Guarantees in Program Synthesis

Qinheping Hu, Jason Breck, John Cyphert, Loris D’Antoni, Thomas Reps

Introduction

Program synthesis is the classic problem of automatically finding a program \( P \) in some search space that satisfies a given correctness specification. Unfortunately, it is not always enough to produce any correct solution.

1. Synthesizers may return a worse solution.
2. Enumeration-based synthesizers have no ability to prove there is no solution in infinite search space.

Contributions

To address the above two problems, we introduce two types of guarantees in program synthesis: quantitative objectives and the ability to prove unrealizable—no solution.

Syntax-Guided Synthesis (SyGuS)

We illustrate the syntax-guided synthesis by an example of synthesizing a function computing the maximum of two integers.

A logic formula

\[ \phi(P) : \forall x, y. P \geq x \land P \geq y \land (P = x \lor P = y) \]

A grammar \( G \)

\[
\begin{align*}
\text{Start} := & \text{Start} + \text{Start} | \text{ITE}(\text{BExpr}, \text{Start}, \text{Start}) | x | 0 | y | 1 \\
\text{BExpr} := & \text{NOT}(\text{BExpr}) | \text{Start} > \text{Start} | \text{Start AND Start}
\end{align*}
\]

 Specifications

Search space

Enumerating an infinite space

Search space

A “better” potential solution

A “better” potential solution

SyGuS + Quantitative Objective

QSyGuS

In SyGuS with Quantitative Objective (QSyGuS), users can assign weights to grammar productions and ask the solver to find solutions with minimized/maximized weights.

For example, if the user wants to minimize the number of ITE in the above SyGuS problem, he can assign weights to productions as follow:

Weighted grammar \( W \):

\[
\begin{align*}
\text{Start} := & \text{Start} + \text{Start} | \text{ITE}(\text{BExpr}, \text{Start}, \text{Start}) | x | 0 | y | 1 \\
\text{BExpr} := & \text{NOT}(\text{BExpr}) | \text{Start} > \text{Start} | \text{Start AND Start}
\end{align*}
\]

Observe that weights of terms in the above grammar is equal to the number of ITE in the terms.

Algorithm of finding optimized solution

Idea: iteratively refining current solution.

Observation

The problem of finding a solution \( P \) in \( G_{<1} \) is already unrealizable for the following input examples

\[ E : P(0,0) = 0, P(1,0) = 1, P(0,1) = 1, P(0,2) = 2 \]

Idea

We reduce the problem of checking unrealizability based on the examples to the following verification problem that can be solved using off-the-shelf verifiers

\[
\begin{align*}
\text{int}[4] \text{ L} & = \text{Start}(x_0,y_0,x_1,y_1,x_2,y_2,x_3,y_3); \\
& \text{if}(??)?\{ \text{return} (0,0,0,0); \} // \text{Start -> 0} \\
& \text{if}(??)?\{ \text{return} (1,1,1,1); \} // \text{Start -> 1} \\
& \text{if}(??)?\{ \text{return} (y_0,y_1,y_2,y_3); \} // \text{Start -> y} \\
& \text{else}{}; // \text{Start -> Start + Start}
\end{align*}
\]

\[
\begin{align*}
\text{int}[4] & \text{ R} = \text{Start}(x_0,x_0,y_0,y_1,x_1,y_1); \\
\end{align*}
\]

\[
\begin{align*}
\text{int}[4] & \text{ P} = \text{Start}(0,0,0,1,1,0,2,0); \\
& \text{assert} (P[0]!=0 || P[1]!=1 || P[2]!=1 || P[3]!=2);
\end{align*}
\]

The SyGuS problem is unrealizable

Iff the assert always holds

Future Work

• Other quantitative objectives in program synthesis:
  • Semantic quantitative objectives
  • Resource bounded synthesis
• Proving unrealizability for synthesis problems beyond SyGuS