



Software and Societal
Systems Department

Authoring conceptual diagrams by codifying visual representations

Thesis Defense
Ph.D. in Software Engineering

Abstract

Visual representations like diagrams are powerful tools for thought. Diagrams are used extensively to understand abstract relationships, explain complex ideas, and solve difficult problems.

I conducted an interview study to understand how domain experts create diagrams and identified key limitations in current tools. Our participants reported how they create, adapt, and reuse visual representations. However, due to limitations of current tools, notably the trade-offs between direct manipulation tools and programming languages, reusing representations is still challenging.

The findings from these studies informed the design of PENROSE, a language-based system that allows authors to codify domain-specific concepts and their visual representations. In PENROSE, the visual representation is user-defined in a constraint-based specification language; diagrams are then generated automatically via constrained numerical optimization. The system is designed to be user-extensible to many domains. In contrast to tools that specify diagrams via direct manipulation or low-level graphics programming, PENROSE enables rapid creation and exploration of diagrams that faithfully preserve the underlying visual representation.

Atop PENROSE, I built EDGEWORTH, a tool designed to help educators easily create visual problems. EDGEWORTH works in two main ways: firstly, it takes a single diagram from the user and systematically alters it to produce many variations, which the educator can then choose from to create multiple problems. Secondly, it automates the layout of diagrams, ensuring consistent high quality without the need for manual adjustments. I collected a dataset of diagrammatic multiple-choice problems to show that EDGEWORTH can create problems in three domains: geometry, chemistry, and discrete math. EDGEWORTH generated usable answer options within the first 10 diagram variations in 87% of authored problems. I then performed a user study to measure authors' efficiency at creating translation problems using EDGEWORTH, compared with a conventional drawing tool. The results show that once authors make a correct diagram, they are about 3 times faster at making diagrammatic options for translation problems using EDGEWORTH compared to Google Drawings. Finally, in response to walkthrough demonstrations, expert educators gave positive feedback on EDGEWORTH's utility and the real-world applicability of its outputs.

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