Analyzing and Improving Visualizations of Formal Models

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Background

Formal methods are powerful tools in validating system behavior, but their use of complex notations make understanding and debugging difficult.
Visualizations may help in these tasks.

Research Questions

- **How do practitioners use these visualizations and how are they helpful?**
- **What are the limitations of current tools and what do they desire?**

Interview Study

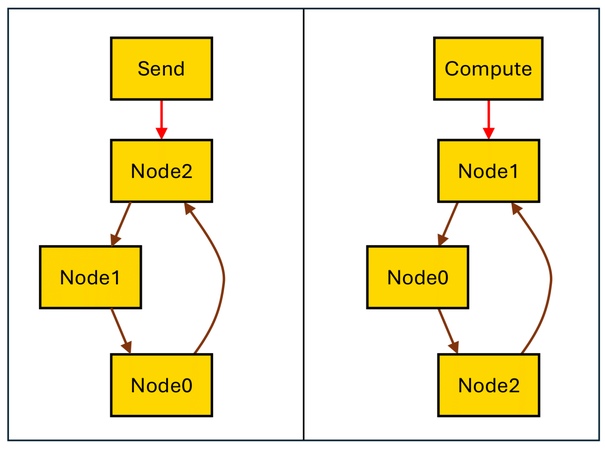
- Pre-screened interview study
- Semi-structured interviews with 15 users of formal modeling tools, including: Alloy (8), TLA+(3), BMethod (2), Spin (2), TSL Synthesis (2), P (1), Racq (1), Lean (1)

How are visualizations helpful?

- **Simplify understanding of models**
  - *"When the interactions between state machines are really complicated, … I go look for the visualization … it helps me keep track of what are the state machines that are running"* (P4)
- **Quickly validate and debug models**
  - *"Visualizations act really well as some sort of sanity check for our specifications … [and are] extremely helpful in finding sub-graphs that are closed loops … this tells you that maybe you need to go back and look at your specifications"* (P3)
- **Abstract away technical details to present to non-expert stakeholders**
  - *"There is a large audience of people who cannot understand Alloy text, … but these visualizations can make perfect sense to them."* (P2)

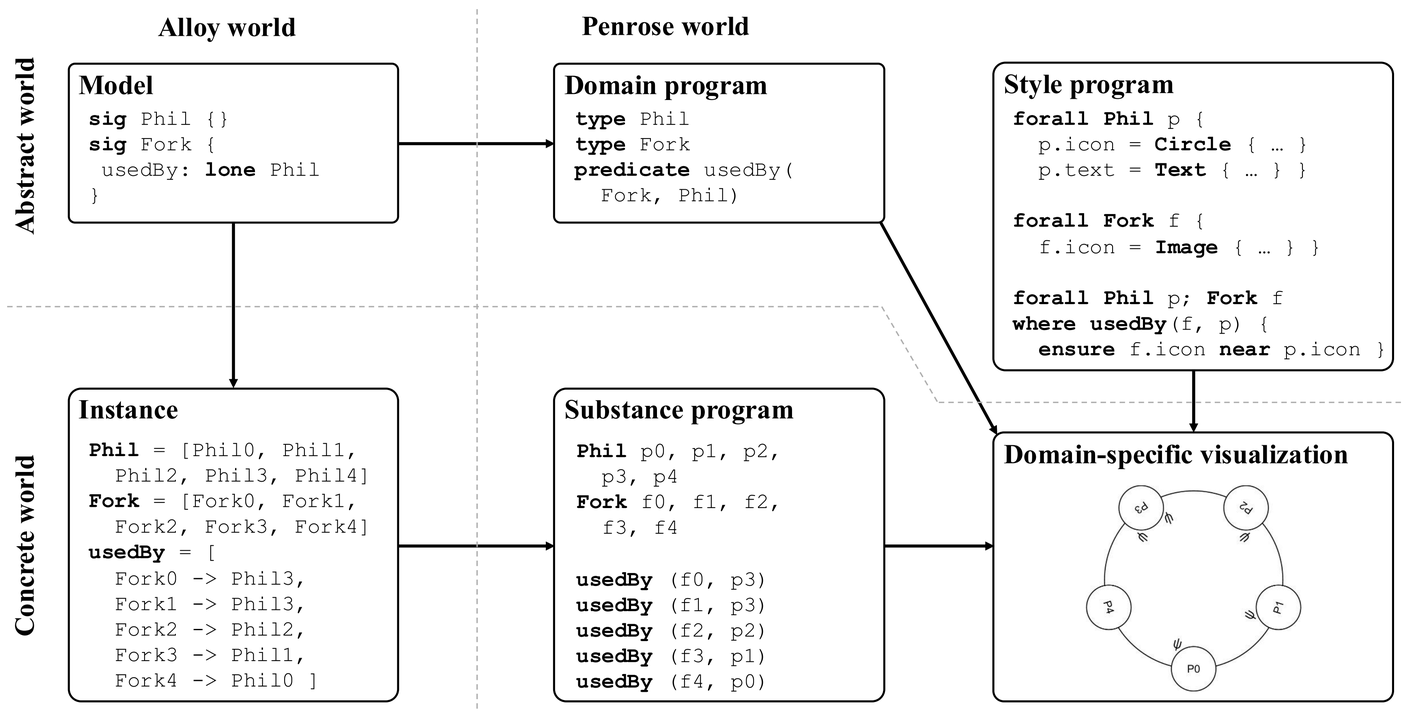
What are the limitations of current tools?

- **Lack of domain specificity make visualizations confusing.**
  - *"We understand how a train moves and how it visually looks, and none of this [built-in visualization] matches that. For exploratory tasks, it is challenging to use the visualizer."* (P7)
- **Lack of positional consistency of elements across states complicates bug finding.**
  - *"These graphs look isomorphic, the whole thing looks like identical structure. … But the node I was looking at before has moved down to the bottom…That's weird."* (P2)



An example of an Alloy visualization modeling the leader-election protocol that lacks both domain specificity and positional consistency across states.

Penlloy Visualization Tool for Domain-Specific Visualizations



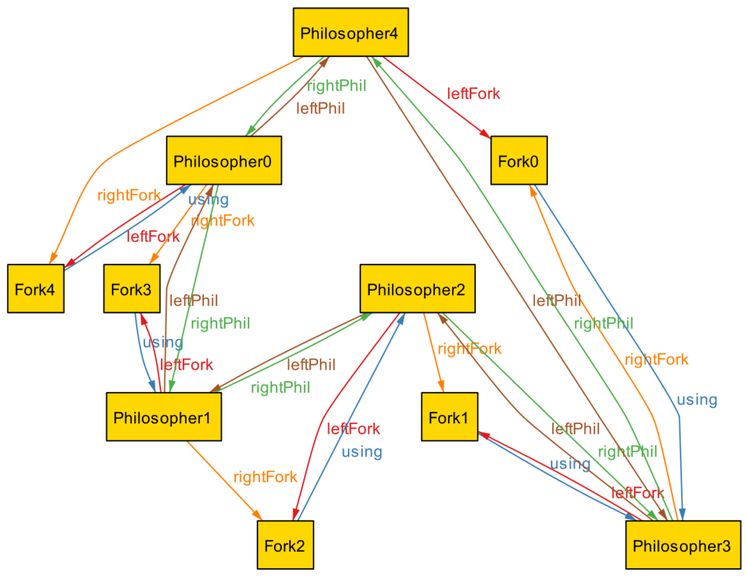
How Penlloy works, visualized with the Dining Philosopher's Problem

We explore domain specificity in visualizations with **Penlloy**, an **Alloy** visualizer using the **Penrose** engine.

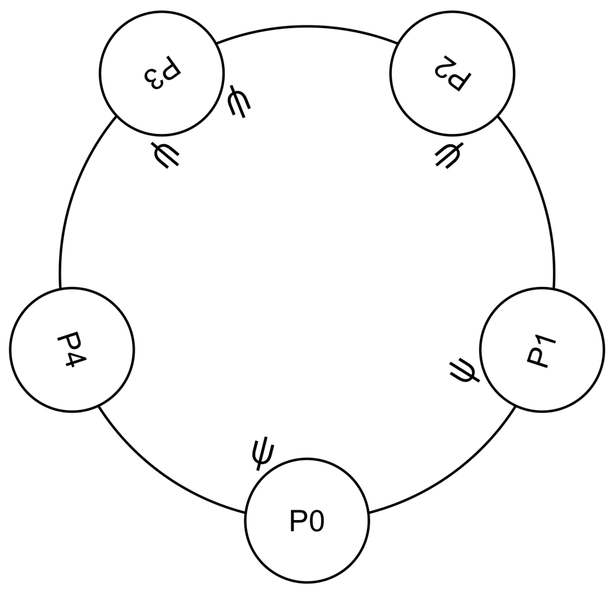
Why Alloy?
- Built-in visualizer to work off
- Widely used across many SE applications

Why Penrose?
- Versatility in creating complex visualizations
- Strength in reasoning about geometric relations between shapes

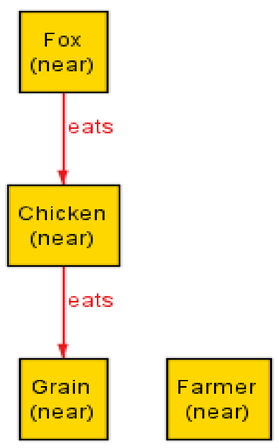
Alloy vs Penlloy Visualization Examples



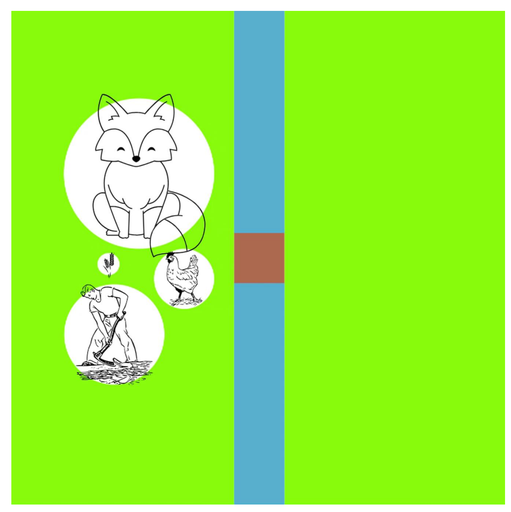
Default Alloy output – Dining Philosophers Problem



Penlloy-styled output - Dining Philosophers Problem



Default Alloy output – River Crossing Puzzle



Penlloy-styled output – River Crossing Puzzle

Current and Future Work

- **Addressing visual consistency in multi-state visualizations**
  - Encoding multiple notions of visual consistency as constraints and objectives within Penlloy.
- **Empirical evaluation of visual consistency**
  - Conducting a human-subject experiment to evaluate the effects of visual consistency in formal methods visualizations.
  - Experiment includes debugging tasks with consistent and inconsistent visualizations.
- **Automatic inference of domain-specific visualizations**
  - We want to generate constraints automatically from user provided diagrams.