

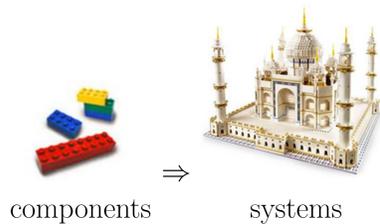
The Earlier the Better: A Theory of Timed Actor Interfaces

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1. Component-based design



Questions:
What are the right building blocks?
Which ones to use? How to connect them?
What is a component? How to reason about components?

4. Compositionality

- If $B \sqsubseteq A$ and $B' \sqsubseteq A'$ then $(B||B') \sqsubseteq (A||A')$, and $(B \circ B') \sqsubseteq (A \circ A')$, and ...
- If $B \sqsubseteq A$ then B preserves interesting properties of A

Many existing frameworks, e.g., interface theories [dAH01]. But:

- focus on functional/correctness models and properties;
- not suitable for cyber-physical systems: timing, performance.

7. Actors

Formal descriptions of components:

$$A = (P, Q, R_A)$$

P : set of input ports.

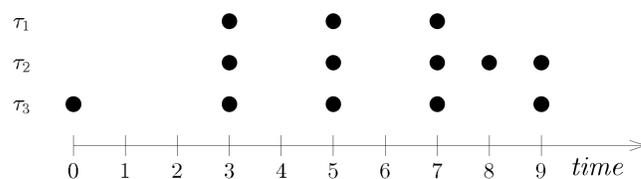
Q : set of output ports.

$R_A \subseteq Tr(P) \times Tr(Q)$: relation between input and output event traces.

8. Event traces

Event trace: port-wise vector of event sequences.

Event sequence: sequence of "pure" (non-valued) events in time.



10. The earlier-the-better refinement

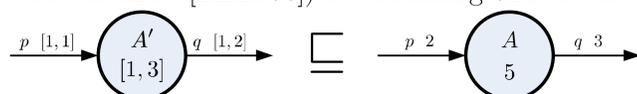
$B = (P, Q, R_B)$ refines $A = (P, Q, R_A)$, denoted $B \sqsubseteq A$, iff

(1) $\text{in}_A \subseteq \text{in}_B$ (legal inputs of A are also legal in B);

(2) $\forall x \in \text{in}_A, \forall y : xBy \implies \exists y' : y \sqsubseteq y' \wedge xAy'$ (outputs of B come no later than those of A).

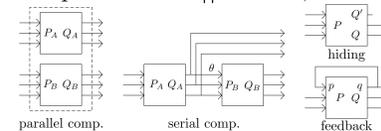
Where $y \sqsubseteq y'$ if events in y happen no later than those in y' . E.g., $\tau_3 \sqsubseteq \tau_2$, $\tau_2 \sqsubseteq \tau_1$, but $\tau_1 \not\sqsubseteq \tau_2$.

Example: CSDF (cyclo-static dataflow [BELP96]) actor refining SDF actor:



2. Composition

- Components: A, B, \dots
- Composition operators: $A||B = C, C \circ D = E, \dots$



- Substitutability:** can I replace C by F in E ?

5. This work

A compositional theory for timing and performance properties.
Deterministic abstractions for non-deterministic systems!

E.g., MP3 player: \longrightarrow

- Deterministic specification: throughput = 44.1kHz, latency = 50 ms.
- Performance preserved by stepwise refinement.

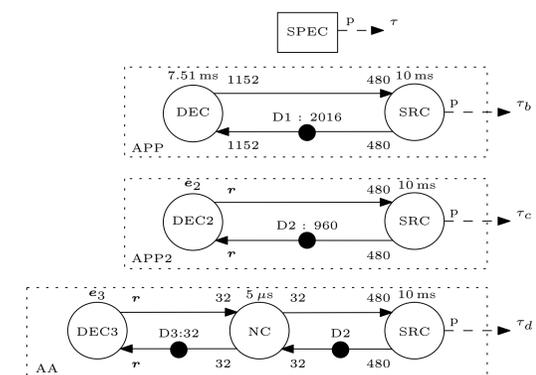
3. Abstraction-Refinement

Two faces of the same golden coin!

$B \sqsubseteq A$:

- A is an abstraction of B
- B is a refinement of A

6. Example: MP3 player

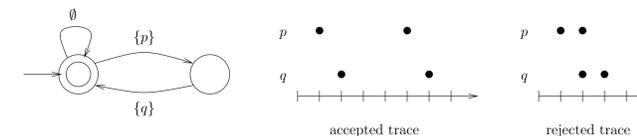


9. Examples of actors

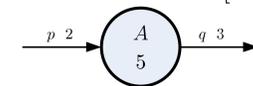
Variable-delay actor $\Delta_{[d_1, d_2]}$:

$$x\Delta_{[d_1, d_2]}y \text{ iff } |x(p)| = |y(q)| \wedge \forall n < |x(p)| : \\ x(p)(n) + d_1 \leq y(q)(n) \leq x(p)(n) + d_2 \\ \wedge (n > 0 \implies y(q)(n) \geq y(q)(n-1)).$$

Finite-automaton actor:



SDF (Synchronous Data Flow [LM87]) actor:



$$xAy \text{ iff } |y(q)| = 3 \cdot \min_{p \in P} (|x(p)| \div 2)$$

$$\wedge \forall n < |y(q)| : y(q)(n) = 5 + x(p)((n \div 3 + 1) \cdot 2 - 1)$$

11. Results

- Refinement is compositional w.r.t. parallel, serial and feedback composition (under some conditions).
- Refinement preserves worst-case throughput and latency.
- Algorithms to check refinement and compute compositions for various finite representations (SDF, automata, ...).
- Semantical unification of existing frameworks (dataflow, automata, service curves, ...).

12. References

- [BELP96] G. Bilsen, M. Engels, R. Lauwereins, and J.A. Peperstraete. Cyclo-static dataflow. *IEEE Tran. on Signal Processing*, 44(2), 1996.
- [dAH01] L. de Alfaro and T. Henzinger. Interface theories for component-based design. In *EMSOFT'01*. Springer, LNCS 2211, 2001.
- [GTW10] Marc Geilen, Stavros Tripakis, and Maarten Wiggers. The earlier the better: A theory of timed actor interfaces. Technical Report UCB/Eecs-2010-130, EECS Department, University of California, Berkeley, Oct 2010. Shorter version to appear in 14th Intl. Conf. Hybrid Systems: Computation and Control (HSCC'11).
- [LM87] E. Lee and D. Messerschmitt. Synchronous data flow. *Proceedings of the IEEE*, 75(9):1235-1245, 1987.