Measuring with Timed Patterns

CAV'15

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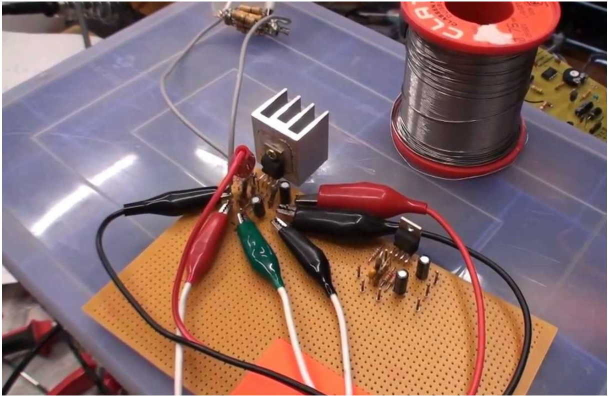
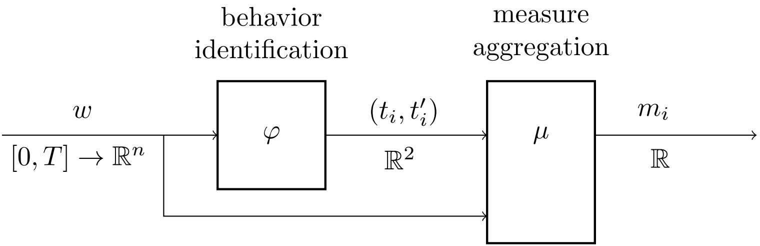
Measurements current practice...

- scripts, signal processing blocks, etc.
- ad-hoc approach



Declarative language for measurements



- **timed** regular expression φ describes intervals where measure can be taken
- continuous aggregating operators μ: duration, integral, maximum, etc.

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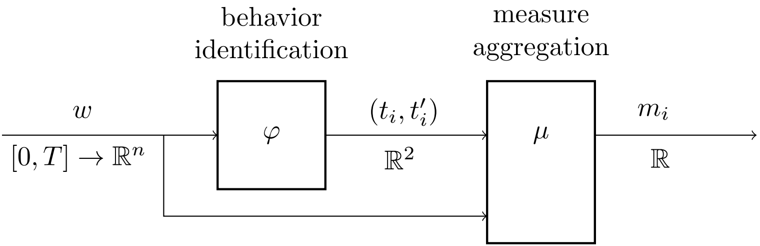

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Timed regular expressions – interval semantics

Definition (Syntax of TRE)

$$\varphi := \epsilon \mid p \mid \varphi \cdot \varphi \mid \varphi \vee \varphi \mid \varphi \wedge \varphi \mid \varphi^* \mid \langle \varphi \rangle_{[l,u]}$$

p proposition, and l, u integer constants.

Definition (Semantics of TRE)

$(t, t') \in [\![\epsilon]\!]_w$	iff	$t = t'$
$(t, t') \in [\![p]\!]_w$	iff	$\forall t < t'' < t',\ p \in w[t'']$
$(t, t') \in [\![\varphi \cdot \psi]\!]_w$	iff	$\exists t \leq t'' \leq t',\ (t, t'') \in [\![\varphi]\!]_w$ and $(t'', t') \in [\![\psi]\!]_w$
$(t, t') \in [\![\varphi \vee \psi]\!]_w$	iff	$\ldots$
$(t, t') \in [\![\varphi \wedge \psi]\!]_w$	iff	$\ldots$
$(t, t') \in [\![\varphi^*]\!]_w$	iff	$\ldots$
$(t, t') \in [\![\langle \varphi \rangle_{[l,u]}]\!]_w$	iff	$l \leq t' - t \leq u$ and $(t, t') \in [\![\varphi]\!]_w$

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Timed pattern matching

Theorem (FORMATS'14)

The set of matches $[\![\varphi]\!]_w$ is computable as a finite union of 2d zones

Proof principle

Structural induction over φ

$$z_p \rightsquigarrow t_i < t < t' < t_{i+1}$$

$$z_{\varphi \cdot \psi} \rightsquigarrow z_\varphi \circ z_\psi$$

$$\dots$$

$$z_{\langle \varphi \rangle_{[l,u]}} \rightsquigarrow z_\varphi \wedge l < t' - t < u$$

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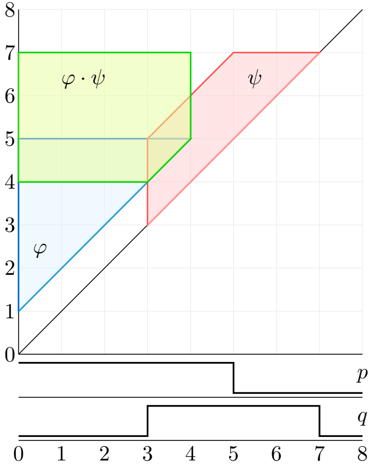
Example

Expressions:

$$\varphi = \langle p \rangle_{[1,5]} \qquad \psi = \langle q \rangle_{[0,2]} \qquad \varphi \cdot \psi$$

Set of matches:



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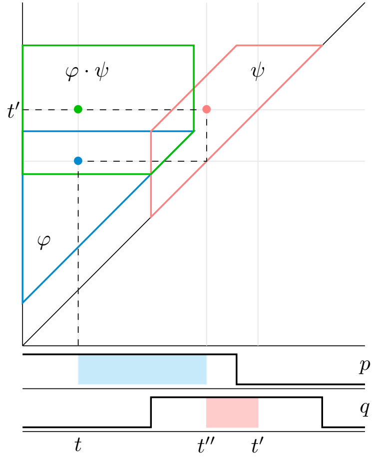

Conditional expressions

Introduce **preconditions** and **postconditions**.

Definition (Syntax of Conditional TRE)

$$\varphi := \ldots \mid \varphi \cdot \varphi \mid \ldots \mid \varphi \,?\, \varphi \mid \varphi \,!\, \varphi$$

Definition (Semantics of Conditional TRE)

$$\ldots$$

$(t, t') \in [\![\varphi \cdot \psi]\!]_w$ iff $\exists t \leq t'' \leq t'$ $(t, t'') \in [\![\varphi]\!]_w$ and $(t'', t') \in [\![\psi]\!]_w$

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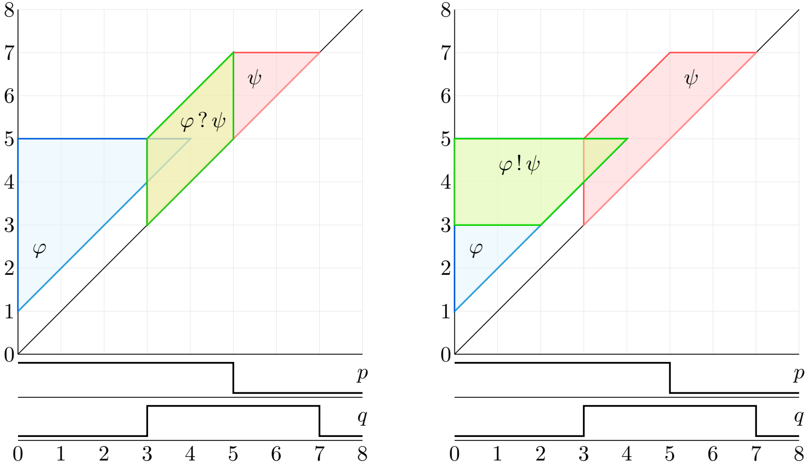

Expressions with events

Events

Zero-duration expressions:

$$\uparrow p = \overline{p}\,?\,\epsilon\,!\,p \qquad \text{(rising edge)}$$
$$\downarrow p = p\,?\,\epsilon\,!\,\overline{p} \qquad \text{(falling edge)}$$

Event-bounded expressions

Syntactically enforced:

$$\psi := \uparrow p \mid \downarrow p \mid \psi \cdot \varphi \cdot \psi \mid \psi \cup \psi \mid \psi \cap \varphi$$

with φ arbitrary expression

Proposition (Finiteness)

Event-bounded expressions have a **finite** *set of matches.*

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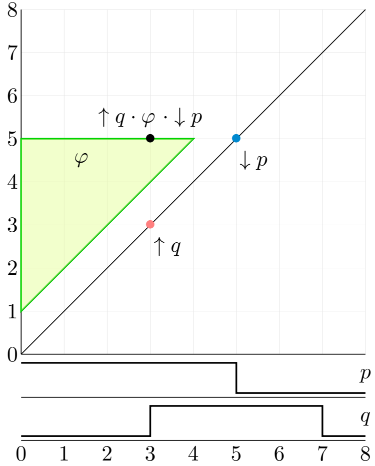

Measurements

Measure Pattern

A Conditional TRE

$$\varphi = \alpha \,?\, \psi \,!\, \beta$$

with arbitrary conditions α, β, and ψ event-bounded.

Measure Expression

An expression

$$\mu(\varphi)$$

with φ a measure pattern, and $\mu = \mathbf{duration}, \mathbf{sup}_x, \mathbf{integral}_x, \ldots$ continuous aggregation operator.

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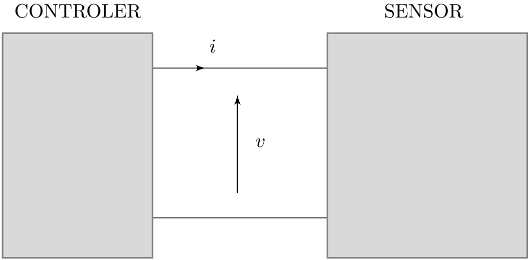
DSI3 standard



- Analog communication protocol

- Communication via **pulses** on
  - voltage line v
  - current line i

- Two phases with different **nominal levels**
  - discovery mode: v in range V_0 to V_1
  - command and response mode: v in range V_2 to V_3

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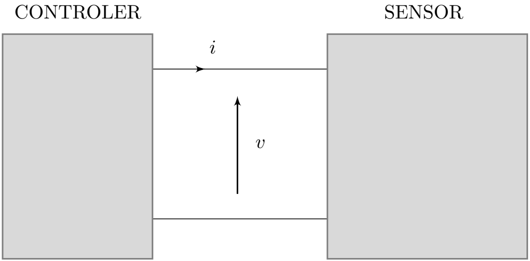

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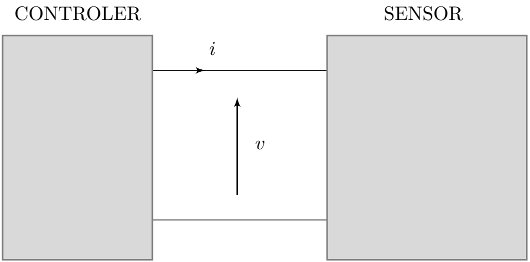

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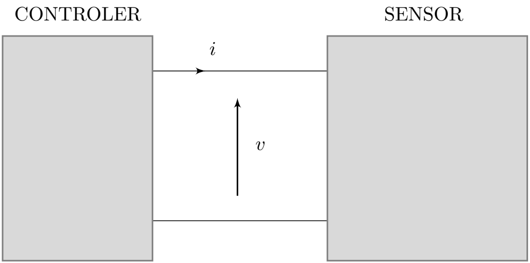
Model and requirements



- Behavioral model:
  - gaussian distribution of pulse timing
  - uniform distribution of sensor load resistance
- Simulation: 100 sequences of discovery + command and response
- Measurements:
  1. time between consecutive discovery pulses
  2. energy transmitted through power pulses

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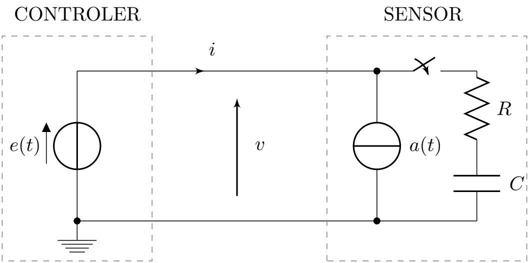

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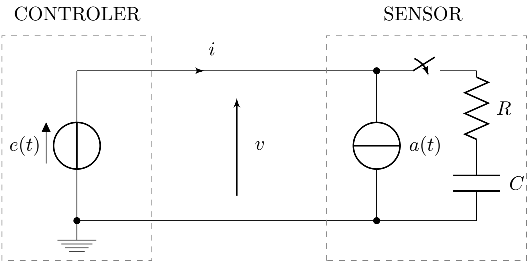

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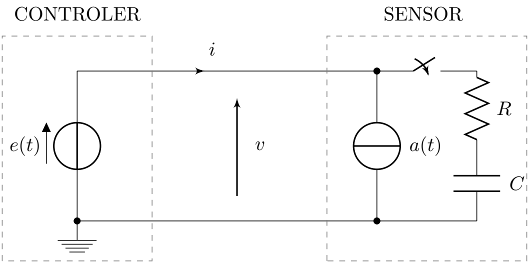

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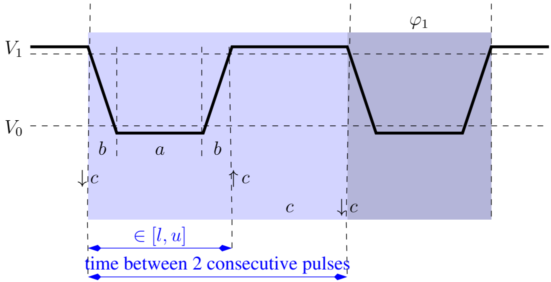

- Voltage levels:

$$a \equiv v \leq V_0 \qquad b \equiv V_0 \leq v \leq V_1 \qquad c \equiv v \geq V_1$$

- Pulse pattern:

$$\varphi_1 \equiv \downarrow c \cdot \langle b \cdot a \cdot b \rangle_{[l,u]} \cdot \uparrow c$$

- Measure expression: $M_1 = \textbf{duration}(\varphi_1 \cdot c \,!\, \varphi_1)$

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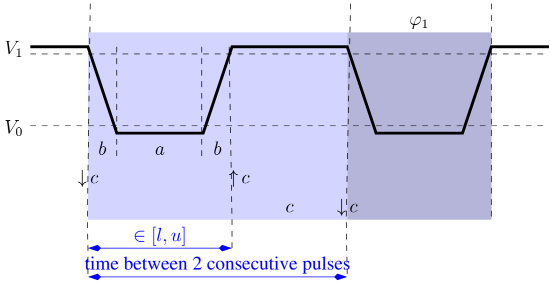

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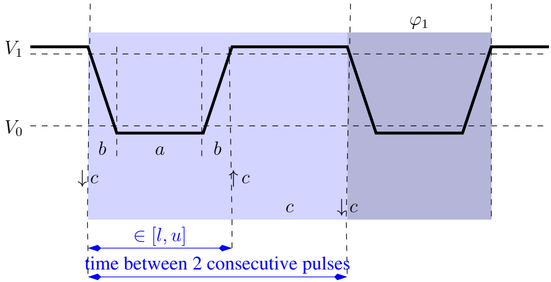

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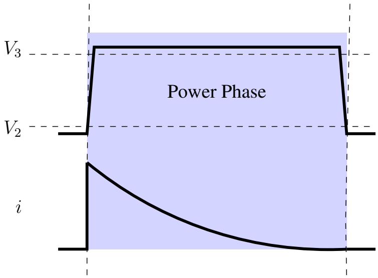
Measurement 2: energy transmitted during power pulses



- Voltage levels:

$$e \equiv v \geq V_2 \qquad f \equiv V_2 \leq v \leq V_3 \qquad g \equiv v \geq V_3$$

- Pulse pattern:

$$\varphi_2 \equiv \uparrow e \cdot f \cdot g \cdot f \cdot \downarrow e$$

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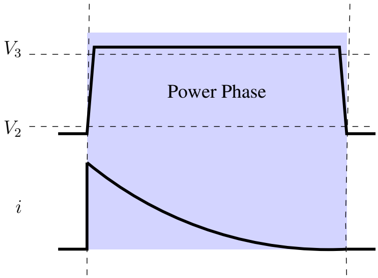

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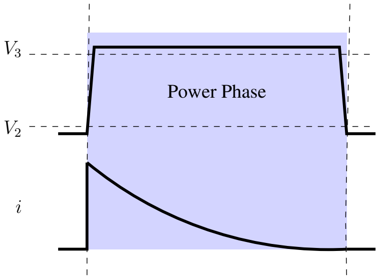

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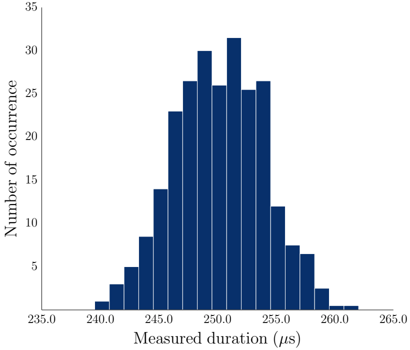
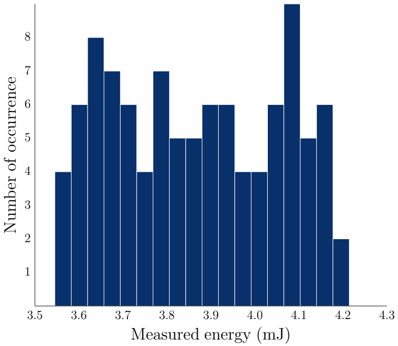
Results



Number of occurrence
35
30
25
20
15
10
5
235.0
240.0
245.0
250.0
255.0
260.0
265.0
Measured duration (μs)



Number of occurrence
8
7
6
5
4
3
2
1
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
Measured energy (mJ)

Performance

Computation time (seconds) relative to sampling rate:

	Measure 1				Measure 2			
samples	T_p	T_φ	T_μ	T	T_p	T_φ	T_μ	T
1M	0.047	0.617	0.000	**0.664**	0.009	0.004	0.011	**0.024**
5M	0.197	0.612	0.000	**0.809**	0.050	0.005	0.047	**0.103**
10M	0.386	0.606	0.000	**0.992**	0.101	0.005	0.100	**0.216**
20M	0.759	0.609	0.000	**1.368**	0.203	0.005	0.260	**0.468**

Program:

- TRE matching algorithms based on IF library
- Python signal processing library

Conclusion

Present

- declarative language for mixed-signal measurements
- general and efficient to monitor

Future

- language extension
- online measurements