Combining Analytical and Evolutionary Inductive Programming

Neil Crossley    Emanuel Kitzelmann    Martin Hofmann    Ute Schmid

Cognitive Systems Group
Faculty Information Systems and Applied Computer Science
University of Bamberg

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Inductive Programming (IP)

Automatic construction of recursive (functional) programs from input/output-examples or other kinds of incomplete specifications.

Example

I/O-examples (containing variables):

\[
\begin{align*}
\text{Switch(}[ \ ]) &= \text{[ ]}, \\
\text{Switch(}[X]) &= \text{[X]}, \\
\text{Switch(}[X, Y]) &= \text{[Y, X]}, \\
\text{Switch(}[X, Y, Z]) &= \text{[Y, X, Z]}, \\
\text{Switch(}[X, Y, Z, V]) &= \text{[Y, X, V, Z]}
\end{align*}
\]

Induced program:

\[
\begin{align*}
\text{Switch(}[ \ ]) &= \text{[ ]}, \\
\text{Switch(}[X]) &= \text{[X]}, \\
\text{Switch(}[X, Y \mid Xs]) &= \text{[Y, X \mid Switch(Xs)]}
\end{align*}
\]
Analytical vs. Evolutionary IP

**Analytical IP**
- Detect syntactic regularities between I/O-examples and derive recursive function definition from them.
- Assumes syntactically restricted program schema.
- Fast.

**Evolutionary / Generate-and-Test IP**
- Enumerate program class, use I/O-examples for testing only.
- Allows for fairly unrestricted program classes.
- Expensive.
Combining Analytical and Evolutionary IP

Try to combine the strengths of both approaches to overcome its weaknesses.

The approach: **Connect both methods in series.**

1. Efficiently generate an unfinished *program sketch* in a restricted program space by analytical induction.
2. Use this sketch as seed for an evolutionary search in an unrestricted program space.
## Implementation

### Tools

- **Igor2** to analytically construct a program sketch.
- **ADATE** to evolve the final program based on Igor2’s sketch.

### Necessary Implementation Steps

- A new stop criterion for Igor2.
- An algorithm that builds a valid ADATE specification from an Igor2 specification and a program sketch.

*We have not yet implemented the method but hand-coded ADATE specifications for our initial experiments.*
The ADATE Search

- Systematic (no randomization), global search.
- Several heuristics and program transformation operators, specialized to evolve recursive functional (SML) programs.
- Programs with low syntactic complexity and low time complexity are preferred.
- ADATE starts with a single individual, typically the empty program that only raises an exception.
- Then search goes towards bigger-and-bigger and better-and-better programs.
ADATE Specifications

Main Elements of an ADATE Specification

- Type- and (help-)function definitions.
- Declarations/definitions of target function \( f \) and main function (a context program that calls \( f \)) \( \text{main} \), e.g.,
  \[
  f \left( \text{<params>} \right) : \text{<type>} = \text{raise D1}
  \]
  \[
  \text{main} \left( \text{<params>} \right) : \text{<type>} = f \left( \text{<params>} \right)
  \]
- I/O-examples
  more generally: training inputs and an output evaluation function.
Example of a Sketch Developed by IGOR2

I/O-examples

\[
\begin{align*}
\text{Switch}([\ ])) &= [ ] \\
\text{Switch}([X]) &= [X] \\
\text{Switch}([X, Y]) &= [Y, X] \\
\text{Switch}([X, Y, Z]) &= [Y, X, Z] \\
\text{Switch}([X, Y, Z, V]) &= [Y, X, V, Z]
\end{align*}
\]

Solution

\[
\begin{align*}
\text{Switch}([\ ])) &= [ ] \\
\text{Switch}([X]) &= [X] \\
\text{Switch}([X, Y | Xs]) &= [Y, X | \text{Switch}(Xs)]
\end{align*}
\]
Example of a Sketch Developed by IGOR2

I/O-examples

\[
\begin{align*}
\text{Switch}([ ]) &= [ ] \\
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Solution

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\begin{align*}
\text{Switch}([ ]) &= [ ] \\
\text{Switch}([X]) &= [X] \\
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Example of a Sketch Developed by IGOR2

**I/O-examples**

\[
\begin{align*}
\text{Switch}([ ]) &= [ ] \\
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**Solution**

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\text{Switch}([ ]) &= [ ] \\
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\]
Example of a Sketch Developed by **IGOR2**

### I/O-examples

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Switch}([,])$</td>
<td>$[,]$</td>
</tr>
<tr>
<td>$\text{Switch}([X])$</td>
<td>$[X]$</td>
</tr>
<tr>
<td>$\text{Switch}([X, Y])$</td>
<td>$[Y, X]$</td>
</tr>
<tr>
<td>$\text{Switch}([X, Y, Z])$</td>
<td>$[Y, X, Z]$</td>
</tr>
<tr>
<td>$\text{Switch}([X, Y, Z, V])$</td>
<td>$[Y, X, V, Z]$</td>
</tr>
</tbody>
</table>

### Solution

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Switch}([,])$</td>
<td>$[,]$</td>
</tr>
<tr>
<td>$\text{Switch}([X])$</td>
<td>$[X]$</td>
</tr>
<tr>
<td>$\text{Switch}([X, Y \mid Xs])$</td>
<td>?</td>
</tr>
</tbody>
</table>
Unassisted

- The sketch is not used at all; ADATE is simply given the same examples as Igor2 and must find the solution from scratch.
- Base line to test whether providing a seed really helps.

Example

```haskell
f ( xs:list ) : list = raise D1
main ( xs:list ) : list = f ( xs )
```
The target function $f$ is redefined according to the sketch; $? \mapsto \text{raise D0}$.

The Sketch may be revised by ADATE.

Example

```fsharp
fun f Xs =
    case Xs of
        nill => Xs
    | cons(Y1, Y2) => case Y2 of
        nill => Xs
    | cons(W1, W2) => raise D1

fun main Xs = f Xs
```
The sketch is introduced as a predefined function $g$ called by $\text{main}$; $?$ is replaced by a call to $f$.

The sketch is saved from being revised.

Example

```haskell
fun f Xs = raise D1

fun g Xs =
  case Xs of
    nill => Xs
  | cons(Y1, Y2) => case Y2 of
      nill => Xs
    | cons(W1, W2) => f Xs

fun main Xs = g Xs
```
Functions

Any auxiliary functions inferred by \textsc{Igor2} may be included into the seed—either as predefined function to be called by $f$ or as an inner function of $f$ also subject to transformations.
<table>
<thead>
<tr>
<th>Problem</th>
<th>Type of Seed</th>
<th>Time</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switch</td>
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<td>4.34</td>
<td>302</td>
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<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>Restricted</td>
<td>18.37</td>
<td>240</td>
</tr>
</tbody>
</table>
Conclusion

- Analytical methods and generate-and-test based methods alone cannot solve relevant problems for different reasons.
- Idea: Combine both approaches.
- First experiments show, that the evolutionary system ADATE indeed can benefit from a partial solution (efficiently generated by IGOR2) as starting point.
- One problem is the different preference biases of IGOR2 and ADATE.