Liveness of Communicating Transactions

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(joint work with Vasileios Koutavas and Matthew Hennessy)

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  - **Isolation**: The effects of a transaction are concealed from the rest of the system until the transaction commits
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  - **Durability**: After a transaction commits, its effects are permanent.
- However, **isolation limits concurrency**
  - The semantics of traditional transactions is sequential schedules
  - Traditional transactions do not offer an abstraction for recovery from distributed errors (e.g. deadlocks)

Communicating Transactions

- We drop isolation to increase concurrency
  - There is no limit on the communication between a transaction and its environment
- The transactional system guarantees:
  - **Atomicity**: Each transaction will either run in its entirety or not at all
  - **Consistency**: Faults caused by a transaction are automatically detected and rolled-back, together with all effects of the transaction to its environment
  - **Durability**: After all transactions that have interacted commit, their effects are permanent (coordinated checkpointing)
- We are interested in safety and especially liveness properties
  - First theory of liveness in the presence of transactions
  - We have studied the transactional properties of communicating transactions in [CONCUR'2010]

Safety

Safety: “Nothing bad will happen” [Lamport’77]

- A safety property can be formulated as a safety test T^{ω} which signals on channel ω when it detects the bad behaviour
- P passes the safety test T^{ω} when $P \mid T^{\omega}$ cannot output on ω
    - This is the negation of passing a “may test” [DeNicola-Hennessy’84]

Liveness

Liveness: "Something good will eventually happen" [Lamport'77]

- A liveness property can be formulated as a liveness test T^ω which detects and reports good behaviour on ω.
- P passes the liveness test T^ω when all future states of $P \mid T^\omega$ can output on ω
  - This is a "should test" [Binksma-Rensink-Vogler'95, Rensink-Vogler'07]
  - It excludes pathological traces
- We will later see why "must testing" [DeNicola-Hennessy'84] is not appropriate for transactions

TransCCS [CONCUR 2010]

Syntax:	P, Q	$::=$	$\sum \mu_i . P_i$	guarded choice
		$\mid$	$P \mid Q$	parallel
		$\mid$	$\nu a.P$	hiding
		$\mid$	$\mu X.P$	recursion
		$\mid$	$[\![P \rhd_k Q]\!]$	transaction (k bound in P)
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Default

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Alternative

TransCCS [CONCUR 2010]

Syntax:

$$\begin{array}{llll}
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Main reductions:

R-COMM

$$\frac{a_i = \overline{b}_j}{\sum_{i \in I} a_i.P_i \mid \sum_{j \in J} b_j.Q_j \to P_i \mid Q_j}$$

R-EMB

$$\frac{k \notin R}{[\![P \triangleright_k Q]\!] \mid R \to [\![P \mid R \triangleright_k Q \mid R]\!]}$$

R-CO

$$\frac{}{[\![P \mid \mathsf{co}\ k \triangleright_k Q]\!] \to P}$$

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$$a.c.\omega + e.\mho \mid \llbracket \overline{a}.\overline{c}.\mathrm{co}\ k + \overline{e} \triangleright_k r \rrbracket$$

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\xrightarrow{\text{R-COMM}}\ & \llbracket\ c.\omega \mid \overline{c}.\mathsf{co}\ k \triangleright_k a.c.\omega + e.\mho \mid r \rrbracket \\
\xrightarrow{\text{R-COMM}}\ & \llbracket\ \omega \mid \mathsf{co}\ k \triangleright_k a.c.\omega + e.\mho \mid r \rrbracket \\
\xrightarrow{\text{R-CO}}\ & \omega
\end{aligned}
$$

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$$\xrightarrow{\text{R-AB}} a.c.\omega + e.\mho \mid r \quad \text{(The environment is restored)}$$

Simple Example (all traces)

$$\begin{tikzcd}
a.c.\omega + e.\mho \mid \llbracket \overline{a}.\overline{c}.\mathsf{co}\ k + \overline{e} \rhd_k\ r \rrbracket \arrow[rr, "\text{R-Ab}"] \arrow[d, "\text{R-Emb}"'] & & {\color{red} a.c.\omega + e.\mho \mid r} \\
P_1 \arrow[d, "\text{R-Comm}"'] \arrow[dr, "\text{R-Comm}"] \arrow[urr, "\text{R-Ab}"'] & & \\
& P_2 \arrow[uur] & \\
P_2 \arrow[d, "\text{R-Comm}"'] \arrow[uuurr] & & \\
P_3 \arrow[d, "\text{R-Co}"'] \arrow[uuuurr] & & \\
{\color{red} \omega} & &
\end{tikzcd}$$

Restarting transactions

$$a.c.\omega + e.\mho \mid \mu X.\,[\![\overline{a}.\overline{c}.\mathsf{co}\ k + \overline{e} \rhd_k X]\!]$$

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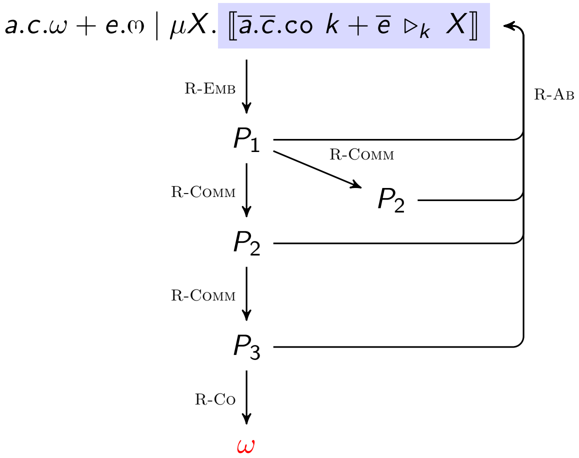

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P_1 \arrow[d, "\text{R-Comm}"'] \arrow[dr, "\text{R-Comm}"] \arrow[u, bend right=60, "\text{R-Ab}"'] & \\
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Infinitely aborting loop

Compositional Semantics

- The embedding rule is simple but entangles the processes
- We need to reason about the behaviour of $P|Q$ in terms of P and Q
- We introduce a compositional Labelled Transition System that uses secondary transactions: $[\![P \triangleright_k Q]\!]^\circ$

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$$
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\xrightarrow{\mathtt{emb}\ k} & [\![a.c.\omega + e.\mho \rhd_k a.c.\omega + e.\mho]\!]^\circ & & \xrightarrow{\mathtt{emb}\ k} & [\![\overline{a}.\overline{c}.\mathrm{co}\ k + \overline{e} \rhd_k r]\!] \\
\xrightarrow{k(a)} & [\![\ c.\omega \rhd_k a.c.\omega + e.\mho]\!]^\circ & & \xrightarrow{k(\overline{a})} & [\![\ \overline{c}.\mathrm{co}\ k \rhd_k r]\!] \\
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Compositional Semantics (2)

The behaviour of processes in TransCCS can be understood by CCS-like "Clean" traces derived by the LTS that:

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- enable compositional reasoning:
  - $\mathcal{L}(P \mid Q) = \mathcal{L}(P)\ \mathbf{zip}\ \mathcal{L}(Q)$
  - $\mathcal{L}(P) \subseteq \mathcal{L}(Q) \quad \text{implies} \quad \mathcal{L}(P \mid R) \subseteq \mathcal{L}(Q \mid R)$

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Definition (Basic Observable)

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Theorem (Characterization of safety preservation)

$S \sqsubsetapprox_{\mathrm{safe}} I$ *iff* $\mathcal{L}(S) \supseteq \mathcal{L}(I)$

Liveness

Definition (P Passes liveness Test T^ω [Rensink-Vogler'07])

$P \,\mathrm{shd}\, T^\omega$ when $\forall R.$ $P \mid T^\omega \rightarrow^* R$ implies $R{\Downarrow_\omega}$

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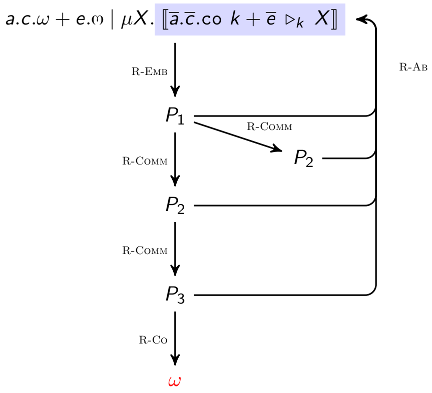

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$P \,\mathrm{shd}\, T^\omega$ when $\forall R.\quad P \mid T^\omega \rightarrow^* R$ implies $R{\Downarrow_\omega}$

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P_2 \arrow[uu, bend right=60, "\textsc{R-Ab}"'] \arrow[d, "\textsc{R-Comm}"'] & P_2 \arrow[luu, bend right=40, "\textsc{R-Ab}"'] \\
P_3 \arrow[uuu, bend right=60, "\textsc{R-Ab}"'] \arrow[d, "\textsc{R-Co}"'] & \\
\omega &
\end{tikzcd}$$

must testing
would consider
the infinite loop

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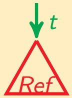
Definition (Tree Failures [Rensink-Vogler'07])

(t, Ref) is a **tree failure** of P when

$$\exists P'.\quad P \overset{t}{\Rightarrow}_{CL} P' \quad \text{and} \quad \mathcal{L}(P') \cap \mathit{Ref} = \emptyset$$



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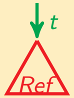

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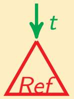

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Theorem (Characterization of liveness preservation)

$S \sqsubseteq_{\text{live}} I$ *iff* $\mathcal{F}(S) \supseteq \mathcal{F}(I)$

Simple Examples

Let $S_{ab} = \mu X . \llbracket a.b.\mathrm{co}\ k \triangleright_k X \rrbracket$ $\quad \mathcal{L}(S_{ab}) = \{\epsilon, ab\}$

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- $S_{ab} \eqsim_{\text{safe}} I_2 = \mu X.\ [\![a.b.\text{co } k + e \triangleright_k X]\!]$ $\qquad \mathcal{L}(I_2) = \mathcal{L}(S_{ab})$
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  - If in **CCS** $P \sqsubset\!\!\!\sim_{\text{safe}} Q$ then also in **TransCCS** $P \sqsubset\!\!\!\sim_{\text{safe}} Q$
- No way to encode non-prefix-closed traces in **CCS**; thus no fully-abstract translation from **TransCCS** to **CCS**

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    - $(a, \{bd\}) \in \mathcal{F}(a.b.c + a.b.d)$
  - **TransCCS** distinguishing liveness test in the paper
- Thus no sound translation from **TransCCS** to **CCS** that is the identity on CCS terms

Also in [APLAS 2010]

- Canonical class of tests for liveness and safety
- See how restarting transactions add fault tolerance to CCS (Ex. 6)
- A sound, but incomplete bisimulation proof method, using the “clean” LTS transitions
- Many examples

Conclusions

Communicating transactions:

- Traditional transactions without the isolation requirement
  - No limit on communication or concurrency
- Simple safety and liveness theory
  - First theory of liveness in the presence of transactions
- **Future directions:** Reference implementation/evaluation of the construct in a programming language.

Advertisement

Joint Trinity/Microsoft Research PhD on extending Haskell with communicating transactions. We need a good student :)

ACD Properties

$$\begin{tikzcd}
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P_2 \arrow[d, "\text{R-Comm}"'] \arrow[uu, bend right=70, "\text{R-Ab}"'] & \\
P_3 \arrow[d, "\text{R-Co}"'] \arrow[uuu, bend right=80, "\text{R-Ab}"'] & \\
\omega &
\end{tikzcd}$$

A commit step makes the effects of the transaction permanent (**Durability**)

An abort step:

- restarts the transaction
- rolls-back embedded processes to their state before embedding (**Consistency**)
- does not roll-back actions that happened before embedding
- does not affect non-embedded processes

The semantics of transactions transactions are non-prefix-closed traces (**Atomicity**).