Exploring Aspects in the Context of Reactive Systems
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An attempt at understanding AOP in the semantical framework we know best!

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This paper...

- Reactive systems and the synchronous approach
  Programming with products of automata
- Candidate aspects in reactive programming
- A declarative (i.e., not constructive at all!) setting
- Candidate weaving mechanisms
- Conclusion
Reactive Systems and the Synchronous Approach

AIR

Heater

Reactive System

Temperature

ON, OFF
Reactive Systems and the Synchronous Approach

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**Heater**

**Temperature**

**AIR**

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**Discrete time**

0 1 2 3 4 5 6 7 8 ...
Reactive Systems and the Synchronous Approach

Languages:

• Lustre, Signal: dataflow
• Esterel: imperative with control structures
• Argos (inspired by Statecharts): explicit automata
Reactive Systems and the Synchronous Approach

Languages:

- Lustre, Signal: dataflow
- Esterel: imperative with control structures
- Argos (inspired by Statecharts): explicit automata

All these languages have a common semantical basis:

- deterministic and reactive Mealy machines +
- synchronous product +
- encapsulation
A modulo 8 counter - the program
A modulo 8 counter - the program

\textit{a/}

\textit{a/carry0}

\textit{a/mod8}
A modulo 8 counter - the program
A modulo 8 counter - the program
A modulo 8 counter - the program

\[ a/ \]
\[ a/carry0 \]
\[ carry0/ \]
\[ carry0/carry1 \]
\[ carry1/ \]
\[ carry1/mod8 \]
A modulo 8 counter - the program

carry0, carry1

a/
carry0

a/carry0

carry0/
carry0/carry1

carry1/
carry1/mod8

a/ mod8

a/
a/
a/
a/
a/
a/
a/
a/
a/
A modulo 8 counter - the program
A modulo 8 counter - the dataflow view

- bit 0
- carry0
- bit 1
- carry1
- bit 2
- mod8
A modulo 8 counter - the dataflow view
Basic Automata

A signal alphabet: $A = \{\alpha, \beta, \gamma, \ldots\}$
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A signal alphabet: \( A = \{ \alpha, \beta, \gamma, \ldots \} \)
A Boolean Mealy machine: \( M = (S, s_0, I, O, T) \)
Inputs/Outputs: \( I, O \subseteq A \)
Transitions: \( T \subseteq S \times \mathcal{B}(I) \times 2^O \times S \)
\( \mathcal{B}(I) \): Boolean Expressions with variables in \( I \)
A *signal* alphabet: \( \mathcal{A} = \{ \alpha, \beta, \gamma, \ldots \} \)

A Boolean Mealy machine: \( M = (S, s_0, I, O, T) \)

Inputs/Outputs: \( I, O \subseteq \mathcal{A} \)

Transitions: \( T \subseteq S \times \mathcal{B}(I) \times 2^O \times S \)

\( \mathcal{B}(I) \): Boolean Expressions with variables in \( I \)

\( \beta/\omega, \delta \)

\( \alpha \land \neg\beta/\delta \)

\( \neg\gamma/\epsilon \)

+ determinism and reactivity
Parallel composition with no synchronization

Cartesian product with conjunction of guards, union of output sets.
Synchronization: what we want to obtain (1)
Synchronization: what we want to obtain (2)
Synchronization: what we want to obtain (3)
Synchronization: the encapsulation
Synchronization: the encapsulation

Keep the transition $c/e$ if and only if:

$$(b \in e \implies c \land b \neq \text{false}) \land (b \not\in e \implies c \land \neg b \neq \text{false})$$

+ hiding of $b$.
Candidate Aspects

The synchronous broadcast is very powerful... yet, some transformations seem difficult to implement in a structural fashion.
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- clock (or filter) a system so that it does not emit anything when an additional signal is present
Candidate Aspects

The synchronous broadcast is very powerful... yet, some transformations seem difficult to implement in a structural fashion.

- Reinitialize the system on the occurrence of an additional signal $r$
- clock (or filter) a system so that it does not emit anything when an additional signal is present
- Add a validity bit to each input, and output a default value instead of the value computed by the system, whenever the validity bit is false.
Reinitialize the counter with $r$
Reinitialize the counter with $r$
Reinitialize the counter with \( r \)
Reinitialize the counter with $r$
Reinitialize the counter with $r$

and here ??
A Declarative Setting (1)

Start from a program $P$
with inputs $I \cup I'$ and outputs $O \cup O'$. 
A Declarative Setting (I)

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Define an aspect $A$ by:

- additional inputs and outputs $I''$ and $O''$
- a set of traces on $I' \cup I''$ and $O' \cup O''$ defining the semantics of $P \triangleleft A$
A Declarative Setting (1)

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Define an aspect $A$ by:
- additional inputs and outputs $I''$ and $O''$
- a set of traces on $I' \cup I''$ and $O' \cup O''$ defining the semantics of $P \bowtie A$

The set of traces may be specified by a temporal-logic formula, or an reactive synchronous observer, or ...
A Declarative Setting (2)
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I
I'
I''

P
O
O'

P < A
O'
O'*
O*

looks like
oke’?

Aspect A
oke’?

ok’?
A Declarative Setting (2)
A Declarative Setting (3)

Comparing the behaviours of $P$ and $P \triangleleft A$:

- Projecting on a set of variables
A Declarative Setting (3)

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- Accepting time shifts ($P \triangleleft A$ responds later than $P$)
A Declarative Setting (3)

Comparing the behaviours of $P$ and $P \triangleleft A$:

- Projecting on a set of variables
- Projecting on a set of instants in time
- Accepting time shifts ($P \triangleleft A$ responds later than $P$)
- A combination of these three criteria
- ...

Aspects and Reactive Systems
Weaving Mechanism (1)
Weaving Mechanism (1)

select states according to a path
Weaving Mechanism (I)

select states according to a path
select \( c_i \) satisfying condition \( C \)
Weaving Mechanism (1)

- Select states according to a path.
- Select $c_i$ satisfying condition $C$.
- Reinforce the $c_i$'s by $m$, add outputs.
Weaving Mechanism (1)

- Weaving Mechanism (1)
- \( m.c1/00 \)
- \( m.c2/000 \)
- \( m.c1/000 \)
- \( c2/02,00 \)
- \( m.c1/01,00 \)
- \( c3/03 \)

- Select states according to a path
- Select \( ci \)'s satisfying condition \( C \)
- Reinforce the \( ci \)'s by \( m \), add outputs
- Complete the automaton (need \( 000, path' \))

Diagram with states and transitions:

- \( init \) to \( m.c1/00 \)
- \( m.c2/000 \) to \( init \)
- \( m.c1/000 \) to \( m.c2/02,00 \)
- \( m.c1/01,00 \) to \( m.c2/02,00 \)
- \( c3/03 \) to \( m.c2/02,00 \)
The Global Picture

(informal) Candidate aspects
The Global Picture

(informal)
Candidate aspects

Declarative Setting
The Global Picture

(informal) Candidate aspects

Operations on Automata

Declanative Setting
The Global Picture

(informal)
Candidate aspects

Make the idea more precise

Declarative Setting

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Operations on Automata

Validation
The Global Picture

(informal) Candidate aspects

Make the idea more precise

Implementation?

Operations on Automata

Declarative Setting

Validation
The Global Picture

- (informal) Candidate aspects
- Make the idea more precise
- Implementation?
- Operations on Automata
- Validation
- A general controller-synthesis problem
An Open Question

For any of the candidate aspects, would it be possible to implement it using existing constructs?
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Given a program $P$, and a new signal $r$, is there a context $C$ of existing operators (parallel, encapsulation) such that:

$C[P]$ behaves as: $P$ reinitialized when $r$?
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(for example, using feedback?)

can be studied on an example, but how to characterize what cannot be implemented with existing constructs?
Conclusion, further work

• The general setting is almost ok

• Try to find a minimal set of automata transformations to implement aspect weaving and validate them according to the declarative setting.

• Find real-life examples that could benefit from the AOP point of view