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Software reuse holds the promise that complex software systems can be built faster, at lower cost, and with higher quality by reusing existing software artifacts. However, despite numerous success stories and decades of research, the promise has not been fulfilled. This situation has lead to a renewed "interest in understanding how and where reuse can be effective and why it has proven so difficult to bring the seemingly simple idea of software reuse to the forefront of software development" (Krueger, 1992, p. 133). We still lack a thorough understanding of how individuals reuse software artifacts, what obstacles they encounter, and how to overcome those obstacles. This lack of understanding makes reuse an uncertain endeavor -- we cannot effectively and efficiently support reuse with technology if we do not understand the reuse process.

This study explores the cognitive processes of reuse in the context of object-oriented analysis (OOA). Three general research questions are investigated:

1. How do individuals reuse a given OOA artifact (the *source*) when modeling a new problem (the *target*) in an unfamiliar domain?

2. How does the degree of similarity between the source and target impact the amount and nature of reuse?

3. How does the analyst's level of experience impact the amount and nature of reuse?

Prior research in cognitive psychology on analogical reasoning and expertise provide the theoretical and empirical grounding for this study. First, in an unfamiliar domain, an analyst does not have domain-specific solutions available from his or her past experience. In this situation, analysts might reason analogically from a given source artifact and/or from abstract, domain-independent solution patterns the analyst has developed with experience. In either case, the process of reuse is expected to incorporate analogical reasoning. Analogical reasoning involves first constructing a set of correspondences

between elements in the source and target domains and then using these correspondences to solve the target problem. The first research question explores the extent to which analogical reasoning explains the reuse process.

Second, theories of analogical reasoning differentiate between two types of similarity, structural similarity and surface similarity. Structural similarity is the degree to which the source and target domains have a common underlying, relational structure. In OOA terms, this translates into the degree to which the source and target domains have common inter-object relationships or abstract patterns. Surface similarity is the degree to which the source and target domains have the same object and attribute names and values. In OOA terms, this translates into the degree to which the source and target domains use the same vocabulary for classes and attributes. Research on analogical reasoning indicates that structural similarity, not surface similarity, is critical to analogy (Gentner 1983; 1989). This implies that OOA artifacts with high structural similarity are more reusable than artifacts that are structurally dissimilar. The second research question compares reuse when the analyst is given an OOA artifact that is structurally similar versus structurally dissimilar to the target problem.

Third, research on both analogical reasoning and design problem solving shows that experts and novices differ greatly in the knowledge and skills used in problem solving. Experienced analysts have a larger "mental repository" of both domain-dependent and domain-independent solution schemas than do novices. This means that experienced analysts will have a larger repository of cognitive artifacts available to reuse. In addition, experienced analysts are better at recognizing structural similarity than are novices. Novices tend to focus more on the surface features of a problem than on its underlying structure. Thus, novice analysts may attempt to reuse artifacts even when the artifact is structurally dissimilar to the target problem. These observations lead to the expectation that experienced analysts will be better reusers than will novices. The third research question compares the reuse process for analysts with different levels of expertise in object-oriented systems development.

To investigate these questions, an experimental study was conducted using concurrent verbal protocols to trace cognitive processes (Ericsson & Simon, 1993). The study included thirty-seven participants (fifteen undergraduate and seventeen graduate students taking an OO systems development course, and five professional OO developers). Participants were asked to think-aloud as they performed an OOA task. Three experimental conditions were studied: theoretically "good" reuse condition (high structural similarity), theoretically "poor" reuse condition (low structural similarity), and a control condition. In the first two conditions, participants were given an OOA artifact to reuse; in the third condition, no artifact was provided. Level of experience was used as a control variable. Dependent variables included the amount of reuse of the given artifact and the amount of reuse of cognitive artifacts from prior experience.

Quantitative and qualitative analysis of twenty-five verbal protocols showed that reuse did follow an analogical reasoning pattern, with a few variations. Source-target structural similarity had a significant impact on the amount of reuse. More reuse occurred in the

structurally similar condition than in the structurally dissimilar condition, regardless of experience level. Experience also had a significant impact on reuse. Novices *attempted* to reuse more often than did experienced analysts. However, the experienced analysts were much more effective and efficient reusers than were novices.

There are several implications of these findings. First, theories of analogical reasoning appear to be appropriate for studying software reuse, an area sorely in need of theoretical grounding. Second, structural similarity is critical to the reusability of an artifact. This is true for both novice and experienced analysts. Novices are able to recognize a "good" reusable artifact from a "poor" one. This, in turn, has implications for tool developers, as retrieval tools which focus on surface similarity (e.g., keyword searches) will often fail to retrieve artifacts with structural similarity. Third, while novices reused more often than experienced analysts, these reuse episodes reflect attempts which may or may not have been successful. The novices were able to recognize that the source artifact was reusable, but struggled in their application of the source to the target. The experienced analysts reused quickly and effectively. This indicates that measures of reuse which focus on "count" things such as how many times a reusable component is accessed or copied will miss the fact that many of those accesses do not result in application and that experienced designers are able to "do more with less". Comparing experts and novices, novices engaged in more reuse activity than did experts. However, the novices' reuse activity was often unproductive, whereas the experts were able to quickly and accurately recognize and apply the analogy. Thus, while novices engaged in more reuse activity, they were not as successful at reusing as were the experts.

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