Interpreting Design Drawings by Analogy

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Motivation and Goals

Visual analogical mapping and transfer can be used to derive a structural model of a drawing by analogy, and, moreover, the problem of analogical mapping can be guided by using functional knowledge. We view the interpretation of drawings of designs as deriving a structural model of the components and connections of the depicted device. This problem is not deductive in nature but, rather, it is abductive, as there is no a priori reason a shape must represent one object and not another; only with significant help from the design context can a model be derived, and in particular we propose to do it by deriving the model by analogy to a similar drawing with a known structural and teleological model. This requires (1) an analogical mapping from the source (known) drawing to the target drawing that is derived on the basis of shapes and spatial relations be derived, and (2) a transfer and adaptation process by which the old model is transferred to the new drawing and adapted to it. In this paper we are focusing, in particular, on the first task, that of analogical mapping.

Analogical mapping is known to be very hard. Computing an analogical mapping from a source to a target or query with no further information to guide the search, to determine what ought to correspond to what, is very difficult. We propose to focus the search for a mapping by employing functional knowledge represented in the teleological model.

Let us consider, for example, the task of mapping the target drawing illustrated in figure 1(a) to the source drawing illustrated in figure 1(b), both drawings of a piston and crankshaft. If an agent has a low-level geometric reasoner to recognize the shapes and spatial relations between them, then we can treat this shape representation as a set of (mostly binary) relations—*A* contains *B*, *C* is parallel to *D*, and so on. This, then, is a labelled graph. Analogical mapping must then find a projection of the one graph onto the other that preserves some but not necessarily all of the relations. This is the well-known NP-Hard problem of *maximum common subgraph*.

We begin with a teleological model of the source case, based on Structure Behavior Function (SBF) models of physical devices. SBF models treat functional models as consisting of three pieces: (1) the structural model of the components and connections and their functionally relevant properties, (2) a model of the behavior and the causality in the device, and (3) the functional specification of those aspects of a device's behavior most directly relevant to its use. In this work, we extend these SBF models of physical devices into Drawing Shape Structure Behavior Function (or DSSBF) teleological models by incorporating drawing and shape level specifications of devices. The overall schema of DSSBF is illustrated in figure 2.

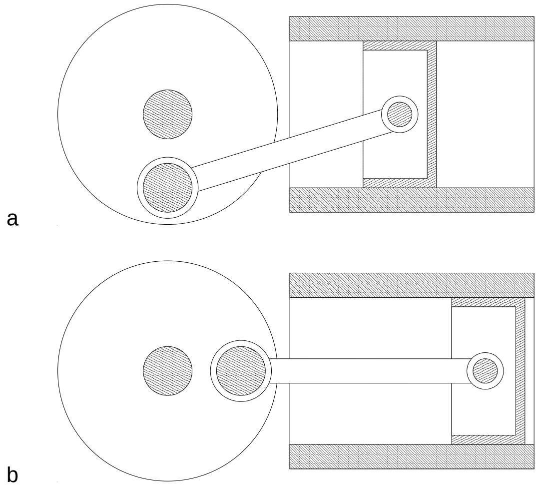

Figure 1: (a) A sample source drawing of a piston and crankshaft assembly. The components depicted are the cylinder, the piston, the crankshaft, and the connecting rod. (b) A target drawing; the same device, with the piston now at the top of its range of motion ("top dead center").

We have developed an algorithm for generating all partial mappings between a given source case and a target problem, based on a maximal clique algorithm of Bron and Kerbosch (Bron & Kerbosch 1973). If individual *maps* between individual source and target relations are vertices in a correspondence graph, and the system links two such vertices when those maps are consistent, then a maximal partial mapping (a *mapping* is a set of individual *maps*) will be a maximal complete subgraph of this correspondence graph—a maximal clique (Koch 2001). The Bron-Kerbosch algorithm ("algo-

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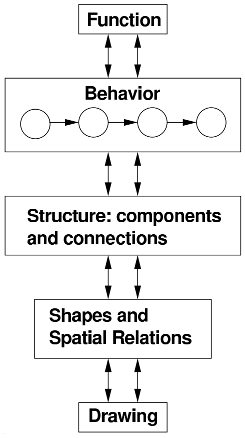

Figure 2: The overall schema of a Drawing Shape Structure Behavior Function (DSSBF) model, from function at the top through the causal and behavioral model, the structural components and connections, shapes and spatial relations depicting them, and finally to the original drawing.

rithm 457”) enumerates all maximal cliques of a graph, and tends to find the bigger cliques before the smaller cliques when certain heuristics are employed. It does this using a greedy, recursive, branch and bound operator that attempts to extend a given clique with every member of a given set of candidates, while excluding members of a “closed” set (these candidates are the individual *maps*). The largest maximal clique returned is the largest partial *mapping*.

The algorithm begins with the source shape model from the DSSBF model, and a target shape model generated by a low-level geometric reasoner. Our algorithm marks certain source relations as “important” so that no mapping is returned that does not involve at least one of these relations; this can drastically reduce the search space, and is how functional knowledge is employed in focusing the search. The rank of importance takes certain relations involving shapes that are connected to the device’s function and behavior, thus tracing through the DSSBF model from function through behavior and structure down to shape. In our example, the function is to turn the crankshaft, and the crankshaft is depicted by the big circle, so that shape is marked as important. Also, the connecting rod and the piston are both moving components and have behaviors associated with them, and so the shapes depicting them, too, are marked as important. Such maps become a starting point from which the mappings can be found.

These mappings allow term-by-term comparison of the source and target, so that the similarities and differences between them with respect to a potential alignment of the images can be employed and reasoned about. Once the algorithm has a mapping between the source and target shape models, it needs to transfer the structural model. The basic problem is that we have mappings between shapes in each drawing, and from those mappings we can hypothesize that they should therefore depict the same components and connections. Thus, the steps are to begin with the mapped shapes, and transfer the components and connections depicted by those mapped shapes, reconstructing the model iteratively. This scheme is illustrated in figure 3.

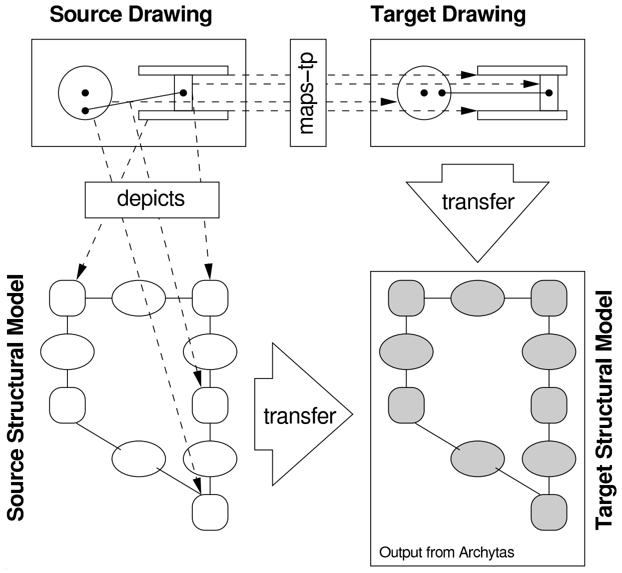

Figure 3: The transfer process. Given a mapping from source (on the left) to target (on the right), and an association between the source shapes and the structural model (below left), a new hypothetical structural model for the target is constructed by analogy.

In this paper, we considered the task of deriving a structural model of a kinematics device from a representation of the shapes and spatial relations in a 2D line drawing of the device. Our method derived the structural model of the target drawing by analogy to a similar source drawing for which a teleological model is already known. The method for analogical mapping generates partial mappings between the shape-level spatial representations of the target and source drawings. The method uses the teleological model to infer which shapes are functionally important and uses these shapes to guide the mapping process. The Archytas system implements this analogical method. It shows that knowledge of the functional role of shapes and spatial relations can guide the analogical mapping task.

Acknowledgments

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References

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