Evaluation of Runtime Monitoring Methods for Real-Time Event Streams

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Jan. 21. 2015

Overview

1. Motivation
2. Background
3. Comparison
   - Comparison based on standard arrival curves
   - Comparison based on complex arrival curves
4. FPGA evaluations
5. Summary

Outline

Motivation

Real-time system at runtime

Why real-time system needs to be monitored?

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- System events are monitored
- Violation is reported by the monitor

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- Dynamic counters (Kai et.al, 2011)

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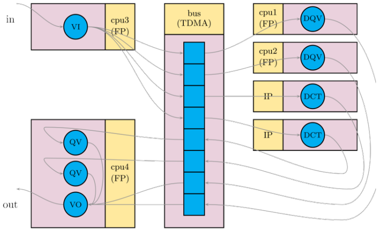
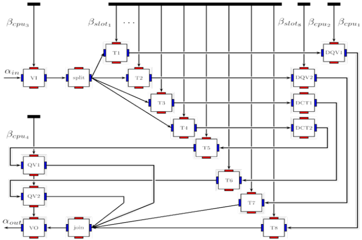
- Developed a new approach to apply dynamic counters to monitor periodic-burst events
- Prototyped hardware implementations on FPGA and presented FPGA resource usage

Outline

Arrival Curve (Modular Performance Analysis)





System view of the M-JPEG The corresponding RTC-MPA model

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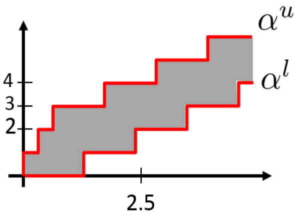
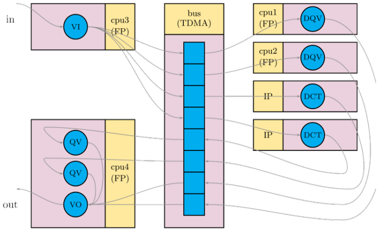
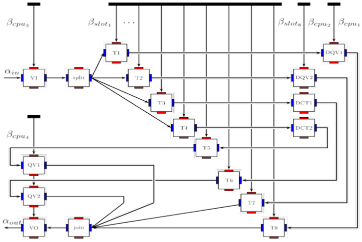


Arrival curve: Event stream model, $\alpha^l(t-s) \leq R[s,t) \leq \alpha^u(t-s),\ \forall t \geq s \geq 0$, where $R[s,t)$ denote the number of events in the time interval $s \leq \tau < t$.





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The corresponding RTC-MPA model

Distance Function (Compositional Performance Analysis)

Minimum/maximum distance function

The minimum distance function $d^{min}(n)$ specifies the minimum distance between $n+1$ consecutive events in an event stream.

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An example: periodic events with jitter

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- $(a)\ Upper\ Arrival\ Curves : \alpha^u(\Delta) = \lfloor \frac{\Delta+J}{\delta} \rfloor$
- $(b)\ Lower\ Arrival\ Curves : \alpha^l(\Delta) = max\{0, \lfloor \frac{\Delta-J}{\delta} \rfloor$

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- (b) $Maximum\ Distance\ Functions : d^{max}(n) = n \cdot \delta + J$

Dynamic counter

Assumption

Any monotonous and time-invariant arrival curve can be conservatively approximated as the minimum on a set of staircase functions with the form $\alpha_i^u(\Delta) = N_i^u + \lfloor \frac{\Delta}{\delta_i} \rfloor$.

$$\forall \Delta \in \mathbb{R}_{\geq 0} : \alpha^u(\Delta) \geq \min_{i=1..n} (\alpha_i^u(\Delta))$$

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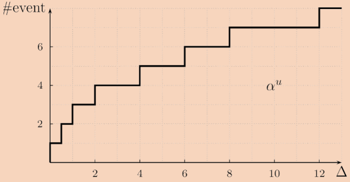
Method: one dynamic counter is responsible for monitoring one staircase function



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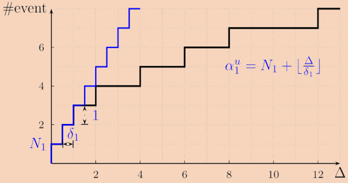

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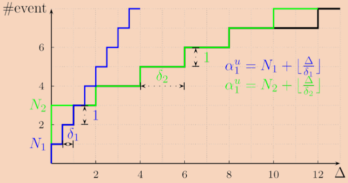

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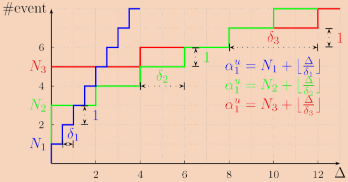

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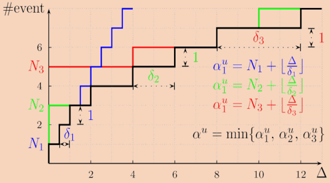

l-repetitive function

Definition

A l-repetitive function is a special minimum distance function that satisfies: $d(n) = \begin{cases} d_n(given), & n \leq l, \\ \max\limits_{\omega \in [1,l]} (d(\omega) + d(n-\omega)), & n > l. \end{cases}$

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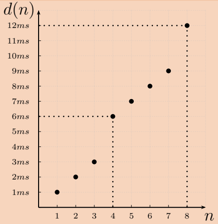

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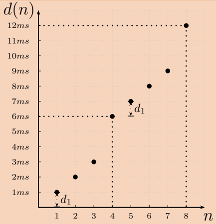

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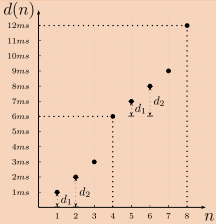

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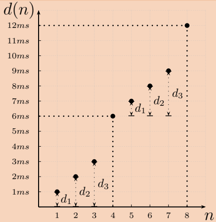

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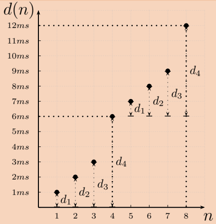
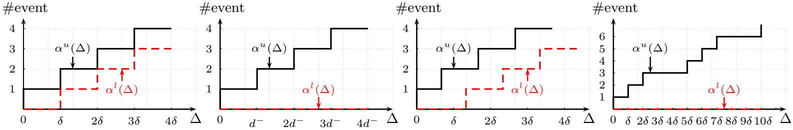


Outline

Standard arrival events (Richter et al., 2003)

Periodic events, Sporadic events, Periodic events with jitter,Periodic burst events.



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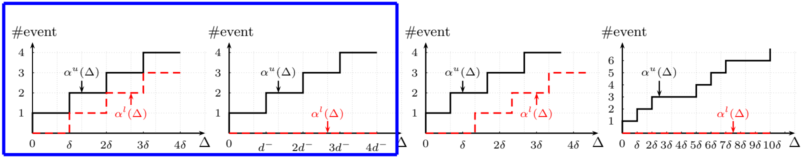

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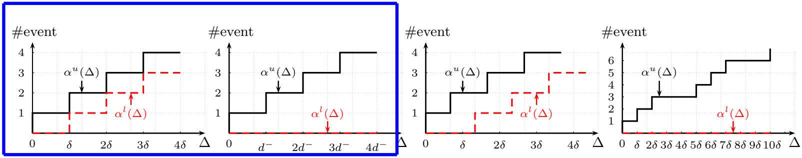

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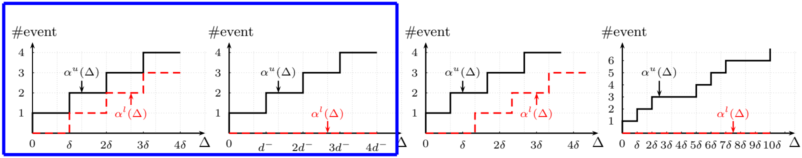

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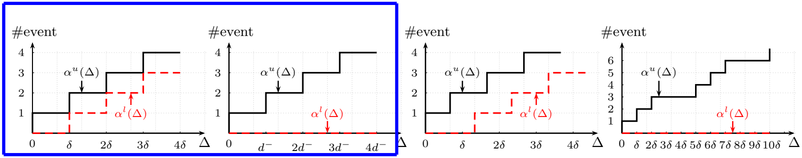

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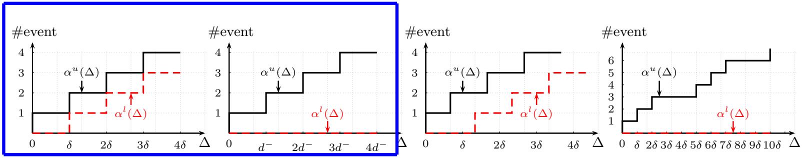

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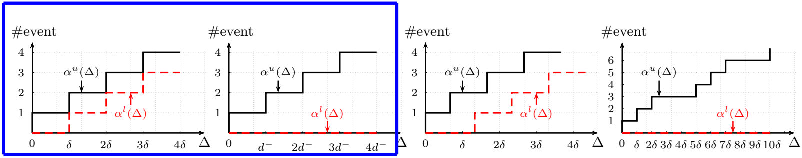

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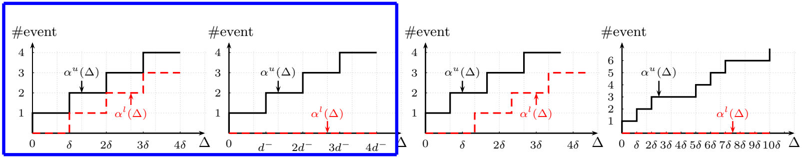

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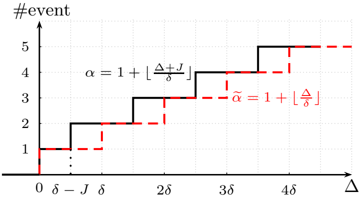

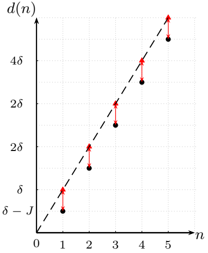

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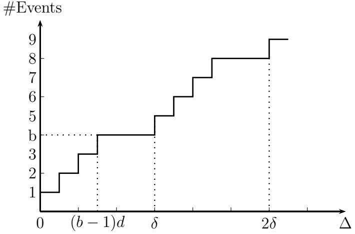
The jitter always exist when using dynamic counters or l-repetitive function

1. Only one dynamic counter
2. $l = 1$ for l-repetitive function

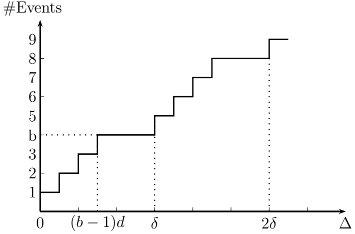
Periodic burst events



Definition

$\alpha^u(\Delta) = \lfloor \frac{\Delta}{\delta} \rfloor b + \min(\lceil \frac{\Delta - \lceil \frac{\Delta}{\delta} \rceil b}{d} \rceil, b)$
where d is the minimum timing separation, b is the maximum events within an interval δ.

Periodic burst events



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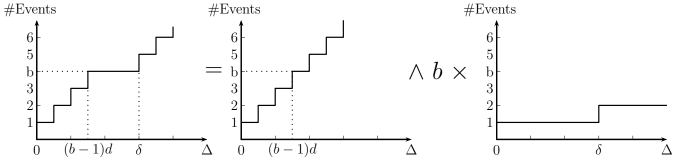
Monitoring method

1. l-repetitive function: $l = b$
2. dynamic counters: ?

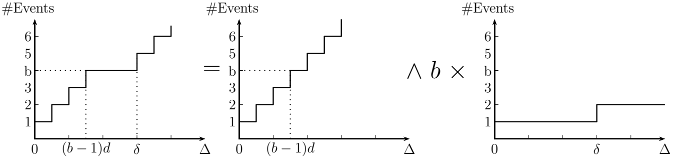
Dynamic counters

Dynamic counters



Periodic burst is equivalent to a staircase function with a period d, and the constraint of b staircase functions with a period of δ.

Dynamic counters



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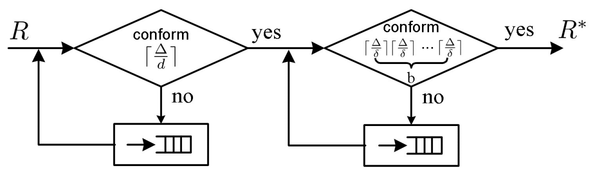

A case study of monitoring periodic burst by dynamic counters

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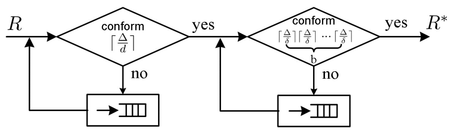
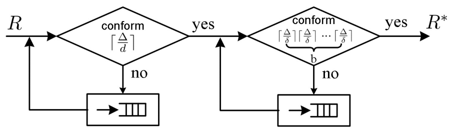


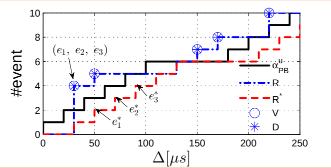
A case simulation: $b = 6$, $\delta = 180$, and $d = 20$

A case study of monitoring periodic burst by dynamic counters

Periodic burst is equivalent to a staircase function with a period d, and the constraint of b staircase functions with a period of δ.



A case simulation: $b = 6$, $\delta = 180$, and $d = 20$



Complex arrival curve of Type 1

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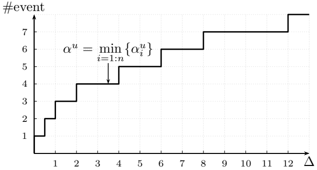

Arrival curve is the minimum of a set of staircase functions, i.e.,
$\alpha^u = \min_{i=1:n} \{\alpha_i^u\}$, where $\alpha_i = N_i^u + \lfloor \frac{\Delta}{\delta_i} \rfloor$ $(N_i^u < N_{i+1}^u,\ \delta_i < \delta_{i+1})$

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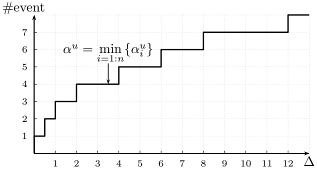

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1. Dynamic counters: *n* counters

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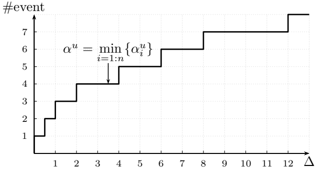

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1. Dynamic counters: n counters
2. l-repetitive function: ?

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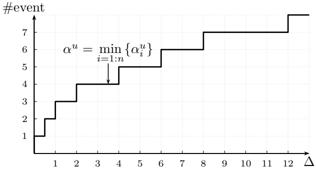
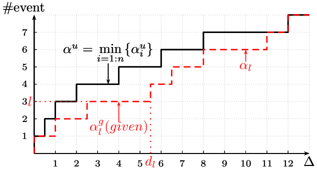


For l-repetitive function

Complex arrival curve of Type 1



For l-repetitive function

1. Assume the repetitive segment is α_l^g that is given in the offline analysis. $\alpha_l(\Delta) = \begin{cases} \alpha_l^g(\Delta)(given), & if\ \Delta \leq d_l, \\ \alpha_l^g(\Delta - k \cdot d_l), & if\ \Delta > d_l. \end{cases}$

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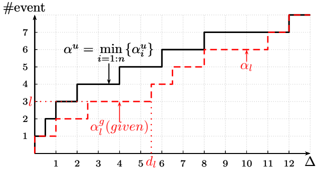

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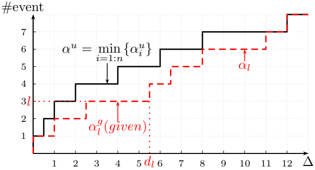
2. $\lim_{\Delta=+\infty}\{\min_{i=1..n}\{\alpha_i\}(\Delta) - \alpha_l(\Delta)\} = N_x^u + \lfloor \frac{\Delta}{\delta_{max}} \rfloor - \frac{\Delta}{d_l} l \geq 0. \Rightarrow$ $d_l \geq l \cdot \delta_{max}$.

Complex arrival curve of Type 1



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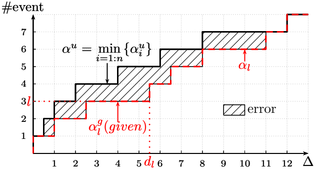

For l-repetitive function

1. Error percent (EP): $EP(\Delta) = \frac{\int_0^{\Delta}(\alpha^u(t) - \alpha^a(t))\mathrm{d}t}{\int_0^{\Delta}\alpha^u(t)\mathrm{d}t}$.

Complex arrival curve of Type 2

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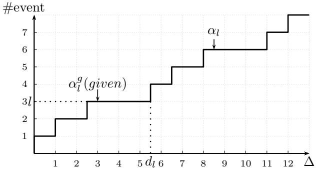

Arrival curve is segmentally repetitive, and each segment is sub-additive,

i.e., $\alpha_l(\Delta) = \begin{cases} \alpha_l^g(\Delta)(given), & if\ \Delta \leq d_l, \\ \alpha_l^g(\Delta - k \cdot d_l), & if\ \Delta > d_l. \end{cases}$

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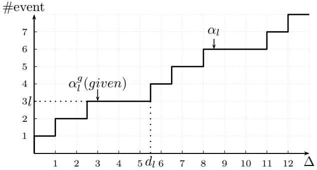

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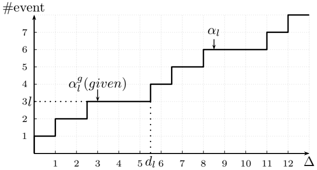

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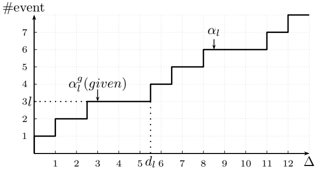

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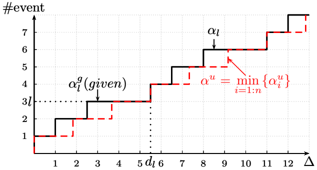

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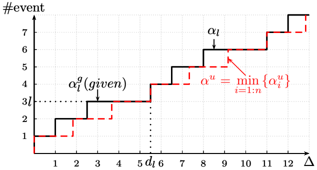

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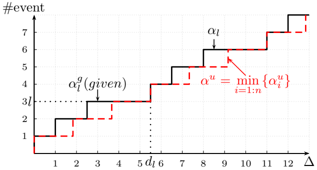

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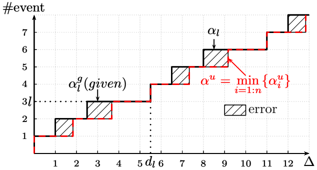

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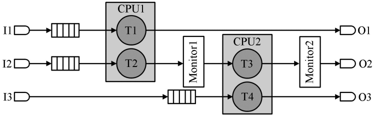
A case study



Specifications

Input Events	I1: periodic (P $= 60ms$) I2: periodic (P $= 5ms$) I3: periodic (P $= [60..110]ms$)
Execution times	T1: $35ms$, T2: $2ms$, T3: $4ms$, T4: $12ms$
scheduling parameters	priority T1: high, priority T2: low priority T3: low, priority T4: high

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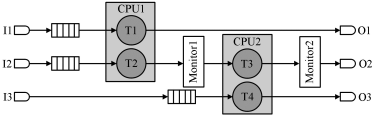

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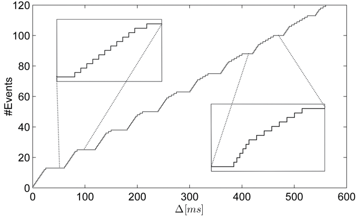
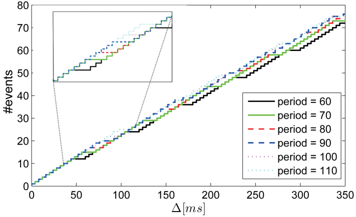


Arrival curve in Monitor 1



Arrival curve in Monitor 2

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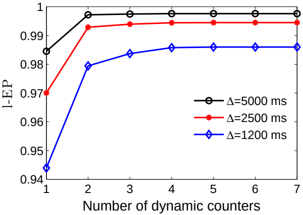
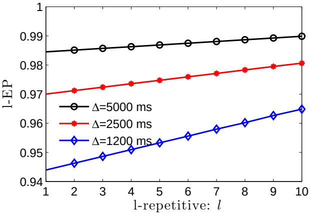


Result in monitor 1 by dynamic counters



Result in monitor 1 by *l*-repetitive function

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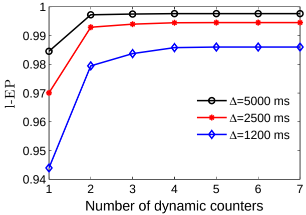

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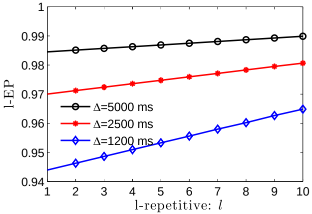

Result in monitor 1 by l-repetitive function

The needed number of dynamic counters or l in repetitive segment with respect to the period of input I3.

period [ms]	60	70	80	90	100	110
#DC	13	16	18	21	23	25
l	12	15	17	20	22	24

Outline

Setup

Prototype both approaches in ALTERA Cyclone III EP3C120F780

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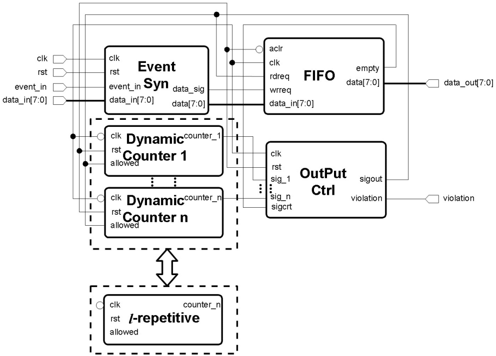
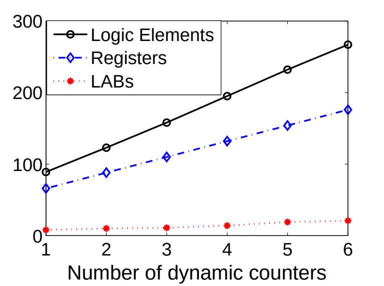
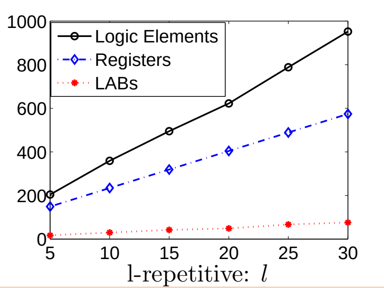


FPGA Resource

Resource usage with the number of dynamic counters or l in l-repetitive function



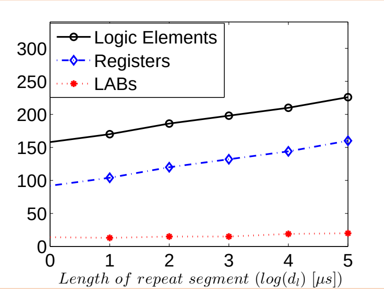
Dynamic counters



l-repetitive function

FPGA Resource

Resource usage with the length of repetitive segment



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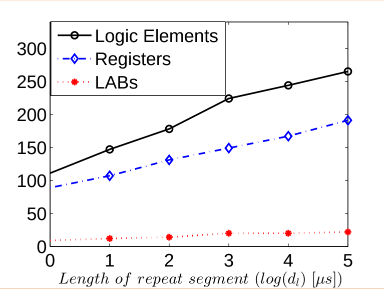

l-repetitive function

Outline

1 Motivation

2 Background

3 Comparison
- Comparison based on standard arrival curves
- Comparison based on complex arrival curves

4 FPGA evaluations

5 Summary

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1. Analyzed the difference of dynamic counters monitoring and l-repetitive function monitoring by using standard arrival curves, and two typical complex arrival curves.
2. Developed a new monitoring scheme for dynamic counters to monitor periodic burst events
3. Prototyped the two monitoring approaches in FPGA, and found resource overhead is more sensitive to the number of dynamic counters, and not sensitive to the length of one repetitive segment.