Title

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Analogy and Representation: Support for the Copycat Model

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Abstract[1]

We report two experiments which assessed the psychological validity of the Copycat framework for analogy, which proposes that analogy is a process of creating a representation. Experiment 1 presented subjects with two letter string analogies: "If **abc** is changed to **abd** how would **kji** be changed in the same way?", and the same statement but with **mrrjjj** as the string to be changed. Each subject attempted to solve both analogies and order of presentation was varied. The predictions of Copycat very closely matched the performance of human subjects on the first analogy people solved. However, the second analogy task showed substantial asymmetrical transfer effects that the model does not directly predict. Substantially greater transfer was observed from the **mrrjjj** analogy, for which it is hard to produce a highly structured representation, to the easier to represent **kji** analogy, than vice-versa. In Experiment 2 the first part of the statement of the problem was "If **aabbcc** is changed to **aabbcd**...". In this case **kji** becomes harder to represent than **mrrjjj**. As predicted, this version yielded more transfer from **kji** to **mrrjjj** than the reverse. In both experiments transfer was asymmetrically with greater transfer from less structured to more structured problems than the reverse. Overall the study supported Copycat's contention that representation is a vital component for understanding analogical processors.

Copycat (Hofstadter, 1985; Hofstadter & Mitchell, 1988; Mitchell, 1990; Mitchell & Hofstadter, 1989, 1990) is a program that creates analogical inferences in a simple domain, a micro world consisting of the 26 letters of the alphabet and associated concepts. The program solves problems such as, given that **abc** changes to **abd**, what does **srqp** change to analogically? Or how would **mrrjjj** change? (Note that the string to be changed will be presented in **bold-face**, while strings that are possible answers will be in *italics*) Copycat differs from most other models of analogy (e.g., Holyoak & Thagard, 1989; Falkenhainer, Forbus, & Gentner, 1989) in that other models take an existing representation of a situation and build an analogy from that representation. Copycat instead proposes that building the representation interacts crucially with the mapping of the analogy. In Copycat, representations are not just something from which analogies are derived; rather, the construction of a representation is viewed as the most basic analogical process. Consequently, analogy is viewed as a much more general process than most other models of analogy envisage.

Copycat limits its domain to letter strings because analogy is viewed by Copycat's authors as too complicated to be initially studied in a complex domain (Hofstadter, 1985). For Copycat, representing an analogy involves forming relevant, coherent structures at an appropriate level of abstraction. For example, a link may be formed between the letters *a* and *b* because *b* is the alphabetic successor to *a*. Or a link may be formed between the letters *a* and *m* because they are both the left-most letters in their strings. Forming structure can also require deciding which aspects are to be taken literally and which are allowed to "slip" to related concepts. For example, *c* is the predecessor of *d*, but under appropriate conditions a representation may be built that allows the concept of "predecessor" to slip such that the "predecessor" relationship is mapped to the opposite "successor" relation. In Copycat these slippages, like all aspects of building the representation, occur as the result of competition between different interpretations. What these interpretations may be is not limited by the initial representation as it is in the other analogy models mentioned above. Letter string analogies incorporate all of the problems Hofstadter and

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Mitchell consider important: they have structure, they may lead to "slippage", and they often have competing interpretations. Because letter string analogies are a relatively simple domain, they make it possible to isolate the important aspects of analogy without having to incorporate many domain-specific mechanisms.

However, because Copycat solves a different domain of problems than that of most other computational models of analogical processes, it is very difficult to directly test Copycat against other models of analogy. It is in its underlying approach that Copycat differs from these other models, rather than in predicting specific different results. It is also unclear how best to test Copycat as a psychological model of analogical reasoning. Copycat is not designed to model human behavior at a fine grain, although Mitchell (1990) intends the Copycat internal architecture and external behavior to provide a plausible model of human analogy making. Another factor that makes it difficult to test Copycat as a model is that clearly many aspects of human experience are excluded from its micro world (e.g., people generally know the alphabet better forwards than backwards). In this study we make some initial attempts to experimentally test implications of the Copycat approach.

It would increase the psychological plausibility of the Copycat model if it could produce similar answers to letter-string analogy problems to those people generate. Copycat is intended as a model of a single individual, but it is impractical to ask the same person to solve one of these problems a thousand times and compare the frequency of responses to that generated by a thousand runs of the Copycat program. Therefore we instead gave analogy problems to a number of people, with the assumption that their responses would reflect the biases of a single individual over time. Mitchell (1990) gave analogy problems to people to solve and found that Copycat could produce the most common answers people advanced, but it was unable to generate the full range of answers that people did. However, even human data for responses that Copycat was able to generate had a clearly different frequency distribution for those responses than that Copycat produced. This suggest that Copycat may be limited as a model of human behavior, reflecting either limitations of the current instantiation of Copycat (as Mitchell acknowledges) or the model's general approach to analogy making.

Rather than simply comparing the frequency of Copycat's responses to human data, we sought to evaluate Copycat's claim that the interaction of representation and mapping is critical to analogical reasoning. We were unable to test this claim directly, but instead sought to test a prediction that appears to be consistent with this claim. If representation is critical, then particular transfer effects may be predicted when subjects try to solve successive analogy problems. (The Copycat program has never attempted to model transfer; however, there appears to be no conceptual problems with doing so) In Experiment 1 we presented subjects with two analogies: 'Suppose that the letter string **abc** was changed to **abd**; how would you change the letter string **kji** in the same way?'; and the same analogy but with **mrrjjj** as the string to be changed. These two problems were chosen from among the many that Copycat has attempted because they both had at least two reasonably frequent answers, suggesting that they had enough inherent ambiguity of interpretation to be affected by attempts to solve preceding problems. Copycat generated three main answers to the **kji** problem: *kjh*, *kjj*, and *lji*. Each of these answers reflect a different representation of the problem. To produce *kjh* Copycat builds a representation in which the **kji** string is a left-to-right sequence of letters that precede each other in the alphabet, while **abc** is a string in which the letters are alphabetic successors. The opposing nature of these structures causes the concept of changing the right-most letter (derived from "**abc** changes to **abd**") to its successor to "slip" to "change the right-most letter to its predecessor". The string *lji* results from a similar representation but instead of letting "change predecessor" slip to "change successor", the idea of "change right-most" slips to "change left-most". In contrast, the answer *kjj* can be produced with relatively little structure, by directly transferring the idea "change to successor of left-most" with no direct influence from the string to which it is being applied. Little structure can be effectively built however to represent the **mrrjjj** analogy problem. The most common answers Copycat produces are *mrrjjk* and *mrrkkk*, both of which are the result of transferring the unmodified rule of "change right-most element to successor", with the only aspect producing differences being the question of what constitutes the "right-most element". More structure is built for *mrrkkk* than for *mrrjjk*, as the answer *mrrkkk* requires the grouping of *jjj* into a single element that then maps to the element *c*. However, Copycat gives both of the common **mrrjjj** solutions a much higher *temperature* (temperature is Copycat's measure of the amount of structure it builds for an analogy, with low temperature indicating large amounts of structure are built) than it calculates for the *kjh* and *lji* answers for the **kji** analogy.

To examine transfer effects, approximately half the subjects received **kji** first and half received **mrrjjj** first; then each subject received the other analogy. It would be unsurprising to find some transfer effects, as the idea of changing the right-most letter to the successor is applicable to both analogies. But if subjects are trying to build comprehensive representations of these problems (as Copycat seems to suggest they would) then there should be an asymmetry of transfer effects. It should be relatively difficult to transfer **kji** answers to **mrrjjj** because it is expected that subjects will build a relatively highly structured representation of **kji**, a representation that will then be a poor fit to **mrrjjj** if subjects try to make use of the whole representation they have built. However, little structure can be built for **mrrjjj**, allowing relatively unencumbered transfer of the idea "change to successor of right-most letter".

Experiment 1

Subjects were from the introductory psychology subject pool at the University of California, Los Angeles. A total of 140 subjects attempted the analogies either during or after participating in another experiment. Sixty-six subjects did the **kji** analogy first and 74 did **mrrjjj** first. Subjects had to decide on one best response to each analogy and were given as long as they wanted to complete the task. However, they could not return to the first analogy after completing it, or start the second without completing the first.

	kjh	kjj	ijl	lji	ijk	Other
first	24	14	5	15	0	8
second	9	43	3	9	2	8

Table 1. Frequencies of each answer to the **kji** analogy for subjects receiving **kji** first or second.

Table 1 reports the frequency of each response to **kji** that occurred more than twice for subjects solving this analogy first or second[2]. Let us first consider the results for subjects solving the problem first. Copycat generated the most common answers that people produced, but subjects form a number of answers that Copycat is not reported to have produced, although

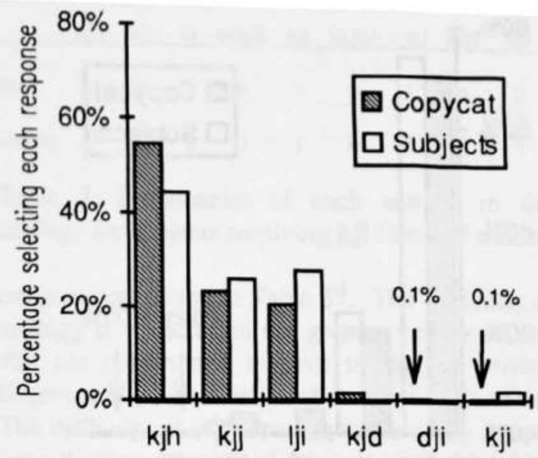

Figure 1. A comparison of the frequency of each response to the **kji** analogy when solved first for Copycat and human subjects (as a percentage of the subset of responses that Copycat is capable of generating).

	mrrjjk	mrrkkk	mrriii	mrrjjjj	jjjmrr	mrsjjk	mrsjjj	Other
first	11	34	0	1	3	5	1	10
second	5	11	4	3	1	3	3	36

Table 2. Frequencies of each answer to the **mrrjjj** analogy for subjects receiving **mrrjjj** first or second.

none have a high frequency. As discussed above, Mitchell (1990) also found this limitation of Copycat, and explanations she offers account for many of the non-Copycat answers. In order to test Copycat on its own terms we used only the subset of answers that Copycat was also capable of generating and computed the frequency of each answer as a percentage of the frequency of all answers in this subset. These percentages are presented in Figure 1, together with the frequency with which Copycat generated each answer over a thousand runs as reported by Mitchell (1990). Copycat's frequencies are very close to those of the subjects. The hypothesis that the distribution of results is the same for Copycat and for people cannot be rejected (using all cells with an expected value greater than 1.0, $X^2(3) = 2.65$, *n.s.*).

Table 2 reports the frequency of all responses to **mrrjjj** which more than two subjects generated[3]. This

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[2] Other answers were: *kln, kji, jig, kli, hij, kij, lkj, jkl, kjd, kji, qji, kjk, ijk, klj, kjp.*

[3] Other answers were: *jms, mrt, mrrkkkk, mrtjjk, mmrrkk, mrrjjjwwww, mrrk, mrrjji, mrrfff, rjmjrj, msskkk, mtrjjj, mjjjrr, jjrrmj, rrmjjj, mrrjjjkkkk,*

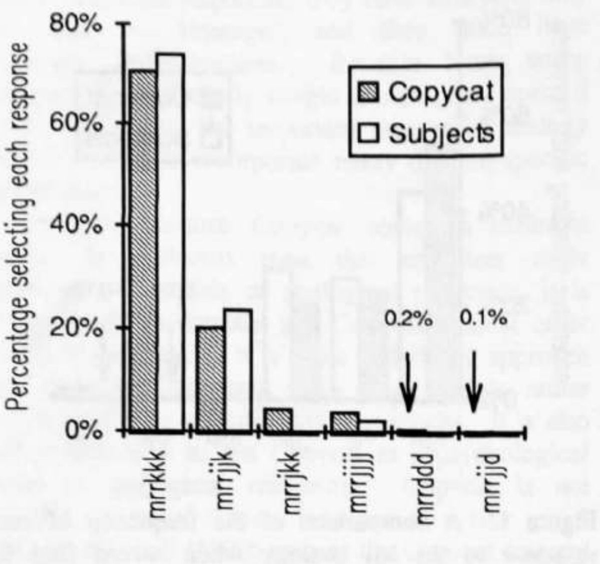

Figure 2. A comparison of the frequency of each response to the **mrrjjj** analogy when solved first for Copycat and human subjects (as a percentage of the subset of responses that Copycat is capable of generating).

data follows a similar pattern to the **kji** results. The main difference is that a greater variety of answers are produced and fewer subjects give the more common answers. This reflects the intuition that **mrrjjj** is a harder analogy for which to produce a systematic answer. Figure 2 presents the comparison of Copycat's results with those of the human subjects, again limiting the comparison to answers that Copycat had produced. Again the hypothesis that frequencies are the same for Copycat and people cannot be rejected (using all cells with an expected value greater than 1.0, $X^2(4) = 2.79$, *n.s.*). These data suggest that the underlying ideas on which Copycat is based have some validity, given that within its limitations Copycat produces results remarkably close to those for human subjects. It is unclear why Mitchell (1990) was less successful in matching Copycat's results to human performance, as Mitchell does not give enough details of her methodology to know if there were major procedural differences with the present study. One difference is that she used fewer subjects (32 for **mrrjjj** and 10 for **kji**).

Comparing the frequencies of responses to the same problem when done second instead of first shows strong order effects. As Table 1 indicates, for the **kji** problem the most common answer, *kjh*, becomes significantly less common ($X^2(1)= 11.34$, $p<.05$) when the problem is solved second. The answer *kjj* becomes the most common answer and is significantly more frequently generated than when **kji** is solved first ($X^2(1)= 19.67$, $p<.05$). For the **mrrjjj** analogy the two most common answers (*mrrkkk* and *mrrjjj*) collectively are generated less often when **mrrjjj** is solved second, $X^2(1)= 30.76$, $p<.05$. (While *mrrkkk* is generated relatively less often than *mrrjjk* when **mrrjjj** is solved second, this difference is not significant, $X^2(1)= 2.19$, *n.s.*) The hypothesized asymmetry of transfer was found. Of the 34 subjects who produced *mrrkkk* when doing **mrrjjj** first, 23 answered *kjj* to their second analogy. However, of the 14 subjects answering *kjj* when they were given **kji** first, only two answered *mrrkkk*. This asymmetry is significant ($X^2(1) = 11.32$, $p<.05$). Similarly, of the 11 subjects answering *mrrjjk*, 10 subsequently answered *kjj*, but of the 14 answering *kjj* only three give *mrrjjk* as their answer to **mrrjjj**, again demonstrating a significant asymmetry of transfer ($X^2(1)= 11.91$, $p<.05$). The greater variety of answers generated when **mrrjjj** is solved second is also consistent with the claim underlying the asymmetry hypothesis, that it will be more difficult to systematically transfer a highly structured representation than a less well structured one. If subjects try to fit their relatively highly structured representations formed for the **kji** analogy, they may end up distorting their representation of the **mrrjjj** analogy in unusual ways. An example of this was provided by subjects who generated *mrriii*, an answer never produced except when **mrrjjj** is solved second. It appears that subjects may be transferring the idea of taking the predecessor of the last element from their answer for **kji** (three of the four subjects who did this had answered *kjh* to the **kji** analogy). In contrast, there is relatively little difficulty in transferring the unstructured representations of the **mrrjjj** analogy to the **kji** analogy, so there is no increase in the generation of unusual answers when **kji** is solved second. If this interpretation is correct then it is not simply the idea of "change last element" that is transferred between the two problems, but the whole representation of the problem. While Copycat does

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mrruuu, mrrjjd, mssjjj, mrrkk, mrrsss, mrrjkk, mrrhhh, jmmrrr, mrrggg, mqqjjj, nrjjjj, mrsjjj, mrrttt, jjjmrs, mrrnnnn, jjjrrm, mrrzbd, mrrjjj, mrrmmmm, mrrlll, mjjrr, morij, mrrzzzz, mrsjkl. These responses also illustrate a limitation of Copycat that people do not seem to share, namely, the same element cannot have two interpretations in Copycat. For example, *mrrkkkk* violates this constraint because the *kkkk* element is both the numerical and alphabetic successor to *jjj*.

not directly deal with transfer between analogies, these results are consistent with its general approach of emphasizing analogy making as an interaction between representation and mapping.

Experiment 2

In Experiment 2 we constructed analogies that should exhibit a reversal of the asymmetry of transfer found in Experiment 1. This was accomplished by making **kji** the analogy with less structure to represent, so that it should transfer to a **mrrjjj** analogy; and **mrrjjj** the analogy for which more structure can be built, so that it should show less transfer to **kji**. To create problems to test this hypothesis we replaced the initial part of the analogy "**abc** was changed to **abd**" with "**aabbcc** was changed to **aabbcd**". The same two strings then had to be changed: **kji** or **mrrjjj**. The representation of **kji** is now much more difficult, because there is no simple map of its three elements to the six elements of **aabbcd**. Even greater difficulties arise if subjects try to incorporate the idea of "splitting" the last element (as **cd** can be seen as the splitting of the **cc** element) into their representation. In contrast, the **mrrjjj** analogy now has a straightforward representation available: simply map each letter in **aabbcd** to each in **mrrjjj** and change the rightmost element to its successor. The major complication in representing **mrrjjj** in Experiment 1 was trying to group six elements so as to map to three, but this difficulty is now eliminated. Neither of these analogies have been given to Copycat, though there is little doubt that it would be able to produce some plausible answer to even these poor analogies, just as people proved able to do so. The aim of this experiment was to test the hypothesis that an asymmetry of transfer would be found, consistent with Experiment 1. The nature of the asymmetry is hypothesized to be that subjects solving the **kji** analogy (for which little structure may be formed) first would display more transfer to the **mrrjjj** analogy (for which relatively more structure can be formed) than subjects solving **mrrjjj** first would display transfer to the **kji** analogy.

Subjects were 104 students from the introductory psychology subject pool at the University of California, Los Angeles who participated in this experiment as a filler task within other experiments (primarily a memory experiment). Sixty subjects solved **kji** first and 44 solved **mrrjjj** first.

The frequency of responses for the subjects to the **kji** analogy for all answers that occurred more than

	kjh	kjj	lji	kkjjih	kji	kkjjij	iijjkl	kjih	kjk	Other
first	14	17	5	6	3	0	3	4	0	8
second	3	14	2	1	1	4	2	1	3	13

Table 3. Frequencies of each answer to the **kji** analogy for subjects receiving **kji** first and second.

twice are presented in Table 3[4]. The difficulty of this analogy is reflected in the greater variety of answers that are constructed relative to the **kji** analogy in Experiment 1, especially when **kji** is solved second. The difficulty of representing this analogy is apparent from the large number of subjects who added letters to the string in attempting to map three elements to six.

	mrrjjk	mrrjji	mrrjjg	mrrjjh	mrrjk	mrrjj	mrrjk	Other
first	23	0	2	2	1	1	2	13
second	27	5	1	2	2	3	1	19

Table 4. Frequencies of each answer to the **mrrjjj** analogy for subjects receiving **mrrjjj** first and second.

The frequencies of responses for the subjects to the **mrrjjj** analogy for all answers that occurred more than twice are presented in Table 4[5]. The **mrrjjj** analogy does not show a clear order effect. Both before and after solving the **kji** analogy, about half of the subjects appear to have settled on the simplest representation: changing the rightmost letter to its successor and therefore producing *mrrjjk*.

Examination of the transfer effects supported the asymmetry hypothesis. Of the 17 subjects who produced *kjj* as their answer to **kji** when doing that analogy first, 14 subsequently generated *mrrjjk* as their answer to **mrrjjj**. However, of the 23 subjects who produced *mrrjjk*, only 10 generated *kjj* as their answer to **mrrjjj**. This difference in proportions was significant ($X^2(1)= 6.16, p<.05$). Similarly, five of the fourteen subjects who produced *kjh* as their answer to **kji** subsequently generated *mrrjjk* as their response to **mrrjjj**. But only one of the 23 subjects who produced *mrrjjk* subsequently generated *kjh* ($X^2(1)= 6.30, p<.05$). Thus transfer tended to be from **kji** to **mrrjjj**

[4] Other responses recorded were: *jih, kjil, kkjjil, ijl, lkj, kjid, kjf, kkjjl, kki, iijjk, kkjjim, lkji, lkji, lkjjii.*

[5] Other responses recorded were *mmmmrrrrjjkk, mrsjjj, jjmmrr, mrrjjd, mrrjjh, rrjjmj, mrrjjq, jjrrmn, mrrjjo, mrrjjp, jjjmrs, mrrjjn, mrrjd, mrrjkl, mrrjkk, mrrjjt, mrrjjj, jjjmr, mrrjcj, nrrjjj, mrr, mrrjjm.*

rather than the reverse, which is the opposite direction to that found in Experiment 1. However, this reversal is consistent with previous results if we accept that in Experiment 2 it was more difficult to build a highly structured representation of **kji** than for **mrrjjj**.

Conclusions

The general approach of Copycat appears to be supported by our results. Subjects who appeared to adhere to the limitations of Copycat's micro world actually produced very similar behavior to Copycat when solving their first analogy problem. The asymmetrical transfer results indicated that the apparent ease of transferring a representation predicts the amount of transfer observed, which is consistent with Copycat and its emphasis on building representations as the crucial part of making an analogy. However, we have not definitively tested Copycat or rejected alternative models of analogy making (e.g., Holyoak & Thagard, 1989; Falkenhainer, Forbus, & Gentner, 1989) which may be able to handle the transfer effects we found if appropriately setup. But it may not be possible to construct definitive tests given that currently Copycat solves very different problems from those that other analogy making models attempt and Copycat represents a different approach to the whole question.

In ongoing work we are trying to further investigate the psychological plausibility of Copycat and its approach. In particular, we are examining how subjects represent these types of problems by using the generation and transfer methodologies we describe here and by having subjects rate the quality of a set of possible answers.

Acknowledgments

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