Strategic Port Graph Rewriting: An Interactive Modeling and Analysis Framework

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Motivation and approach

In the context of software development and analysis, we address two challenges:
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- Provide a modeling framework for complex systems

Complex Systems

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\[
\begin{align*}
&<\text{State, Evolution Step, Control}> \\
&<\text{Graph, Set of Rules, Strategy}>
\end{align*}
\]

Strategic Graph Program
Motivation and approach

In the context of software development and analysis, we address two challenges:

- Provide a modeling framework for complex systems
- Preserve all computations and provide interactive visualisation tools to help analysis and debugging

**Complex Systems**

- <State, Evolution Step, Control>
- <Graph, Set of Rules, Strategy>

**Strategic Graph Program**

**Derivation tree analysis**
Rewriting ingredients

In general, a rewriting process is:
- Non terminating,
- Non confluent,
- Highly concurrent
Rewriting ingredients

- **In general, a rewriting process is:**
  - Non terminating,
  - Non confluent,
  - Highly concurrent

- **A strategy language**
  - Some steps may be correlated (one followed by another),
  - Iterated until some condition is met,
  - or may occur only in some parts of the graph.
  - Non-deterministic choices: for simultaneous exploration of multiple rewriting scenarios and backtrack to test alternate strategies

- **A derivation tree**
  - History mechanism to record evolutions and choice points
  - Track properties along different scenarios
The PORGY environment features:

- Design port graphs and port rules and visualise them.
- Interactive application of a rule on a port graph.
- Creating and running a strategy.
- Exploration and analysis of a derivation tree.
  - Tooltips (get information)
  - Small multiples and animation (show the evolution of the graph)
  - Histograms (to follow graph parameter over rewriting operations)
Port Graphs

[IbanescuBK03], [AndreiK07], κ-calculus [DanosL04], BioNetGen [BlinovYFH05]}

- Inspired by protein-protein interactions;
- Port graphs are graphs with multiple edges and loops, where:
  - Nodes have explicit connection points, called **ports**.
  - The edges attach only to ports of nodes.
  - Nodes, ports and edges have properties (ex: color, arity, boolean value, string, ...).

Actually equivalent to usual labeled graphs, but with more structure.
Notion of position: where to apply a rule in a graph?

- Top-down or bottom-up traversals do not make sense.
- PORGY's solution is located graphs along with located rewrite rules.

Goal: compute a morphism $g$ of the left-hand side inside the graph

: position subgraph
: ban subgraph

A rule called « newrule »
Notion of position: where to apply a rule in a graph?

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A rule called « newrule »

NOK! There is no A or B nodes in the position subgraph.
Notion of position: where to apply a rule in a graph?

- Top-down or bottom-up traversals do not make sense.
- PORGY’s solution is located graphs along with located rewrite rules.

Goal: compute a morphism $g$ of the left-hand side inside the graph.

A rule called « newrule »

OK! The matching will only be possible with the B node of the position subgraph.
Notion of position: where to apply a rule in a graph?

- Top-down or bottom-up traversals do not make sense.
- PORGY's solution is **located graphs** along with **located rewrite rules**.

Goal: compute a morphism $g$ of the left-hand side inside the graph

A rule called « newrule »

NOK! All A nodes are banned
A **located graph** $G^P_Q$ consists of a port graph $G$ and two distinguished subgraphs $P$ and $Q$ of $G$, called resp. the **position subgraph**, or simply **position**, and the **banned subgraph**.

A **located rewrite rule** consists of a port graph rewrite rule $L \Rightarrow R$ and two disjoints subgraphs $M$ and $N$ of $R$. It is denoted $L \Rightarrow R^N_M$.

- Rewriting must take place at least partially in $P$ and not in $Q$.
- To apply a rule, $g(L) \cap P \neq \emptyset$ and $g(L) \cap Q = \emptyset$
- $G$ is updated to $(G \setminus g(L)) \cup g(R)$
- $P$ is updated to $(P \setminus g(L)) \cup g(M)$
- $Q$ is updated to $g(N)$
Grammar: rule applications and strategies

Let $L$, $R$ be port graphs; $M$, $N$ positions;

$$n \in \mathbb{N}; \ p_{i=1\ldots n} \in [0,1]; \sum_{i=1}^{n} p_i = 1$$

(Transformations) $T ::= L \Rightarrow R_{M}^{N}$

(Applications) $A ::= \text{Id} | \text{Fail} | \text{all}(T) | \text{one}(T)$

(Strategies) $S ::= A | S ; S | \text{repeat}(S) | \text{while}(S) \text{ do } (S)$
$$| (S) \text{orelse} (S) | \text{if}(S) \text{ then } (S) \text{ else } (S)$$
$$| \text{ppick}(S_1, p_1, \ldots, S_n, p_n)$$
$$| U$$
Let *attribute* be an attribute label; *n* a valid value for the given attribute label; *function-name* the name of a built-in or user-defined function.

**Position Update** $U ::= \text{setPos}(F) | \text{setBan}(F) | \text{isEmpty}(F)$

**Focusing** $F ::= \text{CrtGraph} | \text{CrtPos} | \text{CrtBan} | \text{AllNgb}(F) \mid \text{OneNgb}(F) | \text{NextNgb}(F) \mid F \cup F \mid F \cap F \mid F \setminus F \mid \emptyset \mid \text{Property}(\rho, F)$

**Properties** $\rho ::= (\text{Elem, Expr}) | (\text{Function, function-name})$

*Elem* := Node | Edge | Port

*Expr* := Label $==$ *n* $|$ Label $!=$ *n* $|$ *attribute* *Relop* *attribute* $|$ *attribute* *Relop* *n*

*Relop* := $==$ $|$ $!=$ $|$ $>$ $|$ $<$ $|$ $>$= $|$ $<=$

**Other constructs** : \text{not}(S) ::= \text{if}(S)\text{then}(\text{Fail})\text{else}(\text{Id})

\text{try}(S) ::= (S) \text{orelse} (\text{Id})
Examples : spanning tree computation
Examples: spanning tree computation

Very simple strategy for one solution: \texttt{one(start);repeat(LC0)}

Strategy to find all solutions (\texttt{all()} not fully implemented yet): \texttt{all(start);repeat(LC0)}
The strategy code with only one rule which mark a visited node:

```plaintext
setPos(CrtGraph);
one(newrule);

setPos(Property(Node, "state"=="true", CrtGraph));
setPos(AllNgb(CrtPos));

while(not(isEmpty(CrtPos))) do (  
if(newrule) then (  
newrule  
) else (  
setPos(AllNgb(CrtPos)\Property(Node, "state"=="true", CrtGraph))  
)  
);

setPos(CrtGraph);
not(newrule)
```
Examples: simple connectivity test
Examples: simple connectivity test
A *strategic graph program* is given by a set of port graph rewrite rules $\mathcal{R}$, a strategy expression $S$ (built from $\mathcal{R}$) and a located graph $G_P^Q$. We denote it $[S_{\mathcal{R}}, G_P^Q]$, or simply $[S, G_P^Q]$ when $\mathcal{R}$ is clear from the context.

In the paper, we give rule based semantics of the strategy language: small step operational semantics, specified using transition rules on configurations (multisets of strategic graph programs)

Some properties:

- $[S, G_P^Q]$ is *terminating* (Id or Fail) if there is no infinite transition sequence from the initial configuration $[S, G_P^Q]$.

- The sublanguage that excludes the *while* and *repeat* constructs is terminating.
Characterisation of Terminal Configurations:
For every strategic graph program \([S, G_P^Q]\) where \(S \neq \text{Id}\) and \(S \neq \text{Fail}\), there exists a configuration \(C\) such that \([S, G_P^Q] \rightarrow C\).

\([S, G_P^Q]\), if terminating, reduces to configurations that contain graph programs of the form \([\text{Id}, G_P'^Q]\) or \([\text{Fail}, G_P'^Q]\) (called values).

Each strategic graph program in the sublanguage that excludes non-deterministic operators (\(\text{OneNgb}, \text{one}, \text{ppick}, \text{orelse}\)) and \(\text{repeat}\) has at most one program result which is a set of values (\(\text{Id} / \text{Fail}\)).
Conclusion

PORGY, an interactive visual environment for port graph transformation. Programming with rules and strategies, including focusing capabilities. Simple and intuitive visualisation and interaction.

Porgy is a set of Tulip plugins, about 20 000 lines of C++ code (with Qt library for GUI). Tulip is a graph visualisation and manipulation framework (see http://tulip.labri.fr)

Strategy developed with the Boost Spirit library (only 1 500 lines of code).
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Other on-going applications:

Encoding Interaction Nets [laffont:90] programs
Specification/modelling biochemical systems and other complex systems.
Social Network Analysis (SNA, propagation models)
QUESTIONS????

Feel free to ask for a live demo!!!

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