State Machine Visualization Based on Gestalt Principles and Its Applications

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Abstract

This dissertation proposes an approach to visualizing/graphically animating state machines based on Gestalt principles for humans to find invariants of the state machines. This approach mainly addresses the question "Can Gestalt Principles help humans to understand state machines well?," where to understand state machines is defined as knowing invariant properties of the state machines. The more humans know invariant properties of the state machines, the better humans understand the state machines.

State machine visualization is one possible way to make humans gain insights into state machines because humans are good at visual perception. Graphically animating state machines is one approach to state machine visualization. To graphically animate state machines, it is necessary to design what are called state picture templates such that a series of state picture template instances (or state pictures) can be regarded as a movie film. Any state picture templates of a state machine do not work well for our purpose, and we need to carefully design a state picture template of a state machine so that graphical animations based on it help humans to find likely invariants of the state machine. We use Gestalt principles, a set of principles/laws that describes how humans group similar elements, recognize patterns, and simplify complex images when humans perceive visual objects, to design state picture templates of state machines. Because likely invariants of a state machine may not be true invariants of the state machine, we first use model checking to check if likely invariants have counterexamples and then use interactive theorem proving to judge if likely invariants left are true invariants of the state machine. We basically use a tool called State Machine Graphical Animation (SMGA) that takes a state machine template and a state sequence of a state machine, and generates a graphical animation of the state machine. However, SMGA is not mature enough.

This dissertation addresses how likely invariants of protocols/systems can be found by humans who use the graphical animation approach. In particular, this research shows the importance of the state picture template and gives practical tips for users to design complex protocols/systems. Those tips are inspired and evaluated by Gestalt principles. We also propose guidelines of how to use the tips for finding likely invariants. To make the guidelines more effective, SMGA is revised by integrating it with Maude, a specification/programming language and processor that is equipped with many useful facilities, such as a reachability analyzer (the search command), a parser for context-free grammars plus associative-commutative (AC) binary operators and a pattern matcher for the grammars plus AC binary operators. The revised version of SMGA is called r-SMGA in which such powerful features of Maude can be used. The search command can be used as an invariant model checker.

Case studies are conducted to demonstrate the usefulness of the proposed approach and r-SMGA. Based on experiments with new features of r-SMGA and the guidelines proposed, several likely invariants are found, and most of them survive with the search command feature of r-SMGA and are proven true invariants with interactive theorem proving. When conducting interactive theorem proving for a likely invariant that has survived with the search command, we can use some of other such likely invariants as lemmas, provided that we have found an enough number of likely invariants of a state machine.

Keywords: state machine graphical animations; r-SMGA; likely invariant discovery; Gestalt principles; interactive theorem proving.