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.

$$process(\Box)$$

- A system as a term composed of processes.

$$process(\Box) \odot process(\Box) \odot process(\Box) \odot \ldots$$

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

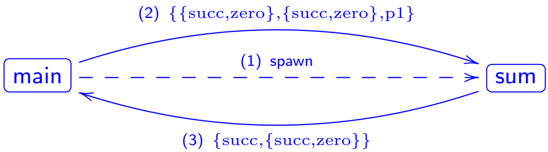
We consider an Erlang-like language with...

- 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

$$
\begin{array}{rcl}
\mathsf{main}(X,Y) & \to & P = \mathsf{spawn}(\mathsf{sum},[\,]),\\
 & & P\ !\ \{X,Y,\mathsf{self}()\},\\
 & & \mathsf{receive}\\
 & & \quad Z \to Z\\
 & & \mathsf{end}.\\
\mathsf{sum}() & \to & \mathsf{receive}\\
 & & \quad \{N,M,P\} \to P\ !\ \mathsf{add}(N,M)\\
 & & \mathsf{end},\\
 & & \mathsf{sum}().\\
\mathsf{add}(N,M) & \to & \mathsf{case}\ N\ \mathsf{of}\\
 & & \quad \mathrm{zero} \to M\\
 & & \quad \{\mathrm{succ},X\} \to \{\mathrm{succ},\mathsf{add}(X,M)\}\\
 & & \mathsf{end}.
\end{array}
$$



Modelling Concurrency

System specification structure

Definition (System specification structure)

An actor system is specified as a constructor TRS $\mathcal{R} = \mathcal{E} \cup \mathcal{A} \cup \mathcal{S}$ 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 $\mathrm{p}(pid, t, m)$ 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).

$$\mathrm{p}(0, \mathrm{main}(t_1, t_2), [\,])$$

System definition

Definition (System)

A system is denoted by a term $\mathsf{s}(k, m, procs)$ 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.

$$\mathsf{s}(2, [\,], \mathsf{p}(0, \mathsf{self}(\ldots), [\,]) \odot \mathsf{p}(1, \mathsf{sum}, [\,]))$$

where $\odot$ is an AC constructor symbol.

Definition of concurrent actions

In our specification language, concurrent actions have the form

- self($p[, cont]$)
- spawn($p, expr[, cont]$)
- send($p, t[, cont]$)
- rec($clauses[, cont]$)

where *clauses* is a list of the form $[(pat_1, expr_1), \ldots, (pat_n, expr_n)]$

Unfortunately, reducing these actions could be **problematic**.

Program specification

We expect the user to specify a program like this:

$$
\begin{array}{rcl}
\mathrm{main}(x, y) & \to & \mathrm{spawn}(p, \mathrm{sum}, \\
 & & \quad \mathrm{self}(s, \\
 & & \quad\quad \mathrm{send}(p, d(x, y, s), \\
 & & \quad\quad\quad \mathrm{rec}([\mathrm{clause}(z, z)])))) \\
\mathrm{sum}() & \to & \mathrm{rec}([\mathrm{clause}(d(n, m, p), \mathrm{send}(p, \mathrm{add}(n, m), \\
 & & \quad\quad\quad\quad \mathrm{sum}))]) \\
\mathrm{add}(0, m) & \to & m \\
\mathrm{add}(\mathrm{succ}(n), m) & \to & \mathrm{succ}(\mathrm{add}(n, m))
\end{array}
$$

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 instantation 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).

Preprocess of concurrent actions

Basically, for each concurrent action with a continuation, we introduce an auxiliary function to handle this continuation.

E.g., given the following rule:

$$\ell \quad \rightarrow \quad \mathsf{self}(p, cont)$$

the preprocessing will produce the following rules:

$$\ell \rightarrow \mathsf{self}(id, vars)$$

$$\mathsf{fself}(id, vars, p) \rightarrow cont$$

and the system rules take care of calling fself with the appropriate p

Compiled program

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

System rules

$$\mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{self}(h, vs), ms') \odot ps) \to \mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{fself}(h, vs, pid), ms') \odot ps)$$

$$\mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{spawn}(h, vs, t), ms') \odot ps) \to \mathsf{s}(\mathsf{succ}(k), ms, \mathsf{p}(pid, \mathsf{fspawn}(h, vs, k), ms') \odot \mathsf{p}(k, t, [\,]) \odot ps)$$

$$\mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{send}(pid', t, t'), ms') \odot ps) \to \mathsf{s}(k, ms{+}{+}[\mathsf{m}(pid, pid', t)], \mathsf{p}(pid, t', ms') \odot ps)$$

$$\mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{rec}(h, vs), m : ms') \odot ps) \to \mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{frec}(h, vs, m), ms') \odot ps)$$
$$\mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{no\_match}(h, vs), m : ms') \odot ps) \to \mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{frec}(h, vs, m), ms') \odot ps)$$
$$\mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{no\_match}(h, vs), [\,]) \odot ps) \to \mathsf{s}(k, ms, \mathsf{p}(pid, \mathsf{rec}(h, vs), [\,]) \odot ps)$$

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!