Towards Modelling Actor-Based Concurrency in Term Rewriting

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**Actor model**

Program: a pool of processes which interact by exchanging messages.

Each process has a local mailbox (not shared).

A process can:
- Send a message to another process.
- Receive a message.
- Update its local state.
- Create new processes.

This is the model underlying Erlang or Scala.
Actor model in sequential TR

Our goal: model an Erlang-like language within sequential TR.

To achieve this, we will describe:

- A process as a term.
  \[ \text{process}(\square) \]
- A system as a term composed of processes.
  \[ \text{process}(\square) \odot \text{process}(\square) \odot \text{process}(\square) \odot \ldots \]
Modelling actor-based concurrency in sequential TR

The traditional approach is based on implementing an interpreter (an operational semantics):

- A complex implementation is required.
- A significant overhead is introduced.
- One can end up analyzing the interpreter rather than the model (the model becomes data).

In this paper, instead, we aim at the following:

- We keep the sequential part untouched.
- We introduce only a few rules to deal with concurrent actions (some restrictions will be needed).
Problems with sequential TR

When modelling an Erlang-like language,

- Functional part: Straightforward.
- Concurrent part:
  - Difficult.
  - These actions have side effects.
Language properties

We consider an Erlang-like language with...

- Functional features:
  - Pattern matching.
  - Eager evaluation (\(\approx\) innermost rewriting).
  - Evaluation of the first matching clause only.

- Concurrent actions for processes:
  - `self`: Returns the pid of the process.
  - `spawn`: Creates a new process.
  - `send`: Sends a message to a process.
  - `receive`: Find a message from the mailbox that matches the given patterns. Suspend execution if there is no match.
Example of an actor-based program

main($X, Y$)  →  $P = spawn(sum, [])$,
$P ! \{X, Y, self()\}$,
receive
   $Z \rightarrow Z$
end.

sum()  →  receive
   $\{N, M, P\} \rightarrow P ! add(N, M)$
end,
sum().

add($N, M$)  →  case $N$ of
   zero  →  $M$
   $\{\text{succ}, X\} \rightarrow \{\text{succ}, add(X, M)\}$
end.

A. Palacios (Valencia, Spain)  Modelling Actor-Based Conc. in TR  WPTE 2015  7 / 20
Modelling Concurrency
Definition (System specification structure)

An actor system is specified as a constructor $\mathcal{R} = \mathcal{E} \cup \mathcal{A} \cup \mathcal{S}$ where:

- $\mathcal{E}$ is the functional component.
- $\mathcal{A}$ specifies the evaluation of concurrent actions.
- $\mathcal{S}$ defines a scheduling policy.
Process definition

Definition (Process)

A process is denoted by a term \( p(pid, t, m) \) where:

- \( p/3 \) is a constructor symbol.
- \( pid \) is the process identifier (a constructor constant).
- \( t \) is the process’ term.
- \( m \) is the mailbox (a list of constructor terms).

\[
p(0, \text{main}(t_1, t_2), [])
\]
System definition

Definition (System)

A system is denoted by a term $s(k, m, procs)$ where:

- $s/3$ is a defined symbol.
- $k$ is a natural number (used to produce fresh pids).
- $m$ is a global mailbox of the system.
- $procs$ is a pool of processes.

$$s(2, [], p(0, \text{self(...)}, [])) \circ p(1, \text{sum}, [])$$

where $\circ$ is an AC constructor symbol.
Definition of concurrent actions

In our specification language, concurrent actions have the form

- \( \text{self}(p[, \text{cont}]) \)
- \( \text{spawn}(p, expr[, \text{cont}]) \)
- \( \text{send}(p, t[, \text{cont}]) \)
- \( \text{rec}(\text{clauses}[, \text{cont}]) \)

where \( \text{clauses} \) is a list of the form \([(pat_1, expr_1), \ldots, (pat_n, expr_n)]\)

Unfortunately, reducing these actions could be \textbf{problematic}. 
Program specification

We expect the user to specify a program like this:

\[
\begin{align*}
  \text{main}(x, y) & \to \text{spawn}(p, \text{sum}, \text{self}(s, \text{send}(p, d(x, y, s), \text{rec}([\text{clause}(z, z)])))) \\
  \text{sum}() & \to \text{rec}([\text{clause}(d(n, m, p), \text{send}(p, \text{add}(n, m), \text{sum}))]) \\
  \text{add}(0, m) & \to m \\
  \text{add}(\text{succ}(n), m) & \to \text{succ}(\text{add}(n, m))
\end{align*}
\]
Problems with original specification

In the previous example, the pid $p$ is passed as an argument to the spawn function.

But $p$ is also used in the send function, where the instantiation of $p$ is required.

Two ways of solving this:

- Using narrowing (an extension of rewriting that allows the instantiation of variables in the reduced term).
- Apply some preprocessing to avoid this situation (our approach).
Basicallty, for each concurrent action with a continuation, we introduce an auxiliary function to handle this continuation.

E.g., given the following rule:

\[ \ell \rightarrow \text{self}(p, \text{cont}) \]

the preprocessing will produce the following rules:

\[ \ell \rightarrow \text{self}(id, vars) \]

\[ \text{fself}(id, vars, p) \rightarrow \text{cont} \]

and the system rules take care of calling \text{fself} with the appropriate \( p \)
Compiled program

\[
\begin{align*}
\text{main}(x, y) & \rightarrow \text{spawn}(\text{main1}, [x, y], \text{sum}) \\
\text{fspawn}(\text{main1}, [x, y], p) & \rightarrow \text{self}(\text{main1}, [x, y, p]) \\
\text{fself}(\text{main1}, [x, y, p], s) & \rightarrow \text{send}(p, \text{d}(x, y, s), \\
& \quad \quad \text{rec}(\text{main1}, [x, y]) \\
\text{frec}(\text{main1}, [x, y], z) & \rightarrow z \\
\text{sum} & \rightarrow \text{rec}(\text{sum1}, []) \\
\text{frec}(\text{sum1}, [], \text{d}(n, m, p)) & \rightarrow \text{send}(p, \text{add}(n, m), \\
& \quad \quad \text{sum} \\
\text{frec}(h, vs, t) & \rightarrow \text{no\_match}(h, vs) \\
\text{add}(0, m) & \rightarrow m \\
\text{add}(\text{succ}(n), m) & \rightarrow \text{succ}(\text{add}(n, m))
\end{align*}
\]
System rules

\[ s(k, ms, p(pid, self(h, vs), ms')) \odot ps \rightarrow s(k, ms, p(pid, fself(h, vs, pid), ms')) \odot ps \]

\[ s(k, ms, p(pid, spawn(h, vs, t), ms')) \odot ps \rightarrow s(succ(k), ms, p(pid, fspawn(h, vs, k), ms')) \odot p(k, t, []) \odot ps \]

\[ s(k, ms, p(pid, send(pid', t, t'), ms')) \odot ps \rightarrow s(k, ms++[m(pid, pid', t)], p(pid, t', ms')) \odot ps \]

\[ s(k, ms, p(pid, rec(h, vs), m : ms')) \odot ps \rightarrow s(k, ms, p(pid, frec(h, vs, m), ms')) \odot ps \]
\[ s(k, ms, p(pid, no_match(h, vs), m : ms')) \odot ps \rightarrow s(k, ms, p(pid, frec(h, vs, m), ms')) \odot ps \]
\[ s(k, ms, p(pid, no_match(h, vs), [])) \odot ps \rightarrow s(k, ms, p(pid, rec(h, vs), [])) \odot ps \]

Note that concurrent actions are constructor symbols and not functions.
Conclusion and future work
Conclusion and future work

We have introduced a simple concurrent language that follows the actor model and can be specified within term rewriting.

This is an ongoing work. Currently, we are working on the following extensions:

- Formally define the specification language and its properties.
- Prove the correctness of the preprocessing stage and implement it.
- Prove the semantic equivalence between the original concurrent language and its specification in term rewriting.
  (in order to keep the usual semantics, innermost rewriting and priority rules are required)
- ...
Thanks for your attention!