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Mental imagery often plays a role in problem solving, particularly when the problem is complex [2] or the subject must devise a procedure for arriving at a solution [3]. For this reason, imagery use is strongly associated with highly creative problem solving [5]. How are problems transformed into imagery, or solved thereafter? Researchers have pointed out that good problem visualizations capitalize on the imagery machinery's ability to detect and reinforce visual properties such as symmetries, similarities, alignments, relations of size, gestalts (e.g., [4]).

We propose that the transformation to such 'good visualizations' hinges on the discovery of problem invariants: parameters that may be varied or removed without affecting the basic structure of the problem. Invariants indicate ways in which the problem can be decomposed into critical and optional subproblems. In imagery, self-similarities such as repeated patterns, symmetries, and alignments are strongly indicative of invariants. Visual problem solving is a cycle of visualization, discovery of invariants, and reduction to new visualizations that are progressively simpler (reducing cognitive load or increasing alignments or other systematicities that support chunking) and more revealing (with causal structure more salient to the visual system).

To study visualizations in problem solving, we posed four difficult problems in tilings, population dynamics, physics, and mechanical design to seventeen undergraduates, and collected protocols of their reported use of imagery. Although these problems are easily solved when converted to formal representations–logic, geometric series, algebraic equalities, and topological partitions–most subjects reported working through a progression of visualizations. Our analyses found that most successive visualizations were linked via invariants, and that these invariants were 'noticed' as visual properties of the imagery. For example, in solving Wickelgren's [6] checkers-and-dominos problem (figure 1), subjects noted that

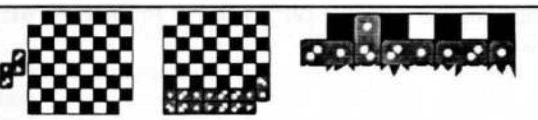

Figure 1: Use of an invariant to simplify the question: Can the mutilated board be tiled with dominos?.

repeated patterns in the checkerboard led them to see how the solution was invariant to the number of pairs of rows, allowing them to reduce the problem to a two-row board.

In one problem, subjects were asked to find a workable connection topology between weights in a kinetic mobile (à la Alexander Calder). Using the invariants discovered by these students, we developed an imagery simulator that robustly designs mobiles with complicated connection topologies and systems of leverages. The simulator models imagery as maps of activity that evolve through simple cell-parallel calculations. Imagery operations such as movement, alignment, fitting, and grouping are accomplished by field couplings in which activity in one map generates potentials that influence activity in another. Figure 2 shows the fields

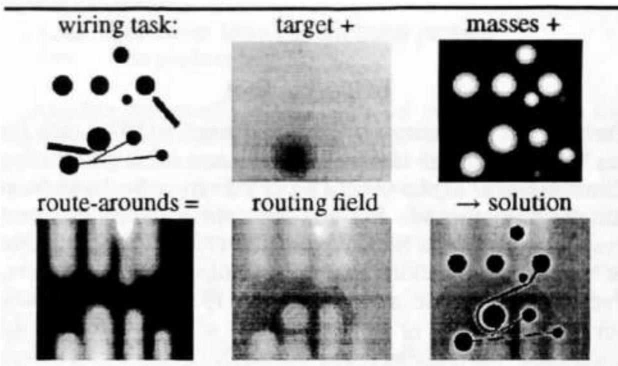

Figure 2: Constructing a routing-field for "wiring" a mobile.

used to route a connecting wire in accordance with an invariant that guarantees mechanically valid mobiles. Figure 3 shows

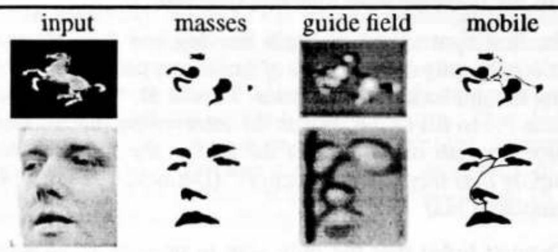

Figure 3: Mobiles derived from images.

some of the finished mobiles that this imagery system has designed. Coupled potential fields can be implemented as neural networks whose organization mimics hypothesized maps in the visual cortex[1]. Thus we can map out and partially automate a full reduction from a high-level design problem to low-level massively parallel computations between maps of neuron-like computing elements.

References

[1]Brand, M. (1996). Visual problem solving using coupled potential fields. Technical report, MIT Media Lab.

[2]Denis, M. (1991). Imagery and thinking. In C. Cornoldi and M.A. McDaniel, editors, *Imagery and Cognition*, chapter 3. Springer-Verlag.

[3]Kaufmann, G. (1990). Imagery effects on problem solving. In J.T.E. Richardson, P.J. Hampson, D.F. Marks, editor, *Imagery: Current developments*, chapter 7. Routledge.

[4]Kosslyn, S.M. (1994). *Image and Brain*. MIT Press.

[5]Shepard, R.N. (1978). Externalization of the image and the act of creation. In B.S. Randhawa, editor, *Visual Learning, Thinking, and Communication*. NY: Academic Press.

[6]Wickelgren, W.A. (1974). *How to solve problems*. NY: W.H. Freeman and Company.