Simultaneous Synthesis of Multiple Functions using Genetic Programming with Scaffolding

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Overview

- **Scenario:** several functions to be synthesized, potentially dependent on each other (multisynthesis).
- **Sequential** and **parallel** approaches to multisynthesis.
- A novel application of scaffolding to calls to other functions being synthesized.
- Computational experiments prove parallel multisynthesis more effective.

Scaffolding

A technique devised originally to facilitate evolution of recursive programs [1].

The principle: If the argument of a recursive call occurs on the list of fitness cases, return the associated output (rather than recursively calling the program).

Key observation: Scaffolding can also be used in multisynthesis.

Sequential Synthesis (SEQ)

Functions are synthesized in an order provided by the user. Subsequent runs add to instruction set all previously synthesized programs (I – the common instruction set).

<table>
<thead>
<tr>
<th>Run 1:</th>
<th>Run 2:</th>
<th>Run 3:</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="seq_run1.png" alt="Diagram" /></td>
<td><img src="seq_run2.png" alt="Diagram" /></td>
<td><img src="seq_run3.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

Parallel Synthesis (PAR)

Functions are synthesized simultaneously. Each function may call other functions, but cyclical calls are not allowed. GP is expected to discover potential dependencies between the functions being synthesized.

| ![Diagram](par_run1.png) | ![Diagram](par_run2.png) | ![Diagram](par_run3.png) |

Benchmarks and Program Representation

- **Instruction set:** a subset of the Scala programming language.
- **Benchmarks:** various generic methods of the List class. Each benchmark has three functions to be synthesized:
  - one dependent function,
  - two helper functions.
- **Program representation:** purely functional; only function calls, immutable values and constants.
- **Solution:** a triple of programs.

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>Dependent function</th>
<th>Helper functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>last</td>
<td>last(list:List[T]):T</td>
<td>at, size</td>
</tr>
<tr>
<td>patch</td>
<td>patch(list:List[T],d:Int,p:List[T],u:Int):List[T]</td>
<td>drop,take</td>
</tr>
<tr>
<td>slice</td>
<td>slice(list:List[T],d:Int,u:Int):List[T]</td>
<td>drop,take</td>
</tr>
<tr>
<td>splitAt</td>
<td>splitAt(list:List[T],i:Int):(List[T],List[T])</td>
<td>drop,take</td>
</tr>
</tbody>
</table>

Exemplary synthesized solution:

- `splitAt`: `tuple(take(list, i), drop(list, i))`
- `drop`: `slice(list, n, * (7, 4))`
- `take`: `takeRight(reverse(takeRight(reverse(list), n)), n)`

<table>
<thead>
<tr>
<th>Method</th>
<th>last</th>
<th>patch</th>
<th>slice</th>
<th>splitAt</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEQ</td>
<td>2.23</td>
<td>2.13</td>
<td>1.36</td>
<td>2.69</td>
<td>2.10</td>
</tr>
<tr>
<td>SEQ&lt;sub&gt;opt&lt;/sub&gt;</td>
<td>1.11</td>
<td>1.73</td>
<td>0.97</td>
<td>1.56</td>
<td>1.34</td>
</tr>
<tr>
<td>PAR</td>
<td>2.00</td>
<td>1.50</td>
<td>0.72</td>
<td>1.80</td>
<td>1.51</td>
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<tr>
<td>PAR&lt;sup&gt;+&lt;/sup&gt;</td>
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<td>0.59</td>
<td>1.94</td>
<td>1.48</td>
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<td>2.17</td>
<td>1.55</td>
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<td>1.40</td>
<td>1.05</td>
<td>1.88</td>
<td>1.63</td>
</tr>
</tbody>
</table>

**Results**

- **The table:** average numbers of synthesized functions in best-of-run programs.
- **Conclusions:** parallel synthesis gave on average better results on the number of correctly synthesized functions than SEQ<sub>opt</sub>.
- The presence of multiple contracts (constraints) changes the fitness landscape.

Configuration

- Population size: 500
- Evaluation budget: 150000
- Mutation (0.5) and crossover (0.5)
- Runs per variant: 25

Tested variants:

- `<opt> : Optimal ordering of functions.
- `<exp> : NSGA2 selection with 3 criteria: numbers of tests passed for each target function.
- `<s> : scaffolding with an oracle used for calls to other functions.

Acknowledgments

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References