Dodson first correlate the idiosyncratic features of various ceratopsian skulls with similar features in mod-

ern organisms. Such correlations are suggested by simple visual inspection of head forms, as shown in figure 3.2 (Farlow and Dodson, 1975, p. 357). In this figure, various modern organisms, *i.e.*, lizards and ungulates, are grouped in rows according obvious similarities in headgear, with representative ceratopsian skulls placed on the right-hand side of each row according to the same criterion.

Their second step is to infer behavioral significance from the analogy suggested by each row in figure 3.2. Farlow and Dodson adopt a threefold distinction among types of intraspecific combat that was originally developed to describe ungulate behavior (see also Molnar, 1977, pp. 176–80). Type 1 combat usually involves two animals standing parallel to each other, head to flank, and swinging their heads and horns laterally against their opponent's side. This kind of combat behavior is displayed by some iguanas, North American mountain goats, chamois, and, spectacularly, by giraffes. Type 2 combat involves a face-to-face confrontation in which opponents lock horns and commence shoving or wrestling. Bison and steer exhibit this kind of behavior, as well as certain chameleons and the marine iguana. Type 3 combat also includes face-to-face confrontations, but with considerable fencing and evasion rather than locking horns. Many modern deer and antelope employ this style of combat, as do rhinos. Given that many ceratopsians can be placed in the same groups as these mammals on morphological grounds, it may be inferred that they engaged in the same types of combat.

Their third step is to pursue the "functional comparisons" (Farlow and Dodson, 1975, p. 356) or "expectations" (Molnar, 1977, p. 176) implied by the second step. For Farlow and Dodson, this step chiefly involves producing adaptive explanations

for the variations in ceratopsian frills and horns. Fortunately, the theory of combat types employed in the second step above also comes with a ready-made, evolutionary explanation, namely that the elaboration of cranial headgear is part of an evolutionary trend towards the cephalization of combat and display (Molnar, 1977, pp. 166–7). In other words, ornaments for sexual display often become concentrated on the head, especially in quadrupeds.

Type 1 combat is taken to be the primitive condition among ceratopsians and is explained as a displacement of combat equipment from the teeth to the face in general (Farlow and Dodson, 1975, pp. 356–7). The bony frill of early ceratopsians may have evolved primarily as a display item, to signal sexual maturity to mates, and to intimidate rivals. From primitive forms, ceratopsians evolved into two distinct lineages, each specializing in a certain form of combat and display. One lineage developed long frills combined with long brow horns over the eyes and a short nasal horn on the nose. In these species, display probably comprised tilting the head forward so that the long frill would rise vertically high into the air and the brow horns would project past the face. Combat would have been of type 2, in which each antagonist could catch the other's projecting horns on his own and commence shoving and twisting without severe risk of being stabbed (Farlow and Dodson, 1975, pp. 357–8). The other lineage of ceratopsians developed short frills and short brow horns, but a long nasal horn. In these animals, combat would have been of type 3, in which the risk of a stabbing injury would be more immediate since the long nasal horn of each combatant could not have been as reliably neutralized by his opponent as is the case with long brow horns (Farlow and Dodson, 1975,

p. 358). In both of these lineages, the cranial accoutrements represent a response to the needs of sexual display and the determination of social rank without requiring potentially lethal combat. The non-lethal nature of these forms of combat allows both winners and losers to continue living in the same herd, a situation that is often to their mutual advantage. The morphological similarity between ungulates and ceratopsians suggests that the analogy between them extends to the level of adaptive explanation.[1]

A portion of this analogy is given in table 3.1. The chameleon, steer, and *Torosaurus* analogs described there represent the species that perform type 2 combat. The evolutionary explanation linking this method of combat to the long brow horns of each species may be read from the system mappings of each domain. The fact that a chameleon, for example, has such horns enables it to perform type 2 combat, which contributes to discouraging its rivals. Female chameleons are impressed by this result, which confers reproductive privileges on the male. Thus, the performance counts as an adaption for impressing female chameleons. Also, the explanation of horns and frills as display/intraspecific-combat equipment suggests that ceratopsians, like many modern organisms, should show marked sexual dimorphism. In other words, one sex (usually the males) should possess this equipment to a much greater degree than the other (Farlow and Dodson, 1975, p. 357). Recent finds of ceratopsian fossils suggests that they follow this pattern as well (Sampson et al., 1998).

Recently, Sampson (1995) has suggested a fourth step to add to the ceratop-

[1]Some ceratopsian morphology does not fit quite so cleanly, but Farlow and Dodson (1975, pp. 358–9) explain these by appeal to further evolutionary principles or analogs.

Chameleon	Steer	Torosaurus
chameleon	steer	torosaurus
type-2-combat$_c$	type-2-combat$_s$	type-2-combat$_t$
long-brow-horns$_c$	long-brow-horns$_s$	long-brow-horns$_t$
rivals$_c$	rivals$_s$	rivals$_t$
mates$_c$	mates$_s$	rivals$_t$
have$_c$(chameleon,l-b-h$_c$)	have$_s$(steer,l-b-h$_s$)	have$_t$(torosaurus,l-b-h$_t$)
perform$_c$(chameleon,t-2-c$_c$)	perform$_s$(steer,t-2-c$_s$)	perform$_t$(torosaurus,t-2-c$_t$)
discourage$_c$(chameleon,rivals$_c$)	discourage$_s$(steer,rivals$_s$)	discourage$_t$(torosaurus,rivals$_t$)
impress$_c$(chameleon,mates$_c$)	impress$_s$(steer,mates$_s$)	impress$_t$(torosaurus,mates$_t$)
enable$_c$(have$_c$,perform$_c$)	enable$_s$(have$_s$,perform$_s$)	enable$_t$(have$_t$,perform$_t$)
because$_c$(discourage$_c$,perform$_c$)	because$_s$(discourage$_s$,perform$_s$)	because$_t$(discourage$_t$,perform$_t$)
cause$_c$(discourage$_c$,impress$_c$)	cause$_s$(discourage$_s$,impress$_s$)	cause$_t$(discourage$_t$,impress$_t$)
adapt$_c$(perform$_c$,impress$_c$)	adapt$_s$(perform$_s$,impress$_s$)	adapt$_t$(perform$_t$,impress$_t$)

Table 3.1: The chameleon/steer/*Torosaurus* component of the multiple analogy as given in the middle row of figure 3.2. This table represents the outcome of step 3 of Farlow and Dodson's procedure of functional comparisons.

sian/ungulate analogy.[2] As noted above, Farlow and Dodson identify ceratopsian lineages with combat types. Sampson (1995, p. 40) generalizes this move by invoking sexual selection as an explanation for *all* the analogies considered here:

> Every animal species has its own particular system by which individual animals recognize and select mates, and many use visual cues. Were these cues to diverge between two populations (resulting, for example, in two horn types) because of mate competition, the groups might no longer recognize each other as the same species, and consequently stop interbreeding.

What Sampson presents, in effect, is a general schema or evolutionary scenario which gives a single explanation of the links among morphology, behavior and evolution in all the cases considered above, whether mammal, reptile, or dinosaur.

The above discussion suggests that the following constraints apply to the construction of multiple analogies concerning ceratopsians:

1. Organisms are grouped into rows based on visual similarities in their headgear, and into columns based on their evolutionary affiliations. Each slot in the resulting table is occupied by organisms that meet these criteria.

2. A representative member of each slot is used to exemplify the relevant group.

3. A distinct function, *e.g.*, combat of type 1, 2, or 3, is associated with each row in the source domains and is mapped to the corresponding row in the target domain.

[2]Sampson (1995, p. 39) also suggests that the second step could be extended to include beetles in with mammals and lizards, but does not go on to explore this additional source analog.

4. Explanations for each function, in terms of adaptations consistent with the theory of sexual selection, are mapped from the source domains to the target domain.

This recipe generalizes the MT schema in which a single source analog is retrieved from memory (*cf.* step 1 above), and attribute (2), relational (3), and system (4) mappings are established. The contribution of visual representations to the analogy construction process is discussed further in section 3.4.1.

3.3 *Archaeopteryx*: The first bird

Since it is the oldest bird-related fossil organism known, *Archaeopteryx* represents the closest approach to the first avians (birds) that evolved the ability to fly. The phylogenetic relationship of *Archaeopteryx* to other organisms, especially dinosaurs, continues to be controversial (Hecht et al., 1984; Shipman, 1998), but the significance of *Archaeopteryx* for constructing scenarios of the evolution of avian flight is most important here. Broadly speaking, there are two competing theories. The *arboreal* theory states that *Archaeopteryx*'s ancestors developed flight capabilities by climbing trees, leaping from limb to limb or leaping out of the limbs and gliding or parachuting to the ground. The *cursorial* theory states that *Archaeopteryx*'s ancestors developed flight by running along the ground and then leaping into the air and flapping. Work on these theories typically involves comparisons of *Archaeopteryx* anatomy to that of other flying, gliding, and parachuting creatures such as bats, birds, fish, frogs, insects, lizards, pterosaurs, and squirrels, to name a few (for a full list, see Schaller, 1984).

Generally speaking, arguments in favor of the arboreal theory seek to interpret the anatomy of *Archaeopteryx* as adapted to tree-climbing, and also ill-adapted to taking off from the ground. The classic development of the arboreal theory is that of Heilmann (1927) (see Bowler, 1996, pp. 277–80). Heilmann (1927, pp. 100–5) compares the claws on the wings of *Archaeopteryx* to the claws on the wings of nestlings of several modern species of birds, most especially the Hoatzin, a South American relative of the cuckoo. Hoatzin chicks are equipped with claws on each wing which they use, along with their beaks, to clamber around the trees above their nests. Heilmann (1927, p. 101) notes that the shape and proportions of the wing bones in Hoatzin hatchlings closely resembles those in the homologous bones of *Archaeopteryx*, rendering both "well fitted for climbing":

> The hand of either is much longer than the arm and forearm; the proportions of the first and second digits also correspond. This is surely no mere coincidence.... That [*Archaeopteryx*], therefore, has been able to climb the branches in nearly the same way as the Hoatzin-nestling, seems very probable indeed.

But, while Hoatzin hatchlings climb well, they cannot fly, partly because they do not develop flight feathers on the section of their wings nearest to their bodies until they mature (Heilmann, 1927, p. 105). Since *some* airfoil in that section would seem to be necessary for *Archaeopteryx* to fly, Heilmann proposes that *Archaeopteryx* probably had a *patagium*—a fold of skin—connecting the inner wing to the side of the body, by analogy with flying mammals:

> Such a fold of skin is the first to appear when the evolution of a "flying"

> mammal sets in, and therefore it does not seem unlikely that an incipient patagium was present in some forerunner of birds, in due time giving place to the fully developed wing of feathers.

Heilmann adds that ostrich and chicken hatchlings have small patagia which he claims are vestiges that they inherited from *Archaeopteryx*. But there is no evidence that ostriches and chickens inherited this condition from *Archaeopteryx* as opposed to having evolved patagia independantly. Thus, the argument that *Archaeopteryx* had patagia rests solely on the analogy with flying mammals.

However, there is a flaw in the *Archaeopteryx*/mammal analogy. As Heilmann (1927, pp. 198–9) later admits, the patagium in flying mammals always connects their forelimbs to their hindlimbs. This situation is fine for flying mammals since they descended from quadrupeds that use all four limbs for locomotion. But the attachment of wings to legs would interfere with the separate use of fore and hindlimbs in *Archaeopteryx* since it probably descended from bipeds that use legs for locomotion and arms for manipulation. It would be like a human playing basketball with the arms and legs on each side fastened together with rubber bands. Heilmann instead suggests a comparison with the frilled gecko, which has a patagium or "flank wing" *not* attached to its limbs (Schaller, 1984, p. 339). Figure 3.3 reproduces Heilmann's concept of the predecessor of *Archaeopteryx*, known as *proavis*, with its gecko-like patagia in place. Heilmann (1927, p. 199) concludes that an ancestor of *Archaeopteryx* may have had a mammal-like patagium, but that it was quickly replaced by descendants with patagia that more closely resemble those of the frilled gecko.

Figure 3.3: *Proavis*, the hypothetical ancestor of *Archaeopteryx*, reconstructed by Heilmann (1927, p. 200) with patagia like the frilled gecko. This creature also appears in the *Rite of spring* sequence of the Disney film *Fantasia* in 1940.

Heilmann's analogy between *Archaeopteryx* and Hoatzin nestlings is two-fold. On the positive side, the similarity between the claws and wing bones of Hoatzin nestlings and adult *Archaeopteryx*es supports the hypothesis that *Archaeopteryx* was arboreal in habit. On the negative side, the analogy suggests that *Archaeopteryx* did not have enough flight feathers to allow it to fly. Hoatzin hatchlings, after all, cannot fly precisely because their patagia prevent them from developing the necessary feathers on the portion of their wings next to their bodies. When they mature, the patagia disappear and the feathers develop. But most biologists, including Heilmann, believe that *Archaeopteryx* could fly, if not with the greatest facility. So, Heilmann repairs the Hoatzin/*Archaeopteryx* analogy by adding a further source analog, namely the frilled gecko, which possesses patagia connecting only its forelimbs to its sides, thus providing an airfoil for improved lift without encumbering its arms by a connection with its legs. Table 3.2 gives a representation of Heilmann's composite analogy.

The cursorial theory of the origin of flight is most notably developed by Ostrom. Ostrom attacks the analogies proposed by Heilmann and others, and develops analogies between *Archaeopteryx* and theropod dinosaurs, modern ground birds, and modern birds of prey. Ostrom (1974) criticizes the *Archaeopteryx*/Hoatzin hatchling/gecko analogy on two grounds (see also Gauthier and Padian, 1984, p. 194). First, the analogy implies that the wings of *Archaeopteryx* were adapted to serve two locomotory functions at one time, both climbing and flying. Ostrom (1974, p. 35) counters that the two activities are unrelated from a functional, anatomical standpoint, and thus on general principle would not both be subserved by one

Gecko	Hoatzin	Archaeopteryx
frilled-gecko	Hoatzin	*Archaeopteryx*
	wing-claws$_h$	wing-claws$_a$
patagium$_g$		patagium$_a$
	clambering$_h$	clambering$_a$
gliding		flying
have$_g$(f-g,patagium$_g$)		have$_a$(*Archaeopteryx*,patagium$_1$)
	have$_h$(Hoatzin,wing-claws$_h$)	have$_a$(*Archaeopteryx*,wing-claws$_a$)
perform$_g$(f-g,gliding)		perform$_a$(*Archaeopteryx*,flying)
	perform$_h$(Hoatzin,clambering$_h$)	perform$_a$(*Archaeopteryx*,clambering$_a$)
enable(have$_g$,perform$_g$)		enable(have$_a$,perform$_a$)
	enable(have$_h$,perform$_h$)	enable(have$_a$, perform$_a$)

Table 3.2: Heilmann's gecko+Hoatzin/*Archaeopteryx* analogy. Note the use of selected features of the frilled gecko to partially overcome disanalogous mappings between the Hoatzin hatchling and *Archaeopteryx* domains. Ostrom attacks this analogy on the basis that two locomotory functions, clambering and flying, cannot generally be subserved by adaptations of the same organ, *i.e.*, the wing. The fact that wings count as adaptations for catching food and fleeing predators is omitted from the table.

anatomical structure. Second, Ostrom (1974, pp. 35, 38–9) instead argues that the anatomy of *Archaeopteryx* is much more similar to that of its theropod, dinosaur relatives, such as *Ornitholestes*, *Velociraptor*, and *Deinonychus*, which are generally agreed to be cursorial predators, and which Ostrom (1969) himself had first described.[3] Ostrom (1974, p. 34) draws particular attention to the similar shapes and proportions of the forelimb claws of all these organisms, claiming that they are adaptations for grasping and holding prey.

The hindlimb claws of *Archaeopteryx* are also similar to those of the theropods, as well as modern cursorial birds. *Archaeopteryx* has a *reversed hallux*—it's 'big toe' points backwards—like modern birds, and is of similar proportion to the other claws as observed in modern ground birds and in contrast to perching birds (Ostrom, 1974, p. 36). The relative shortness of the reversed hallux is therefore consistent with a cursorial adaptation. Ostrom (1974, p. 37) illustrates these feature comparisons with a diagram showing *Archaeopteryx* hindlimb claws in an arrangement with those of modern birds (figure 3.4). Each column III shows the bird's middle 'toe,' and column I the hallux. The shape and relative length of the *Archaeopteryx* claws compares most closely with those of the ground birds, and are significantly different than those of the other birds. These similarities and dissimilarities in shape and arrangement imply that the feet of *Archaeopteryx* were adapted for cursorial locomotion, just as the feet of chickens and pheasants are. By the same token, they imply that *Archaeopteryx* was not adapted for perching or treetrunk climbing.

[3]The phylogeny of *Archaeopteryx* and its relation to the theropod dinosaurs remains in some dispute. Burke and Feduccia (1997) maintain that *Archaeopteryx* is not related to the theropods. The truth of this matter may, however, be set aside for present purposes.

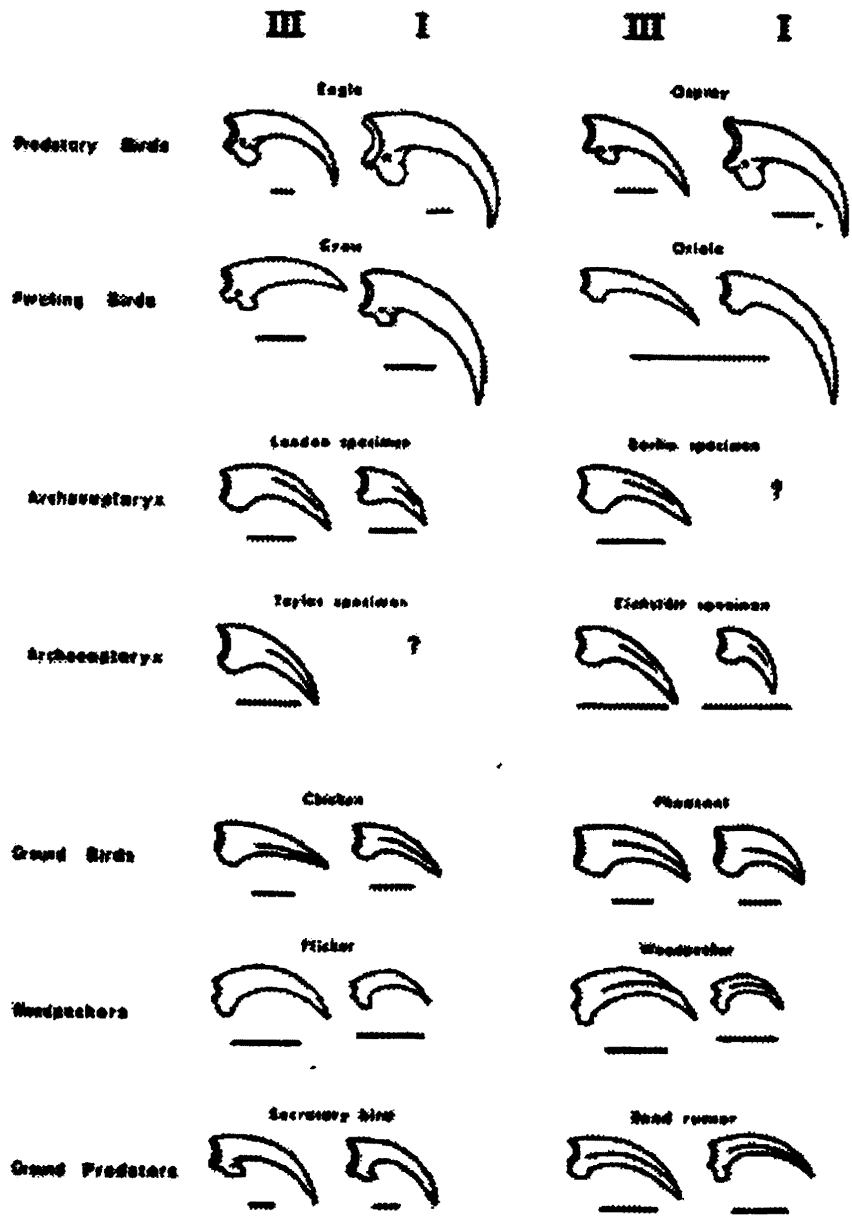

Figure 3.4: Terminal phalanges (without horny claws) from the feet of selected bird types compared with those of four specimens of *Archaeopteryx* (Ostrom, 1974, p. 37). The columns display the middle "toe" (III) and the hallux (I) of each bird. The four *Archaeopteryx* feet are most like those of ground birds and unlike those of all the other birds, ground predators in particular. The horizontal lines equal 5 cm on the scale of each claw.

Ostrom (1974, p. 36) also argues that the dissimilarities with the feet of cursorial predators such as the secretary bird and the road runner imply that *Archaeopteryx* could not grasp prey with its feet, a function which could thus fall to the claws on the wings.

Having discussed anatomy, Ostrom (1974, pp. 34–5) explains the evolution of the flapping behavior of *Archaeopteryx* as the result of a predatory strategy of pursuing prey animals over the ground and trapping them between its wings. In effect, some *Archaeopteryx* ancestor would have curtained the prey off with its extended wings and wing-feathers in order to grasp the prey with its forelimb claws or its mouth. The motion of the wings in this maneuver would resemble the arm motions of a person pursuing and swatting a fly by clapping his hands together in front of him. Extending and grasping motions concatenated in this way approximate the flapping motions of bird flight and might have enabled the organism to take briefly to the air. Selection pressure for full flying capabilities would then take over. Ostrom (1974, pp. 34–5) draws an analogy between this hypothetical strategy and the activities of fighting cocks and certain predatory birds who use their wings to flail at each other or at prey; Ostrom (1974, p. 28) provides a photograph of a red-tailed hawk attacking a banded water snake as an instance of the behavior to which he is referring.

Ostrom disputes the analogies suggested by Heilmann, pointing out that Heilmann's conclusion goes against general principle. Ostrom instead develops a cursorial theory based partly on analogies between the forelimbs of *Archaeopteryx* and related theropod dinosaurs, between the hindlimbs of *Archaeopteryx* and modern

birds, and between the predatory behavior of *Archaeopteryx*'s ancestors and modern birds.

Analogies have continued to play an important role in theories on the origin of avian flight. Yalden (1984) for example, disputes Ostrom's diagram displaying similarities between *Archaeopteryx* claws and those of ground-dwelling birds by presenting a similar diagram with claws of his own selection. Yalden (1984, pp. 96–7) argues that comparisons between the claws of *Archaeopteryx* and those of the trunk-climbing vertebrates

> suggest a moderately close analogy with the cobego *Cynocephalus* [a squirrel]. The curved claws, their orientation, the elongated limbs, and the general anatomy of the hand all conform to that analogy at least as well as to Ostrom's predatory analogy, and the sharpness of the claws fits a tree climbing analogy better.

Feduccia (1993) pursues this and related comparisons further.

Rayner formulates several objections to Ostrom's cursorial hypothesis. Rayner (1991, p. 200) notes that there are no modern analogs to Ostrom's proposed animal that feeds with its wings while running. Also, while Ostrom's cursorial scenario explains the use of wings for generating *lift*, it does not explain how the wings came to be used to generate *thrust*—a service provided by the legs in running (Rayner, 1984, p. 280). Instead, Rayner offers a scenario for the evolution of avian flight by comparison with a scenario for the evolution of flight in bats. Bat evolution can be asserted with greater confidence than bird evolution, partly due to confidence in the interpretation of the bat fossil record and partly due to the close analogy be-

tween ancestral bats and modern gliding mammals such as flying squirrels. Despite their obvious anatomical differences, Rayner (1991) cites experimental evidence to the effect that birds and bats share very similar aerodynamic qualities. Ultimately, Rayner proposes a "compromise" scenario in which *Archaeopteryx* figures as a cursorial predator that achieved flight by taking off downhill or running into the wind. This scenario suffers, in turn, from the lack of a modern analog, an organism observed to fly in the fashion that Rayner proposes. Rayner (1984, p. 283) does note that the "woolly flying squirrel *Eupetaurus* of the Himalayas lives above the tree line and and glides among rocks." The difficulty with this source analog is that *Eupetaurus* evolved its gliding behavior below the tree line and later moved up. Thus, its behavior would count as an evolutionary *preadaptation*, whereas his proposal for *Archaeopteryx* would count as an *adaptation*. A mapping between adaptation and preadaptation would tend to weaken his proposed analogy.

The debate over *Archaeopteryx* and the evolution of avian flight reveals several interesting aspects of the role of multiple analogy in evolutionary biology. *Archaeopteryx*'s fossil anatomy is ambiguous as to whether it was adapted to an arboreal or cursorial (or mixed) habitat. Supporters of the arboreal theory, such as Heilmann, concentrate on the wing claws of *Archaeopteryx* and cite analogs among modern tree-climbing birds and mammals. Supporters of the cursorial theory, such as Ostrom, cite homology—the phylogenetic relationship between theropod dinosaurs and *Archaeopteryx*—to explain the data in favor of the arboreal theory and cite analogs among modern cursorial birds to support their alternative scenarios. The literature on *Archaeopteryx* provides an excellent example of

how multiple analogies may be used positively to construct or support one's own theory and negatively to exploit disanalogies in competing theories (section 2.5.5. The development of multiple analogies in the *Archaeopteryx* literature has become more sophisticated, with increasing stress laid on the confidence in the correctness of composite source analogs evidenced by Rayner. The distribution of analogies over the whole literature illustrates the epistemological difficulties involved in constructing analogies in the presence of so many potential source analogs and, by the same token, shows how such difficulties may be handled by distributing analogy construction socially within a group of scientists.

3.4 Implications for multiple analogies

Sections 3.2 and 3.3 present material that is in some ways very similar to that presented in section 2.4 regarding the Coelacanth. But these sections also confront us with a variety of issues not dealt with previously. These issues may fall into two categories. The first category concerns cognitive issues such as the use of visual representations and the analogical comparison of entire evolutionary scenarios. The second category concerns issues in the philosophy of biology, *e.g.*, the nature of scenario building and the fecundity of multiple-analogy construction as a research practise. It would be convenient to deal with these subjects in order, cognitive issues first and biological second, but the content of each issue requires a different approach. The issue of visual representations is dealt with first in section 3.4.1 (cognitive), then scenario building in section 3.4.2 (biology), followed by multi-stage analogies in section 3.4.3 (cognitive) and the issue of fecundity in section 3.4.4

(biology).

3.4.1 Visual representations

Many aspects of the ceratopsian and *Archaeopteryx* analogies lend themselves in some ways to visual representations (pictures in the mind's eye, as it were), as opposed to verbal or propositional representations typically given in the tables above. Indeed, the use of visual representations in sciences such as evolutionary biology is to be expected since much of the evidence for evolutionary explanations concerns large material objects with important visual features. The occurrence of visual mental imagery in other sciences such as physics and chemistry has been studied by a number of scholars; see Miller (1984), Root-Bernstein (1985), and Giere (1996). We might expect cognitive processes to use the original medium of representation where that representation is most appropriate, provided that it is capable of meeting the demands made on it. The important attributes of fossils are often visual in nature, so we may expect visual imagery to be the representation of choice for reasoning about them (Shelley, 1996; Thagard and Shelley, 1997).

Some aspects of visual representation are closely comparable to verbal representations. Recall Watson's observation of two immature *Undina* inside the abdominal cavity of a mature *Undina* from chapter 2. Watson claimed that they were young gestating inside their mother because they were situated in the back of her abdominal cavity, because they both appeared to be in good condition and because they both rested in the same orientation. Schultze disputed this conclusion and maintained that the two fish were in fact inside the larger fish's stomach, implying

that they were prey. Griffith and Thomson supported Watson's original hypothesis. The basic data offered in these disputes is visual, concerning the appearance, orientation, and position of the young *Undina* inside the larger one. The position, for example, of the two young *Undina* might be represented as a sort of visual mental image, a picture of them as they lie within the ribs of the larger fish. The question of whether or not they are in the digestive or reproductive tract of the larger *Undina* could be considered by the mental operation of constructing what could be called a *mental movie*, a visual reconstruction of showing how young fish trapped inside a larger one that died would have been deposited on the sea floor and fossilized. Alternatively, spatial predicates might be used, *e.g.*, *inside-of(little-fish,digestive-tract)* (see Larkin and Simon, 1987). The two systems appear to be equally well suited to the task at hand, therefore this kind of visual information could be usefully dealt with by translating it into a predicate-and-arguments style representation.

The visual representations employed in the ceratopsian and *Archaeopteryx* examples seem to inform their respective analogies to a larger degree. Figures 3.2 and 3.4 indicate that the arrangement of the visually salient attributes of the analogs into graph or table-like structures may constitute a step in analogy formation and explication. The shape, location, and orientation of horns and claws are indispensable data in judgments of their gross similarity and their analogy of function and adaptation. These physical resemblances are most easily represented visually, whether in visual mental images or in drawings on a sheet of paper.

The choice of representation at higher relational- and system-level mappings

may vary. Representations concerning, say, the proportions of skeletal components to one another might be given as verbal predicates, but even system-level concepts such as *cause* may be represented visually. For instance, the chameleon / steer / *Torosaurus* analogy can be represented by predicates (see figure 3.1), or it can be represented by a visual mental movie of two steer shoving each other over a potential mate and substituting two *Torosaurus* males instead, in which case the relevant causal relations are represented by the scene showing the outcome of the contest. The system-level mappings follow from visualizing the *process* of intraspecific combat and its consequences.

People vary quite a bit in their visual cognitive abilities, so that the possibility raised above might seem incredible to people who do not experience vivid visual mental imagery. But such abilities do exist. Grandin (1995, pp. 20–1), an autistic person with a Ph.D. in Animal Science, tests the animal-handling equipment that she designs by running through it in her imagination:

> I visualize my design being used in every possible situation, with different sizes and breeds of cattle and in different weather conditions. ... When I do an equipment simulation in my imagination or work on an engineering problem, it is like seeing it on a videotape in my mind. I can view it from any angle, placing myself above or below the equipment and rotating it at the same time.

Grandin (1995, p. 143) also visually runs through the equipment from the perspective of the cattle, envisioning what they would see on their way through. Roe (1951, pp. 461–2), in her study of visual mental imagery used by academic re-

searchers, gives an account of a biologist who conjures up mental movies of the Cretaceous in order to watch how events develop. From the statistics she gathered, Roe concludes that the use of visual imagery is typical among biologists and other scientists whose jobs involve reasoning about the visual attributes of large objects. It is quite possible, then, that the multiple analogies such as those constructed regarding ceratopsians were generated visually.

Holyoak and Thagard (1995, pp. 113–4, 194) note that visual representations may enhance analogy construction, but restrict their consideration to proportional analogies. But if, as the ceratopsian example suggests, multiple analogies may work with visual representations at a higher level of abstraction, then the extent of visual analogies needs to be re-evaluated. So, for example, sequences of visual mental images, or mental movies, may be used to represent causal relations in analogy construction just as predicates such as *cause* do in verbal representations. Consider the visual analogy presented in figure 3.5, taken from the front of a recent Christmas card. The figure portrays two analogous physical processes juxtaposed in one scene. The scene itself might be represented as a proportional analogy: Just as a man's car might run out of gas, so Santa's reindeer might run out of hay. But the analogy only makes sense if higher-level information is considered, namely that gas enables a car to run, just as hay enables a reindeer to run (or fly). Connecting the event depicted on the card with its causes requires the viewer to consider the process of Santa's predicament: running into trouble, landing his sleigh, unhitching the empty reindeer, tucking it under his arm, and heading down the road in search of hay for the reindeer to eat. This sequence is based upon the stereotypical process

Figure 3.5: A visual analogy taken from the front leaf of a Christmas card. The scene juxtaposes similar events from two analogous sequences representing the causes and outcomes of transportation difficulties.

a person might go through when his car runs out of gas: he pulls over, removes an empty jerry can from the trunk, and heads down the road in search of a gas station for gas to fill the can. In a visual representation, the causes linking one event to the next could be encoded in the manner of either man's actions. Santa's angry look, for example, informs the viewer that Santa's situation is not one that he intended to be in. Thus, his situation must have been caused by a misfortune or oversight. People are adept at reading such abstract information from these cues; thus, abstract information could be represented *in terms* of the manner and attitudes of objects in a visual image and read off when necessary. Multiple analogies may be constructed using visual images with mappings constructed between similar representations of this kind. The multiple analogies depicted in figure 3.2 are far more telegraphic than figure 3.5, making it difficult to judge the extent of visualization involved in their construction, but the two figures show a suggestive congruence in their juxtaposition of animals prepared for similar activities.

Figures 3.2 and 3.4 also indicate the importance of graphic representations to the structuring of analogies. In both figures, graphic representations of source and target anatomical features are situated within a system of columns and rows. In figure 3.4, the primary graphic dimension is vertical, with distance from the center being used as a rough index of adaptive distance compared to *Archaeopteryx*. In figure 3.2, rows serve to group similar features together into a sort of ascending order of combat types. Columns separate the source domains on the left from the ceratopsian target domain on the right. These graphic representations appear to encourage Gestaltist tendencies to complete figures, thus encouraging complete

consideration of the visual features that participate in each analogy. Gestalt principles generally concern the grouping of similar objects together and the completion of partially filled-in figures, both of which can make obvious contributions to analogical reasoning. Conversely, unfilled locations in a figure are potential cause for concern; certainly the two unfilled locations in the "lizard" column of figure 3.2 do not add confidence in the lizard/ceratopsian component of the analogy proposed there.

Another advantage of graphic representations is the ease with which multiple source analogs are added: One need only add more rows or columns with new categories of animal. The ability to do so supports the general character of the analogy. In terms of the processes of analogy construction, this additive quality supported by graphic representation gives the analogizer the ability to construct complex analogies in a serial, piece-by-piece manner. (Recall the recipe used by Farlow and Dodson, section 3.2). In section 2.5.1, it was argued that multiple analogies are constructed in parallel. This situation holds so long as the cognitive load caused by parallel processing does not exceed the performance limit of the analogizer. In other words, parallel processing is fine until it becomes to confusing, or costly in cognitive terms. As Donald (1991, p. 329) argues, people tend to use cognitively external representations, which he calls the *external memory field* (EXMF), such as drawings, when their own working memory capacity is insufficient to carry out a "thought project":

> Humans do not think complex thoughts exclusively in working memory, at least not in working memory as traditionally defined; it is far too

> limited and unstable. In modern human culture, people engaged in a major thought project virtually *always* employ external symbolic material, displayed in the EXMF, as their true "working memory." They use their biological working memory system, along with their perceptual apparatus, more as an iterative data-crunching device, or a processor of visual analog images.

In other words, people will tend to iterate serially back and forth through the steps of a major thought project using external aids to memory, such as the carefully arranged drawings made by Ostrom (figure 3.4) and Farlow and Dodson (figure 3.2). The cognitive advantage of these external representations, then, is that each source analog and its relation to the target (and the other sources) may be considered one at a time, thus making possible the careful construction of an effective multiple analogy.

The way in which visual and verbal representations are made to work together is fairly direct in cases of spatial information such as *inside-of*: One can be translated into the other without much difficulty. In other cases, translation between visual and verbal representations is not so direct. In the instance of causal information, translation from visual to verbal may be accomplished by harnessing people's ability to read such information from perceptual scenes to the task of reading that same information from visual mental images. This procedure is essentially the one suggested by Donald for the use of drawings as external forms of working memory storage. In short, visual and verbal representations, as they appear in multiple analogies, may be relatively separate from one another and are combined by the

ways in which they divide the cognitive load involved in a "major thought project". This situation suggests that comparisons and other low-level activities involved in the construction of multiple analogies do not occur cross-modally. That is, detailed comparative activity undertaken in one modality, either visual or verbal, tends to remain in that modality. Processes involving both modalities interact at a high level of abstraction.

Visual representations appear to have made an important contribution to the multiple analogies described in this chapter. Visual mental imagery is important in virtue of the fact that it is the visually salient attributes of the anatomical features of ceratopsians and *Archaeopteryx* that are the items of concern for evolutionary biologists. Some aspects of visual representations, such as spatial relations, are not very different from the predicate representations discussed in chapter 2. But the use of visual mental imagery to represent higher-level, causal information *is* very different. The use of visual imagery also extends to the use of external memory storage, *e.g.*, drawings. Drawings lend themselves well to the construction of multiple analogies since they facilitate the construction of tables to which columns and rows may be added iteratively as needed. The use of visual imagery is typically concerned with visually salient attributes and relations and is combined with verbal representations at a high or abstract level using a perceptual process of reading off verbal information from the visual image.

3.4.2 Evolutionary scenarios

Multiple analogies in evolutionary science also participate in other, higher-level forms of representation, namely the *scenario*. Scenarios, which are also called *models*, *historical-narrative explanations* (Bock, 1984), or *Darwinian histories* (Kitcher, 1993), have been the subject of much controversy since the attack by Popper (1960) on the scientific status of "historicism" in general and evolutionary biology in particular (1974). Scenarios are an obvious way to represent hypotheses about the evolution of organisms, but are often criticized as being merely "just-so" stories beyond confirmation or falsifiability (Gould and Lewontin, 1978). Certainly, if scenarios are ruled out as forms of scientific explanation, then much of the work in evolutionary biology and similar disciplines such as geology (Gould, 1987) and cosmology (Brush, 1996) do not qualify as scientific.

A number of evolutionary scientists have discussed scenarios in terms of the constraints that apply to constructing them properly. These constraints serve to maximize "congruence" between the information about a particular set of organisms and the theory of evolution in general. Here is a five-step schema proposed by Padian (1987, p. 5):[4]

1. Define the adaptation under consideration in functional terms, and define the group(s) in which it appears as monophyletic units;

2. Analyze the group(s) phylogenetically, emphasizing (a) their relationship to other groups and (b) the relationships of taxa within the group;

[4]Very similar formulations are given by Bock (1984, p. 202) and Gans (1985, p. 2).

3. Use phylogenetic analysis to determine the sequence of appearance of characters presumed to be related to the adaptation under consideration;

4. Compare these adaptations and their sequences of origination in other taxa. Distinguish characteristics necessary to the adaptation from those that are associated with the adaptation by virtue of their appearance in a given taxon;

5. Consider additional lines of evidence (*e.g.*, genetic, biochemical, physical, populational, etc.) that may bear on the evolution of the adaptation, as a test of the phylogenetic-functional scenario.

In other words, biologists should pick out an adaptation to focus on, construct the phylogenies or family trees of organisms possessing the adaptation, examine the trees to see how the adaptation evolved in each case, compare the results for each family with those for other families, and consider any further, relevant evidence. In practise, this sequence of steps cannot always be adhered to in the order presented by Padian, partly because the identification of an adaptation in step 1 (especially in extinct organisms) may depend on analogies to modern organisms in step 4 (Padian, 1991, p. 158). Because step 4 can influence the phylogeny constructed in previous steps, Bock (1984, p. 202) prefers the term *pseudophylogeny* for the 'family trees' produced by steps 1 and 2.

For current purposes, the correspondence of Padian's recipe to actual practice is less important than the representation to which it gives rise. The result of such a procedure is essentially an annotated family tree of a group of organisms. The annotation breaks the tree up into stages, each of which tracks episodes in the career of an organic character or the species that possess it. The organisms

identified with each stage "must be viable and must be able to interact with their presumed environments" (Bock, 1984, p. 202). This criterion applies to steps 1 and 2 above. Transitions from stage to stage are labeled as to the nature of change involved, *i.e.*, as *adaptations*, *preadaptations*, *vestiges*, *etc* (see Gans, 1985, pp. 4–5). This criterion applies to step 3 above. To this point, felicity of the scenario to phylogenetic (homological) information has been emphasized. Now, analogical information becomes most relevant.

On the relevance of analogy to each stage in the proposed scenario, Bock (1984, p. 202) notes that it is desireable, but not absolutely required, to be able to cite known organisms as analogs for the organisms proposed for each stage in an evolutionary scenario. If no analogous organisms can be cited, then the scenario is counted as seriously, if not fatally, flawed. He emphasizes that this point is especially important for the purpose of evaluating rival scenarios, one of which enjoys a number of such analogs while the other scenario enjoys none. Basically, the availability of good analogs counts towards the viability of the organisms associated with each stage of the proposed phylogeny. A lack of analogs counts against viability. The existence of *many* analogs further increases confidence in the scenario (see also Gans, 1985, p. 7).

The conflicting hypotheses over the reproductive biology of *Latimeria* provides a simple example of scenario-building in action; see figure 2.1. The scenario consists simply of one stage, namely the inheritance of a single reproductive strategy from a hypothetical ancestor (labeled "Ur-Coelacanth" in figure 2.1). The scenarios put forward by Watson and Schultze depends on all three Coelacanth species conserving

the same, homologous trait of viviparity or ovoparity, respectively. The scenario put forward by Griffith and Thomson relies on multiple analogies with modern organisms, exemplified by the shark *Hexanchus*.

A scenario for the evolution of ceratopsian dinosaurs proposed by Farlow and Dodson (1975, p. 354) is displayed graphically in figure 3.6. The scenario matches the theory of combat types to ceratopsian phylogeny: Each group of ceratopsians is associated with one type of intraspecific combat. The "primitive" group is associated with Type 1 combat, the "long-frilled" group with Type 2 combat, and the "short-frilled" group with Type 3 combat. The types of frills and horns belonging to each group count as adaptations for the different types of combat, and the phylogeny is arranged parsimoniously so that each kind of adaptation arises only once. Farlow and Dodson omit any lines of decent from the figure in order to emphasize the fact that it is derived from comparisons (step 3 in Padian's scenario-building recipe discussed above) rather than motivated by more direct evidence (steps 1 and 2). New discoveries have altered the details of ceratopsian phylogeny somewhat, but the three groups identified by Farlow and Dodson continue to be recognized as such (Dodson, 1996, pp. 252–9).

The avian-flight scenario proposed by Ostrom (1979) is shown in figure 3.7. The phylogenetic relationship pictured there is essentially one of direct inheritance: *Archaeopteryx*, at the bottom of the figure, has adapted the insect-catching characteristics of its ancestor to the function of flapping flight. The figure is nicely constructed to emphasize visual simplicity of the proposed adaptations of *Archaeopteryx*. As Ostrom (1979, p. 55) notes, "it is not difficult to visualize how

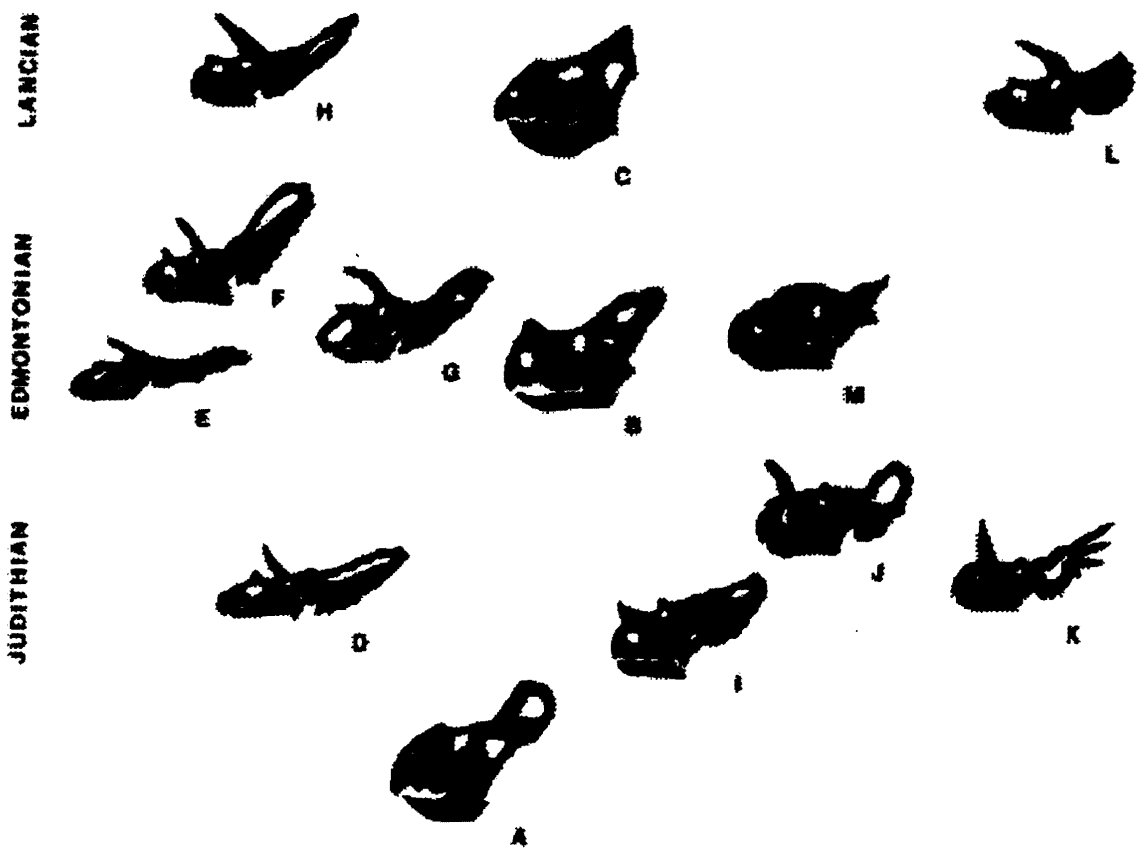

Figure 3.6: Rough phylogeny of ceratopsian dinosaurs from the Judithian, Edmontonian, and Lancian periods of the Upper Cretaceous (Farlow and Dodson, 1975, p. 354). The phylogeny distinguishes three groups of ceratopsians: a "primitive" group, labeled A through C in the central column; a "long-frilled" group D through H in the left-hand area; a "short-frilled" group I through M in the right-hand area. Lines displaying phylogenetic relationships were deliberately omitted by Farlow and Dodson to express uncertainty on details of inheritance.

Figure 3.7: The reconstruction by Ostrom (1979, p. 55) of the evolution of flight in *Archaeopteryx*. The top half of the figure depicts a proto-*Archaeopteryx* using its feathers as aids to catching insects. The bottom half of the figure shows *Archaeopteryx* in a similar pose for the purposes of comparison, although *Archaeopteryx* was likely capable of flying after its prey.

advantageous these paired 'insect nets' [wings] would be in snaring leaping insects, or even in batting down escaping flying insects." Unfortunately, there are no modern analogs to this proposed scenario, which considerably weakens its force.

The evolutionary scenarios discussed in this chapter may be understood as instantiations of a general schema for evolutionary explanation. Here is a verbal representation of this schema (see also Brandon, 1990, pp. 165–76):

Explanation target

- What cause brings about a particular **characteristic** in a given **species**?

Explanatory pattern

1. The descent of the **species** from its **ancestors** is given in its **phylogeny**.

2. The scenario identifies **stages** in the **phylogeny**.

3. The **characteristics** of the **species** at each **stage** tend to enable those **species** to survive and reproduce.

4. The **species** at each **stage** inherit their **characteristics** from their **ancestors.**[5]

5. Any changes in inherited **characteristics** are caused by **selection pressures.**

The terms given in boldface type are variables to be filled in for any particular instantiation of this schema (see Thagard, 1996, p. 66). The best scenario, and therefore the best explanation for the explanation target, is the scenario that best satisfies the conditions connected with each of the variables. Some conditions are particularly important in this respect. What counts properly as a conserved or derived characteristic (condition 4) means identifying a characteristic as an unmodified inheritance, *adaptation*, *preadaptation*, *vestige*, *etc*, with all the conditions which apply to making such an identification (see Shelley, 1999). Assessing the viability of species (condition 3) is also an important and non-trivial task. Any of conditions 1–5 may be supported by analogies where they are applicable, although 3 is the condition most emphasized in practice where analogy is concerned.

[5]Brandon (1990, pp. 171–4) refers to this information as *trait polarity*.

There is no condition stated on the number of stages into which a scenario must be divided. A fixed rule is probably out of the question, but the number given in practice seems to be inversely proportional to the confidence with which the characteristic in question can be identified (condition 5). A scenario divided into many stages includes fewer species and their changing characteristics in each stage. Conversely, a scenario divided into few stages includes more species and their characteristics in each stage. If a characteristic and the selection pressures acting on it can be confidently identified, then it can still be picked out from among many others in a scenario of few stages. If not, then a scenario of more stages is needed to isolate the characteristic in question from all the other characteristics.

The evolutionary-scenario schema given above differs from the sort advocated by Kitcher (1993) in one important respect. Kitcher views evolutionary explanations as arguments, and therefore views scenario schemata as abstract argument patterns (Darden, 1991, p. 197). This view requires that some conditions within the explanatory patterns laid out by Kitcher (1993, pp. 27–8, 44–7) be made to follow from other conditions by connectives like *therefore*. Instantiations of such schemata constitute deductive-style demonstrations that the distribution of characters in a species follows in some way from the distribution of characters in its ancestors under the influence of certain selection pressures.

The schema given above is not an abstract argument pattern. This schema aims at providing scenarios rather than arguments, where a scenario is a representation showing how well certain hypotheses about natural history can be subsumed under the theory of evolution (see Darden, 1991, p. 197). In other words, a scenario is a

means for measuring the fit between information about individual species and the theory of evolution in the large. Arguments about what follows from what assume more importance where theoretical issues rather than details of particular family trees are at stake. For present purposes, the most important difference between the two types of schemata is that argumentative patterns do not admit analogies, single or multiple. None of the support rendered by analogies to evolutionary explanations appears in the argumentative schema, which relies strictly on deductive or probabilistic inferences. In the subsumptive schema described above, analogies may be applied to the fulfillment of the given conditions as circumstances warrant. This property alone makes the subsumptive schema a better account of the scenario-building described above, where analogies are clearly important.

Multiple analogies play an important role in scenario building as it is described in this section. The more analogs that can be offered in favor of the viability of an organism at a stage in a scenario, the better. Of course, such multiple analogies are not constructed by a simple addition of sources. Consider the processes of abstraction and extension, by which many analogs are represented by exemplary ones (section 2.5.3). Supplementation is another process important in scenario building, where the viability of a reconstructed species is supported by comparison with a species constructed from pieces of observable ones (section 2.5.4). Thus, scenario-building in terms of the above schema is one of the most important purposes fulfilled by multiple analogies in evolutionary biology.

It is interesting to note that this kind of relation between multiple analogies and scenarios does not appear to be confined to evolutionary biology. Much the

same relationship holds in the domain of political decision making, as shown by Khong (1992). In this domain, multiple analogies contribute to decisions among several policy options. Khong discusses how the analogies of Munich, Korea, and Dien Bien Phu collectively contributed to President Johnson's decision in 1965 to escalate U.S. involvement in Vietnam by committing 100,000 ground troops to fight in that country. This option was just one of several available scenarios for American involvement in Southeast Asia at the time. Thus, the relationship between multiple analogies and scenarios is not confined to evolutionary science.

3.4.3 Multi-stage analogies

The importance of analogies to justifying the viability of proposed stages of evolutionary scenarios is emphasized by Bock (section 3.4.2). But step 4 of Padian's scenario-building procedure suggests a broader application of analogy: Not only should comparisons be made at each *stage* of a scenario, but between *sets* of stages in different scenarios. Rayner (1984, pp. 284–6), for example, pursues a detailed analogy between the evolution of flapping flight in bats from gliding flight in ancient bats to the evolution of flapping flight in birds (section 3.3). The upshot of this comparison is the suggestion that a sequence of gliding to flapping stages should be expected in both scenarios. Essentially the same logic is employed to support the claim that a gliding stage occurred in the evolution of the pterosaurs or "flying reptiles" (Padian, 1991).

Multi-stage analogies should not be confused with the multiple analogies discussed above. Multi-stage analogies are simply analogies, single or multiple, that

concern the generality of evolutionary scenarios as a whole. If Padian and Rayner are correct about the stringency of the constraints on the evolution of flapping flight in vertebrates, then a gliding stage should indeed be expected in all relevant scenarios. Such a result would be an important contribution to evolutionary theory. As such, multi-stage analogies are worthy of mention for their potential contribution to the theory of evolution, but there no obvious, special connection between them and multiple analogies as there is for scenario building.

3.4.4 Fecundity

Goldman (1992, p. 195) defines five measures of the epistemic benefits of social practises, including *fecundity*: The fecundity of a practise is its ability to lead to large numbers of true beliefs for many practitioners. A similar measure may be defined for analogies: The fecundity of an analogy is its ability to lead to the satisfaction of more goals for many analogizers. Multiple analogies are evidence of the fecundity of individual analogical comparisons.

Multiple analogies reflect the fecundity of analogical reasoning in two ways. The first way is by extension (section 2.5.5). When biologists suggest additional source analogs in support of the analogies of their collegues, they satisify their social goals and demonstrate the fecundity of the analogies in question. Thus, the extent to which an analogy admits additional source analogs is one measure of its fecundity as defined above.

The second way in which multiple analogies reflect the fecundity of analogical reasoning is by *schema application*. Gick and Holyoak (1983) show that people are

better able to solve problems by analogy if they are first presented with *several* similar problems and corresponding solutions. It appears that people tend to abstract the common elements of the solved problems into a schema and then proceed to apply that schema to the unsolved problem. Similarly, multiple analogies sometimes encourage the formation of schemata which may then be applied to novel aspects of the source and target domains of the original multiple analogy.

Consider the following example. In his general survey of dinosaur/ungulate analogies, Molnar (1977) pursues the Popperian scheme of Rudwick (1964) for making inferences to function from fossil morphology. Rudwick (1964, pp. 32–4) recognizes the need for analogical comparison, but insists that it is limited to clues arising from superficial resemblances, and nothing more. Calling inferences based on analogy "pseudo-methods", Rudwick (1964, p. 33) insists on the deduction of functions from first principles, despite the potentially excessive requirements of such a method:

> All we need, ideally, is a knowledge of the operational principles involved in all actual or conceivable ... mechanisms possible in this universe.

The idea of deducing natural history from first principles is reminiscent of the boast ascribed to Archimedes that he could move the Earth with a lever if given the right place to stand.

Although Molnar follows Rudwick's suggestion and presents many of his arguments in the form of deductions, he arrives at basically the same conclusions as Farlow and Dodson. Not surprisingly, Molnar makes frequent use of non-deductive arguments in his exposition, including a number of further analogies. Interestingly,

Molnar (1977, p. 180) concludes his article by suggesting that Farlow and Dodson's multiple analogies could be expanded:

> It is tempting to analogize the later protoceratopsids (*e.g.*, *Montanaceratops*) with the surviving primitive bovids [cattle] and the ceratopsids with the larger, more advanced bovids in terms of horn development. Because such primitive bovids are usually forest-dwelling forms, and the more advanced ones plains-dwelling, such an analogy would suggest similar habitats respectively for the later protocertopsids and ceratopsids.

In other words, Molnar is tempted to apply the pattern of ceratopsian/ungulate analogies elaborated by Farlow and Dodson but to issues of habitat in addition to issues of sexual selection. If ceratopsians and modern ungulates are analogous in their adaptations to sexual selection, then they might also be analogous in their adaptations to living in forests or plains. What Molnar appears to be doing, then, is forming a schema from Farlow and Dodson's multiple analogy and applying it to another problem with the same sources and target. To the extent that multiple analogies lend themselves to this kind of practise, they may be considered fecund by the definition given above. Since single analogies have a lesser tendency to lead to schema formation, they may be considered less fecund than multiple analogies.

3.5 Summary

The ceratopsian and *Archaeopteryx* examples indicate the importance of multiple analogies in scenario construction in evolutionary biology. The two examples are very different in some ways: Multiple analogies seem to have been decisive in changing the scientific explanation of ceratopsian horns and frills, but they have simply stimulated the controversy over evolutionary explanations of the origin of flight in *Archaeopteryx*. In the former case, multiple analogs all appear to support the same conclusion, namely that the outlandish headgear of male ceratopsians arose as a result of sexual selection rather than for defense against predators. In the latter case, multiple analogies appear to support both of the competing arboreal and cursorial explanations of the origin of flight in *Archaeopteryx*. But the different outcomes in the two examples serve to highlight the importance of the contribution of multiple analogies to theory construction and evaluation in each case. Where multiple analogies point in one direction, theory change occurs in that direction. Where multiple analogies point in opposite directions, controversy continues.

Both examples also highlight the contribution of visual mental imagery to the construction of multiple analogies. Visual mental imagery may be realized in a predicate-and-arguments form encoding spatial relations in a manner similar to the verbal representation now most prominent in the *Multiconstraint theory* and other theories of analogical thinking. However, visual imagery may also comprise more strictly visual forms of representation such a visual appearance or even visual, mental movies. The salience of visual information in the application of evolutionary biology to particular species, *e.g.*, the shape of bones, their relative spatial

layout, and how they might interact during locomotion, seem to prompt the use of visual imagery when evolutionary explanations are constructed. This fact may explain why evolutionary biologists are often found to be visual thinkers. Multiple analogies may be constructed with visual imagery much as they are with verbal representations.

However, the cognitive demands of dealing with multiple visual mental images are very high and mental images tend to be unstable. For these reasons, graphic visual representations may also participate in the construction of multiple analogies. Graphic representations are external versions of mental images and seem to function as an extension of working memory. Graphic representations are not unstable, and may be used to put separate images into significant arrangements, as demonstrated in figures 3.2 and 3.4.

Mental and graphic images may be used to store high-level or abstract information, at least in a form that may be read off into verbal representation. It is probably at this level that verbal and visual representations interact, rather than being interleaved in any particular low-level cognitive process. A high-level connection between visual and verbal cognitive processes is compatible with the view put forward by Crick (1994) that the neocortex of the brain (the frontal lobe) functions as an integrator of information from the higher levels of the perceptual cortices such as the visual cortex. In other words, low-level processes involved in vision and audition do not interact directly; high-level ones interact through the intermediary of the neocortex.

It was argued in chapter 2 that the constraint of *purpose* controlled the use of

multiple source analogs in analogy construction. The ceratopsian and *Archaeopteryx* examples discussed here support this position. These examples show the importance of analogies and multiple analogies in particular to the purpose of scenario building. Once the constraints on scenario building are properly understood, it becomes clear that multiple analogies tend to play a central role in determining the plausibility of one scenario over another. This fact has been appreciated by evolutionary biologists but has not been much discussed in the literature on the philosophy of biology. But it is necessary to understand where multiple analogies fit in the grand scheme of evolutionary explanation in order to understand the details of abstraction, exemplification, supplementation *etc*, as they arise in particular cases. Here, the grand scheme of evolutionary explanation is scenario building.

Another issue in the philosophy of biology concerning multiple analogies is their fecundity as a means of pursuing the goals of evolutionary science. Multiple analogies may be described as fecund in two ways. First, the process of extension taken up in chapter 2 shows that multiple analogies are fecund in the sense that they show how more researchers may construct more analogies. Second, multiple analogies may be considered fecund in the sense that they lend themselves to the formation and application of schemata. Such schemata may then be applied by other researchers in the construction of further analogies. These facts support the conclusion that multiple analogies are an effective social practise in evolutionary biology.

Having undertaken a study of multiple analogies in evolutionary biology in some depth, it is now necessary to add some breadth to this research by examining the nature and role of multiple analogies in other areas, such as archaeology.

Chapter 4

Multiple analogies in archaeology

The archaeologist who ha[s] ventured into ethnography would need to guard against basing all his assumptions on one contemporary culture. The point is that these assumptions must be based on a whole range of possibilities, not on any single ethnographic model.

Karl Heider

4.1 Analogies in archaeology

The use of analogies in archaeology has been both widespread and controversial. It is easy to understand why analogies should be widely used by archaeologists: Those archaeologists who set themselves the task of constructing hypotheses concerning bygone cultures naturally resort to comparisons between those cultures and the ones that the archaeologist may find (or read about) today. The number of possible explanations for some array of bones, ruins, refuse, and discarded tools is very large.

Some process by which modern day cultures generate similar arrays seems like an obvious place to begin the work of understanding the culture that left it.

As noted in section 2.1, the antiquarians who first became interested in archaeological issues used analogies for just this kind of reconstruction. For example, in 1699, Edward Lhywd (a protegé of Robert Plot) drew an analogy between the stone arrowheads made and used by contemporary North American Indians and arrowheads of unknown origin found on the ground in the Scottish Highlands. Noting the physical similarities between the two kinds of arrowheads, Lhywd proposed that the Scottish arrowheads were of ancient, human origin and used for hunting, as they were among the natives of North America. Describing his excursion through the Highlands to a friend, Lhywd says that he was "most diverted" by such arrowheads in use as amulets among the Highlanders, who believed them to be made by malicious elves and fired at men and animals from the sky (Gunther, 1945, p. 425):

> I doubt not but you have often seen of those Arrow-heads they ascribe to elfs or fairies: they are just the same chip'd flints the natives of New England head their arrows with at this day; and there are also several stone hatchets found in this kingdom, not unlike those of the Americans. ... These elf arrow-heads have not been used as amulets above thirty or forty years; but the use of the rest is immemorial: whence I gather they were not invented for charms, but were once used in shooting here, as they are still in America. The most curious, as well as the vulgar throughout this country, are satisfied they often drop out of the air, being shot by fairies, and relate many instances of it; but for my part, I

> must crave leave to suspend my faith, untill I see one of them descend.

Lhywd and other antiquarians used the analogy with North American Indians to reject not only the "vulgar" elf theory for stone arrowheads found in Europe, but also the more widely accepted theory that such items were the result of natural processes in the air or ground. This example typifies the role of analogy in archaeological thought.

But some archaeologists have raised objections to the pervasive use of analogy in their field. Some object that the reconstruction or explanation of particular, bygone cultures is not a primary goal of their profession, preferring instead the inference of laws or general principles governing human cultures. Gould (1980, p. x), for example, considers analogy to be part of the "intellectual wreckage" of traditional archaeological reasoning and proposes instead that

> The first element of any convincing approach to ethnoarchaeology involves establishing a basis for uniformitarianist kinds of generalizations about human behavior that are not subject to alteration or amendment....

Gould suggests that such generalizations would describe ways in which the natural environment invariably constrains human behavior and human material remains. However, Gould's objection is based in part on his strict adherence to a shared-attribute account of analogy (see Wylie, 1982), and should be considered with this point in mind.

Other archaeologists object to analogies because of their exclusion from logical-positivist theories of science. Binford (1967a, p. 235) states that

> The basic form of archaeological argument, or of any argument which seeks to formulate general propositions, should be logico-deductive.

In the same vein, Binford (1967b, p. 10) suggests that analogy serves, at most, to "provoke certain types of questions" which may be properly investigated in the logico-deductive manner. Here, Binford contends that if archaeology is to be scientific, and since analogies are not a proper part of scientific reasoning (following Popper), then archaeology must eschew analogies or at least exclude them from the so-called context of justification.

Finally, some archaeologists simply observe that analogies are not a source of logically valid inferences and point to cautionary tales that demonstrate how analogies lead to conclusions known to be false on other grounds. Heider (1967), for example, indicates how the material culture of the Dani people of New Guinea would tend to mislead archaeologists who might interpret that culture by comparison with familiar analogs. Heider (1967, p. 62) concludes with a plea for the use of multiple analogies in archaeological interpretation:

> ... the archaeologist who ha[s] ventured into ethnography would need to guard against basing all his assumptions on one contemporary culture. The point is that these assumptions must be based on a whole range of possibilities, not on any single ethnographic model.

In other words, archaeological conclusions should be informed by *several* relevant source analogs, not just the first one that the archaeologist considers. Unfortunately, Heider does not clarify how this sort of multiple comparison is to be accomplished.

Clearly, archaeology is fertile ground for anyone interested in issues of analogical reasoning. Because of the central place that analogy has assumed in archaeological research, the archaeological literature is well stocked with good examples of analogies in action. Many of these examples are, in fact, examples of multiple analogies suitable for investigation here. Because of its important similarities and differences with evolutionary biology, an examination of multiple analogies in archaeology can be expected to indicate the generality of the account of multiple analogies given in chapters 2 and 3. The most obvious similarity between the two disciplines is that they both involve the explanation of past events as evidenced by material remains. It is this common situation that makes analogical comparisons between past and present so important in both fields of research. The most obvious difference between archaeology and evolutionary biology is the lack of a unifying theory in archaeology corresponding to the neo-Darwinian synthesis in evolutionary science. Thus, although archaeologists are faced with a similar situation as evolutionary biologists, they do not have the same recourse to unifying concepts such as *adaptation* when generating hypotheses. In archaeology, then, multiple analogies must be constructed with less assurance that appropriate, system-level concepts are available.

In addition to the issues that archaeological examples raise on the nature of analogical reasoning, the controversy in archaeology over the place of analogy indicates that analogical reasoning raises important issues on the nature of archaeology. This part of the philosophical tradition in archaeology has examined various problems inherent in analogical reasoning and produced a range of recommendations, from

abandoning analogy to expanding it to multiple analogies. But, in the absense of any account of multiple analogies, the significance of this last recommendation has gone unexamined. With the account of multiple analogies developed here, however, the importance of multiple analogies to theoretical issues in archaeology may be addressed at last.

This chapter is aimed at constructing a dialog of sorts between archaeology and philosophy on the subject of multiple analogies along similar lines to the dialog conducted between biology and philosophy in the previous chapters. The purpose of this dialog is to explore the nature and role of multiple analogies in archaeological reasoning, and to examine the implications that multiple analogies have for philosophical issues in archaeology.

Section 4.2 describes multiple analogies used in the explanation of marks on prehistoric Peruvian pots;

Section 4.3 presents multiple analogies constructed for research into the significance of figurine legs from Neolithic Greece;

Section 4.4 discusses a multiple analogy used to defend a hypothesis that early North Americans did hunt mammoths;

Section 4.5 addresses the implications of these cases for the *Multiconstraint theory* in the areas of visual representation, target concept specificity, and supplementation, while

Section 4.6 presents the implications of reasoning by multiple analogy for philosophical issues in archaeology.

The result is an increased understanding of the nature of analogical reasoning for both philosophers and archaeologists.

4.2 Peruvian pots

A cogent and straightforward example of a multiple analogy in archaeology is provided by Donnan (1971). The example concerns the significance of odd marks or incisions found on the necks of Moche clay pots excavated along the north coast of the Peruvian Andes. Examination and excavation of 26 Moche (A.D. 100–800) sites yielded a copious collection of, among other things, utility-grade clay pots. These pots were made of coarse clay and showed signs of having been used over a fire, but showed no indications of having been decorated in any way. Most likely they were meant not for display, but for the routine storage and preparation of food.

Roughly ten percent display curious marks on their necks. The marks are small and inconspicuous, highly variable, and apparently made without care with a blunt instrument or a fingertip. The marks are also always confined to a single, small area on the neck of each pot on which they occur. Similar marks on clay pots from archaeological digs in other areas have yet to be reported. The question is simply: What is the meaning, if any, of these odd marks?

Donnan suggests a solution in terms an analogy with pots made by modern potters in central Peru. He reports that modern potters in this area put very similar marks, called *signáles*, on the necks of their coarse pots under two very particular circumstances. The first circumstance is illustrated by the potters of the village of Taricá which is a center of local ceramic production. On some occasions, the potters

sharing a single facility, either a kiln or storage shed, belong to separate economic units, *e.g.*, families. In order to distinguish their pots from those belonging to other economic units using the same facility at the same time, one or all parties mark their own pots with *signáles*. After the pots are ready, each potter can identify his own and market them separately.

The second circumstance is illustrated by traveling potters who visit isolated communities in the hinterland, such as Quihuay, to make and sell pots.[1] After taking sufficiently many orders for pots, the potters then produce and deliver them. On occasions when potters from different economic units travel together, they typically fire their pots in the same kiln in order to save on fuel costs. In order to distinguish their pots from those of other potters fired in the same lot, one or all parties mark their own pots with *signáles*. After the pots are ready, each potter can identify his own and deliver them appropriately.

This analogy may be represented as in table 4.1. The most important part of the analogy for present purposes is the set of system mappings. The system mappings in each domain briefly describe a plan of action for sharing pot production facilities while keeping the pots of different potters separated. The potters incise *signáles* on their pots in order that (*e.g.*, *in-order-that*$_{q0}$) the *signáles* may serve to identify those pots later on. Such an identification enables (*enable*$_q$) the potters to separate their pots from the pots of others. This separation, in turn, contributes to the ultimate goal (*in-order-that*$_{q1}$) of sharing fuel. The plans employed at Quihuay and Taricá are essentially the same, except that there is a wider range of things than

[1]Some of these potters are actually from Taricá, and make the rounds of remote villages in the spring.

Quihuay	Taricá	Moche
potters_q	potters_t	potters_m
pots_q	pots_t	pots_m
$\textit{signáles}_q$	$\textit{signáles}_t$	marks
fuel	facilities_t	facilities_m
$\text{incise}_q(\text{potters}_q,\text{pots}_q,\textit{signáles}_q)$	$\text{incise}_t(\text{potters}_t,\text{pots}_t,\textit{signáles}_t)$	$\text{incise}_m(\text{potters}_m,\text{pots}_m,\text{marks})$
$\text{identify}_q(\textit{signáles}_q,\text{pots}_q)$	$\text{identify}_t(\textit{signáles}_t,\text{pots}_t)$	$\text{identify}_m(\text{marks},\text{pots}_m)$
$\text{separate}_q(\text{potters}_q,\text{pots}_q)$	$\text{separate}_t(\text{potters}_t,\text{pots}_t)$	$\text{separate}_m(\text{potters}_m,\text{pots}_m)$
$\text{share}_q(\text{potters}_q,\text{fuel})$	$\text{share}_t(\text{potters}_t,\text{facilities}_t)$	$\text{share}_m(\text{potters}_m,\text{facilities}_m)$
$\text{in-order-that}_{q0}(\text{incise}_q,\text{identify}_q)$	$\text{in-order-that}_{t0}(\text{incise}_t,\text{identify}_t)$	$\text{in-order-that}_{m0}(\text{incise}_m,\text{identify}_m)$
$\text{enable}_q(\text{identify}_q,\text{separate}_q)$	$\text{enable}_t(\text{identify}_t,\text{separate}_t)$	$\text{enable}_m(\text{identify}_m,\text{separate}_m)$
$\text{in-order-that}_{q1}(\text{separate}_q,\text{share}_q)$	$\text{in-order-that}_{t1}(\text{separate}_t,\text{share}_t)$	$\text{in-order-that}_{m1}(\text{separate}_m,\text{share}_m)$

Table 4.1: A representation of the Quihuay+Taricá/Moche analogy given by Donnan (1971). The analogy imputes to the Moche a similar plan to that employed in Quihuay and Taricá for sharing production facilities while distinguishing pots.

fuel to share in the latter location. This plan is then imputed analogically to the Moche.

Donnan's analogy appears to be a strong one by the standards of the MT, the only difficulty being one of justifying the use of both the Taricá and Quihuay source domains instead of either one alone. Donnan (1971, p. 464) is quite clear about the reason: The activities of potters at Quihuay and Taricá take place under physical and economic circumstances that an archaeologist must regard as distinct. As noted above, in Quihuay the potters travel to their customers and take orders, whereas in Taricá the potters await their customers at a fixed location. But, in both cases, similar marks are made on the pots. It is curious, then, that Donnan draws no conclusions about the physical and economic practices of the Moche, whether Moche potters traveled the countryside (call this proposition 'A') or stayed in town ('B') or both ('A or B'). He says only that his analogy "provides an interesting hypothesis which could be tested when more data are made available" (Donnan, 1971, p. 466). The disjunction *A or B* seems a little indefinite, which might explain why Donnan stopped short of imputing it to the Moche it in the target of his analogy. This observation suggests that multiple analogies may be (1) favored when the use of several analogs permits the recognition of important distinctions (relevant to the field in question, *e.g.*, archaeology), and (2) limited in scope so that no disjunctive or indefinite predicates need to appear in the target analog.

Two further aspects of this analogy require comment. First, the connection between the sources and target gains credence due to the strong visual similarity of the modern *signáles* with the marks found on Moche pots. Donnan (1971, p. 466)

remarks that

> when the [modern] potters were shown ancient marks on fragments of Moche cooking vessels, they invariably identified them as *signáles*....

In other words, the appearance of the marks together with their position on the pots immediately reminds potters of *signáles*. Donnan also observes that the potters show no surprise at the age of the Moche vessels, suggesting the possibility of a continuous tradition of *signáles* in the region. But Donnan also observes, correctly, that his analogy is quite strong whether the tradition is continuous or not. Although not well captured by predicates such as those in table 4.1, visual similarities are often important in the construction of analogies (Holyoak and Thagard, 1995, pp. 113–4, 194), particularly in archaeology (Shelley, 1996).

Second, Donnan (1971, p. 466) draws attention to a further similarity between the Moche and present-day Peru, namely that marks or *signáles* are only infrequently found on pots. Most cooking pots past or present bear no such marks at all. Probably, this situation results because potters do not often share their facilities, although Donnan does not explicitly address this point. But, if this point were addressed, it might be possible to extend the analogy represented in table 4.1 to include the reasons that potters have to share facilities, and the infrequency with which those reasons apply in practice. Or, since the present analogy stands well on its own, it might be better to construct an *additional* analogy with the new information. The two analogies could then be linked in some other way than inclusion in one structure, perhaps by independently supporting predicates in the target, Moche domain.

4.3 Greek figurine legs

Another example of a multiple analogy involving clay artifacts is given by Talalay (1987). This example concerns the possible function of 18 unusual clay fragments found by archaeologists in five sites belonging to the Neolithic Peloponnese. The fragments appear to be clay replicas of individual, female legs with protruding buttocks, a painted or incised pubic triangle, incisions indicating a hand on the upper thigh, and simple, painted patterns of chevrons and stripes (Talalay, 1987, pp. 162–3). Traditionally, the legs have been interpreted as broken-off parts of Mother Goddess figures, but there is no evidence of any torsos to which the legs might once have been attached. But there is good evidence that each leg was once half of a pair of legs and that, in fact, these pairs of legs were manufactured in order to be broken apart (Talalay, 1987, p. 163). The question is: Why would anyone do that?

Historical and ethnographic analogies suggest that such objects might have been tokens which served to (1) seal a contract, or (2) attest to the identity of its bearer for special recognition. As Talalay notes, the ancient Greeks sometimes used the term *symbolon* to designate an object that may be split in half in order to seal an agreement or to facilitate later recognition. Examples of the former kind (1) are mentioned by Herodotus and appear to correspond to clay plaques excavated from the Athenian Agora. The plaques were cut in half along an irregular line so that each half could be joined only with its original partner. Possessors of such half-plaques could thus be uniquely identified as parties to a particular deal. Euripides uses the term *symbolon* in the second sense (2) in the *Medea*, where Jason offers

a number of them to Medea so that, once in exile from Corinth, she can expect hospitality from people who recognize them as tokens of their friendship with Jason.

Similarly, the classical Romans used *tesserae hospitalis* to describe tokens that were split up between friends so that those friends or their descendants might recognize each other and treat each other accordingly (2). Both Cicero and Plautus provide examples.

Non-western examples also exist for both uses of split tokens. The now obsolete Japanese term *warifu* was used to designate the tearing of pieces of material or paper in two in order to record an economic transaction (1). Each half was retained by one of the two parties involved as proof of their part in the deal. A similar practice allegedly exists in the American mafia, in which a bill of large denomination, carrying matching serial numbers at either end, is torn in two. Each party to a deal keeps one half as a promissory note that the rest of the transaction will be completed at the proper time and place (1).

In ancient China, bronze figures such as lions or cats were cast in two pieces in order to identify messengers. The leaders of two groups would each keep one half of such a figure. When messengers were sent from one to the other, the messenger was given one half of a figure which could then be matched with the other half upon his arrival. The figure thus served to identify the messenger as legitimate (2). A common dramatic device in fairy tales of the Far East concerns two children who are separated at birth and each given one half of a unique object. When the children grow into adults, they are reunited under unusual circumstances and their relationship is proven by matching the halves of the object back together (2).

Part of Talalay's analogy may be represented as in table 4.2. Talalay actually presents six source analogs, three for each of her basic divisions of (1) contractual records and (2) tokens of recognition; the Mafia source is of type 1, while the fairy tale source is of type 2. There are several important points to note about this analogy.

First, this example of multiple analogy shows a greater divergence of attributes than that of *signáles* and Peruvian pots discussed above (section 4.2). It is only at the relational, and especially the system levels where the correspondences become very close. This situation is the natural result of the wide variety of contexts on which Talalay has drawn. This variety has its pros and cons (Talalay, 1987, pp. 166–7). On the one hand, it suggests that the phenomenon is widespread and therefore applies readily to Neolithic Greece in particular. On the other hand, it suggests that the phenomenon has many diverse manifestations and therefore provides only vague conclusions. In her summary, Talalay (1987, p. 166) expresses this vagueness as a disjunctive conclusion:

> In each instance, the object served either as a contractual device or as an identifying token between individuals or groups, symbolizing an agreement, obligation, friendship, or a common bond.

In table 4.2, this vagueness is captured by the use of very general predicates in the target domain, *e.g.*, $recognize_{p0}(second\text{-}party_p, bond)$ where *recognize* and *bond* might have a variety of meanings in specific instances. The upshot of this situation is that a coherent analogy may indeed be constructed, but in somewhat non-specific terms. Vagueness is indeed the price for the sort of disjunctive conclusion that

Mafia	Fairy tale	Peleponnese
serial-number	token	figure
right-half	first-half	right-leg
left-half	second-half	left-leg
first-party$_m$	first-child	first-party$_p$
second-party$_m$	second-child	second-party$_p$
deal	father	bond
part-of$_{m0}$(serial-number,right-half)	part-of$_{f0}$(first-half,token)	part-of$_{p0}$(right-leg,figure)
part-of$_{m1}$(serial-number,left-half)	part-of$_{f1}$(second-half,token)	part-of$_{p1}$(left-leg,figure)
match$_m$(right-half,left-half)	match$_f$(first-half,left-half)	match$_p$(right-leg,left-leg)
keep$_{m0}$(first-party$_m$,right-half)	keep$_{f0}$(first-child,first-half)	keep$_{p0}$(first-party$_p$,right-leg)
keep$_{m1}$(second-party$_m$,left-half)	keep$_{f1}$(second-child,second-half)	keep$_{p1}$(second-party$_p$,left-leg)
agree-to$_{m0}$(first-party$_m$,deal)	belong-to$_{f0}$(first-child,father)	recognize$_{p0}$(first-party$_p$,bond)
agree-to$_{m1}$(second-party$_m$,deal)	belong-to$_{f1}$(second-child,father)	recognize$_{p1}$(second-party$_p$,bond)
because$_{m0}$(match$_m$,part-of$_{m0}$)	because$_{f0}$(match$_f$,part-of$_{f0}$)	because$_{p0}$(match$_p$,part-of$_{p0}$)
because$_{m1}$(match$_m$,part-of$_{m1}$)	because$_{f1}$(match$_f$,part-of$_{f1}$)	because$_{p1}$(match$_p$,part-of$_{p1}$)
because$_{m2}$(keep$_{m0}$,agree-to$_{m0}$)	because$_{f2}$(keep$_{f0}$,belong-to$_{f0}$)	because$_{p2}$(keep$_{p0}$,recognize$_{p0}$)
because$_{m3}$(keep$_{m1}$,agree-to$_{m1}$)	because$_{f3}$(keep$_{f1}$,belong-to$_{f1}$)	because$_{p3}$(keep$_{p1}$,recognize$_{p1}$)
attest-to$_m$(match$_m$,deal)	attest-to$_f$(match$_f$,father)	attest-to$_p$(match$_p$,bond)

Table 4.2: A representation of the analogy constructed by Talalay (1987) to the target of Neolithic clay legs found in the Peleponnese.

Donnan was evidently anxious to avoid.

A second point to note regarding the analogy represented in table 4.2 is that it captures only the logical or paradigmatic information from each source domain considered and leaves aside the narrative or syntagmatic information that is also given in each case. That is to say, although each source analog is provided in the form of a short anecdote describing a prototypical sequence of events involving two parties acting on a mutual understanding, the source columns in table 4.2 describe no sequence of events at all. This selectiveness is appropriate since Talalay is solely in pursuit of the socio-economic *function* of the Neolithic clay legs, and not in pursuit of whatever activities might have accompanied their use. There is certainly potential for confusion here. In the Eastern fairy tale, for example, the splitting and subsequent reunion of the two halves kept by each child parallels the splitting and subsequent reunion of the children themselves. However apt, this analogy of motifs is irrelevant to Talalay's purpose and, if included in table 4.2, would only serve to weaken the coherence of the analogy where the problem at hand is concerned.

4.4 Clovis mammoth harvesting

A final example of reasoning with multiple analogies in archaeology concerns the possible role of human hunters in the extinction of the mammoth in North America. Mammoths became extinct in North America roughly 11,000 years ago, at about the same time that the "Clovis hunters" are thought to have swept across the continent. Clovis points, or stone spearheads similar to those found at Clovis, New Mexico, are sometimes found in association with the archaeological remains of mammoths,

suggesting that the owners of the spears used them to kill the mammoths. Perhaps human hunting was the factor that brought about the mammoths' extinction.

Before any such general hypothesis can be evaluated, the hypothesis that humans harvested mammoths *at all* must be examined. The simple association of Clovis points with mammoth remains does not prove that the spears were used to dispatch the mammoths. The association could be accidental, or the mammoth might have been scavenged rather than hunted. But there are analogies with the hunting of elephants in modern Africa which suggest that mammoth hunting is a definite possibility (see Kelley and Hanen, 1988, pp. 338–43). For example, tribes such as the semi-nomadic Efe pygmies and the village-dwelling Lese still hunt elephants in the Ituri Forest in the Congo and therefore suggest themselves as analogs of ancient mammoth hunters (Fisher, 1992). One problem with these analogies is that these modern hunters typically break open the femurs and humeri of the elephants in order to extract the fat and marrow stored in them. Marrow is sought out by the elephant hunters because it tastes good and supplies needed dietary fats that are scarce in animal muscle tissues. Yet there is very little evidence that the Clovis hunters ever broke open mammoth bones in search of marrow (Haynes, 1991, pp. 292–3). Thus, the comparison of mammoth hunting with elephant hunting seems to produce a significant *disanalogy* that weighs against the hypothesis that the Clovis people hunted or harvested mammoths at all (Haynes, 1991, p. 304).

Haynes (1991, pp. 304–9) attempts to overcome this disanalogy by developing a multiple analogy mapping non-human carnivores and different modern elephant hunters to Clovis hunters. First, Haynes (1991, pp. 304–8) notes that the degree to

which large carnivores consume a carcass depends upon the difficulty they have in obtaining their next meal. When the prospects for another meal are low, carnivores tend to clean their plates, whereas when prospects are good, carnivores tend to eat what they like and leave the rest. North American wolves display this behavior when their typical prey, bison, deer, and moose, are vulnerable (Haynes, 1991, p. 306):

> Wherever North American wolves find hunting easy, they often wander away from prey herds and carcasses to explore other parts of the landscape. They may choose to risk losing contact with prey and even voluntarily abandon uneaten meat because they have the security of knowing that if more meat cannot be procured, then at least they can return to the old carcass sites. Spotted hyenas in southern Africa have the same kind of security during very dry seasons; when ungulates are weakened by drought conditions and starvation, hyenas are content to nibble at the carcasses of elephants, as a result of which many carcasses remain largely intact.

Haynes (1991, p. 308) proceeds to suggest that the Clovis hunters may similarly have made light use of mammoths when those mammoths were under stresses such as drought. Like modern elephants, a drought or late winter freeze-up would have weakened the mammoths and caused them to congregate at sources of water, making them especially vulnerable to predation in numbers. Clovis hunters encountering groups of mammoths under such conditions might have dispatched them with relative ease and utilized them lightly due to their abundance. This analogy

would tend to explain why archaeologists typically find the largely intact remains of groups of mammoths at Clovis "kill" sites.

Haynes (1991, pp. 308–9) adds that there *are* examples of modern elephant hunts by humans in which the carcasses are lightly utilized: at elephant culls designed to reduce elephant populations within a specific region. At these events, whole herds of elephants are shot dead within seconds. Carcass use is very light—generally restricted to the removal of lower jaws and tusks—because the hunters have other sources of food and do not subsist on elephant meat or marrow. Thus the femurs and humeri of the elephants are left intact. If Clovis hunters similarly killed mammoths *en masse* and butchered them quickly, then they would leave groups of intact skeletons just as archaeologists have found.

The analogy developed by Haynes may be represented as in table 4.3. The mappings at the system level describe a scenario in which wolves and hunters are able to kill large numbers of elephants, mammoths, or bison because the animals are weak and clustered together. The fact that they kill so many prey animals easily enables the predators to ignore the marrow contained in the femurs and humeri of their prey. Thus, since they prefer other forms of food anyway, the predators ignore the marrow altogether, leaving the marrow-bearing bones intact for archaeologists to find many years later.

Unlike the analogy by Talalay discussed in section 4.3, this analogy concerns the explanation for a series of events, which is why it is given in terms of physical requisites, *e.g.*, *enable*, and causes. The purpose of this exercise is to infer a plausible scenario that would result in collections of many mammoths without broken

Elephant culls	Bison kills	Mammoths kills
hunters_e	wolves	hunters_m
many-elephants	many-bison	many-mammoths
	drought	freeze-up
	water-holes_b	water-holes_m
marrow-bones_e	marrow-bones_b	marrow-bones_m
groceries	fresh-meat_b	fresh-meat_m
	cluster-at_b(many-bison,water-holes)	cluster-at_m(many-mammoths,water-holes)
	weaken_b(drought,many-bison)	weaken_m(freeze-up,many-mammoths)
kill_e(hunters_e,many-elephants)	kill_b(wolves,many-bison)	kill_m(hunters_m,many-mammoths)
ignore_e(hunters_e,marrow-bones_e)	ignore_b(wolves,marrow-bones_b)	ignore_m(hunters_m,marrow-bones_m)
prefer_e(hunters_e,groceries)	prefer_b(wolves,fresh-meat_b)	prefer_m(hunters_m,fresh-meat_m)
	enable_{b0}(cluster-at_b,kill_b)	enable_{m0}(cluster-at_m,kill_m)
	enable_{b1}(weaken_b,kill_b)	enable_{m1}(weaken_m,kill_m)
enable_e(kill_e,ignore_e)	enable_{b2}(kill_b,ignore_b)	enable_{m2}(kill_m,ignore_m)
cause_e(prefer_e,ignore_e)	cause_b(prefer_b,ignore_b)	cause_m(prefer_m,ignore_m)

Table 4.3: A representation of the analogy between wolves and elephant cullers with Clovis hunters from Haynes (1991). Note that the *elephant cull* domain is left deliberately incomplete.

marrow bones. The analogy constructed by Haynes provides just such a scenario by plausibly supporting the predicate $ignore_m$ in the target, Clovis domain. If the Clovis hunters did ignore marrow bones when they killed many mammoths, then the result would be just the kinds of remains that archaeologists do, in fact, find. From this we may conclude, at least, that the Clovis hunting scenario built up by the analogy is a plausible explanation for the findings made by archaeologists today.

Another important point to note about the analogy represented in table 4.3 is that the *elephant* source domain is only partially complete. In fact, this incompleteness reflects the fact that only some of the information about modern hunters engaged in elephant culls is relevant. Elephants are not culled because they are weak or because they cluster around water holes. They are culled simply because there are too many of them. We are invited to consider only the fact that these hunters ignore the elephant marrow bones because this fact suggests that humans will act in the same way, out of a motive similar to that of wild carnivores such as wolves. In effect, the *elephant* source domain is used mainly to substitute *hunters* for *wolves*, and *elephants* for *bison*. This substitution allows Haynes to sharpen his conclusions in two ways: (1) to address humans specifically rather than predators in general, and (2) to describe those humans hunting elephants, which are much more similar to mammoths than bison are. By making these substitutions, Haynes makes his target analog as specific as possible to the task at hand, thus enhancing its suitability for his purposes.

4.5 Implications for multiple analogies

The above discussion indicates that multiple analogies are indeed part of the practice of archaeological inference. But several issues regarding the nature of reasoning by multiple analogy remain vague. The remainder of this section provides a discussion of some specific points that were not addressed in the examples discussed above. In particular, this section addresses issues concerning the role of visual mental imagery, specificity, and supplementation in multiple analogies.

4.5.1 Visual imagery

Like many biologists, archaeologists often seem to be visual thinkers—that is, they are disposed to think about things by imagining them in their "mind's eye" (section 3.4.1). This fact is not surprising for people in a discipline that demands the interpretation of multitudes of macroscopic objects, like bones, stone tools, pot shards, and so on. The shape, orientation, and relative position of solid objects may be important data for an archaeologist to explain in the process of constructing a theory. The examples of multiple analogy discussed above seem to show the influence of these cognitive demands.

In the cases of the Moche pots (section 4.2) and Greek figurine legs (section 4.3), the physical appearance of some object is itself the thing to be explained by the archaeologist. In table 4.1, for example, the predicates *signáles* and *marks* represent the physical attributes that require explanation. Visually, as Donnan points out, the marks on Moche pots are very similar to the modern *signáles*, which suggests that they might all be explained as the result of similar processes. This similarity

is not captured by the verbal representations *marks* and *signáles*, which do not much resemble one another at all. Thus, the representation of this analogy given in table 4.1 probably fails to capture what Donnan actually had in mind when he considered the problem. The MT recognizes the role of visual similarity in attribute matches as in this case, but the details of how visual similarity may be represented (as required for a computer model) are not yet clear. A number of cognitive models of visual representations and procedures have been put forward, *e.g.*, shape grammars (Leyton, 1989, 1992), array theory (Glasgow and Papadias, 1992), and graph grammars (Thagard and Shelley, 1997), but none of these frameworks has been applied to models of analogy. Adapting current models of analogy to use these representations (or *vice versa*) would undoubtedly shed some light on the whole issue.

Visual imagery is also not confined to the representation of static, physical properties such as the shape. Physical *processes* may also be visualized in progress. In Talalay's analogy among split objects, the processes of splitting and fitting back together may be represented in action in the mind's eye. In other words, rather than having the representation $match_m$, one might simply imagine a shadowy mafia figure tearing a thousand dollar bill in half and then later matching the halves together. This sort of representation could be thought of as a mental movie as opposed to a mental word. Psychological research indicates that both visual and linguistic representations are activated in the process of reading, depending on whether the reading material is concrete or abstract (Paivio, 1983). The same may well be true of analogy construction, depending on whether one is interested in the vertical or

horizontal directions as outline below.

The vertical direction of an analogy concerns the associations within each domain, such as the *mafia* column in table 4.2. Verbal representations are better suited for this direction in the sense that system-level predicates such as *because* are almost inherently abstract, making it somewhat difficult to conceive of them as represented by mental movies. What is the visual representation of *because*? The horizontal direction concerns mappings between domains, where visual representations may still be appropriate. The visual similarity between mental movies of $match_m$ and $match_p$, for example, are quite adequate to sustain a mapping between them for the purposes of perceptual similarity. The ability of people to use different cognitive representations, at least from visual to verbal, according to the demands of the task at hand has been demonstrated in experiments on problem-solving (Kaufmann, 1990). The same ability appears to be operative in the examples of archaeological reasoning discussed above.

Visual imagery may be especially important for analogical reasoning with *multiple* sources. One of the limitations of using visual imagery is its very concreteness. Visual images, mental or physical, typically represent details about the appearance of objects that may prove to be ultimately irrelevant to completing any particular task, at least where the use of single images is concerned (Finke, 1989; Chambers and Reisberg, 1992). But, as the Gestalt psychologists noted in the case of visual perception, similar elements of an image tend to be percieved as belonging together in a group. For example, by the principle of *common fate*, objects that appear to undergo the same movement in the same way are perceived as belonging to a single

unit. If this principle may also be applied to mental movies such as $match_m$ and $match_p$, then the common fate of the banknote and the figurine legs would make those objects appear to belong together. In other words, a mapping between the mental movies of $match_m$ and $match_p$ would be made in which common fate counts as semantic similarity. Since the principle works for several objects as well as for two objects, multiple mappings are as easy to create as single ones. Perhaps other Gestaltist unit-forming principles could be used to represent perceptual similarity in visual images and mental movies.

In this circumstance, then, the presence of visual details facilitates rather than hinders the process of analogy construction. Details tend to make sundry objects within an image more distinct from one another, which makes comparisons with similar objects in other images easier. Objects shared among *several* images stand out even more for this same reason. Thus, the relative wealth of information in imagery seems to aid the identification of properties shared by *several* source domains. In the analogy put forward by Talalay, for example, the visual similarity of acts of breaking or tearing objects in half across six different sources probably aided Talalay in aligning the broader activities in which those acts occurred. In other words, noting the visual similarity of the acts of breaking an object in halves and then matching those halves from several domains may well have been the cue for the construction of analogies among those domains. The remainder of this construction process might then consist of aligning the other objects found upon inspection of each object-breaking scene. *e.g.*, the characters doing the breaking and matching.

4.5.2 Specificity

Wylie (1985, p. 98) notes that the use of multiple sources may contribute to the strength of an analogy by increasing confidence that the presence of some feature in all domains is not merely a coincidence. On this view, the motivation for expanding an analogy in the horizontal direction is the same as that for expanding it in the vertical direction. Recall Mill's view (section 1.5) that the strength of an analogy is proportional to the absolute number of features shared by the source and target. Cast in terms of the MT, this principle would state that the strength of an analogy is proportional to the number of mappings or rows that it conveys. Wylie suggests that the strength of an analogy is also proportional to the number of sources or columns that it conveys.

There are, however, a couple of difficulties with this tentative principle. The first limitation is simply that a very large number of sources would tend to cause confusion in the mind of the analogizer. In other words, the utility of multiple sources is subject to the number which an archaeologist can keep straight in his mind (or computer). The second and more serious limitation is the vagueness that multiple sources might introduce into the target. In the models of analogy discussed in chapter 1, only mappings between *identical* features are contemplated. But, as is the case in the MT, most actual analogies contain mappings between similar but *non-identical* features. The result is that, in order to be coherent with all the predicates in the multiple source domains, some predicates in the target domain may be vague or broadly defined. In short, there is a potential trade-off between the specificity of the representation of the target and the number of sources given

in an analogy.

Effects of this trade-off are evident in the pot and figurine leg analogies discussed above (sections 4.2 and 4.3). In his discussion of their pots, Donnan avoids drawing any conclusions about whether the Moche potters located themselves centrally or whether they traveled around taking orders for their wares. Each of the two sources he describes support only one alternative, meaning that his conclusion, were it included in the target domain, would have to be coherent with both possibilities. It seems that such a non-specific conclusion is undesirable enough to cause Donnan to avoid the issue altogether, which leaves him with a very strong analogy strictly concerning the sharing of potting facilities.

Talalay takes a different approach, including a large number of somewhat divergent sources in her analogy. As a result, her conclusion is somewhat vague, stating that the clay legs of the Neolithic Peleponnese functioned as (1) symbols of a contractual undertaking or (2) means of future recognition. These concepts are similar, but not identical, and are therefore represented in the target by the broad notion of a *bond*. But the sacrifice of specificity in this representation may be warranted by the specificity retained by the predicate $match_p$ (table 4.2). In other words, Talalay's purpose was to motivate the conclusion that the figurine legs were intended to be split into matching halves, a conclusion that cannot otherwise be regarded as obvious. The sources that she gives remain very coherent where the concept of *match* is concerned, so the support of six sources is worth the resulting vagueness elsewhere in the analogy.

4.5.3 Supplementation

An important exception to the trade-off relationship described above (section 4.5.2) is given by Haynes (section 4.4). Haynes does not add the *elephant cull* source simply to increase the number of sources in favor of his hypothesis, nor to make his conclusion less specific. Rather, this source is added to overcome some specific dissimilarities between his main source and the target domain.

Initially, Haynes draws a single analogy between carnivores such as wolves and prehistoric humans in the hunting of bison and mammoths, respectively. But humans and wolves are not simply comparable where their motivations and general psychology are concerned, nor do mammoths and bison present quite the same challenges to either predator. The semantic dissimilarities in the relevant mappings leave the single analogy somewhat weak as a result. The dissimilarities are partially hidden by the use of predicates like *ignore* and *prefer* to describe both human and animal actions and motivations in table 4.3. In effect, their application tends to anthropomorphisize the wolves, whose mental states may not be adequately or appropriately described in predicate notation. But it is difficult to give any description of the mental states of animals in English *without* resorting to such metaphors. To overcome these dissimilarities, a human source analog is offered in only enough detail to address the problem.

This process of using one source to repair another may be called *supplementation* (see section 2.5.4), and it appears to be a generally useful strategy for building up a composite source out of components that are inadequate when considered on their own (Wylie, 1985, p. 106). Some archaeologists, *e.g.*, Gould (1980) (see section 4.1),

have claimed that reasoning by analogy limits them to construing each past culture solely in terms of some present one, thus making it impossible to understand past cultures that are unlike any culture of today. The process of supplementation in multiple analogies clearly enables the archaeologist to overcome this objection, just as the same process helps biologists to overcome the limitations of the fossil record (section 2.5.4).

4.6 Analogies in archaeological theory

The points addressed above highlight qualities of multiple analogical inference that demand the attention of philosophers and cognitive scientists. But the discussion so far does not fully reveal the contribution that a cognitive theory of analogy such as the MT can make to those people interested in issues of archaeological theory and practise. In other words, it remains to show to archaeologists what the above discussion implies about archaeology. The remainder of this section addresses this point, looking specifically at the coverage of the term *analogy* and the advantages in clarity gained by adopting a more adequate theory of the subject, as well as a special difficulty facing archaeologists who seek to use multiple analogies.

As noted in section 4.1, analogy has had a varying career in archaeological theory and practice. For one thing, the term *analogy* has been used to cover a variety of facts about the nature of archaeological inference. Some archaeologists have made very strong claims about the centrality of analogy to archaeological epistemology. Chang (1967, p. 230), for example, states that

> Indeed, in a broad sense, archaeological reconstruction *is* analogy, with

or without explicit ethnological recourse.

Similarly, Ascher (1961, p. 317) states that "the most widely used of the tools of archaeological interpretation is analogy", while Hodder (1983, p. 9) comments that "all archaeology is based on analogy...." Of course, these statements do not gibe with the description of analogy given above. Not every inference made by archaeologists is an analogy. Chang, Ascher and Hodder mean simply that all inferences about the past are informed by knowledge of the present and that comparisons between the two are therefore inevitable. But these varying uses of *analogy* illustrate the need to be clear about what sense of the term is under consideration. For current purposes, *analogy* refers to an inference based on a structured comparison and distinct from deduction, say, and as represented in human cognition.

Mill's model of analogy and analogical inference has had the most influence in archaeology, as it has in philosophy. Recall the version presented by Salmon (1984) (section 1.5):

Objects of type X have properties G, H, *etc.*

Objects of type Y have properties G, H, *etc.*

<u>Objects of type X have property F.</u>

So, objects of type Y have property F.

As it stands, this characterization of analogy is very limited. In fact, it is equivalent to the construction solely of *attribute* mappings in the MT, and leaves the relational and system mappings unrepresented. Of course, Salmon (1984) is well aware that relations between features, as well as causal connections, are relevant to the construction and evaluation of analogies, but these considerations are omitted

from the definition. The practical result of such inadequate formal definitions has been to license archaeologists to present as analogies comparisons that amount only to lists of shared features. This situation does encourage the use of multiple sources in analogy construction, since it is relatively easy to find many objects that simply share some set of features. But these analogies are typically weakened by the lack of consideration for relational and system mappings.

Of course, it is unfair to lay the whole blame for this situation at the door of current, formal definitions of analogy. As Wylie (1985, pp. 65–7) points out, the tradition in 19th century archaeology *was* to construct analogies by simply listing shared features. This habit eventually helped to bring that form of archaeology into disrepute. However, the current tendency to give such lists is likely to be partly a holdover from these former days. But with the increasing sophistication of cognitive theories of analogy, archaeologists would be well advised to turn to theories such as the MT for a more adequate model of analogy construction. As the above discussion shows, this theory can be made to provide for explicit representations of entire analogies, whether single or multiple.

Another methodological difficulty confronting archaeologists when constructing analogies is the diversity of explanatory schemata that might be relevant to any particular case. This point is most clearly made by briefly comparing analogies in archaeology with analogies in evolutionary biology. Recall the multiple analogy given in table 2.3. The system-level mappings describe the adaptive relationships among the rod-pigments in the eyes of various fish and their depth of habitation. Having eyes that best absorb light at wavelengths of 472 and 474 nm enables the

fish *Centroscymnus* and *Ruvettus* to see in deep ocean water (200-300m) because that is the only sort of light which penetrates to such depths. Thus, being able to absorb light at those wavelengths counts as an adaptation to inhabiting deep ocean water. Since the Coelacanth *Latimeria chalumnae* has eyes that best absorb light at a similar frequency, biologists infer by multiple analogy that the Coelancanth lives at a similar depth. The combination of system-level relations in each domain is really just a pre-fabricated template, as it were, provided by evolutionary theory to help decide when something may count as an adaptation. This same template may be applied to many other situations. The point here is that evolutionary theory provides a set of worked-out concepts like *adapt* that biologists may apply in appropriate circumstances.

Archaeologists, although faced with similar sorts of problems as biologists, are not in a similar position. Rather than having one unified theoretical framework to apply, archaeologists may select their unifying concepts from any number of interpretive theories such as culture-historical archaeology, Marxist archaeology, functionalist archaeology, feminist archaeology, Neo-evolutionist archaeology, New archaeology, *etc.* (see Trigger, 1989), any of which may suggest results contradictory to the others. Some archaeologists, *e.g.*, Gould and Watson (1982), suggest that analogies would be improved by selecting explanatory concepts from only one of these possible areas, but many prefer to consider the alternatives that each area provides. But the lack of a unified theory does make archaeological analogies vulnerable to disputes over theory selection. An archaeologist may be accused of using entirely the wrong system relations when constructing an analogy, and the use of

multiple sources only multiplies the opportunities to level such charges. There is no obvious cure for this particular problem, but it points to yet another trade-off that archaeologists must face when using multiple analogies: Increasing the number of sources also means increasing the number of theoretically-motivated challenges that may be raised against the analogy as a whole. Such a difficulty may be particularly acute where some analogical sources are used to supplement others, as in the Clovis-hunter example (section 4.4) where biological and cultural sources were combined without comment on the appropriateness of putting together representations from both of those categories. In similar circumstances, Walker and Shipman (1996, p. 137) comment that human and animal comparisons help to free them from "homocentrism". Perhaps this sort of argument is a line of defense that could be developed.

Finally, it is appropriate to comment on the relevance of multiple analogies to the positivist distinction between the "context of discovery" and the "context of justification", introduced into the archaeological discourse by the New Archaeology of the 1960s (see Wylie, 1985, pp. 86–8). Archaeologists such as Binford (1967b) sought to secure the scientific status of archaeology by applying models of scientific inquiry from positivist philosophers of science. Such models included a rigid distinction between a phase of inquiry in which hypotheses are generated (the "context of discovery") and a phase in which those hypotheses are evaluated (the "context of justification"). The two phases were regarded as independent, meaning that no data used to generate a hypothesis could then be offered as evidence that the hypothesis is correct. Also, justification was held to require the *deduction* of predic-

tions from hypotheses, which, of course, precludes the use of analogical reasoning in this phase. Thus, the New Archaeologists tended to restrict *analogical* reasoning to the context of discovery, in which the uncertainty inherent in analogy could be accepted, however unwillingly.

It has been shown elsewhere that this distinction between the contexts of discovery and justification is untenable (see Wylie, 1985, pp. 87–8). But it is worthwhile noting that multiple analogies also appear to weigh against this distinction. From the examples discussed in this chapter, it appears that sources may be added to analogies for the purposes either of hypothesis generation *or* confirmation. In the case of Donnan's analogy of Moche and Peruvian pots (section 4.2), both Quihuay and Taricá sources seem to have been considered at the time of hypothesis generation. Both sources apply to a single area and time, and both even involve the same people, and thus would have naturally suggested themselves at one time. The other cases, Talalay's and Haynes's analogies (sections 4.3 and 4.4) seem to have been the result of a deliberate search for further confirmation of a hypothesis that was already formed in the light of earlier analogizing. Thus, the formation of these multiple analogies bridges the discovery/justification gap. This situation creates a dilemma in which either multiple analogies or the discovery/justification distinction must go. In this case, the distinction is the clear loser. The occurrence of multiple analogies in archaeological reasoning suggests that confidence in one's conclusions cannot be neatly divided into two separate phases of research.

4.7 Summary

Analogies have always been important to archaeological research and continue to be so. Due to this importance, the field of archaeology is fertile ground for philosophers and cognitive scientists interested in the nature of analogy and the ways in which it applied for scientific inference. In some respects, archaeologists find themselves in a similar situation to evolutionary biologists. Both often construct hypotheses about the past based on comparisons with the present. Also, researchers in both fields base their reconstruction on objects excavated from the ground. This similarity of situation produces some similarities of practice. For example, both archaeologists and evolutionary biologists appear to find visual mental imagery useful when constructing multiple analogies. Also, both kinds of scientists find the process of supplementation useful in overcoming the limited supply of modern analogs upon which they must base their analogies.

In other respects, however, archaeologists and evolutionary biologists are in a very different situation. The theory of evolution provides a set of abstract concepts that biologists may rely upon for construction of multiple analogies. There is no such unifying theory in archaeology. Thus, archaeologists face greater difficulty in constructing convincing multiple analogies. In order to overcome this difficulty, archaeologists often use several source analogs to bolster confidence in their analogies, but then face the trade-off of thereby introducing ambiguities into their conclusions. In other words, archaeologists must pay careful attention to their sources in order to control the specificity of their conclusions.

This chapter also shows that archaeologists interested in the epistemological

issues raised by their discipline can benefit by viewing these issues from the vantage point of cognitive theories like the MT. Applying the MT to analogical reasoning in archaeology helps to clarify what may be covered by the term *analogy* and to redress the inadequacies of older theories of analogy as descriptions of archaeological practise. In addition, the examination of multiple analogies given in this chapter serves to clarify theoretical issues in archaeology arising from the combination of sources in multiple analogies, and emphasises the inability of positivist theories to capture the contribution of analogical reasoning in archaeological science.

This chapter also supports the position that multiple analogies have an important place in scientific reasoning in general. But, of course, multiple analogies are not confined to the sciences. To support the position that multiple analogies, as such, are a general phenomenon of philosophical interest, it is necessary to examine their occurence in other fields. Perhaps the best way of undertaking this task is to examine the role of multiple analogies in philosophy itself. Given the vastness of the literature involved, it would be impractical to attempt a general survey, so the method adopted in chapter 5 is to go to the source, namely Plato.

Chapter 5

Multiple analogies in Plato's *Republic*

Judging by the usual analogy of nature, no form can continue when transferred to a condition of life very different from the original one, in which it was placed. Trees perish in the water, fishes in the air, animals in the earth. Even so small a difference as that of climate is often fatal. What reason then to imagine, that an immense alteration, such as is made on the soul by the dissolution of its body and all its organs of thought and sensation, can be effected without the dissolution of the whole?

Hume, *On the immortality of the soul*, pp. 34–5.

5.1 Analogies in Plato's philosophy

Despite the fact that he condemns analogies as inherently misleading, Plato frequently resorts to them in order to support inferences or move the conversation

along. In fact, analogical reasoning plays a more important role in the middle dialogs than the method of hypothesis—in which a proposition is provisionally adopted as true in order to explore its faults and merits—even though Plato claims that the method of hypothesis is his preferred one (Robinson, 1953, p. 202).

The ubiquity of analogy is sometimes indicated by the characters in the dialogs themselves when, for instance, they tease Socrates for resorting to analogies so often. For example, when Socrates introduces the analogy of the state to a ship (the "ship of state"), Adeimantus remarks on the use of yet another analogy with a bit of sarcasm (6.487e–8a):[1]

> [Socrates:] "The question you are asking," I said, "needs an answer given through an image."
>
> [Adeimantus:] "And you, in particular," he said, "I suppose, aren't used to speaking through such images."
>
> "All right," I said. "Are you making fun of me after having involved me in an argument so hard to prove? At all events, listen to the image so you may see still more how greedy I am for images."

As Robinson (1953, p. 221) notes, Plato uses the term 'image' [*eikôn*] to describe every major analogy in the *Republic*. The term generally refers to paintings or other reproductions, but is broader in meaning and may be rendered as "likeness" or "projection" when it is used to designate a comparison. Socrates is also teased about his frequent use of images in the *Symposium* (221e–2a), when Alcibiades

[1] All translations from the *Republic* in this chapter are from Bloom (1968), unless otherwise noted.

drunkenly praises Socrates to the guests at Agathon's celebratory party (translation from Hamilton and Cairns, 1963):

> [Alcibiades:] Anyone listening to Socrates for the first time would find his arguments simply laughable: he wraps them up in just the kind of expressions you'd expect of such an insufferable satyr. He talks about pack asses and blacksmiths and shoemakers and tanners, and he always seems to be saying the same old thing in just the same old way, so that anyone who wasn't used to his style and wasn't very quick on the uptake would naturally take it for the most utter nonsense. But if you open up his arguments, and really get into the skin of them, you'll find that they're the only arguments in the world that have any sense at all, and that nobody else's are so godlike, so rich in images of virtue, or so peculiarly, so entirely pertinent to those inquiries that help the seeker on his way to the goal of true nobility.

Here, Alcibiades refers to Socrates' habit of comparing human ethical and political virtues to the skills [*technê*] of craftsmen such as blacksmiths, shoemakers, *etc.* These images of virtue sound outlandish at first, but are ultimately very persuasive, certainly to Alcibiades. This kind of attention paid to analogies indicates their importance to the dialectical process in the middle dialogs.

Beginning with Aristotle, philosophers since Plato's time have paid much attention to Plato's analogies, but their reactions have been circumscribed by the theory of analogy used for the purpose. Like Aristotle, most philosophers have applied the *proportional* theory of analogy to this issue, a theory which states that

analogies are four-part structures within a particular system of relationships that may be represented in the form A:B::C:D or "A is to B as C is to D" in English (see section 1.3). Given the inadequacies of this theory as an account of analogy (chapter 2), the result is an inadequate understanding of Plato's analogies. In particular, application of the proportional theory prevents us from understanding Plato's use of multiple analogies.

The purpose of this chapter is to analyze examples of multiple analogies from Plato's *Republic*. Multiple analogies are common in this dialog; indeed, many of the major analogies presented *are* multiple analogies. Recall the analogy between the organization of the human soul on the one hand and the organization of a city and a flock of sheep on the other hand from section 1.2. Lessons learned from the previous chapters are applied to produce a better understanding of the multiple analogies given by Plato, and to find out what Plato's multiple analogies can tell us about multiple analogies in general. This chapter also takes advantage of the opportunity to discuss Plato's own awareness of such analogies or at least the issues raised by them.

Section 5.2 presents Plato's comparison of the soul to eyes, ears, and pruning knives;

Section 5.3 treats Plato's analogy between the health of the body and the justice of the state;

Section 5.4 provides a discussion of Plato's comparison of poets to painters and tragedians;

Section 5.5 reviews the issues raised in the previous sections concerning the nature of multiple analogies, including complementation and narrative representation, specificity, and supplementation;

Section 5.6 presents evidence of Plato's awareness of multiple analogies in the *Republic*.

This chapter gives modern scholars a better appreciation of some of Plato's analogies, of Plato as a sophisticated creator of analogies, and of the cognitive aspects of multiple analogies in the domain of philosophical thinking.

5.2 The function of the soul

A fairly straightforward example of a multiple analogy occurs in Book I of the *Republic*. Socrates, having been challenged by Thrasymachus to show that justice is more desirable than injustice, provides three arguments, the last of which relies on a multiple analogy (1.352d–3e). Thrasymachus has already agreed that justice is a virtue (1.350d); now Socrates wishes to argue that a virtue is the condition that allows a thing to work well. Specifically, Socrates wishes to argue that justice is desirable because it enables the soul to function in the way that is proper to it.

Socrates undertakes the argument by first asking Thrasymachus about the proper functions (or "work") of eyes, ears, and pruning knives (1.352e–3a):[2]

[2]To be precise, Socrates first asks Thrasymachus about the proper function of a horse, but Thrasymachus does not understand the question and Socrates never explicitly returns to that analog.

> [Socrates:] "Look at it this way: is there anything with which you could see other than eyes?"
>
> [Thrasymachus:] "Surely not."
>
> "And what about this? Could you hear with anything other than ears?"
>
> "By no means."
>
> "Then wouldn't we justly assert that this is the work of each?"
>
> "Certainly."
>
> "And what about this: you could cut a slip from a vine with a dagger or a leather-cutter or many other things?"
>
> "Of course."
>
> "But I suppose you could not do as fine a job with anything other than a pruning knife made for this purpose."
>
> "True."
>
> "Then we shall take this to be its work?"
>
> "We shall indeed."

Socrates then points out that each object is able to perform its work because each possesses a particular virtue: sight for eyes, audition for ears, and what might be called knifeness for pruning knives (1.353b).[3] Thrasymachus then admits that each object only works well when it is in possession of its virtue, and poorly otherwise

[3]Actually, only sight is named explicitly. Plato evidently does not wish to discuss any particular virtues at this point in the dialog (Bloom, 1968, p. 337).

(1.353c–d). Socrates then returns to his target, the soul, and gains Thrasymachus' assent to the proposition that living [*zên*] is the work of the soul, and that the soul too must possess a virtue to do its living, *i.e.*, it must possess the virtue of justice (1.353d–e). Also, in the course of this argument, Socrates also develops the thesis that injustice is a vice of the soul.

This analogy may be represented as in table 5.1. Socrates' argument can be read off by examining the system mappings of each domain. These mappings describe a characteristically Platonic position that everything has exactly one ideal function and that each function is subserved by one essence proper to it alone. In the case of eyes, Socrates holds that there exists a virtue of the eye (sight) that enables seeing to be the work of the eye (see Bloom, 1968, p. 337). The activity of seeing may be considered to be the work of the eye because it is peculiar to the eye and because it is subserved by sight, the virtue of the eye. Similarly, Socrates continues, living may be considered to be the work of the soul because it is subserved by justice. Since Thrasymachus has already granted that justice is a virtue of soul, it must therefore be justice that enables the soul to do its work of living.

In terms of table 5.1, then, the proposition that Socrates wishes to support is *enable*$_s$. When it is granted that justice is the virtue that enables the soul to do its work of living well, it follows that we should all want our souls to possess justice, since we all want to live well, and that all whose souls do not possess justice do not live well (1.353e–4a).

There are two points to note about this analogy. First, it displays a certain vagueness where the virtues are concerned. As Bloom (1968, p. 337) points out,

Eye	Ear	Knife	Soul
eye seeing sight	ear hearing audition	knife pruning ?	soul living justice
work-of$_g$(seeing,eye) virtue-of$_g$(sight,eye) peculiar-to$_g$(seeing,eye) subserve$_g$(sight,seeing)	work-of$_e$(hearing,ear) virtue-of$_e$(audition,ear) peculiar-to$_e$(hearing,ear) subserve$_e$(audition,hearing)	work-of$_k$(pruning,knife) virtue-of$_k$(?,knife) peculiar-to$_k$(pruning,knife) subserve$_k$(?,pruning)	work-of$_s$(living,soul) virtue-of$_s$(justice,soul) peculiar-to$_s$(living,soul) subserve$_s$(justice,living)
enable$_g$(virtue-of$_g$,work-of$_g$) because$_{g0}$(work-of$_g$,peculiar-to$_g$) because$_{g1}$(work-of$_g$,subserve$_g$)	enable$_e$(virtue-of$_e$,work-of$_e$) because$_{e0}$(work-of$_e$,peculiar-to$_e$) because$_{e1}$(work-of$_e$,subserve$_e$)	enable$_k$(virtue-of$_k$,work-of$_k$) because$_{k0}$(work-of$_k$,peculiar-to$_k$) because$_{k1}$(work-of$_k$,subserve$_k$)	enable$_s$(virtue-of$_s$,work-of$_s$) because$_{s0}$(work-of$_s$,peculiar-to$_s$) because$_{s1}$(work-of$_s$,subserve$_s$)

Table 5.1: A representation of the analogy from eyes, ears and pruning knives to the soul (*Republic*, 1.352e–3e).

Socrates says nothing about exactly what each virtue consists in. Thrasymachus volunteers that sight is the virtue of the eye, but Socrates avoids the subject by saying that he is not yet ready to consider what each of the virtues in question are (1.353c). Sight counts as the virtue of seeing (and audition as the virtue of hearing) because it is the corresponding psychological faculty, *i.e.*, sense. But there is no such faculty of pruning. Of course, by *virtue* of a pruning knife, Plato means its *excellence* [*aretê*], and a pruning knife may be said to be an excellent one because it possesses the appropriate qualities, but the fact remains that none of these qualities could ever be called a faculty. This ambiguity in the source analogs makes it unclear what sense of virtue is to be understood by the virtue of justice in the target analog. Based on the parallels of sight and audition, justice should mean a *sense* of justice, perhaps an intuitive moral faculty of the sort discussed by Moore (1903). Based on the pruning knife parallel, justice would appear to be the sort of mutual mastery among parts of the soul that Socrates later introduces (see section 5.3). The presence of distinct interpretations in this analogy tends to make the conclusion ambiguous.

The second point is that Socrates makes this analogy do double duty in the sense that, along with virtue, he includes a consideration of vices in his analogizing. Thus, blindness is offered (again by Thrasymachus) as the vice of the eye. This situation is similar to that of the health/justice analog discussed below (section 5.3). Each analog has a positive and negative component and the same pattern of argument (*i.e.*, system relations) apply to both components. Such inclusion of polarity (see Lloyd, 1966) in analogical arguments is unusual in the general case, but is quite

characteristic of Plato at least where analogies concerning justice are concerned. The fact that polarity may be used to perform two jobs in one analogy raises the question of whether such analogies are in fact multiple analogies. An example of a polar analogy in the *Republic* is examined in section 5.3.

5.3 Health and justice

The nature of justice is a central issue in the *Republic*. Plato frequently uses analogies and multiple analogies in order to explicate his concept of justice. In particular, Plato sets out to describe a concept of justice that is comprehensible and manifestly desirable. Socrates completes the first half of this project of establishing such a concept by a comparison between justice in the human soul with health in the human body (*Republic*, 4.444c–e):[4]

> [Socrates:] "Surely healthy things produce health and sick ones sickness."
>
> [Glaucon:] "Yes."
>
> "Doesn't doing just things also produce justice and unjust ones injustice?"
>
> "Necessarily."
>
> "To produce health is to establish the parts of the body in a relation of mastering, and being mastered by, one another that is according to nature, while to produce sickness is to establish a relation of ruling, and being ruled by, one another that is contrary to nature."

[4]For a nice summary of this analogy, see Kraut (1992, p. 315n11).

> "It is."
>
> "Then, in its turn," I said, "isn't it to produce justice to establish the parts of the soul in a relation of mastering, and being mastered by, one another that is according to nature, while to produce injustice is to establish a relation of ruling, and being ruled by, one another that is contrary to nature?"
>
> "Entirely so," he said.
>
> "Virtue, then, as it seems, would be a certain health, beauty and good condition of a soul, and vice a sickness, ugliness and weakness."
>
> "So it is."

Socrates compares health and justice insofar as they count as good things for the body and the soul, respectively.

This analogy may be represented as a single analogy between body and soul as shown in table 5.2. The system mappings may be read to show that Socrates is giving an explanation of why justice is a virtue of the soul by comparison with health as a virtue of the body. A proper mastery among parts of the body causes those parts to produce health ($cause_{b0}$). This health belongs to the body in virtue of the facts that the body is composed of those body parts ($because_{b0}$) and that it is those body parts that produce the health ($because_{b1}$). Furthermore, health counts as a *virtue* of the body because it is a condition in accord with nature ($because_{t1}$). A parallel explanation is also given with regard to vice and sickness. An analogous argument supports the proposition that justice is a virtue of the soul. Of course,

Body	Soul
health	justice
sickness	injustice
body-parts	soul-parts
body	soul
virtue$_b$	virtue$_s$
vice$_b$	vice$_s$
nature	nature
consist-of$_b$(body,body-parts)	consist-of$_s$(soul,soul-parts)
produce$_{b0}$(body-parts,health)	produce$_{s0}$(soul-parts,justice)
produce$_{b1}$(body-parts,sickness)	produce$_{s1}$(soul-parts,injustice)
master$_b$(body-parts,body-parts)	master$_s$(soul-parts,soul-parts)
rule$_b$(body-parts,body-parts)	rule$_s$(soul-parts,soul-parts)
has$_{b0}$(body,health)	has$_{s0}$(soul,justice)
has$_{b1}$(body,sickness)	has$_{s1}$(soul,injustice)
is-a$_{b0}$(health,virtue$_b$)	is-a$_{s0}$(justice,virtue$_s$)
is-a$_{b1}$(sickness,vice$_b$)	is-a$_{s1}$(injustice,vice$_s$)
accord-with$_b$(health,nature)	accord-with$_s$(justice,nature)
contrary-to$_b$(sickness,nature)	contrary-to$_s$(injustice,nature)
cause$_{b0}$(master$_b$,produce$_{b0}$)	cause$_{s0}$(master$_s$,produce$_{s0}$)
cause$_{b1}$(rule$_b$,produce$_{b1}$)	cause$_{s1}$(rule$_s$,produce$_{s1}$)
because$_{b0}$(has$_{b0}$,consist-of$_b$)	because$_{s0}$(has$_{s0}$,consist-of$_s$)
because$_{b1}$(has$_{b0}$,produce$_{b0}$)	because$_{s1}$(has$_{s0}$,produce$_{s0}$)
because$_{b2}$(has$_{b1}$,consist-of$_b$)	because$_{s2}$(has$_{s1}$,consist-of$_s$)
because$_{b3}$(has$_{b1}$,produce$_{b0}$)	because$_{s3}$(has$_{s1}$,produce$_{s0}$)
because$_{b4}$(is-a$_{b0}$,accord-with$_b$)	because$_{s4}$(is-a$_{s0}$,accord-with$_s$)
because$_{b5}$(is-a$_{b1}$,contrary-to$_b$)	because$_{s5}$(is-a$_{s1}$,contrary-to$_s$)

Table 5.2: A representation of the analogy between health in the body and justice in the soul as given in the *Republic* (4.444c–e).

Socrates must go on to argue that justice is choiceworthy because it is a virtue, which means he must explore virtue in greater detail (*Republic*, 4.444e–5c).

Note, however, the redundancy in each domain of the analogy as given in table 5.2. For each predicate pertaining to health in the body, for example, there is a predicate pertaining to sickness. This duplication is a result of the fact that Socrates treats health and sickness as polar or complementary aspects of the human bodily condition. In fact, in Socrates' argument, health and sickness are treated as *analogous* to each other. This fact is not captured in table 5.2, where there is no explicit recognition of it. In the notation adopted in this dissertation, analogous predicates should be placed in the same row with each other. Therefore, the predicates in table 5.2 need to be rearranged to meet this condition.

The whole structure of the body/soul analogy may be captured as in table 5.3. This table gives the same predicates as table 5.2, but divides both source and target in two, separating and placing in correspondence those predicates that belong specifically with health and sickness on the one hand, and justice and injustice on the other. So that they are not duplicated, predicates that are common to both divisions are kept in their former positions between the new columns. The table now reveals the richness of structure of this analogy. As represented in table 5.3, Plato's analogy is clearly a multiple analogy: It has multiple sources, namely health and sickness. Plato has constructed this multiple analogy in a very economical fashion by taking advantage of the complementary nature of health and sickness, and the facility by which such complementary topics may be included in a narrative structure.

Body		Soul	
body body-parts health virtue$_b$	sickness vice$_b$	soul soul-parts justice virtue$_s$	injustice vice$_s$
nature		nature	
master$_b$(body-parts,body-parts)	rule$_b$(body-parts,body-parts)	master$_s$(soul-parts,soul-parts)	rule$_s$(soul-parts,soul-parts)
produce$_{b0}$(body-parts,health)	produce$_{b1}$(body-parts,sickness)	produce$_{s0}$(soul-parts,justice)	produce$_{s1}$(soul-parts,injustice)
has$_{b0}$(body,health)	has$_{b1}$(body,sickness)	has$_{s0}$(soul,justice)	has$_{s1}$(soul,injustice)
consist-of$_b$(body,body-parts)		consist-of$_s$(soul,soul-parts)	
is-a$_{b0}$(health,virtue$_b$)	is-a$_{b1}$(sickness,vice$_b$)	is-a$_{s0}$(justice,virtue$_s$)	is-a$_{s1}$(injustice,vice$_s$)
accord-with$_b$(health,nature)	contrary-to$_b$(sickness,nature)	accord-with$_s$(justice,nature)	contrary-to$_s$(injustice,nature)
cause$_{b0}$(master$_b$,produce$_{b0}$)	cause$_{b1}$(rule$_b$,produce$_{b1}$)	cause$_{s0}$(master$_s$,produce$_{s0}$)	cause$_{s1}$(rule$_s$,produce$_{s1}$)
because$_{b0}$(has$_{b0}$,consist-of$_b$)	because$_{b2}$(has$_{b1}$,consist-of$_b$)	because$_{s0}$(has$_{s0}$,consist-of$_s$)	because$_{s2}$(has$_{s1}$,consist-of$_s$)
because$_{b1}$(has$_{b0}$,produce$_{b0}$)	because$_{b3}$(has$_{b1}$,produce$_{b0}$)	because$_{s1}$(has$_{s0}$,produce$_{s0}$)	because$_{s3}$(has$_{s1}$,produce$_{s0}$)
because$_{b4}$(is-a$_{b0}$,accord-with$_b$)	because$_{b5}$(is-a$_{b1}$,contrary-to$_b$)	because$_{s4}$(is-a$_{s0}$,accord-with$_s$)	because$_{s5}$(is-a$_{s1}$,contrary-to$_s$)

Table 5.3: Another representation of the analogy between health in the body and justice in the soul as given in the *Republic* (4.444c–e).

5.4 Plato's condemnation of the poet

Plato's objections to poets and poetry in the *Republic* are well known. An important component in Plato's argument against admitting poets into the ideal city comes in the form of a multiple analogy in the concluding book of the dialog (10.602c–5c). Socrates wishes to show that poets tend to corrupt the souls of citizens because their poetry appeals to and strengthens the worst elements of the soul at the expense of its best elements.

Socrates begins with his famous proclamation that imitators are "concerned with something that is third from the truth" (10.602c). This proclamation means that a painter, for example, who paints a picture of reins and a bit is merely imitating the work of the smith who made them and who, in turn, is merely following the specifications of the horseman, who actually uses the reins and bit and therefore best understands their true nature (10.601c). Anyone who asked this painter about the nature of reins and bits would presumably get third-hand information in response.[5]

Socrates proceeds by examining the damage to the soul of a person who relies on such third-hand sources for his knowledge of things. Our senses, such as vision, may lead us to erroneous beliefs because they allow one thing to appear differently under different circumstances, *e.g.*, a stick may "may look bent and straight when seen in water and out of it" (10.602c).[6] People may foolishly believe that a stick

[5] Why anyone *should* ask a painter this question is another matter. Presumably it would make more sense to ask the painter about the issues of *painting* reins and a bit. Plato does not address this point, however.

[6] Plato's treatment of the connection between perception and cognition in this passage is somewhat perplexing. See Murphy (1960, pp. 239–43) for further discussion.

in water has actually changed its shape and is therefore a different stick because of the change in its appearance. Such foolish notions may be believed by some people because the "ordinary" part [*phaulôn*] of their soul has somehow gained ascendancy over the "calculating" part [*logistikon*] (10.602d–3a). Socrates insists that paintings similarly allow—even require—a thing depicted to appear different from its true nature, of which the painting is a third-hand representation. Therefore, paintings misrepresent one thing as many, prompt us to dilute our true beliefs about things with many contrary beliefs, and ultimately teach us to ignore the calculating part of the soul as merely one source of judgment among many, when it is always the best source of judgments (10.603a–d).

Now Socrates begins his attack on poetry by comparing the poet with the painter. He has already established that the poet's knowledge of those virtues described in his poems is third-hand (10.598e–601b). He now adds that poetry strengthens the ordinary part of the soul in its audience (10.605a), explaining that this situation is in the poet's interest since most people are naturally ruled by the ordinary parts of their souls and poetry naturally appeals to this part (10.603e–5a). Socrates now epitomizes the comparison between painters and poets while adding another source analog (10.605a–b):

> [Socrates:] "Therefore it would at last be just for us to seize [the poet] and set him beside the painter as his antistrophe.[7] For he is like the painter in making things that are ordinary by the standard of truth;

[7] *Antistrophe* is a theatrical term referring to the movement of the chorus from left to right, or to the song they sing during this movement (Bloom, 1968, p. 200n9). Perhaps Plato is here referring to the song and punning on the fact that the poet produces songs just as the painter produces paintings (10.603b). For present purposes, it may simply be taken to mean 'counterpart'.

> and he is also similar in keeping company with a part of the soul that is on the same level and not with the best part. And thus we should at last be justified in not admitting him into a city that is going to be under good laws, because he awakens this part of the soul and nourishes it, and, by making it strong, destroys the calculating part, just as in a city when someone, by making wicked men mighty, turns the city over to them and corrupts the superior ones. Similarly, we shall say the imitative poet produces a bad regime in the soul of each private man by making phantoms that are very far removed from the truth and by gratifying the soul's foolish part, which doesn't distinguish big from little, but believes the same things are at one time big and at another little."
>
> [Glaucon:] "Most certainly."

The poet is like the painter in two ways: (1) the fruits of his labors present third-hand facsimiles of things as they are, and (2) his facsimiles appeal to and nourish the ordinary part of the soul, thus making that part too strong. Socrates introduces a second source analog to explicate the consequences of this inappropriate situation. Not only does the poet bring about this situation but, in so doing, he enables the ordinary part of the soul to usurp the rule or mastery of the soul that properly belongs to the calculating part, just as an unnamed someone does who enables wicked men to usurp the rule of a city regime. Because of this unhappy change in the souls of its citizens, Socrates claims to be justified in banning the poet from the ideal city. Thus, the second, political source analog does not merely reinforce the

lesson drawn from consideration of the painter, it expands that lesson by comparing its consequences with an unhappy change of political power.

It is not clear from the immediate context if Socrates is referring to any particular change in political power or not. What person could make wicked men mighty and cause control of the city to be turned over to them? The answer may come from the catalog of political changes given in book eight. In particular, Socrates there describes the creation of a tyranny in a way that resembles the overthrow described above. Socrates claims that tyrannies tend to arise from democracies in the following way: (1) a democracy is an excess of civic freedom and therefore encourages all kinds of civic discord (8.563c–e); (2) the political weakness caused by this discord enables the fiercest of its citizens to take over the city, in part by pretending to befriend the city's many and voracious poor (8.564a–7a); (3) the tyrant strengthens his hold on power by getting rid of all his opponents and potential rivals, especially the courageous and intelligent men of the city (8.567b–d); (4) the tyrant surrounds himself with indecent men as guards, because they are the only sort of people he can trust (8.567d–8a). Socrates picks out tragedians, exemplified by Euripides, as contributing to this process (especially step 2) by praising tyrants in their tragedies, which is in their own interest as they are handsomely rewarded by tyrants for doing so (8.568a–d). In other words, the tragedian makes wicked men mighty by telling all and sundry that tyrants are virtuous. It is quite likely, then, that Socrates refers to the tragedian when he speaks in book ten of someone aiding in the establishment of a bad regime.

This interpretation may be represented as shown in table 5.4. Socrates' argu-

Tragedian	Painter	Poet
tragedian	painter	poet
tragedies	paintings	poetry
tyrant	ordinary-part	ordinary-part
superior-men	calculating-part	calculating-part
	objects	virtues
city		soul
$make_t$(tragedian,tragedies)	$make_p$(painter,paintings)	$make_P$(poet,poetry)
praise(tragedies,tyrant)	$appeal\text{-}to_p$(paintings,ordinary-part)	$appeal\text{-}to_P$(poetry,ordinary-part)
	$misrepresent_p$(paintings,objects)	$misrepresent_P$(poetry,virtues)
$strengthen_t$(tragedian,tyrant)	$strengthen_p$(painter,ordinary-part)	$strengthen_P$(poet,ordinary-part)
corrupt(tragedian,superior-men)		destroy(poet,calculating-part)
$rule_t$(tyrant,city)		$rule_P$(ordinary-part,soul)
$because_{t0}$($strengthen_t$,$make_t$)	$because_{p0}$($strengthen_p$,$make_p$)	$because_{P0}$($strengthen_P$,$make_P$)
$because_{t1}$($strengthen_t$,praise)	$because_{p1}$($strengthen_p$,$appeal\text{-}to_p$)	$because_{P1}$($strengthen_P$,$appeal\text{-}to_P$)
	$because_{p2}$($appeal\text{-}to_p$,$misrepresent_p$)	$because_{P2}$($appeal\text{-}to_P$,$misrepresent_P$)
$enable_{t0}$($strengthen_t$,$rule_t$)		$enable_{P0}$($strengthen_P$,$rule_P$)
$enable_{t1}$($strengthen_t$,corrupt)		$enable_{P1}$($strengthen_P$,destroy)

Table 5.4: A representation of the analogy from the painter and tragedian to the poet (*Republic*, 10.605a–b).

ment against poets may be read off by concentrating on the system predicates, which give an explanation of how poets can be the ruin of the soul. The poet strengthens the ordinary part of the soul because he makes poetry, and that poetry *appeals* to the ordinary part of the soul. The appeal of poetry is explained by the fact that it misrepresents the nature of virtues. In these respects, the poet is much like the painter Socrates discussed beforehand. The fact that the poet strengthens the ordinary part of the soul enables the ordinary part to rule the whole soul and thereby destroy its calculating part. In this respect, the poet is much like the tragedian who enables the tyrant to take over the city and corrupt its courageous and intelligent men.

The use of sources in the analogy is obviously different from those discussed above, *e.g.*, in the case of the eye, ear, knife and soul analogy (section 5.2). There, each source analog contained a complete set of mappings to the target analog, with blank entries being filled in by implication or counting against the coherence of the analogy. Here, each source analog contains only a partial set of mappings to the target since each fulfills a slightly different purpose with respect to the analogy as a whole. The comparison with the painter serves to explain how it is that poets strengthen the ordinary part of the soul. This fact alone is not enough to banish the poets outright. The comparison with the tragedian serves to show that the consequences of poet's effect on the soul are to make it unjust in the sense that the wrong part assumes control. It is for this effect that the poet is to be kept out of the ideal city. Because each source analog fulfills a different purpose, the blanks that can be seen in table 5.4 cannot necessarily be counted against the coherence

of the whole analogy.

Of course, the addition of the tragedian serves more than a formal purpose in completing the target analog. A tragedian may be considered a species of poet, and is therefore already a very similar and appropriate standard of comparison. Also, Socrates has already gained assent to a condemnation of tragedians, Homer and Euripides in particular. It is much easier to attach a negative affect of dispraise to poets by connecting them with tragedians, who have already had this affect attached to them. In other words, by comparing poets with tragedians, Socrates is better able to transfer the feeling of disapproval from one to the other (see Thagard and Shelley, ip). Certainly, he has not generated any displeasure with painters adequate to the purpose. Thus, the use of the tragedian source not only completes the informational content of the poet target but also helps to convey the negative affect that Plato wishes to attach to it.[8]

5.5 Implications for multiple analogies

The above discussion exemplifies the ways in which Plato used multiple analogies to explicate concepts and further his arguments. But certain aspects of Plato's use of multiple analogies require further and more detailed discussion. The contribution of narrative or dialogic form is examined in section 5.5.1, while the effect of multiple

[8] Also, since tragedians are associated with the establishment of tyrannies, Socrates may refer again to his famous and frequent comparison of the soul to a city when he says that "the imitative poet produces a bad regime in the soul ...." This analogy has been frequently discussed; see *e.g.*, Robinson (1953, pp. 210–2), Murphy (1960, pp. 68–86), Bambrough (1963, pp. 106–10), Vlastos (1969), Williams (1973), Galis (1974), and Hall (1974). Thus, choosing the tragedian analog with its established and unhappy political connection helps the current argument run briskly along familiar rails.

sources on the specificity of the target is examined in section 5.5.2. The use of sources as a supplement to other sources in the service of multiple purposes is treated in section 5.5.3.

5.5.1 Complementation and narrative representation

Unlike many pre-Socratic philosophers, Plato chose prose instead of poetry for his expositions. More particularly, Plato chose to deliver his philosophy in the form of stories recounting discussions between Socrates (usually) and other characters. This form of presentation has a definite effect on the way in which analogies are developed and structured. Specifically, it seems to facilitate the use of *complementary* structures in both the sources and targets of an analogy.

Table 5.3 shows how complementary concepts may participate in the construction of a multiple analogy. One analog, *e.g.*, health, is taken as a model for a second one, *e.g.*, sickness. For everything that is predicated of health, a complementary predication is made concerning sickness. Both sets of predicates then serve as the source for an analogy with the target concerning the soul, which also displays this complementary structure. Predicates that have no complements with respect to health or sickness are presented independently of both complements. This process of complementation is similar to exemplification as discussed in section 2.5.3 in the sense that health, in this case, serves as an exemplary representative of a class of bodily states. In exemplification, however, the implicit members of each class of analogs in the source domains are assumed to be *consistent* with their exemplar for the purposes of the analogy. So, for example, all members of the deep sea teleost

fish are assumed to be similar to their representative, namely *Ruvettus*, for the purposes of the analogy with Coelacanths (section 2.4). In the process of complementation exhibited by Plato, the members of the class of bodily conditions are not consistent with each other but *opposite*.

Opposition, in this sense, is a curious relationship. It means that predicates that are semantically dissimilar are placed into the same mappings in the overall analogy. For example, the predicates *accord-with*$_b$ and *contrary-to*$_b$ both occur in the eleventh row of table 5.3. By the principle of semantic similarity (section 2.2), such a situation should count against the coherence of the analogy as a whole. But this does not apply to Plato's analogy since the point is simply that health and sickness are alike in their opposition to the opposition between justice and injustice. This likeness of opposition is apparent in the identity of the system relations in which both pairs of opposite concepts participate. So, for example, both *accord-with*$_b$ and *contrary-to*$_b$ occur in analogous *cause* and *because* predicates.

It appears, then, that adopting the purpose of using complementary sources in an analogy affects how those sources cohere with the whole analogy. Within a complementary structure, semantic opposition between certain predicates is expected and, indeed, necessary. Therefore, such opposition counts *towards* the coherence of the analogy as a whole provided it is replicated in both source and target domains. This interpretation is further supported by noting that if complementary predicates did *not* hold true of health and sickness, then the coherence of the analogy would be weakened. In other words, if health is something in accord with nature but sickness—its opposite—is *not* something contrary to nature, then the body/soul

analogy loses coherence.

The complementary structure of the body/soul analogy given in table 5.3 makes it look difficult. Plato, fortunately, used a more efficient representation to construct his analogy, namely narrative representation. In the dialog, Socrates always takes health as the representative source analog, making his comments first about it and then noting afterwards that complementary relations also hold regarding its opposite, sickness. Consider a small part of Socrates' discussion of this analogy (*Republic*, 4.444c–d):

> [Socrates:]"Surely healthy things produce health and sick ones sickness."
>
> [Glaucon:] "Yes."
>
> "Doesn't doing just things also produce justice and unjust ones injustice?"
>
> "Necessarily."

Socrates' two statements introduce the whole of the seventh row of table 5.3. In developing each point of the analogy in a serial, narrative way, it is possible for Plato to simply conjoin an extra set of relations in the source and target by exploiting the fact that sickness is the opposite of health and injustice is the opposite of justice. Thus, although table 5.3 does not represent this fact, the analogy is primarily between health and justice, with sickness and injustice being developed in a sort of secondary or parasitic way, so that the mappings between the latter two sets of predicates follow by a kind of transitive construction. This combination of opposites and transitive construction allows Plato to build up a richly structured, multiple

analogy from only a few basic attributes in an economic and fairly straightforward and plausible way.

Narrative representation seems to especially facilitate the process of multiple-analogy construction by complementation (see Shelley and Thagard, 1996). Consider a similarly structured analogy found in the following Trobriand origin myth (paraphrased from Malinowski, 1926, pp. 46–8):

> The world was originally peopled from underground where humanity had led an existence similar in all respects to the present life on earth. For an unspecified reason, the totem ancestors of the human tribes, including the Dog and the Pig, came to the surface via a special hole called Obukula near the village of Laba'i. The Dog ate the fruit of the *noku* plant, whereupon the Pig said "Thou eatest noku, thou eatest dirt; thou art a low-bred, a commoner; the chief, the *guya'u*, shall be I." And ever since, the Malasi clan, descendants of the Pig, have outranked the Lukuba clan, descendants of the Dog.

The myth states that just as the Dog ate the *noku* plant and became inferior while the Pig pronounced on this act and became superior, people in the Lukuba clan, descendants of the Dog, are inferior to people in the Malasi clan, descendants of the Pig. Malinowski cites this as a classic charter myth, giving the current world order a foundation in a mythical past. The analogical structure of this myth is given in table 5.5. The analogy in this narrative is developed in a similar manner to that developed by Plato: The mythical and current domains are split into complementary halves by placing opposites within each domain in alignment

Myth		Society	
Dog Pig		Dog-descendant Pig-descendant	
noku	decree	Lukuba	Malasi
eat(Dog,noku)	proclaim(Pig,decree)	born-in$_m$(Dog-descendant,Lukuba)	born-in$_s$(Pig-descendant,Malasi)
outrank$_m$(Pig,Dog)		outrank$_s$(Pig-descendant,Dog-descendant)	
cause$_{m0}$(eat,outrank$_m$)	cause$_{m1}$(proclaim,outrank$_m$)	cause$_{s0}$(born-in,outrank$_s$)	cause$_{s1}$(born-in,outrank$_s$)

Table 5.5: A representation of the analogy between mythical history and present social structure among the Trobriand islanders (Malinowski, 1926). See Shelley and Thagard (1996, p. 172).

with each other. Each opposite is conjoined by mentioning it directly after that predicate of which it is the opposite, *e.g.*, the Pig's decree is made directly after the Dog's eating of the *noku* plant.

Narrative representation lends itself to the development of multiple analogies containing complementary sources. Plato was adept at exploiting this possibility, as is shown in this example and also the analogy of the eye, ear, and knife to the soul (section 5.2), where blindness, at least, was considered in addition to sight as its opposite. The exploitation of polar opposites and transitive construction in multiple analogies was a favorite method by which Plato generated and considered very richly structured concepts.

5.5.2 Specificity

Recall the discussion of specificity from section 4.5.2. Specificity concerns situations in which a predicate in the target analog must be filled in by a process of copying (with relevant substitutions of the arguments) from the corresponding predicates in the source analogs. In some multiple analogies, the corresponding predicates are all different, raising the issue of which one to select for copying, or whether to adopt some other strategy to specify what predicate to insert in the target analog. To judge from the archaeological examples, the preferred strategy is to insert in the target a predicate that is just abstract enough to subsume all the corresponding predicates in the sources.

The problem of specificity occurs in the eye, ear, knife, and soul analogy discussed in section 5.2. In that analogy, sight and audition represent the virtues of

the eyes and ears, respectively, when mapped to justice as the virtue of the soul. As noted above, there is no obvious virtue of pruning knives that subserves pruning as sight subserves seeing, for example. Whatever Plato may have had in mind in that instance (he does not state it explicitly), it cannot be taken in exactly the same sense as sight and audition. Therefore, the sense of justice subserving the soul as it goes about its living is vague; the analogy as a whole loses some specificity. This result may not be unwelcome since it is clear from the rest of the *Republic* that Plato would not wish justice to be considered a faculty of the soul exactly as sight may be considered a faculty of the eye. Therefore, it is likely that Plato introduced the knife analog in order *not* to imply that justice is some kind of innate sense of the soul.

In other words, it appears that the *lack* of a predicate in a source analog may be treated much the same as the presence of a different predicate in a multiple analogy. In the MT account of analogies, the lack of a predicate would simply imply the absence of a supportive mapping from that predicate to the corresponding predicate in the target analog. The absence of such a mapping would mean, in turn, that the target predicate would not enjoy as much support from the source analogs. The analogy would simply be less coherent as a result. If the above analysis is correct, however, the coherence of the analogy may be redressed, at least partially, by understanding the target predicate to be less specific in meaning than any of the sources explicitly given. In the case of the eye, ear, knife, and soul analogy, the concept of justice is not understood as a faculty of the soul on the basis of two out of three source concepts. Rather, it is understood as a less specific accompaniment

of the soul on the basis of the concepts of sight and audition *and* the absence of a corresponding concept belonging to pruning knives.

This situation is hinted at in the dialog where other differences between pruning knives on the one hand and eyes and ears on the other are drawn to our attention. Recall from Socrates' statement (section 5.2) that you can see only with eyes and hear only with ears while you may prune not only with pruning knives but also with daggers or leather cutters—but not as well. Thus, whatever-it-is about pruning knives that corresponds to sight in eyes and audition in ears is not obvious but is rather abstract. The abstractness of this whatever-it-is then affects the meaning of *justice* to which it is mapped. In other words, *justice* is understood more abstractly in relation to the soul than sight is to eyes or audition is to ears. This result suits Plato's purposes very well.

Plato makes the most of this particular analogy. He concentrated on the eye and ear sources because these are quite familiar and would bring about quick recognition and consent from his readers (and Socrates' interlocutors). He included the pruning knife analog in order to support his contention that the class of things with their own work is very general (universal, in fact) and also in order to generalize the target concept of justice by omitting its counterpart in this source. In this way, Plato could avoid the unwanted implication that justice is a faculty of the soul.

5.5.3 Supplementation

Plato's condemnation of poets (section 5.4) provides an interesting example of supplementation. Recall from sections 2.5.4 and 4.5.3 that supplementation involves

the use of one source analog to revise or modify another. In this case, Plato first makes an analogy between poets and painters, and then brings in tragedians as an additional source analog to modify the painter analog. Plato makes this addition for two reasons. First, the tragedian source brings with it predicates that are desired but absent from the painter analog. The painter analog conveys the argument that painters are merely imitators of things, and that their paintings are therefore misrepresentations of the true nature of those things. This misrepresentation appeals to the ordinary part of the soul, thus strengthening it with respect to the calculating part.

But Plato does not use the painter analog to spell out the consequences of this inappropriate strengthening, possibly because the claim that a few paintings would throw people's souls into severe disrepair would sound absurd. In the *Sophist* (233d–4b), for instance, the Eleatic stranger talks about a painter who paints images of gods, men, and animals and, by exhibiting them at a distance, deceives some of the younger and duller children into believing that he has actually *created* the objects depicted. In his response to this anecdote, Theodorus treats the situation as a kind of joke since no competent person would be so fooled. Obviously, Plato knew that no one would take such an argument very seriously, which explains why he avoids making it in the *Republic*.

Rather, Plato changes to the tragedian analog. The tragedian matches the painter as an imitator in enough respects to make his inclusion coherent, but the tragedian also brings with him information suitable for association with the disrepair of the soul. It is already acknowledged that, by strengthening the worst men

of cities, tragedians bring about the conditions whereby tyrants come to power and eliminate all the best men. Thus, by adding this analog in the horizontal direction, Plato is able to add crucial predicates in the vertical direction and round out his condemnation of poets.

The second reason Plato adds the tragedian is because tragedians are already a species of poet. The semantic closeness of tragedians and poets as concepts makes a comparison between the two all the more plausible. Although painters and poets are both artists, a painter's work is not performed as a poet's work is. Since Plato maintains that it is primarily the public performance of poetry in plays that brings about it's malignant effects on the soul, he would need to speak in terms of the public performance of paintings if he were to rely on the painter analog. This procedure would be an awkward one at least. It is easier and more effective to instead switch to a discussion of tragedians, whose works are performed in the required way. Thus, the idea that poets can destroy the calculating part of the soul is better supported by mappings with someone whose works urge us to imitate tyrants rather than someone whose works urge us to imitate statues or garden scenes.

In this case, as in general, supplementation is performed when a single source would be inadequate by itself to fulfill the purpose of the analogy. Here, the goal of condemning poets is broken down by Plato into two subgoals. The first subgoal is to suggest the generality of the condemnation by comparing poets with painters. If all painters can be condemned as strengthening the ordinary part of the soul and damaging its calculating part, then all poets can be similarly condemned. Where

this subgoal cannot meet the overall goal, a second is introduced that will overcome the deficit. The second subgoal is to display the potentially terrible consequences for the soul that arise specifically from poetry. With this supplementation, Plato suggests both the generality of his condemnation of poets, and its dire consequences in at least one special case. If not totally convincing, this supplementation comes very close to satisfying the overarching purpose of the analogy, by dividing that purpose into two parts and introducing a separate source analog for each part.

5.6 Plato on multiple analogies

Just as the study of multiple analogies in biology and archaeology informs us both about multiple analogies *and* about their place in those fields, so the study of multiple analogies in Plato's *Republic* should inform us both about multiple analogies and about their place in Plato's philosophy. Having examined Plato's use of multiple analogies, it is time to return to the topic of his view of multiple analogies as such. As indicated in section 1.2, Plato gives us no explicit or extended treatment of the subject. Nevertheless, the subject of multiple analogies does appear to be considered in at least one place in the *Republic*.

As noted in section 5.1, Plato often uses the term image [*eikôn*] to refer to an analogy. More generally, Plato often compares the use of analogies to the creation of physical images through painting. Of course, there is something odd in this comparison, since Plato often condemns painters as people who mislead people's souls for profit while, at the same time, he approves of image making (*i.e.*, making analogies) among philosophers (Robinson, 1953, pp. 204–22). He compares philosophers

to painters, with approval, on no less than five separate occasions in the *Republic* (4.420c–d, 5.472d–e, 6.484c–d, 6.500e–1c, and 6.504d). Obviously, this apparent instance of self-contradiction demands some explanation.

A defense of the use of analogies—and multiple analogies—among philosophers is given in a passage in which Socrates compares the explication of the ideal city to the painting of an image of the city. Socrates seems to hold that image making by philosophers is defensible because, unlike actual painters, philosophers use not mere appearances but the truth or the divine pattern as their guide (*Republic*, 6.500e). Philosophers begin with a clean slate by drawing an outline of the of the ideal city and (*Republic*, 6.501b–c):

> [Socrates:] "After that, I suppose that in filling out their work they would look away frequently in both directions, toward the just, fair, and moderate by nature and everything of the sort, and, again, toward what is in human beings; and thus, mixing and blending the practices as ingredients, they would produce the image of man, taking hints from exactly that phenomenon in human beings which Homer too called god-like and the image of god."
>
> [Adeimantus:] "Right," he said.
>
> "And I suppose they would rub out one thing and draw in another again, until they made human dispositions as dear to the gods as they admit of being."
>
> "The drawing," he said, "would at any rate be fairest that way."

These philosopher-painters whom Socrates describes are making an image of the

laws of the ideal city in the likeness of both divine and earthly practices or dispositions as taken from the form of justice itself and the nature of the just man (5.472c). Like these painters, Socrates asks rhetorically, "Weren't we, as we assert, also making a pattern in speech of a good city?" (5.472d–e). Their analogizing is legitimate because, as philosophers, they have the divine pattern to use as one of their sources.

When Socrates describes the philosopher-painters as looking frequently in *both* directions, he indicates that the construction of a good analogy requires *two* source analogs, in this case at least. Elements of both human and divine likenesses are mixed and blended to form the target image, and the act of drawing is only accomplished with many erasures and revisions. In terms of multiple analogies, Socrates seems to be saying that elements of the source analogs cannot simply be copied into the target, but must be selected and altered where they do not agree with each other. This description seems to match Plato's own practise of constructing multiple images as described above and indicates that Plato had considered the difficulties raised by multiple analogies, even if he did not set down any specific solutions to them.

5.7 Summary

Plato frequently uses analogies to support his position on issues of political philosophy in the *Republic*. Many scholars have investigated Plato's analogies, but, by *analogy*, they have generally understood a conceptual structure akin to the venerable proportional analogy. The application of newer theories such as the MT can

provide us with more comprehensive and detailed insight into Plato as an analogical thinker. Most especially, a better understanding of the nature of multiple analogies can inform us about Plato's use of those kind of analogies as well.

In some respects, the multiple analogies found in Plato's *Republic* are similar to those found in the evolutionary and archaeological literature. Plato uses multiple analogs where a single source analog is inadequate for the purpose (sections 5.2 and 5.4). However, the multiple analogies discussed in this chapter reveal new things about them. Plato's use of complementary source analogs, as in the comparison of justice and injustice to health and sickness (section 5.3), constitutes a novel form of multiple analogy, one that is found in mythological literature as well. Indeed, narrative representation of analogies appears to lend itself to the construction of this kind of multiple analogy.

Plato's analogy between the eye, ear, knife, and soul suggests that the control of specificity of target predicates may be exercised by varying the contents of the source predicates, even to the point of omitting them altogether. Given enough complete source analogs, an appropriately abstract predicate may be filled in where it is lacking in one source, thus creating a less specific understanding of the target.

Plato presents an interesting example of supplementation wherein an additional source, namely tragedians, are brought in both to alter and to fill out the first source analog in his comparison between poets and painters. Plato's ability to create analogies that use multiple sources to fulfill several, interleaved goals presents a challenge to current theories of analogy construction and inference.

Finally, it appears that Plato had some understanding of these issues concern-

ing analogies. Specifically, in his comparison of analogizing to painting, Plato describes an activity that explicitly concerns the creation of a target in view of multiple sources. In fact, the use of a divine source in addition to an earthly source seems to distinguish the construction of philosophically legitimate analogies from the philosophically misleading analogies make in the likeness of a mortal source alone. Unfortunately, although Plato proceeds to describe how to access the divine realm of forms in some detail, he does not revisit the issue of exactly how the forms may be used in the construction of good, multiple analogies.

But there is no doubt that multiple analogies were central to Plato's philosophical method as it is represented in the *Republic*. In the analogy of the cave (*Republic*, 7.514a–8b, 7.532a–3a), Plato compares his method to leading prisoners out of a cave in order to bring them face to face with the Good in the guise of the sun. Plato makes a similar remark concerning his inquiry into justice by analogy between health in bodies and justice in cities (4.435a; see section 5.3)

> Perhaps, considering them side by side and rubbing them together like sticks, we would make justice burst into flame, and once it's come to light, confirm it for ourselves.

Constructing and understanding the multiple analogy between health, sickness, virtue and vice, then, is a miniature version of the philosophical method expounded in the analogy of the cave. Both involve bringing about a direct confrontation with a fire representing the concept of justice or the Good. Understanding Plato's multiple analogies, then, is not simply necessary for understanding one aspect of his way of thinking but is also necessary to understand his conception of philosophical inquiry

as it is described in the *Republic*.

Chapter 6

The very model of a multiple analogy

Alas! my master is really the worst of all plagues. He was the most drunk of all the guests, and yet among them were Hippyllus, Antiphon, Lycon, Lysistratus, Theophrastus and Phrynichus. But he was a hundred times more insolent than any. ... Then he set to beating me with all his heart, shouting, "Slave! slave!" Lysistratus, as soon as he saw him, let fly this comparison at him. "Old fellow," said he, "you resemble one of the scum assuming the airs of a rich man or a stupid ass that has broken loose from its stable." "As for you," bawled my master at the top of his voice, "you are like a grasshopper, whose cloak is worn to the thread, or like Sthenelus after his clothes had been sold."

Xanthias, in Aristophanes' *Wasps*, 1298–1314.

6.1 Multiple analogies in perspective

As indicated in chapter 1, philosophers have tended to overlook multiple analogies in their theoretical treatments of analogy and analogical reasoning, even though they tend to use multiple analogies in practise. There are several possible explanations for this omission. Multiple analogies seem to occur much less frequently than single analogies and might escape attention for that reason. Multiple analogies, then, may simply have been living in the shadow of single analogies, so to speak. Multiple analogies may not seem to be sufficiently similar to single analogies for the two to be treated in the same framework. The listing of several source analogs may seem more like a defective instance of induction by enumeration than like a proper instance of multiple comparisons. Philosophers, like most people, have a natural tendency to approach complex problems by reducing them to simpler ones. Perhaps the problem of multiple analogies has been passed over on the tacit assumption that an adequate theory of single analogies also counts as an adequate theory of multiple analogies.

In the absence of any explicit statements by the philosophers whose views are discussed in chapter 1, there is no point in speculating on which of these reasons (or others) apply to which philosophers. But these explanations do raise issues central to any treatment of multiple analogies and their relationship to single analogies. Why do single analogies overshadow multiple analogies in practise? In what ways are single analogies different from multiple analogies? In what ways are they similar? In short, what is the relationship between single analogies and multiple ones?

The most obvious way to address this question is to compare and contrast

independently developed theories of both these phenomena. But the current state of affairs makes this approach impractical. Because of the long history of inquiry into single analogies, and the recent surge of interest in it within the field of cognitive science, much more is known about single analogies than about multiple ones. Rather than attempt to develop a theory of multiple analogies from scratch, then, it is better to inquire into the relationship between the two forms of analogy by extending an existing theory of single analogies to account for the multiple case. This project requires a suitable theory and a knowledge of the things that the theory must be modified to account for. If the extension is successful, then the comparison is made.

In this dissertation, the *Multiconstraint theory* has been used as the theory of single analogies, while the desiderata for which the *Multiconstraint theory* must be modified have been taken from an examination of multiple analogies drawn from evolutionary biology, archaeology, and Plato's *Republic*. The result has shown up the similarities and differences between the two forms of comparison. Briefly stated, single and multiple analogies are similar in that they fulfill roughly the same purposes by means of structured comparison. In principle, there may be nothing that can be accomplished by multiple analogies that cannot be accomplished by single analogies. In practise, however, no one existing source analog may in fact be adequate for any particular purpose. Single and multiple analogies are different in the sense that issues concerning the interaction of multiple source analogs simply do not arise in the case of single source analogs.

This chapter presents a consolidation of the results of inquiry obtained in the

chapters above. This consolidation comes in the form of an outline for a cognitive model adequate to account for the phenomena of multiple analogies. This model proceeds from the conclusion, drawn in previous chapters, that multiple analogies represent the general case of analogical thinking. In other words, this model is not a model of single analogies applied several times but a model of multiple analogies which aims to subsume single analogies as a special case. The place of different cognitive representations is also addressed, as is the variety of processes in which these representations participate during the construction of multiple analogies.

The relation of purposes to multiple analogies has been emphasized in this dissertation. Since these purposes represent some of the professional goals of evolutionary biologists, archaeologists, and Plato, the examination of multiple analogies tells us something about the nature and aims of science and philosophy as these practitioners saw it. Therefore, this chapter also presents a summary of the lessons learned through multiple analogies regarding these fields of endeavor.

Section 6.2 begins with a basic question in the specification of any cognitive model of multiple analogies, namely *how are the cognitive representations to be parceled out and how do the parcels interact?*

Section 6.3 summarizes the role of purpose as it participates in multiple analogies;

Section 6.4 recapitulates the nature of the various representations discussed above, namely verbal, visual, and narrative;

Section 6.5 reviews the kinds of processes that occur in the construction of multiple analogies, namely abstraction and exemplification, supplementation, and

specificity;

Section 6.6 revisits the significance of multiple analogies for issues in the philosophy of science, especially in evolutionary biology and archaeology;

Section 6.7 presents some discussion of normative aspects of this research for multiple analogies, in the form of five recommendations on how best to construct and use multiple analogies.

Concluding remarks are offered in section 6.8.

6.2 Breaking multiple analogies into parcels

One basic problem that must be resolved in order to construct a cognitive model is to identify what parcels the cognitive representations should be distributed into and how those parcels should interact. Does the cognitive system consist of capsules of collected representations interacting with other capsules, or does each representation independently influence the entire process of multiple analogy construction? In terms of multiple analogies, this question comes down to the question of whether the source analogs can see, as it were, or influence each other during analogy construction or not. The significance of this issue is best illuminated by approaching it from the standpoint of the principle of structural consistency.

Recall that the principle of structural consistency is a complex constraint placed on the syntax of predicates participating in an analogy (section 2.2). It prescribes that, ideally, (i) each predicate in the source is mapped to a unique predicate in

the target and *vice versa*, and that (ii) when two predicates are mapped, their corresponding arguments, if any, are also mapped.

The multiple analogies discussed in previous chapters raise an obvious problem for this principle (section 2.5.1). Multiple analogies routinely involve mapping two or more source predicates with a target predicate. For example, the predicates *eye*, *ear*, and *knife* are mapped with *soul* in one of Plato's analogies (table 5.1). Because this mapping is not one-to-one, this situation violates condition i of the principle. An obvious approach to resolving this problem is to revise the principle into a condition on the process of analogy construction rather than on the structure of analogies.

The best solution to this problem depends upon how stringently the principle of structural consistency is applied to analogical mapping. In Structure-mapping theory (Gentner, 1983), structural consistency is an absolute requirement, meaning that exceptions are not contemplated or, at least, do not qualify as analogies. An obvious way to accommodate multiple analogies in such a framework is to *serialize* the principle. In other words, revise condition i to read: (i′) that each target predicate is mapped to one unique source predicate *at a time*. This solution effectively reduces multiple analogies to a chain of single ones. It also implies an encapsulated model of multiple analogies.

To see what this implication means, consider the problem of accounting for the increased confidence found in inferences based on multiple analogies. For example, by using both *Ruvettus* and *Centroscymnus* as source analogs for comparison with the Coelacanth (section 2.4), Locket (1980) more confidently infers that the Coela-

canth inhabits deep ocean water than he might have inferred in light of only one source analog or the other. Under the serial revision of the principle of structural consistency, this increase in confidence might be accommodated by representing confidence as something associated with the target analog that may be incremented as successive comparisons are successfully made. In effect, the target may be allowed to see and remember multiple sources provided that the sources do not see or influence each other directly.

This solution raises a further issue. In some of the multiple analogies discussed above, source analogs do appear to be able to see one another or influence one another directly. In cases of supplementation such as Haynes's use of modern elephant cullers in addition to wolves in comparison with Clovis mammoth hunters (section 4.4), the culler source seems to be employed specifically to modify the content of the wolf source. The readiest explanation of this situation is that the wolf source and its shortcomings influenced the selection of the culler source. Of course, like the representation of confidence, this influence could be modeled as an indirect one by further enriching the target with a representation of how completely the requirements of the target analog have been served by the sources considered so far. In effect, this would mean attaching to the representation of the target analog an explicit representation of the purpose of the analogy and how well it is satisfied in the light of the available source analogs.

Similarly, as pointed out in section 2.5.1, the target will also have to remember enough about each of the active source analogs to ensure that they are independent, *i.e.*, that the various source analogs considered are not merely copies or rehashes of

each other. A certain amount of information about each analog must be represented in this way, although exactly how much is not clear. It must be enough, at any rate, to compare the source analogs with one another to ensure their mutual exclusivity. Put another way, the target must be associated with enough information to simulate a model in which source analogs are compared directly with one another. Of course, specifying a model which merely simulates another one seems wasteful, implying that it may be rejected on the grounds of parsimony. In other words, it is odd that, in order to keep source analogs from influencing each other during analogy construction, facsimiles of those analogs are associated with the target in order to be compared with each other. Either way, it seems, the source analogs influence each other so they might as well do so directly.

In a non-encapsulated model of multiple analogies, source analogs would influence each other by means of constraints placed directly between them. This approach is a more natural extension of theories such as the MT (Holyoak and Thagard, 1995) or Higher-level perception theory (Mitchell, 1993; Hofstadter, 1995) in which the principle of structural similarity is not regarded as an absolute constraint. In the MT, for example, structural consistency is a soft constraint: Analogies may deviate from perfect structural consistency, although their overall coherence suffers as a result. A good analogy need not be perfectly coherent, simply coherent enough.

As noted in section 2.5.1, multiple analogies are less coherent than single ones according to the MT because they fail to meet the one-to-one criterion for structural consistency. Since this situation produces results contrary to the observations about multiple analogies made in the preceding chapters, the principle of structural

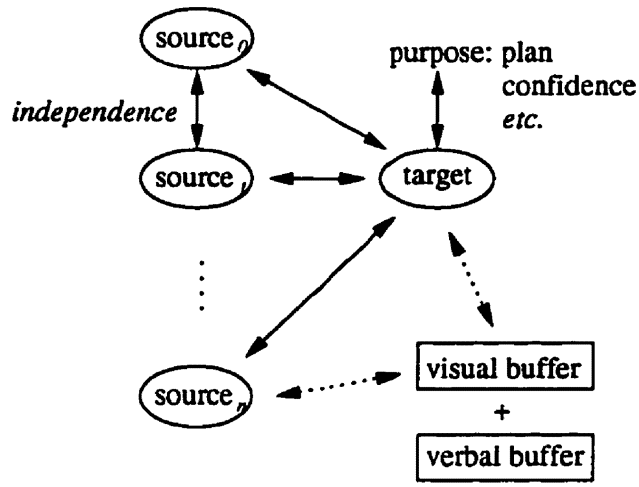

Figure 6.1: An outline cognitive model of multiple analogies.

consistency needs to be modified. In the non-encapsulated case, the principle may be revised to state simply: (i″) that each target predicate is mapped to one unique source predicate *for each independent source analog.* This revision of the structural consistency principle is parallel, rather than serial, in the sense that it does not stipulate that source analogs need to be mapped one at a time.

Any model of analogy that implements this parallel version of structural consistency is clearly non-encapsulated in the sense that it allows source analogs to directly influence one another in the process of analogy construction. This influence would amount to strengthening the mappings among predicates from independent source analogs while weakening those from dependent sources. Thus, analogies constructed with independent sources would be the most coherent ones in the usual sense of the MT. This parallel, non-encapsulated model of multiple analogies may be represented diagramatically as in figure 6.1.

The non-encapsulated approach to the construction of multiple analogies also

implies the view that single analogies are a special case of multiple analogies. If only one source analog is used, then the structural consistency condition i″ is identical to the condition i currently given in the MT. Independence only becomes an issue in cases where multiple sources are included in an analogy.

It then remains to see how issues such as confidence are handled in the non-encapsulated model of multiple analogies. Confidence, and a number of related issues, are best handled under the constraint of purpose, which is discussed below.

6.3 Purpose and planning

The constraint of purpose stipulates that the best analogies are the ones that solve the problem that faces the analogizer (section 2.2). This constraint primarily concerns the system mappings of an analogy. System mappings typically represent the higher-order relationships, such as causes, that obtain in the domains in question (Holyoak and Thagard, 1995, pp. 34–7). For example, Plato asserts that paintings appeal to the ordinary part of the soul *because* they misrepresent the true nature of what they purport to depict (section 5.4). By analogy, Plato claims that poetry has a similar appeal *because* it also appeals to the ordinary part of the soul. This claim is crucial to Plato's purpose of condemning poets since he goes on to claim that appealing to the ordinary part of the soul has dire consequences for a person's character.

In single analogies, the fulfillment of purpose generally amounts to ensuring that an appropriate high-level predicate is present in the system mappings of the analogy. As has often been pointed out in the previous chapters, purpose in multiple

analogies is a more complex issue. For example, it may be the analogizer's purpose not only to establish a certain high-level predicate in an analogy, but to establish it *with a sufficient level of confidence.* This purpose is apparent in the various examples of abstraction and exemplification discussed above. In Plato's eye, ear, knife, and soul analogy, for example, neither the eye nor the ear analogs increase the number or meaning of the system mappings because those analogs are almost indistinguishable from that point of view. There is nothing that can be said of one that cannot be said of the other. What both analogs together *do* accomplish is to suggest the generality of Plato's contention that everything has a specific work to which it is suited better than anything else. In other words, the inclusion of both analogs in the source serves the purpose of increasing confidence in the applicability of the target.

In the MT, purpose is identified with one or more of the high-level predicates in the target of an analogy. Thus, the representation of purpose requires nothing in addition to what is represented within the mappings themselves. However, *confidence* is not represented in Plato's eye, ear, knife, and soul analogy (table 5.1) or any other analogy examined above. In order to represent confidence, then, something must be added to the representation of the analogy. The most obvious representation to add is *purpose*, of which confidence is one possible component. It would be possible, then, for an analogy to fulfill the purpose of activating a particular, high-level predicate to a specified degree of confidence. See figure 6.1.

The concept of purpose extends to more than the representation of confidence. In some cases, different analogs in a multiple analogy may serve different purposes

from one another. Consider Plato's use of tragedians to supplement painters in his comparison with poets (section 5.4). Painters make a good source for Plato's purpose of discussing how artists misrepresent things since the representational function of traditional painting is obvious and familiar. However, painters do not make a good source for the purpose of explicating the dire consequences of artistic endeavors. But tragedians make an excellent source for this purpose. In effect, each source analog can only adequately fulfill a part of Plato's overall purpose. So it is helpful to think of Plato's purpose as being decomposable into parts. In other words, Plato's purpose may be conceived as kind of multi-component *plan*.

A great deal of research has been devoted to the concept of plans and planning. In artificial intelligence, a plan is typically represented as a series of steps which collectively fulfill a specified goal. So, for example, in the movie *Goldfinger*, Auric Goldfinger cooks up a plan ("Operation Grand Slam") to become the richest bullion dealer in the world. The plan includes the following steps:

1. stockpile vast quantities of gold;

2. render much of the remaining gold, *i.e.*, in Fort Knox, useless by making it radioactive.

Step 2 would make the gold obtained in step 1 scarcer and therefore more valuable, while making the U.S. Government much poorer. This situation would fulfill Goldfinger's purpose admirably, if it were not for the interference of James Bond. This view of plans may be applied to the representation of goals and subgoals in multiple analogies. The attachment of planning to the construction of multiple analogies raises a procedural issue: Are such plans constructed before the analogy,

or are they constructed interactively with the other processes of analogy construction?

There appear to be cases of both prior and interactive plan construction among the examples discussed above. In Locket's comparison of Coelacanth eye pigments with those of *Ruvettus* and *Centroscymnus*, for example, the properties of the source analogs appear to have been known in advance of the comparison with the Coelacanth (section 2.4). Thus, Locket had the plan or intention of making a multiple comparison in advance. In Talalay's comparison of Neolithic figurine legs, however, many of the source analogs appear to have been incorporated after the initial comparison suggested itself (section 4.3). Thus, this plan was elaborated interactively with increases in the availability of further evidence. Talalay's plan, then, was probably not finalized in advance of her construction of the multiple analogy. Since interactive planning is required to explain some instances of multiple analogy construction and since it can subsume prior planning as a special case, it is reasonable to say that interactive planning is how the purpose of multiple analogies should be modeled in the general case. See figure 6.1.

There has been controversy among researchers who study analogy as to the centrality of pragmatic considerations such as purpose on analogy construction (see Gentner, 1989, pp. 217–21). The model proposed here places much emphasis on purpose and planning for the generation and understanding of multiple analogies. In some computational models such as SME and Copycat, pragmatic influences on analogy construction are regarded as peripheral. In others, such as PRODIGY (Veloso and Carbonell, 1993), the separate representation of purpose as a plan is a

central element of the system design. Indeed, recent work by Veloso (1997) indicates how the PRODIGY system may be adapted to work with multiple analogs. Perhaps the apparent difference between these views may be reduced by noting that the importance of purpose and planning depends upon the situation and the carefulness of the analogizer. The examples of multiple analogies discussed above were all produced by experts out to support a particular hypothesis or position. Multiple analogies are not always produced by such careful or expert thinkers. Consider the following multiple analogy given in a letter to the editor of the *Nashville Tennessean*, 4 February 1925, regarding the progress in the State Legislature of the law against teaching evolution in schools, the law that later lead to the famous "Scopes-monkey trial" (quoted from Larson, 1997, pp. 51–2):

> I fear we will never stamp out the evolution theory, for old Bruno was burned and old Galileo thrown in prison, and yet the damnable round earth theory is still being taught.

This analogy compares the state government's adoption of a law prohibiting the teaching of evolution with the Catholic Church's adoption of a policy prohibiting the endorsement of Copernican astronomy. Structurally and semantically, the analogy works well. Factually, however, the analogy founders because Galileo and Bruno were prosecuted for supporting the *heliocentric* theory of the solar system and not the round earth theory as the writer states. Of course, it might be said that a comparison with flat-earth supporters better serves the purpose of heaping ridicule upon the Tennessee legislature, but the force of the analogy is greatly diminished once the mistake is realized. Either the purpose in this example was vague and

carelessly conceived or it was more carefully conceived but then carelessly satisfied. In either case, the writer's purpose exerted only an indefinite influence on the analogy that she finally constructed.

A nuanced representation of purpose is not required for every example of multiple analogies. But some examples, particularly those constructed by careful and expert thinkers such as those scientists and philosophers discussed in the previous chapters, do require some explicit and sophisticated representation of purpose. Indeed, producing good multiple analogies may require more attention to purpose and other pragmatic issues than is the case for single analogies.

6.4 Representations

The issue of representation is probably the most contentious in current research on analogies. Computational models of analogy have used almost every form of representation that the field of artificial intelligence has to offer. Each form has advantages and disadvantages as a basis for modeling human analogy construction, and a reasonable discussion of these points would require a book in itself. This section, therefore, does not present a discussion of every possible form of representation and its applicability (or lack of it) to multiple analogies. Instead, the representations already presented in previous chapters, namely verbal, visual and narrative, are discussed here in the light of current computational models of single analogies.

6.4.1 Verbal

Verbal representation consists of the now familiar predicates-and-arguments structures where the predicates and arguments are typically linguistic concepts or words. This form of representation is fundamental to such classic analogy models as the Structure Mapping Engine (SME) (Falkenhainer et al., 1989) and the Analogical Constraint Mapping Engine (ACME) (Holyoak and Thagard, 1989). This form of representation has many advantages: It is easily understood, has been fruitfully applied in the past on other projects, and makes it easy to apply the constraint of structural consistency. It also has a number of disadvantages: It may lead researchers to undervalue non-linguistic factors in analogy construction (Mitchell, 1993), and presents difficulties in capturing perceptual similarity (such as visual resemblance).

Although the model of multiple analogies described above places more emphasis on the content of analogs (*e.g.*, their independence) than previous models of single analogies, structure and structural consistency remain a central requirement. Multiple analogies are more or less coherent depending on how well the revised constraint of structural consistency is met. Since verbal representation lends itself well to the fulfillment of this constraint, it assumes a similar role in multiple analogies to the one that it has in single analogies.

6.4.2 Visual

Visual mental imagery appears to have played an important role in the construction of several of the multiple analogies discussed above. Adjuncts to visual mental

imagery, *e.g.*, pictures and diagrams, have also made a contribution. In some cases, simple resemblance was the important element. In Donnan's comparison of Peruvian pots (section 4.2), the resemblance of the marks on the inside of the Moche pots to the *signáles* of the modern potters appears to have been the whole contribution of visual imagery. The use of imagery, in other words, was confined to the recognition of similar attributes. Structural comparison at the relational and system levels seems to have been carried out using verbal representation.

In other analogies, the contribution of visual imagery was apparently much greater. In cases such as Farlow and Dodson's analogy between ceratopsians and modern animals (section 3.2) and Talalay's comparison of Neolithic figurine legs with other tokens (section 4.3), visual representation of actions and perhaps their causes participated in analogy construction. Both involve the alignment of vivid events such as angry rhinos fencing for mating superiority and shady underworld figures ripping $1,000 bills in half to cement a deal. These scenes record a sequence of events that comprise a representation of objects, their spatial relations, and their effects on each other that may be termed *mental movies.* Aligning events from various mental movies is an important part of multiple analogy construction that operates not only at the attribute level, but also at the relational and system levels.

The role of visual mental imagery in multiple analogy construction varies with the situation and with the analogizer. Visual mental imagery is more likely to be involved in multiple analogy construction if the situation concerns the visual properties and behavior of macroscopic objects and if the analogizer is a visual

thinker. This state of affairs suggests that a general model of multiple analogies must accommodate the use of both verbal and visual representations (at least) and interactions between the two as circumstances warrant.

The issue of visual representation is enjoying a resurgence of interest in computational modeling. The ANALOGY system developed by Evans (1968) used a predicate-and-argument style representation in which the predicates represent visual relations such as *inside(P1,P2)*, meaning that object *P1* sits inside object *P2*. But Evans's work was never followed up. Recently, however, researchers have modified several computational models based on verbal representations to use visual representations instead. The Tabletop system (French and Hofstadter, 1991; French, 1995) is a revision of Copycat that constructs analogies between place settings based partly on their resemblance and spatial arrangement in a tabletop microdomain. The Visual Analogical MaPping (VAMP) system (Thagard et al., 1993) is based on ACME but uses visual representations to model human performance in the task of visual comparison of pairs of objects. The MAGI system (Fergusson, 1994) is a version of SME that uses a set of graphical primitives such as lines, arcs, and curves to represent visual information in comparing pairs of diagrammatic line drawings.

Like Evans's ANALOGY program, these systems stay close to predicate-and-argument representations to capture visual relations among objects or parts of objects. The systems do not represent visual attributes or system-level information in a visual way. Visual attributes could be represented in a visual way by applying current cognitive models of visual imagery (see section 4.5.1). The representation of visual system-level information, *i.e.*, mental movies, might be accomplished by

the inclusion of a *visual buffer* to the model. In the model of visual mental imagery described by Kosslyn (1994), the visual buffer is a chunk of memory used to mediate low-level visual perception, *e.g.*, retinotopic maps, and high-level visual operations, *e.g.*, object recognition and image transformation. In the model proposed here, a visual buffer would serve a similar purpose—that is, it would serve as a kind of movie screen or blackboard upon which different visual movies could be projected sequentially or perhaps simultaneously. See figure 6.1. Thus, similarities among episodes could be detected by observing significant superimpositions or juxtapositions of images as images from multiple sources are projected together. The picture in figure 3.5 of Santa Claus and a motorist both out of fuel may be taken as an example of a visual buffer (externalized) in which two images are projected so as to construct or assess a visual comparison. Also, the buffer could be used by other processes that convert such images into predicate-and-argument representations (and the reverse) as required for structural consistency or even into verbal predicates to re-represent system-level information for purposes of abstraction or interaction with other sources of information.

6.4.3 Narrative

The use of narrative to construct multiple analogies plays an important role in a number of the examples presented in the previous chapters. In some respects, the visual movies just discussed constitute a kind of narrative representation, since they consist of episodes which may be aligned in the mind's eye or on paper. Thus, the mental movie of rhinos clashing over a potential mate is a kind of story which

could also be represented as a verbal narrative. Not surprisingly, narrative more straightforwardly of the verbal kind occurs in the examples taken Plato's dialogs (chapter 5).

The main advantage of narrative as a cognitive representation where the construction of multiple analogies is concerned is that it facilitates the use of several sources through simple concatenation. For example, Plato was able to talk about health *and* sickness in the body in comparison to justice *and* injustice in the state simply by claiming that the same causal relations apply to sickness and injustice that apply to health and justice (section 5.3). This analogy is fairly complex, as can been seen from its representation in table 5.3, but it is easily understood in its narrative form.

Several researchers have recently made strong claims for narrative as a fundamental form of cognitive representation. Schank and Abelson (1995) claim that much of our knowledge about the world comes in the form of stories based on our personal experiences. How experiences are remembered and recalled depends on how they fit into the stories we tell to ourselves and others. Turner (1996) argues that we posses a collection of story schemata or *image schemas* which we combine and project in order to represent sequences of events. Thus, when we say of someone that "a machine took away her job", we combine schemata about an actor grasping a physical object and taking it away, and then project the machine as the actor and job as the physical object. In both of these approaches, narratives are schemata in which certain information is supplied, such as ***someone grasps an object***, and some is left to be filled in from context, such as the boldface words in

the *grasp* schema just given.

In addition, narratives are useful because they relate a series of events to a theme. For example, Aesop's fable of *Androcles and the lion* relates a series of events to a moral, namely that good deeds do not go unrewarded (at least when the recipient of the good deeds is capable of gratitude). It may be the establishment of a relationship of events to a unifying theme that makes narratives easier to remember than a simple list of unrelated items.

No current cognitive model of analogy uses narrative representation for analogy construction. Narrative representation would seem to require the build-up of a schema from the sources of a multiple analogy along with a representation of their common theme or purpose (see Gick and Holyoak, 1983). Unlike the *shared-abstraction* theories of Plato and Aristotle, current models of analogy such as the MT are typically *shared-structure* theories and do not incorporate schemata, although shared-abstraction models have been used in analogy research in various fields of artificial intelligence (see Hall, 1989). However, Fauconnier (1997) presents a theoretical model of analogy which does rely on shared abstractions. In Fauconnier's model, selected information from source and target analogs are projected into a "blending space" where they are combined and manipulated together.

By analogy with the visual buffer proposed in section 6.4.2, narrative representation may be incorporated into the current model of multiple analogies by providing a *verbal buffer* that acts somewhat like Fauconnier's blending space to represent episodes of an ongoing narrative provided they are coherent with the theme of the multiple analogy. Similar or repeated episodic patterns could then be

recognized and manipulated as part of the process of analogy construction. So, for example, the mapping of *accord-with*$_b$ and *contrary-to*$_b$ with their counterparts in table 5.3 could be represented properly as a mapping between two pairs of opposite predicates instead of four arbitrarily organized predicates.

6.5 Processes

Multiple analogies are constructed through a number of different processes. In this dissertation, processes have been distinguished according to the different ways in which multiple source analogs serve their purposes. It is natural to infer that because analogs serve different purposes, they are made to do so in different ways. That is to say, where a means-ends analysis is applied to the problem of multiple analogies, different ends are best explained as the products of different means.

Furthermore, in cognitive modeling, processes are often realized as separate procedures for manipulating cognitive representations. In some models of analogy, however, this move from processes to procedures is explicitly denied, as in the Copycat model (Mitchell, 1993). In this model and its relatives, one procedure, namely the ***parallel terraced scan***, is applied to all problems regardless of the purpose they might serve.[1] In fact, the success of Copycat as an analogy-building model is taken by its authors as a counterexample to the claim that cognitive models need to make the move from processes to procedures at all. Anyone proposing a cognitive model based on a means-end analysis must at least consider this issue.

[1]Strictly speaking, Copycat is premised on the view that purpose is irrelevant to analogy construction.

The position taken here is to sit firmly on the fence between the two extremes. The processes such as supplementation and extension characterized in this dissertation are certainly processes apparent in the construction of multiple analogies, but it is not clear whether each is the product of a corresponding procedure or not. Thus, the discussion below is given strictly in terms of processes, leaving the exact nature of the cognitive procedures that underlie them to future investigation.

6.5.1 Abstraction and exemplification

Abstraction is a process whereby several analogs are represented by one alone. The several analogs in question are not an arbitrary assemblage but a group of items closely related under some description. For example, in the analogy concerning the depth of habitation of the Coelacanth (section 2.4), *Centroscymnus* was used to represent all deep water sharks, while *Ruvettus* was similarly used to represent all deep water teleosts. Any member of each class of fish would make a good analog for comparison with the Coelacanth and their total number would suggest the generality and importance of the adaptation of eye pigment being considered. But actually constructing such a large number of comparisons would be tedious and potentially confusing. Cognitively, it is just as convincing and much more economical to construct an analogy with the members of each class simply by constructing an analogy with a representative of each. The process of abstraction, then, reduces an intractable problem to a tractable one without losing informativeness.

The issue of what to use as a representative of each class remains. Although use could conceivably be made of an idealized member or an average member, in

practise use is made of an exemplary member of each class. The *Centroscymnus* and *Ruvettus* count as exemplary deep water sharks and teleosts, respectively, because each shares the relevant properties with the other members of its class, information about each is readily available, and the analogizer has some experience with each of them.

In the Coelacanth example, an exemplary member of each class of fish involved satisfies the criteria for abstraction. It is not clear, however, that exemplification is always the best response to the needs of abstraction. In a study of analogies taken from newspaper articles (Thagard and Shelley, ip), it is found that source analogs are sometimes chosen not because they are exemplary but because they are stereotypical. Consider the comparison by Dr. William Catalona of the demand for Viagra with the demand for wrinkle cream:[2]

> "It's like the Fountain of Youth," said Catalona. "Viagra is analogous to anti-wrinkle cream. This is something that will turn back the clock and make men the way they were when they were young."

Wrinkle cream does not count as an exemplary "age fighting" item because Dr. Catalona has no personal experience with it. The same may be said of the Fountain of Youth. Rather, wrinkle cream is an item stereotypically used by women to look and feel young. Sometimes, then, stereotypes may be preferred to exemplars for the purposes of abstraction.

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[2]From "Baby Boomers fight aging in a variety of ways", by P. B. Librach, 1 June 1998, Scripps Howard News Service.

6.5.2 Supplementation

The process of abstraction is useful in situations in which many, mutually coherent or consistent analogs are available. Some situations, however, call for a process of repairing or correcting other analogs, and not simply agreeing with them. The process of using multiple sources to repair others may be called supplementation (Spiro et al., 1989). Examples of supplementation are given in each of chapters 2, 3, 4 and 5. Clearly, supplementation is an important form of multiple analogy.

Supplementation presents some special difficulties where cognitive models are concerned. Supplementary source analogs satisfy the following three criteria when they are mapped to existing analogies: (1) they align with the previous source and target analogs as usual, and (2) revise or modify some of the predicates in the previous source analogs with which they are aligned, and (3) they may add mappings to the overall analogy. All three criteria may be problematic.

The first criterion might present difficulties where predicates in the new source are meant to revise predicates in the old one(s). The principle of semantic similarity (section 2.2) suggests that where the analogs in an analogy line up, they should contain similar predicates. But since supplementary analogs are meant to *revise* other analogs, the supplementary analogs must be semantically different than their predecessors. Different predicates align less coherently, which would make the new analogy worse, not better, than the original version. Thus, the principle of semantic similarity would seem to insulate analogies against revision. In practise, fortunately, this problem does not seem to arise. The relational and system predicates in the supplementary sources of the examples reviewed in previous chapters are almost

always identical with those already given in the old analogy. The one exception is in Plato's addition of tragedians to the painter-poet analogy (section 5.4), in which *praise* is mapped to *appeal-to*$_p$ and *appeal-to*$_P$. In this case, the incoherent predicate is not too far removed from the others in the mapping and has very little effect on the target. Thus, in practise, it appears that supplementation can be accommodated within the principle of semantic similarity as currently given in the MT.

If the new predicates are not different, how can they supplement the old ones? This question pertains to the second criterion for supplementation listed above. The answer consists in noting that although the relational and system predicates of supplementary analogs are semantically similar, their attributes are not. In Haynes's analogy regarding Clovis mammoth hunters (section 4.4), the comparison of wolves to humans works well in terms of the alignment of relational and system predicates, but fails to entirely convince Haynes himself because comparisons between human and animal psychology are problematic in general. To overcome this disparity, Haynes adds a supplementary source that concerns human behavior towards elephants. This new source maps humans to humans and mammoths to elephants, which gives a much more satisfying and plausible result. Thomson adds the newt analog to the analogy between *Hexanchus* and Coelacanth largely to replace claspers+organ reproductive attribute of *Hexanchus* with the ritual+gelatin attribute of the newt (section 2.4). In other words, attributes of supplementary source analogs tend to deactivate the attributes of previous source analogs when they are mapped with them. By the same token, they tend to increase the activation

of the corresponding attributes in the target analog.

Plato's use of tragedians to supplement his painter/poet analogy (section 5.4) introduces some new mappings into the previous analogy. Thus, for example, the predicates *corrupt* and $rule_t$ must be placed in new rows in table 5.4. This kind of supplementation initially presents a difficult problem in the sense that the addition of predicates appears trickier than the revision of predicates discussed above. In the latter case, predicates in the supplementary source all align normally with predicates in the target, but in the former case, this condition does not hold. There is no semantic or syntactic information in the analogs to distinguish which kind of supplementation is most appropriate. As noted in section 5.5.3, the difficulty may be overcome by attending to the purpose of the analogy, which appears to comprise a two-step plan for presenting poets as worthy of banishment. The trick for generating or understanding this kind of supplementation, then, is to connect each source analog with a step involved in the overall plan of the analogy. Probably, this way of constructing or interpreting a multiple analogy is a method of last resort, since the chances of confusing addition of mappings with revision of mappings is fairly high. In a cognitive model, an addition of mappings may be contemplated when a revision proves inadequate and thus represents a case in which the purpose of an analogy affects its structure and meaning interactively.

6.5.3 Specificity

The relationship between sources and target can obviously become quite complicated in multiple analogies. Another instance of this complexity arises in cases

where predicates in the target are filled in or inferred from predicates in the source analog. In cognitive models of single analogies, the usual strategy is *copy with substitution*, in which a predicate from the source analog is copied into the target and the appropriate arguments are substituted in to the copy (see footnote Holyoak and Thagard, 1995, p. 30). This strategy runs into a difficulty in multiple analogies because different sources sometimes have different predicates within a mapping. Simple copying is not possible in such a situation.

This difficulty arises in Donnan's analogy concerning Peruvian pots (section 4.2), Talalay's analogy concerning Neolithic figurine legs (section 4.3), and Plato's eye, ear, knife, and soul analogy (section 5.3). In each of these cases, the strategy was adopted of substituting not a copy of a source predicate but the most specific predicate that subsumed the meanings of all the source predicates. In other words, the target predicate is a compromise amongst the sources, rather than a copy of one of them.

There are two things to note about this compromise strategy. First, it implies a trade-off between the number of source analogs and the specificity of the target, at least where the source analogs are not completely similar semantically. Second, it subsumes the copy with substitution strategy applied in the case of single analogies.

In the case of the Moche pots, Donnan avoids any dissimilar predicates in his analogy, even though he had the opportunity to do so. In other words, Donnan could have compared the stay-at-home and travelling potter's practises to those practises of the Moche potters. It appears that Donnan set himself strictly to the task of explaining the marks on the Moche pots and not the doings of the potters

because the former task produced the most specific results. Bearing in mind the controversy in archaeology over the use of analogy (section 4.6), his conservatism is understandable.

Talalay and Plato set themselves the task of supporting a fairly nonspecific target predicate and could therefore accept the lack of specificity involved in their use of several source analogs. In exchange for this lack of specificity in the relevant target predicate, both authors increased confidence in its generality. In all three cases discussed here, specificity describes the way in which source analogs and target predicates are selected in order to best serve the purpose of the analogy. Specificity is thus another way in which purpose and target interact.

It should also be noted that, as with the revised principle of structural consistency (section 6.2), the process of specifying a target predicate as described here subsumes the process of copy with substitution which occurs in the single analogy case. That is to say, copy with substitution may be viewed as a special case of specification where only one source predicate is available. When only one predicate is available as the basis for specifying a target predicate, then simply copying that predicate is the only way to proceed. When, in the general case, several diverse predicates are available, then specificity becomes a more complex process.

6.6 Philosophy of science

One advantage of studying any cognitive phenomenon through actual examples is that a better appreciation is gained not only of the phenomenon itself but also of the areas from which the examples are drawn. This advantage applies no less to multiple

analogies than any other subject. In this dissertation, multiple analogies were taken from the fields of evolutionary biology, archaeology, and Plato's *Republic*. The implications of this study for the cognitive modeling of multiple analogies have been discussed in sections 6.2 through 6.5. In this section, the implications of this study for the philosophy of evolutionary biology and archaeology is discussed.

6.6.1 Disanalogy and extension

As noted in section 2.5.5, the social behavior of Coelacanth biologists conforms to Polemarchus' ethical dictum "help your friends and hurt your enemies". In other words, these biologists tend to extend or point out further positive analogies applicable to the comparisons of their professional compatriots, and tend to point out disanalogies lurking in the comparisons of their professional competitors. Although disanalogies and extensions are not inherently social phenomena, they happen to lend themselves well to the social goals of scientists as described by Polemarchus and therefore occur when these goals are operative.

The relationship of the scientific community to scientific knowledge has become an important issue in the philosophy of science, with philosophers and sociologists taking up a variety of positions on the subject (for a brief overview, see Thagard, 1994). Some have claimed that there is no distinction between scientific theories and the goals of the scientists who endorse them (*e.g.*, Latour and Woolgar, 1986). But cognitive models of social groups indicate that the content of theories and the goals of scientists *both* likely play a role in the growth of scientific knowledge.

For example, Hutchins (1995) has described the navigation of a U.S. Marine

Corps aircraft carrier in terms of the social distribution of cognitive tasks and representations among its navigational crew. Different crew members acquire and communicate various sorts of information, *e.g.*, location fixes, in order to navigate the vessel and ensure that it remains on course. The hierarchical, authority-driven nature of the crew command structure ensures that the relevant tasks have high priority, while the flexibility granted to trusted crew members ensures that decisions are not taken in the absence of unexpected but important information that may come to their attention, such as the presence of a sailboat directly in the path of the aircraft carrier.

A roughly similar situation holds in the scientific community. Groups of like-minded scientists support each other's positions in their various institutions, journals, and conferences, while arguing against the positions of others. As is the case with a navigational crew, the distribution of power and influence in the scientific community constrains how knowledge is generated, but information that does not fit accepted theories also constrains this process. In other words, cognitive representations and processes are distributed throughout the scientific community just as they are in any other community.

6.6.2 Fecundity and theory change

The ways in which the content of multiple analogies interact with the social organization of scientists may be examined from another angle by considering the issues of fecundity and theory change.

On the model of Goldman's principles of the epistemic benefits of the social

practises of scientists (section 3.4.4), the fecundity of an analogy may be defined as its ability to lead to more analogies for many analogizers. The extension of analogies into multiple ones by the addition of source analogs attests to the fecundity of the original analogy on this definition. Thus, for example, the fecundity of Farlow and Dodson's ungulate/ceratopsian analogy is attested to by Molnar's proposed extension of it from sexual competition to habitat preference. The fecundity of the original analogy tends to increase confidence in its application. By pointing out its fecundity, Molnar is also satisfying his social goal of endorsing Farlow and Dodson's theory that ceratopsian horns and frills served the needs of sexual selection, and also his personal goal of writing a publishable paper on the subject. This example indicates that epistemic and social aspects of multiple analogies are complementary rather than mutually exclusive.

Farlow and Dodson's work lead to a change in the dominant theory concerning ceratopsian horns. Previously, it had been widely held that the fancy headgear of ceratopsians was for defense against predators. Since then, the explanation via sexual selection has become the dominant theory (Dodson, 1996). The analogy of ceratopsians with modern ungulates, although it did not fit the prevailing view, proved to be convincing once it was brought to the attention of the paleontological community.

However, in the case of the *Archaeopteryx* (section 3.3), the presence of multiple analogies supporting both the arboreal and cursorial theories has helped to prevent the relevant community from reaching agreement on which theory to adopt (see also Shipman, 1998). In both of these cases, multiple analogies have had a definite

influence on scientific theory change in virtue of both the epistemic support they lend to one hypothesis or the other and the influence of the scientists who put them forward.

6.6.3 Evolutionary scenarios

Also of philosophical interest is the importance of multiple analogies to the construction of evolutionary scenarios (section 3.4.2). Analogies are important to this process because the plausibility of a reconstruction of some extinct organism relies heavily on comparison with modern organisms that have been studied by biologists. Multiple analogies tend to increase confidence in such reconstructions. Furthermore, multiple analogies, especially supplementations, are important in cases where the reconstructed organism does not compare too readily with any one modern animal and *must* therefore be compared with a conglomeration or chimaera of modern organisms. As Padian states, the problem of how best to make such multiple comparisons is one of the hardest that faces biologists interested in the nature of extinct animals.

A related issue in the philosophy of biology concerns the nature of the schemata used to generate evolutionary explanations. Some philosophers such as Kitcher favor argumentative schemata in which evolutionary explanations resemble deductions derived from first principles. Such schemata consist of statements, proceeding from the general to the specific, that follow from each other by connectives like *therefore*. Other philosophers such as Darden propose schemata which measure the degree of fit between particular facts and the theory of evolution. The schemata for

scenario construction proposed in section 3.4.2 is of the latter type. This type of schema better matches the practise of biologists since they do use multiple analogies to show the coherence of their reconstructions with observations of modern organisms. Analogies of any kind simply do not figure in the argumentative type of schema, which therefore misses this aspect of evolutionary explanation.

6.6.4 Archaeological scenarios

A similar issue has occupied archaeologists who have questioned the place of analogy and analogical inference in their discipline (section 4.6). As Wylie puts it, there has been a "reaction against analogy" in modern archaeology, especially the *New archaeology* of the 1960s. This reaction consisted in a rejection of the sometimes sloppy analogy construction of previous archaeologists combined with a questioning of basic aims of archaeology as a science. Is the aim of archaeology to reconstruct past cultures and practises or to infer general laws of culture?

The reconstruction of past cultures typically proceeds through analogical comparisons with modern cultures. Thus, archaeologists who argue in favor of reconstruction typically argue in favor of using analogies. Archaeologists who argue for the inference of general laws of culture typically argue against using analogies. One of the arguments offered against the use of analogies is that the modern cultures available for comparison exhibit as many differences as similarities with bygone cultures (section 4.1). There may not be any one modern culture upon which an adequately convincing analogy can be built for any particular purpose.

This objection loses some of its force when the possibility of multiple analo-

gies is raised. In particular, the supplementation of one analog by another, as in Haynes's analogy concerning Clovis mammoth hunters (section 4.4), offers at least the possibility of overcoming this difficulty. This point supports reconstruction as an aim of archaeology as a science and also motivates further research into multiple analogies as they may be applied in this pursuit.

6.6.5 Discovery versus justification

Some of the impetus for discounting analogies and promoting the inference of general laws as the aim of archaeology came from logical positivist emphasis on deduction in science (section 4.6). Another component of the logical positivist philosophy of science that affected archaeology (and evolutionary biology; see section 3.4.4) was the distinction between the context of discovery and the context of justification. Scientific inquiry was viewed as occurring in two distinct and independent phases, namely *discovery* in which hypotheses are generated and *justification* in which hypotheses are confirmed or rejected.

Because the two phases were held to be independent, data used in the discovery of a hypothesis could not be used in its confirmation or rejection. Clearly, however, some of the multiple analogies presented in this dissertation do not conform to the division of phases. Talalay's multiple analogy concerning figurine legs (section 4.3), for example, was generated in view of some of the source analogs and then justified by the addition of new source analogs dug up by a deliberate search. Either this practise must be rejected as illegitimate, or the strict division of phases of discovery and justification must be so rejected. The cognitive model of multiple analogies

proposed above indicates that confidence in a multiple analogy depends on its components and how well they serve their purpose and not on when or in what order they are put to use. If *confidence*, as it is employed here, is an acceptable source of support for scientific hypotheses, then the discovery/justification distinction cannot be accepted as is. If the distinction is to be maintained, then some reason must be found to reject confidence as a relevant source of support for scientific hypotheses. No such reason is readily apparent.

6.7 Normative aspects of multiple analogies

The primary focus of this dissertation has been to elucidate the nature of multiple analogies and their contributions to thought in various fields. This focus has necessarily meant an emphasis on descriptive assessment of multiple analogies, resulting in a cognitive model. Of course, important normative points have also been raised as the opportunity arose, particularly on the implications for multiple analogies for the philosophy of science. However, it would be useful here to devote some additional space to a broader consideration of the normative aspects of multiple analogies. In other words, some of the value of this work should come in the form of recommendations on what distinguishes good multiple analogies from bad ones. The recommendations presented below should be useful for anyone concerned with critical thinking and nature and role of analogies in science.

Work out multiple analogies explicitly. Perhaps the greatest advantage of modern theories of analogy such as the *Multiconstraint theory* is their richness of

representation and perspicacity of structure. Their richness comes from the large number of relations that they allow to be put to use in analogy construction. In the proportional theory, relations are represented by ambiguous constructions such as a colon ":" or "is to". In the MT and other shared-structure theories, relations are represented explicitly by predicates such as *praise*, *inside-of*, or *cause*. These predicates answer fairly well to the concepts that are active in analogy construction. Working out explicitly which predicates to use in describing an analogy is an excellent method of clarifying for yourself what relations are actually present in an analogy. Explicitness is especially helpful when considering multiple analogies in which several concepts must be aligned together. Concepts that seem very similar at first glance may not turn out to be so similar upon further consideration.

The perspicacity of shared-structure theories like the MT derives from the way in which mappings and the syntax of predicates represent the systematic structure of good analogies. Mappings represent the alignment of concepts in an analogy and can be worked out fairly rigorously by constructing tables of the kind presented in this dissertation. The use of table rows to represent mappings, as presented above, captures the alignment of concepts very well. Table rows also capture the multiple mappings of multiple analogies quite nicely by the simple addition of columns to the table. The rows and columns of the tablular representation, *e.g.*, tables 2.3, 3.1, 4.1, and 5.1, are thus well suited to the purpose of working out multiple analogies.

Working out multiple analogies explicitly in this way is good both for the purposes of constructing multiple analogies and for understanding and criticizing multiple analogies proposed by others.

Define your purpose carefully. The importance of purpose to the construction and understanding multiple analogies has been emphasized a great deal in this dissertation. Although multiple analogies may sometimes be used simply to add color to a story or argument, they otherwise reflect a more-or-less deliberate plan beneath their construction. And these plans are not necessarily simple ones. Recall from section 1.6 that Polya stipulated that *the* purpose of multiple analogies is to construct the most general target analog possible. The examples of multiple analogies analyzed in this dissertation clearly show that the situation is not so simple. Multiple analogies may be used to adjust or further constrain the interpretation of the target analog instead of generalizing it. The purpose of multiple analogies may be fairly complex, with each source analog fulfilling its own part of the overall plan. When constructing a multiple analogy, it is important to define the purpose of the analogy carefully and break it down into components if necessary. If no one source analog can fulfill the requirements, then it may be time to look into using multiple analogs. Each analog should have a specific purpose, perhaps to add confidence in the construction of the target, to revise the failings of previous sources, or to avoid considering aspects of one analog that would weaken confidence in the construction of the target.

The system mappings are particularly important to the purpose of any analogy. These mappings show how relations and attributes of analogs fit together to form an explanation, a plan, or a prediction. In some areas, such as evolutionary biology, groups of system predicates come already assembled in the form of schemata that derive from a general theory. In other areas, there is more freedom or less constraint

on which system predicates are used in which combinations. In either case, the system predicates in the target analog of an analogy must fit together properly to form a coherent synopsis of the whole analog. The multiple analogies presented in this dissertation have typically been explicated or summarized simply by rendering their system predicates into plain English. When a target analog can be thus read off as a satisfactory explanation, scheme, or prediction, then it can be more confidently judged to have fulfilled its purpose. If the system predicates of a target cannot be read off in this way, then different and/or additional source analogs should be considered.

Do not multiply source analogs beyond necessity. Copi and Burgess-Jackson (1992, p. 195) state that the first criterion by which the quality of an analogical argument may be judged is the number of source analogs that it includes. This advice is justified by claiming that the greater the number of source analogs, the higher the probability of the correctness of the conclusion. This advice is based on their version of Mill's shared-attribute theory and is obviously flawed for that reason.

Because the shared-attribute theory lacks any explicit representation of higher-level relations such as causal relations, the best or only way to think about the "probability" of a conclusion based on analogy is that it is proportional to the number of analogs. On a shared-structure theory, causal relations are explicitly considered and can thus be assessed directly rather than through the intermediary of probability.

Consider the example given by Copi and Burgess-Jackson (1992, p. 195):

> If I advise you not to send your shirts to such and such a laundry because I sent one there once and it came back ruined, you might caution me against jumping to conclusions and urge that they ought perhaps to be given another chance. On the other hand, if I give you the same advice and justify it by recounting four occasions on which unsatisfactory work was done by them, and report further that our mutual friends Jones and Smith have patronized them repeatedly with similar unhappy results, these premisses serve to establish the conclusion with much higher probability than did the first argument, which cited only a single instance.

This argument seems to be aimed at establishing, with high probability, the generalization $(x)(shirt(x)\&launder(Laundry, x) \rightarrow ruin(Laundry, x))$, or, in English, if x is a shirt and the Laundry launders it, then they ruin the shirt. On the *Multi-constraint theory*, the analogy would be construed as a causal explanation, which is more typically how people treat this kind of situtation . In other words, the analogy should be construed as support for the proposition that the Laundry ruins shirts (*ruin*) due to some factor f such that *cause(f,ruin)*. To construct the analogy that best supports this conclusion, it would be better not to multiply source analogs but to seek out source analogs that provide some indication of what f is. In this example, it would be better to provide evidence that the Laundry typically uses a bleach that causes colors to run, if that is indeed the root of the problem.

On the theory discussed in this dissertation, the number of source analogs required for an analogy is just the number required to establish in the target the

desired system predicates with the desired specificity and confidence, and no more. This is not to say that there is an obvious, optimal number of analogs for any given analogy; extensions or even contractions may be made as more analogs are considered. But simple and unguided addition of analogs should be avoided.

Counter disanalogies with supplementary sources. Bonner (section 2.5.5) notes that biologists sometimes cringe when offering analogies in anticipation of the faults and disanalogies that their collegues will point out. One way to deal with this situation is to construct analogies for which no disanalogies exist. However, it may not always be possible to find source analogs that satisfy this constraint. It is best, then, when constructing analogies to anticipate objections and look for disanalogies that arise from the analogies that you propose. Where these disanalogies cannot be avoided, they may be overcome, at least on some occasions, by giving supplementary analogs. In effect, this advice amounts to pointing out that the process of supplementation may be preferable to giving up on an analogy (see Spiro et al., 1989).

Of course, a good supplementation is one that fulfills the purpose of the original analogy. But there do not seem to be any general rules for deciding whether a supplementary analog is adequate for its purpose. In other words, the criteria for deciding on the adequacy of supplementary analogs appears to vary from situation to situation. Exploring and clarifying this problem is an important direction for future research on multiple analogies. In the meantime, the best advice is to consider supplementary analogs carefully and try to generate criteria for deciding on their adequacy for the overall purpose of the analogy. This process may suggest criteria

that can be applied more generally.

Think in terms of different representational media. The role of verbal, visual, and narrative representations in multiple analogy construction has been discussed in this dissertation. One point that may be pursued here is the tendency of thinking in one medium to proceed in that medium. In other words, once analogy construction begins using visual mental imagery, say, it tends to continue in that medium. This *inertial* quality of representation has its advantages and disadvantages.

The main advantage for current purposes is that analogs similar in representation to the one under consideration at any given moment will suggest themselves. For example, the mental movie of two ceratopsians fighting over a mate may remind you of the movie of two rhinos fighting over a mate, which may remind you of two elk fighting over a mate, and so on. These sorts of similarity-based remindings may suggest several analogs that could be useful for a given purpose.

This same inertial quality of representation may be a disadvantage if the relevant analogs are not encoded in the same representation as the one currently under consideration. So, for example, thinking in terms of a mental movie will tend to inhibit any reminding of an analog that is represented in verbal fashion.

The advice that follows from these considerations is that you should think about the problem at hand in different forms of representation and thus prompt the recollection of as many source analogs as possible. The best solution to some problem may be suggested by a multiple analogy with sources represented both verbally and visually. It would be a pity to miss solutions in such cases by simply failing to take

into account the diversity of mental representations.

6.8 Concluding remarks

As noted in chapter 1, an adequate cognitive theory of analogy must address a wide variety of issues. Analogical thinking, after all, encompasses a fair variety of activities, one of which is the construction of multiple analogies—that is, analogies with multiple source analogs. Philosophers as astute as Plato, Aristotle, Bacon, and Mill have used multiple analogies in the course of their work, but have not examined them as such.

In this dissertation, I have presented an examination of multiple analogies as such, an examination based on analysis of instances of multiple analogies taken from the works of sophisticated and expert thinkers. This analysis reveals a number of issues concerning analogy and analogical reasoning which simply do not arise in the study of single analogies, *e.g.*, the processes by which multiple analogies are constructed by individual thinkers and by communities of thinkers acting together or in competition. This analysis raises the fundamental issue of whether to regard single or multiple analogies as the basic form of analogical reasoning. Although single analogies are more frequent, parsimony indicates that they should be treated as special cases of multiple analogies for the purposes of cognitive modeling.

This analysis also shows the importance of multiple forms of representation to multiple analogies. Cognitive representations of the verbal, predicate-and-arguments sort are appropriate for many instances of multiple analogies, but visual and narrative representations also come into play and must therefore be part of any general

cognitive model. Different thinkers vary in their abilities to employ one form of representation or another, and one thinker may vary in his or her use of cognitive representations in the process of constructing any one multiple analogy. In the cognitive model proposed here, visual and verbal buffers are proposed to allow for such variation in performance.

This analysis has also served to emphasize the importance of purpose to analogy construction. In some cases, multiple analogies may arise by some process of simple association of one source analog with another, but, in the cases examined above, multiple source analogs are used for specific reasons. Without an understanding of these reasons and how they relate a thinker's analogs to his or her goals, the occurrence of these multiple analogies might seem merely idle or perverse.

Finally, this analysis reveals the importance of multiple analogies to the epistemic goals of scientists and philosophers alike. Multiple analogies make important contributions to the conduct of evolutionary biology, archaeology, and philosophy. Improving our understanding of multiple analogies therefore allows us to improve our understanding of the aims and methods of sophisticated thinkers in these fields of inquiry. No doubt, analysis of multiple analogies in other fields of research would be equally revealing.

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