



# Tracing and Sampling for Real-Time partially simulated Avionics Systems

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Raphaël BEAMONTE    Michel DAGENAIS

Distributed Open Reliable Systems Analysis Lab  
Computer and Software Engineering Department

- Tracing:
  - Study runtime behavior
  - Can be used to measure latency = fundamental for RT debugging
- Tracer requirements:
  - Low-overhead
  - Consistent maximum latency
- M.A.Sc's contribution:
  - Methodology and tool to measure real-time latencies (npt)
  - Usage of npt to measure LTTng-UST latency
  - Improvements to the real-time behavior of LTTng
  - Development of the Non-Preempt Test tool

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# Real-Time Operating Systems

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## Why using the Linux kernel ?

- Able to do Soft Real Time, can reach Hard Real Time :
  - BIOS configuration: would you use hyperthreading ?
  - Kernel configuration: PREEMPT\_RT patch, which is more and more integrated to the standard kernel
  - Software configuration: interrupts redirection, cpu shielding. . .
- The power of the community



# The Linux Trace Toolkit next-generation, LTTng

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Why LTTng is pertinent for RT applications ?

- Both userspace and kernel tracers (same clock source)
- Statically compiled tracepoints
- External process to consume events
- Arbitrary event types (Common Trace Format)
- Per-CPU ring buffers
- Important tracing variables protected by RCU



## M.A.Sc degree

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- Journal paper about LTTng & its real-time behavior (submitted to Operating Systems Review)
- master's thesis writing and submission
  - Available on <http://publications.polymtl.ca>
- master's defense & degree



# What about npt ?

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May 2013's future work:

Identifying new real-time tracing usecases to add to npt (i.e. many events during a period of time, no events during another period, and switch between these two periods)



# Motivation

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- Tracing a real-time application is not necessarily permanent tracing
- Tracing can be triggered by a condition to analyze a specific area
- We will stay temporarily in this specific area: we may need intense tracing for a short period of time, then not need tracing for another period
- `npt` can be improved to be able to model that





## Windows mode vs. non-stop mode

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npt v1.01 introduce the new *windows mode*:

<code>--trace-window=TIME</code>	duration of the trace window when using windows mode
<code>--wait-window=TIME</code>	duration of the wait window when using windows mode

**npt's windows mode:** intense tracing (can depend on tracepoint frequency) for a specified amount of time, then pause; restart these actions as long as necessary.



## Windows mode in npt's main loop algorithm

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```
1:  $i \leftarrow 0$ 
2:  $t_0 \leftarrow \text{read } rdtsc$ 
3:  $t_1 \leftarrow t_0$ 
4: tracepoint nptstart
5: while  $i \leq \text{loops\_to\_do}$  do
6:    $i \leftarrow i + 1$ 
7:    $\text{duration} \leftarrow (t_0 - t_1) \times \text{cpuPeriod}$ 
8:
9:   tracepoint nptloop   ▷ Everytime or frequency dependent
10:
11:   CALCULATESTATISTICS(duration)
12:    $t_1 \leftarrow t_0$ 
13:    $t_0 \leftarrow \text{read } rdtsc$ 
14: end while
15: tracepoint nptstop
```



## Windows mode in npt's main loop algorithm

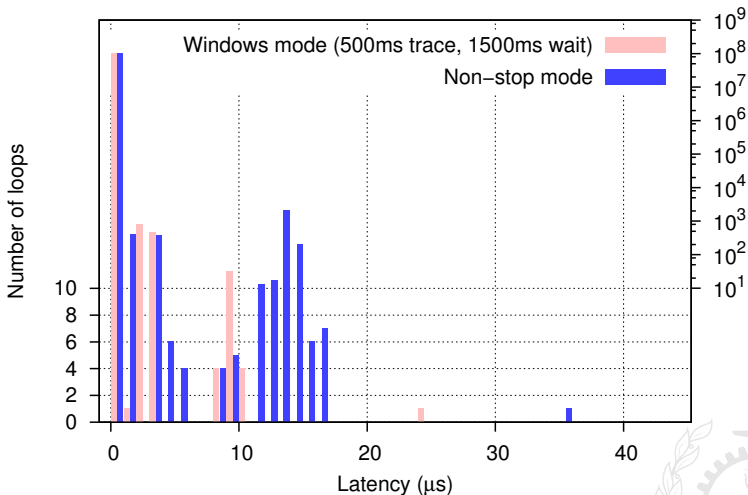
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5: while  $i \leq \text{loops\_to\_do}$  do
6:    $i \leftarrow i + 1$ 
7:    $\text{duration} \leftarrow (t_0 - t_1) \times \text{cpuPeriod}$ 
8:   if mode = windows and window = trace then
9:     tracepoint nptloop▷ Everytime or frequency dependent
10:  end if
11:  CALCULATESTATISTICS(duration)
12:   $t_1 \leftarrow t_0$ 
13:   $t_0 \leftarrow \text{read } rdtsc$ 
14: end while
15: tracepoint nptstop
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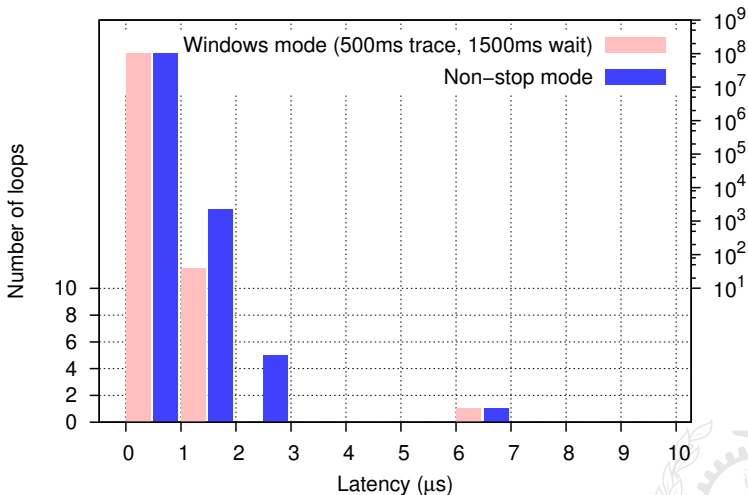
# Latency results with LTTng-UST tracing

Histogram generated by npt for  $10^8$  cycles, on RT kernel, using or not windows mode, with the read-writer mode of LTTng-UST



## Latency results with LTTng-UST tracing

Histogram generated by npt for  $10^8$  cycles, on RT kernel, using or not windows mode, with the read-timer mode of LTTng-UST



## npt v1.01 release

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- npt v1.01 was released officially on october 14, 2013.
- Some people from RedHat and Intel expressed interest in the tool following its release on the linux-rt mailing list; some of them made tests with it.  
Results were qualified as coherent with expectations.



## And now ?

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- Ph.D student
- Currently reviewing the state of the art in Real-time systems performance analysis
  - Virtualization in avionics: how to achieve hard real-time in virtualized systems ? How to analyze the real-time performance in virtualized systems ?
  - Networking in avionics : is it possible to reach hard real-time when depending on the network ? Can we measure the induced latencies ?



## Virtualization in avionics

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Thomas Gaska, Brian Werner, and David Flagg. “Applying virtualization to avionics systems – The integration challenges”. In: *Digital Avionics Systems Conference (DASC), 2010 IEEE/AIAA 29th*. IEEE. 2010, 5.E.1–1–5.E.1–19. DOI: 10.1109/DASC.2010.5655297. URL: <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5655297>

Ideas behind real-time virtualization: scheduling is very important, and the model used by hypervized real-time systems can be applied to virtualized real-time systems.





## Virtualization in avionics

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Sisu Xi et al. *Real-Time Multi-Core Virtual Machine Scheduling in Xen*. Tech. rep. Washington University, Oct. 2013. URL: <http://cse.wustl.edu/Research/Lists/Technical%20Reports/Attachments/1032/rtxenmc.pdf>

New way to schedule virtual machines in Xen, reminiscent the way the Adeos microkernel works.



## Virtualization in avionics

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- Virtualization would allow to centralize data in a smaller number of computers
- It would remove weight by removing computers and interconnection cables
- If we can reach virtualized real-time, what would be LTTng's real-time performance in this context ?



## Networking in avionics

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Richard L. Alena et al. “Communications for Integrated Modular Avionics”. In: *Proceedings of the IEEE Aerospace Conference*. IEEE. Mar. 2007, pp. 1–18. DOI: 10.1109/AERO.2007.352639. URL: <http://ti.arc.nasa.gov/m/pub-archive/1277h/1277%20%28Alena%29.pdf>

Comparison between Avionics Full-Duplex Switched Ethernet (AFDX - ARINC 664) and Ethernet. Different avionics network problematics, such as timing variations and packet losses, are addressed by AFDX.



## Networking in avionics

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Teresa Schuster and Dinesh Verma. “Networking concepts comparison for avionics architecture”. In: *Digital Avionics Systems Conference, 2008. DASC 2008. IEEE/AIAA 27th.* 2008, pp. 1.D.1–1–1.D.1–11. DOI: 10.1109/DASC.2008.4702761. URL: <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4702761>

Evaluation of alternative network concepts for avionics architecture, comparing ARINC 664 standard (using AFDX) with legacy avionics networks. AFDX is once more considered a good fit for avionics requirements, but depends on a specific architecture (ARINC 653).



## Networking in avionics

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- Networking in avionics allows to remove weight by eliminating some of the sensors' cables linked to Integrated Modular Avionics (IMA)
- If we can reach real-time network performance... What would be the real-time network performance of LTTng ?



## What's left of "Tracing and Sampling for RT" project ?

- We did tracing... but what about sampling ? How could it apply to real-time systems ?
- Are performance counters usable for real-time ? Could they be added in userspace traces without affecting latency ?
- Is it possible to have better real-time tracing performance using hardware assisted tracing ?



# Conclusion

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- Non-Preempt Test tool  
(If you have other real-time patterns that could benefit the tool, do not hesitate to share it!)
- Effects of LTTng tracing in special real-time conditions using the *windows mode*.
- Interesting tracks for real-time avionics in virtualization and networking
- Future Work
  - Complete literature review for the Ph.D

Thank you. Any question ?

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**LTTng** [www.lttng.org](http://www.lttng.org)

**mailing list:** [lttng-dev@lttng.org](mailto:lttng-dev@lttng.org)

**npt:** [git.dorsal.polymtl.ca/?p=npt.git](http://git.dorsal.polymtl.ca/?p=npt.git)

**Slides:** [www.dorsal.polymtl.ca/~rbeamonte/  
dorsal-pm-dec2013.pdf](http://www.dorsal.polymtl.ca/~rbeamonte/dorsal-pm-dec2013.pdf)