Minix conference 2016

# Can Minix be "tuned" in order to satisfy hard real-time constraint without loosing its soul

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# Plan

Part 1

- About the title
- Test context
- Dhrystone test
- How the System Benchmarks Index Score evolves with the tick/second

Part 2

- Our real-time problem: the blended hardening technique (BHT)

# About the title

Real-Time systems need (among other things)

- Predictability of behavior
- A real-time scheduler
- A short time quantum so that the scheduler is called often enough
- A fine grain clock

Need not

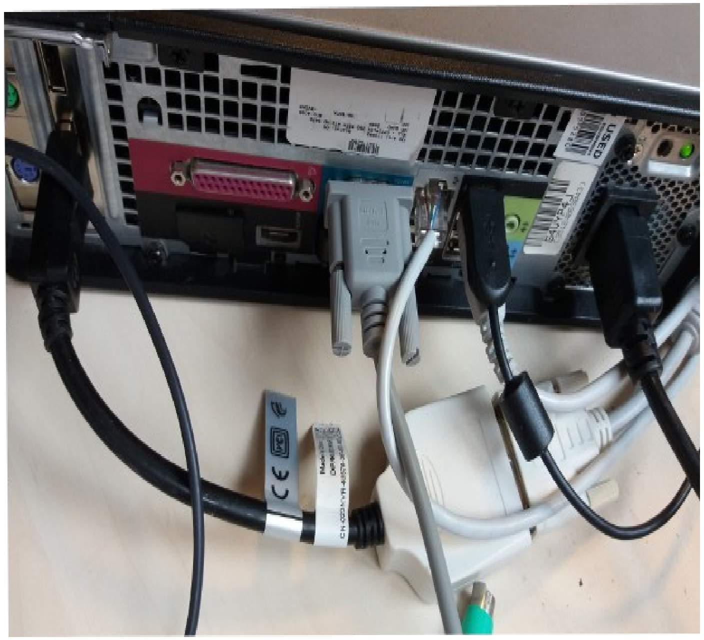
- Being fast, just fast enough for the job

***Traditionally, MINIX has a long time quantum and a coarse clock.***

***How does it behave if we need to reduce both?***

# Test context

- Computer
  - CPU Intel core 2  Quad 2.6 GHz
  - RAM : DDR3 4 GB



# Test context (2)

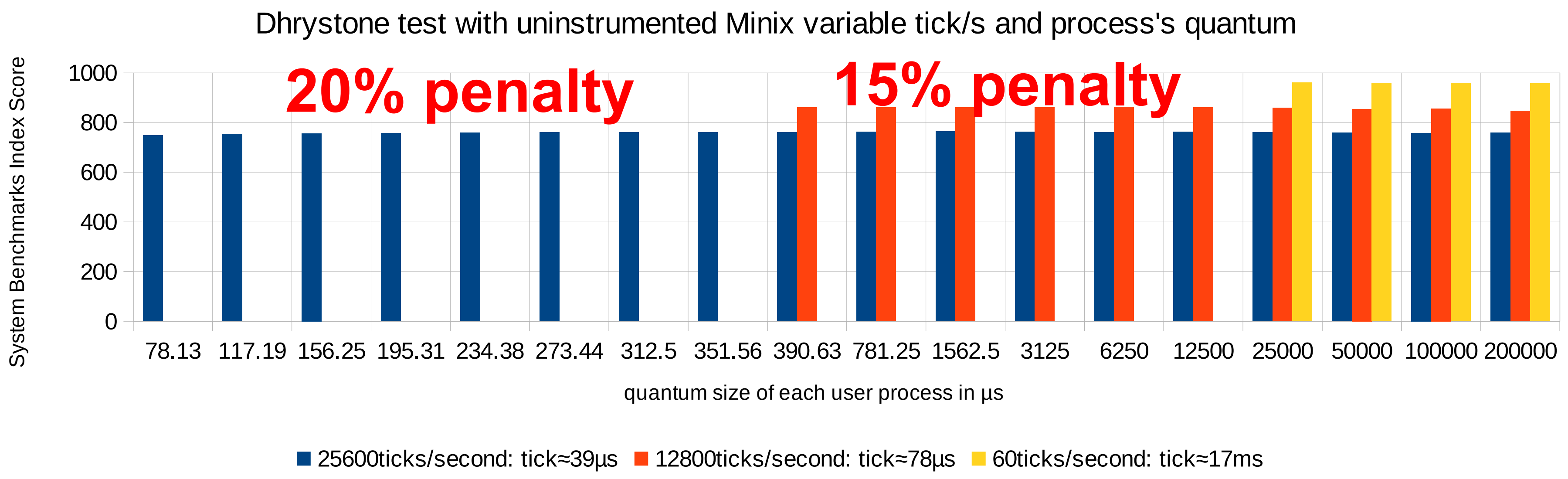
- BYTE UNIX Benchmarks (Version 5.1.2)
  - 1 CPU in system; running 1 parallel copy of tests
  - OS: Minix : 3.2.1
- Test result
  - One run for each result
  - System Benchmarks Index Score (Partial Only)

# Dhrystone test

Dhrystone is a synthetic computing benchmark program developed in 1984 by Reinhold P. Weicker

- intended to be representative of system (integer) programming [wikipedia].

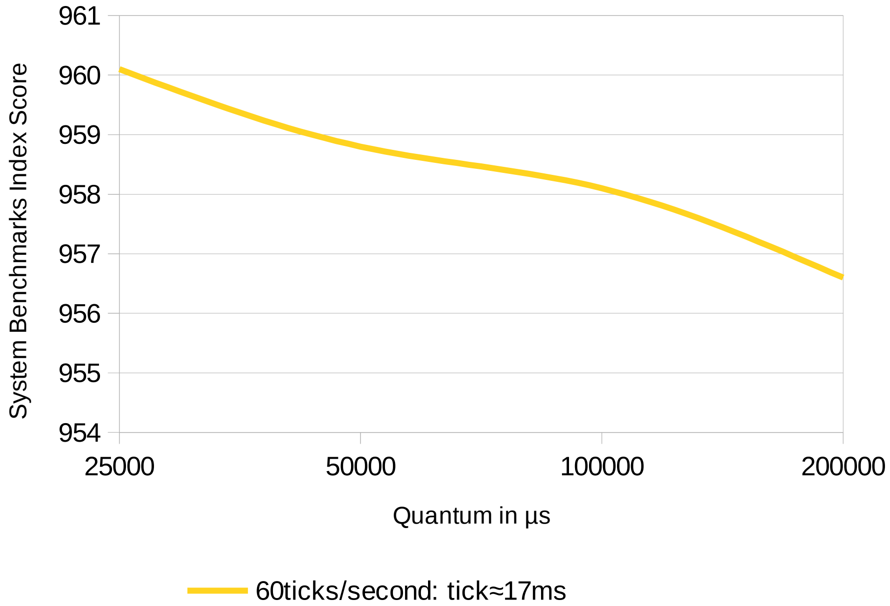
# Evolution of the Index Score with the tick/second

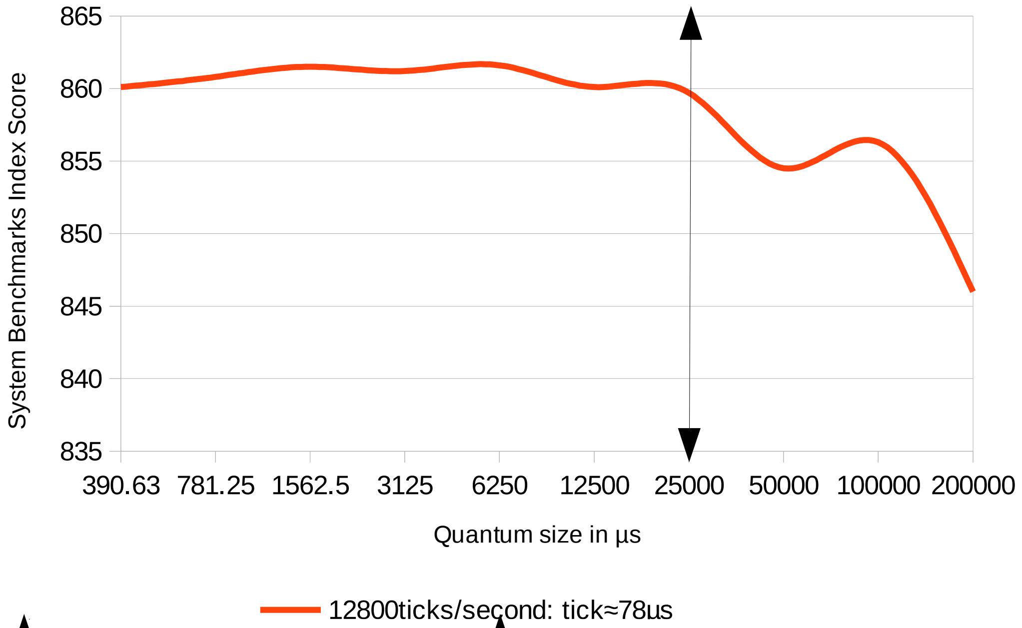


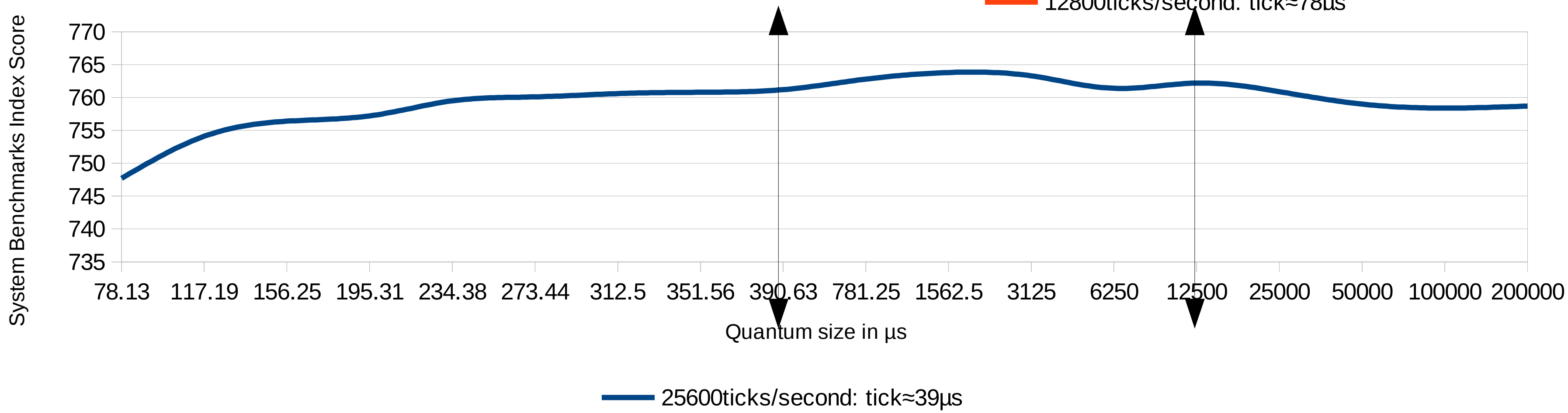

- Moderate penalty with short ticks
- Little change with quantum values

# Evolution of the Index Score with the tick/second

## Zoom on variations with quantum size




**Note that each figure is to be compared to the right part of the next**

# Evolution of the Index Score with the tick/second: with instrumentation (verifying dirty bit)

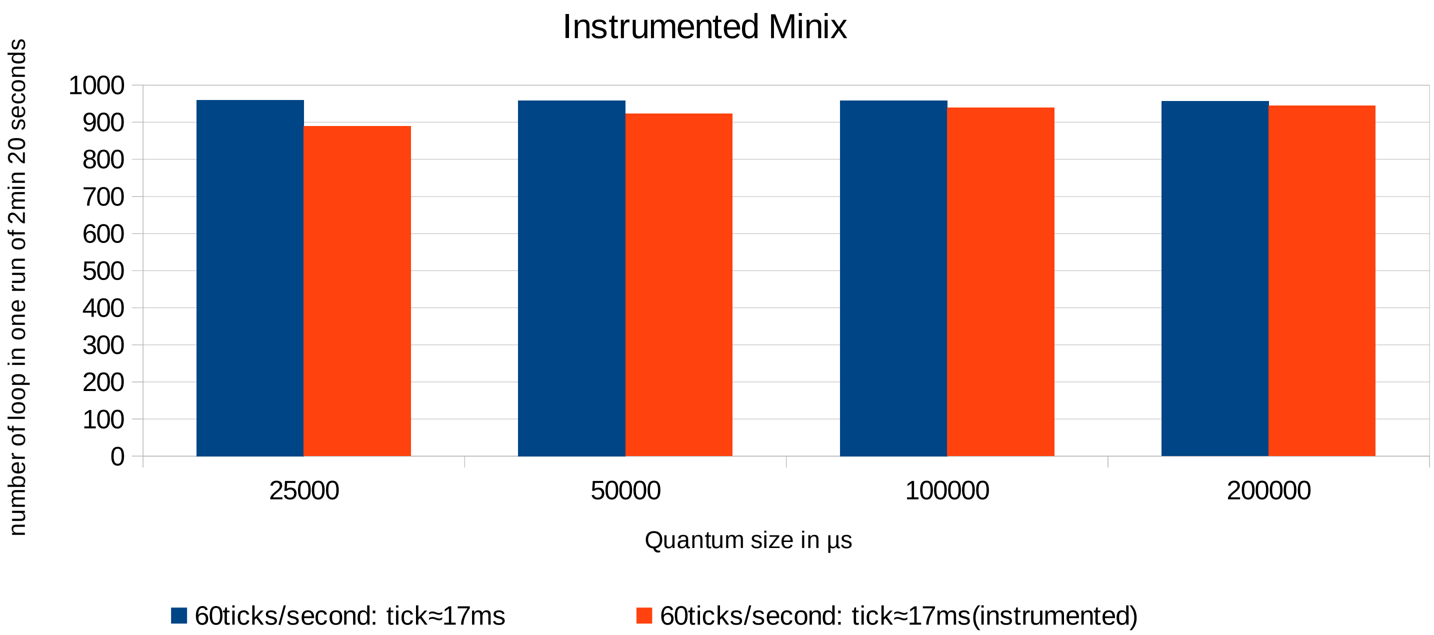
- Aim of instrumentation: measurements of the working set size (number of pages modified during a quantum) of each process
- At end of each quantum of a process:
  - find pages with DIRTY_BIT set in process page table
  - modified pages numbers are stored in a list (*current_ws_list*).
  - Two others lists are maintained:
    - the “previous working set” list (prev_ws_list) is the current working set at end of the previous quantum
    - the “previous previous working set list (prev_prev_ws_list) is the working set at end of the the ante-previous quantum.
    - quantum 0 is the first quantum of the process.

# Evolution of the Index Score with the tick/second: with instrumentation (verifying dirty bit) (2)

- The following numbers of pages are measured
  - **#modified :** #pages present in current_ws_list, i.e. the working set size
  - **#new_in :** #pages present in current_ws_list but are not present in the prev_ws_list
  - **#new_out:** #pages present in the prev_ws_list but not present in the current_ws_list
  - **#def_out :** #pages present in the prev_prev_ws_list but neither present in current_ws_list, nor in the the prev_ws_list: definitively out
  - **#in_out :** #pages present in the current_ws_list but not present in the prev_ws_list and are present in the prev_prev_ws_list: returning pages

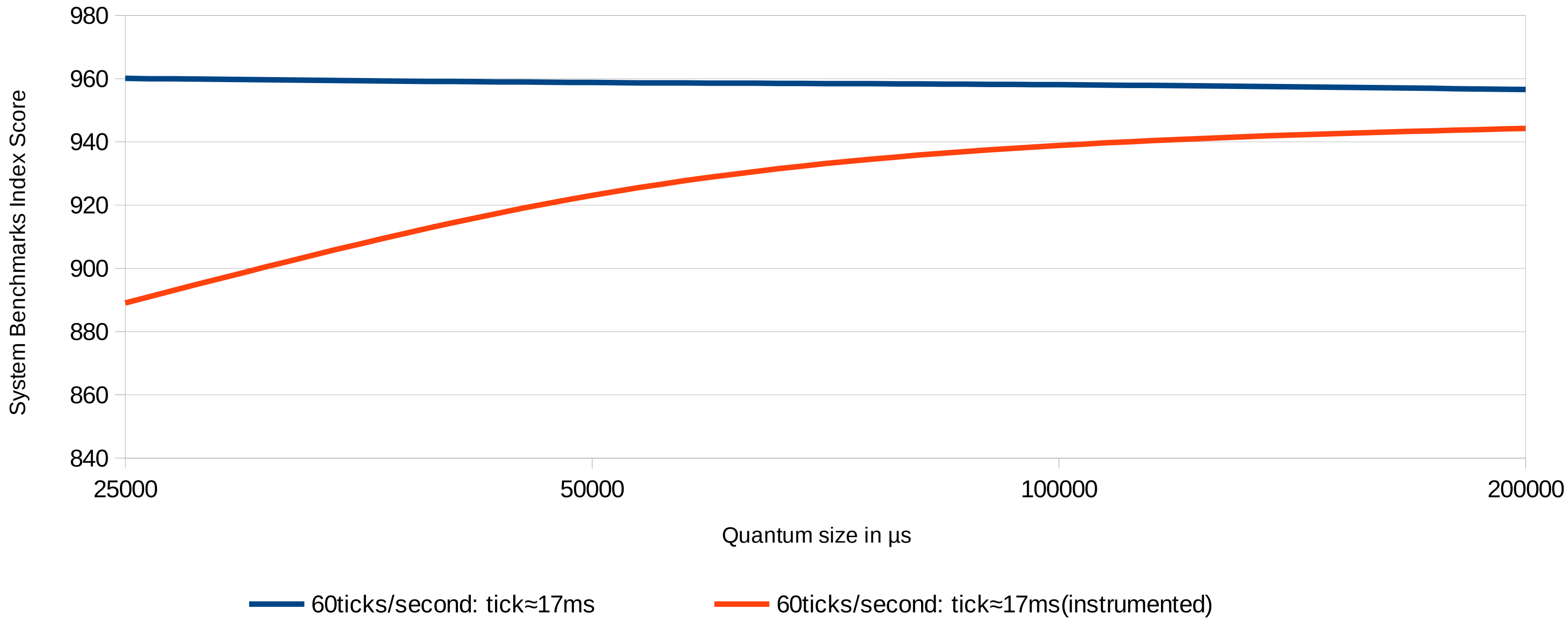
# Evolution of the Index Score with the tick/second: with instrumentation (verifying dirty bit)(3)

## Long traditional tick



# Evolution of the Index Score with the tick/second: with instrumentation (verifying dirty bit)(4)

## Zoom on variations with quantum size

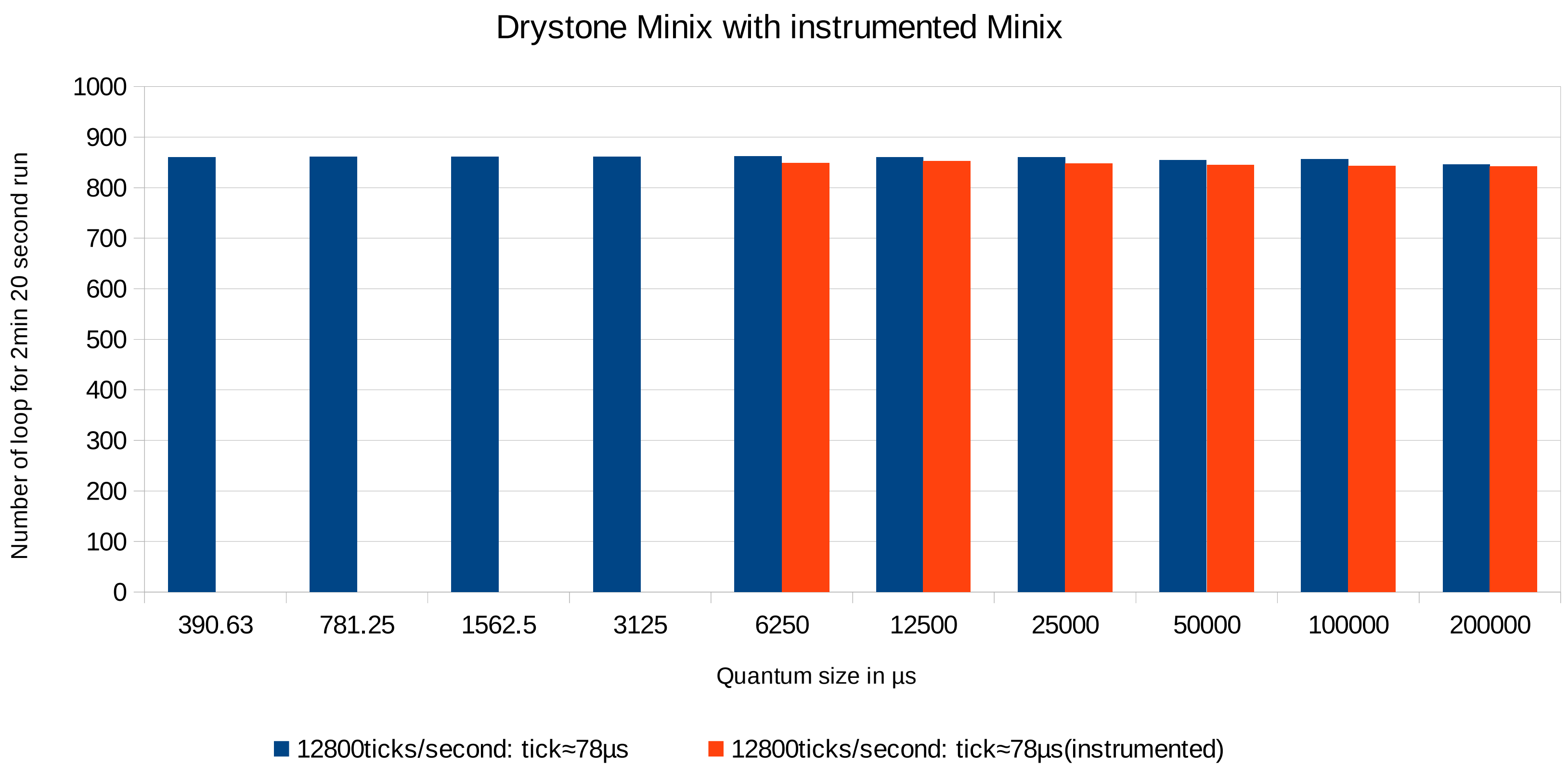



Instrumentation cost is

- 7% for smallest quantum size
- 1.56 % for highest quantum size

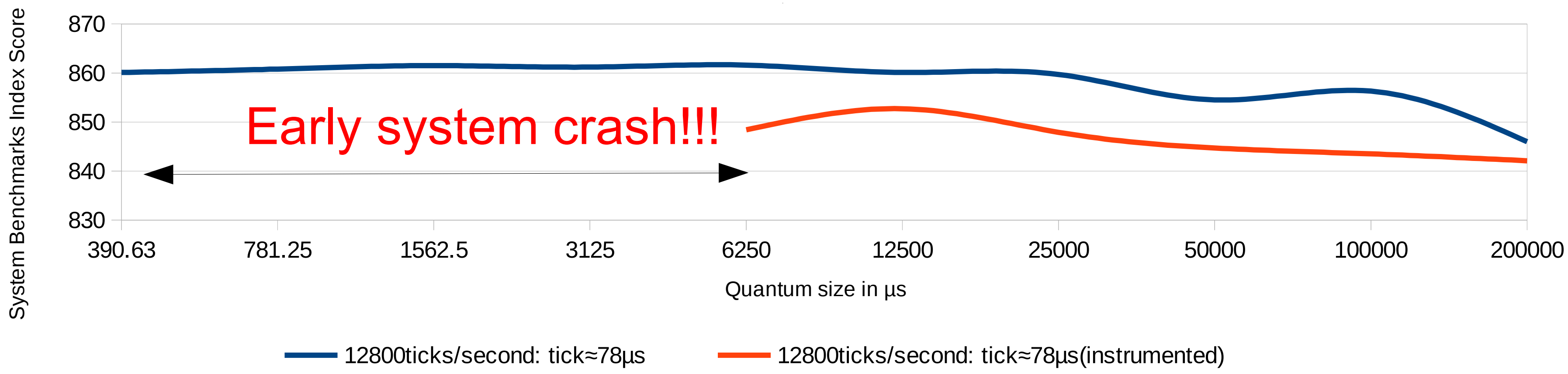
# Evolution of the Index Score with the tick/second: with instrumentation (verifying dirty bit)(5)

## Short tick



# Evolution of the Index Score with the tick/second: with instrumentation (verifying dirty bit)(6)

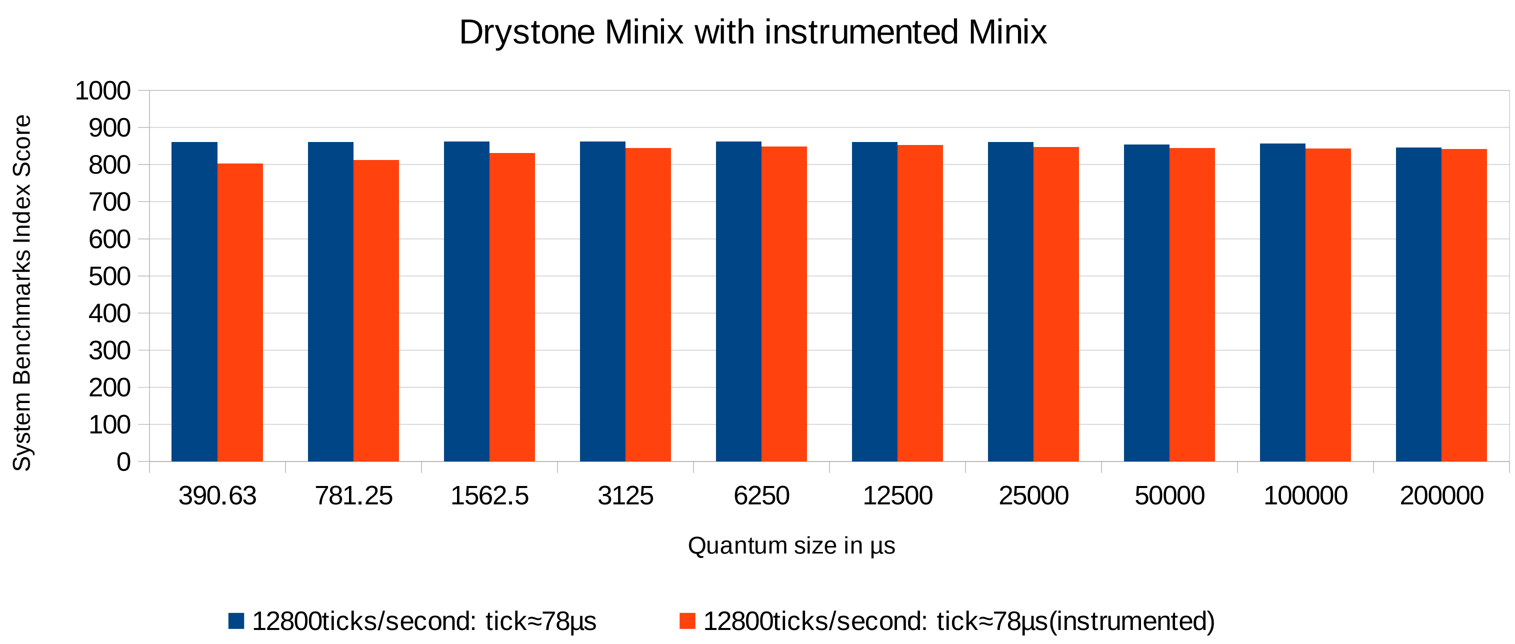
## Zoom on variation with quantum size




- Why does the system crash for smaller quantum size?
  - The presence of an ATI graphic card caused a lot of heat
  - The heat caused address translation errors in the MMU
- Removing the ATI graphic card and ventilating the mother board solved the problem

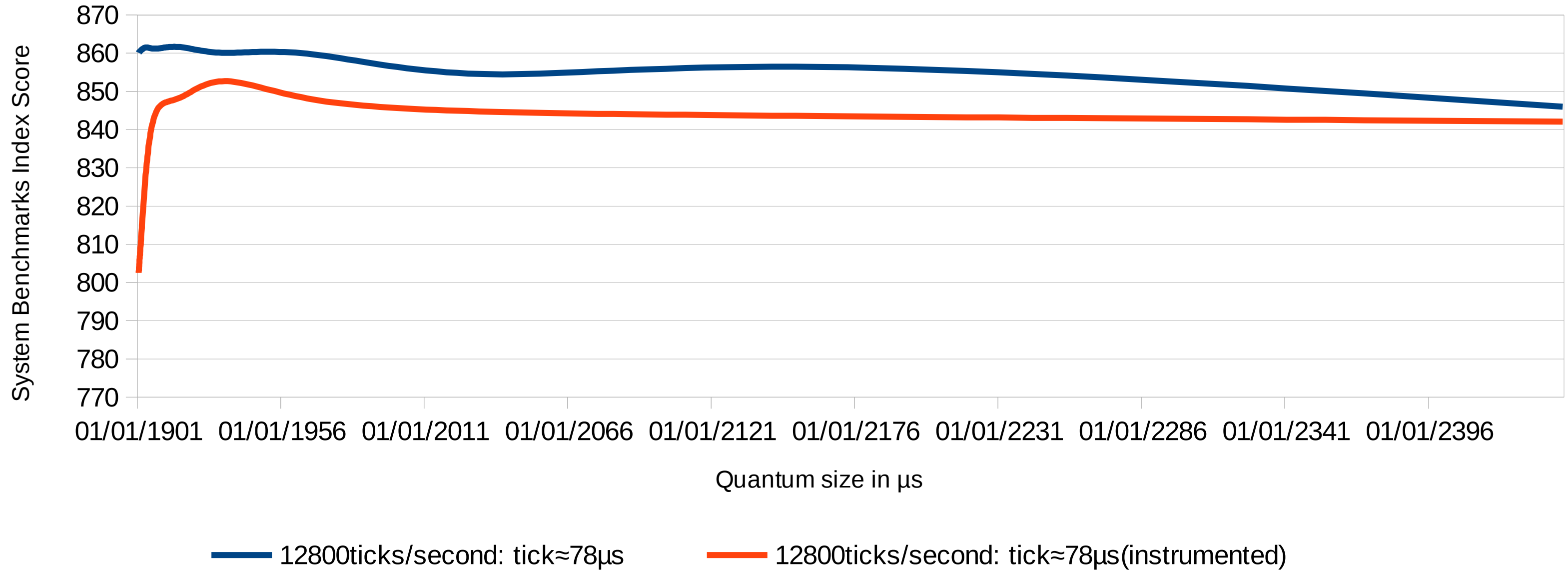
# Evolution of the Index Score with the tick/second: with instrumentation (verifying dirty bit)(7)

## Short tick when the problem was solved



# Evolution of the Index Score with the tick/second: with instrumentation (verifying dirty bit)(8)

## Zoom on variation with quantum size



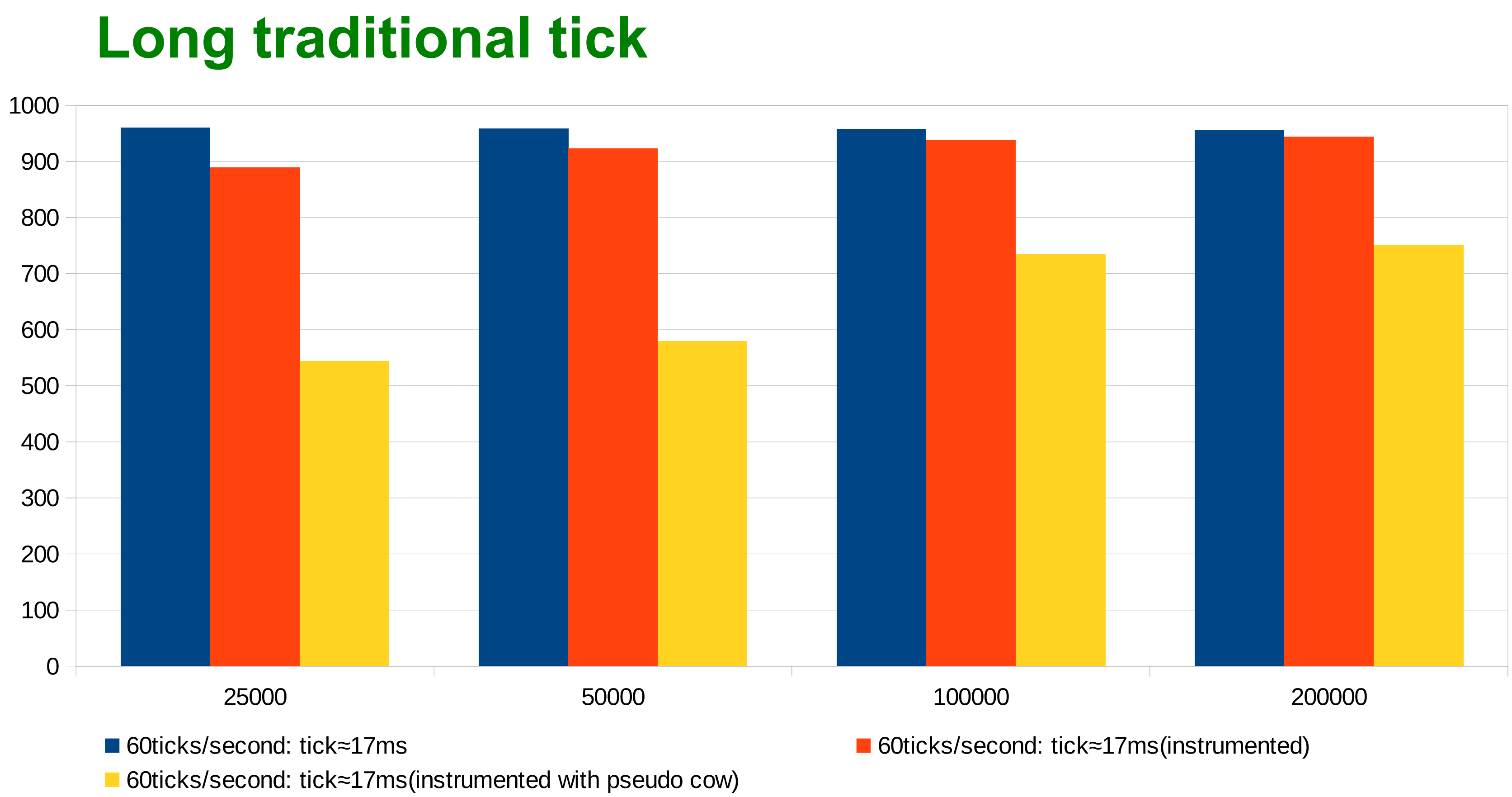

Instrumentation cost is

- 6.7% for smallest quantum size
- 0.8 % for highest quantum size

# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write)

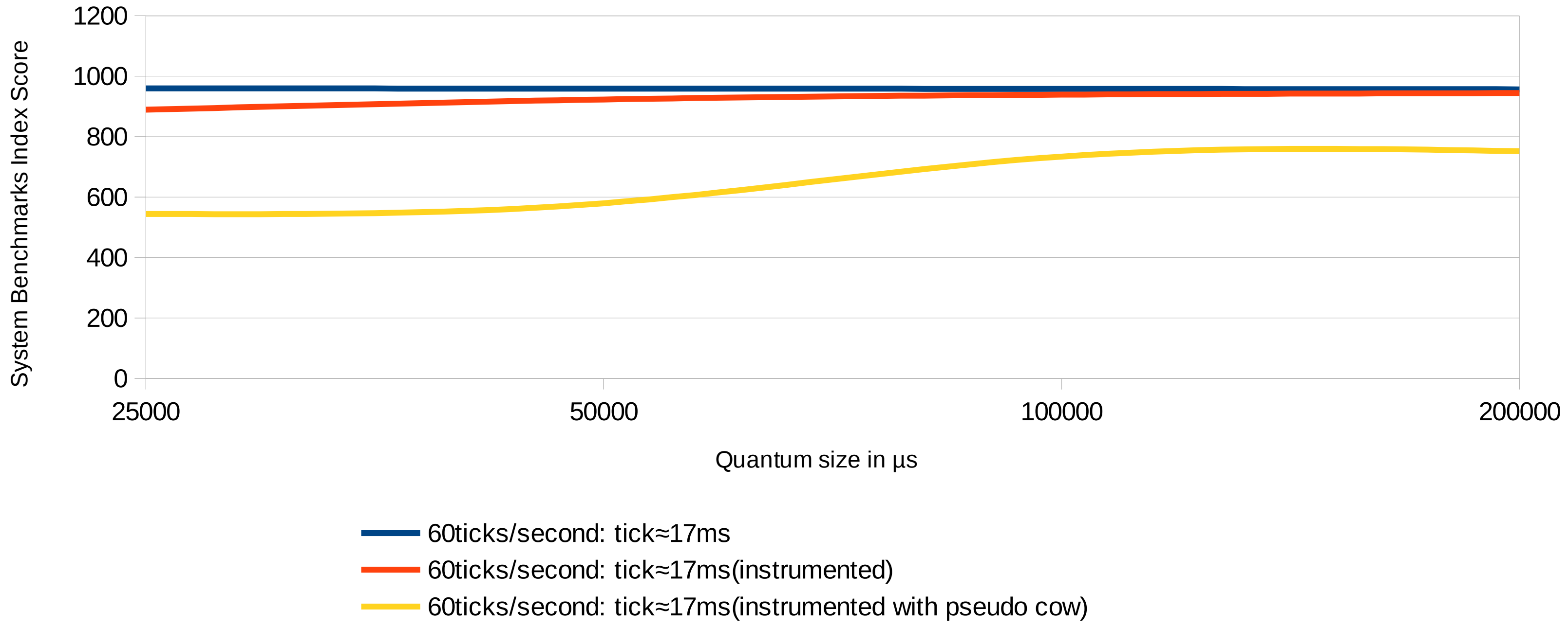
- At end of process quantum 0 (the first quantum):
  - all the process memory space is set to read-only.
    - so that the kernel is warned when the process is going to modify any of its pages
  - current_ws_list is empty
- During each quantum :
  - the current working set (current_ws_list) of the process is increased when a page fault occurs; pages are then set to R/W.
- At the end of each quantum :
  - the modified pages are set back to read only.
  - current_ws_list is reset to empty

# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write)(2)



# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write)(3)

## Zoom on variations with quantum size



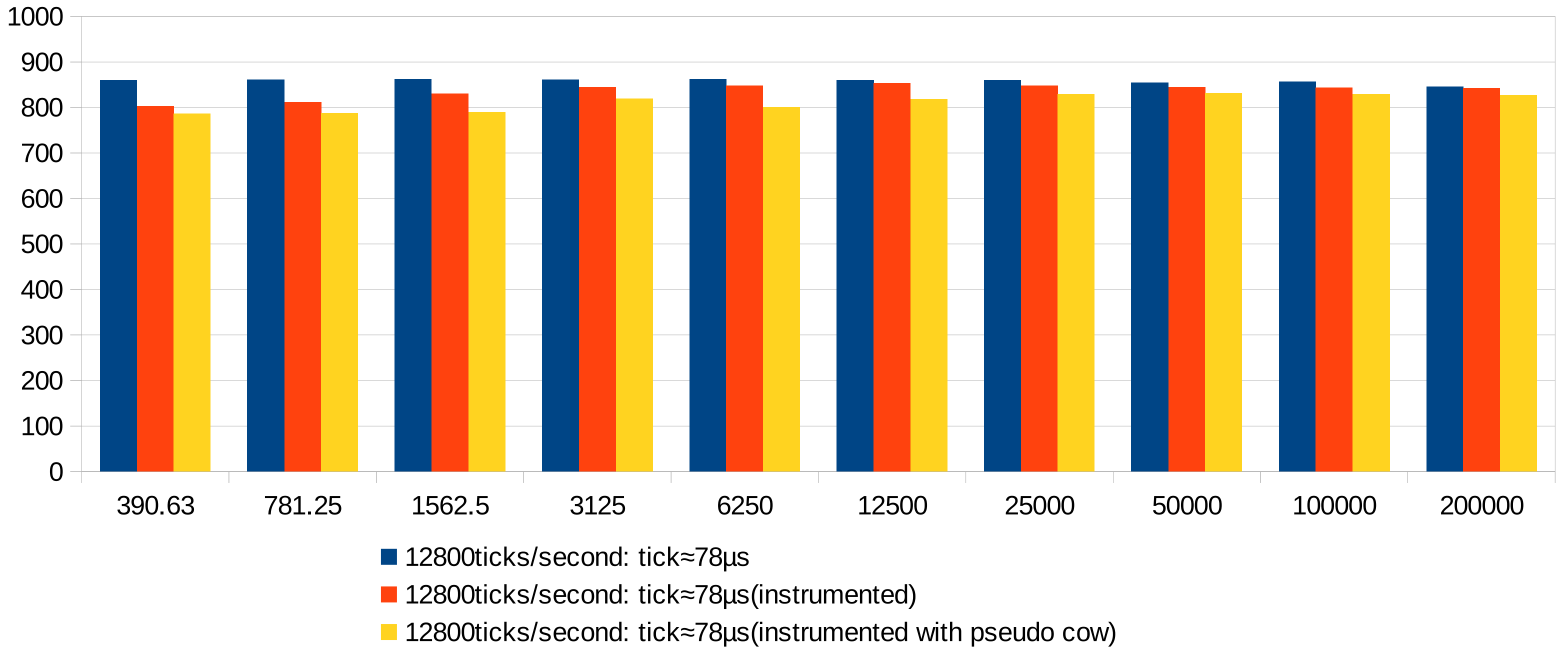

The frequent copy-on-write cost is:

- 43.28% for smallest quantum size
- 21.42 % for highest quantum size

**Not so good!!! let's improve the algorithm.**

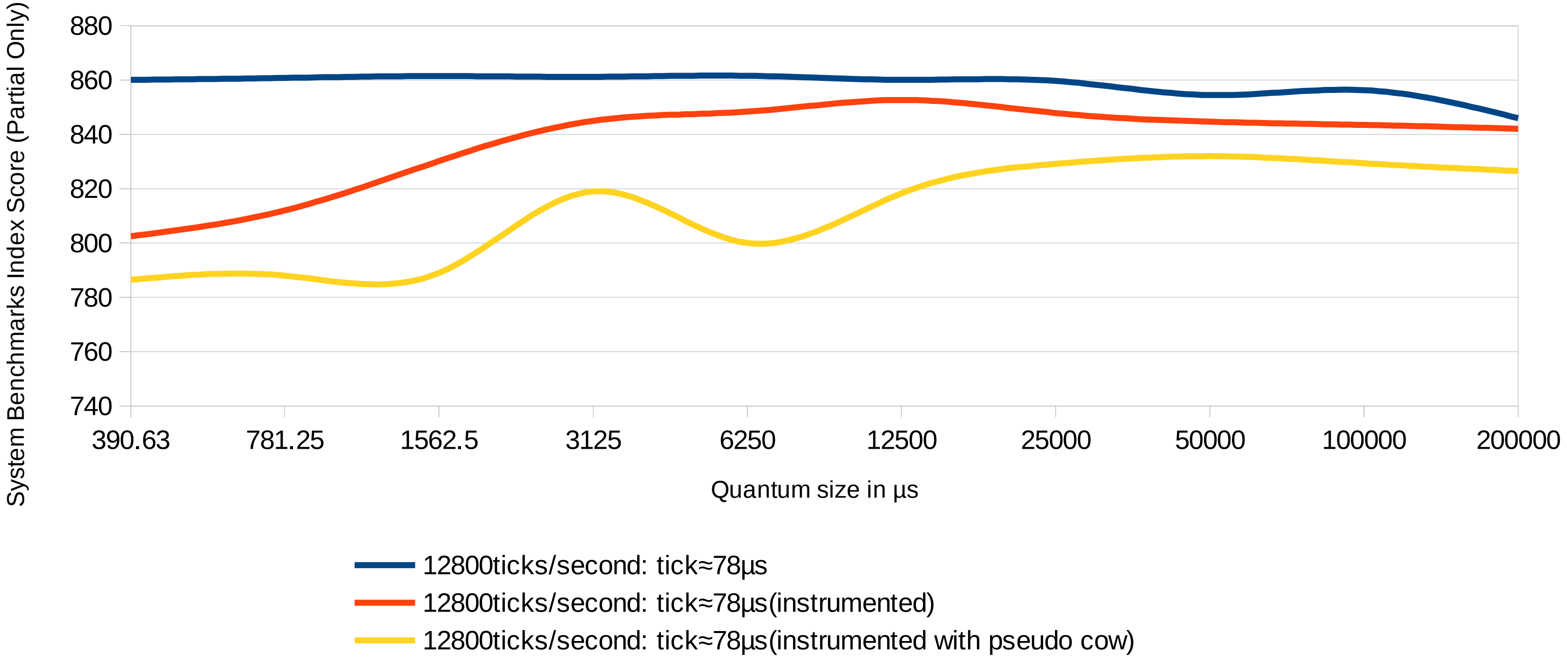
# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write)(4)

## Short tick



# Evolution of the Index Score by the tick/second: with instrumentation (pseudo copy-on-write)(5)

## Zoom on variations with quantum size




The frequent copy-on-write cost is:

- 8.56% for smallest quantum size
- 2.3 % for highest quantum size

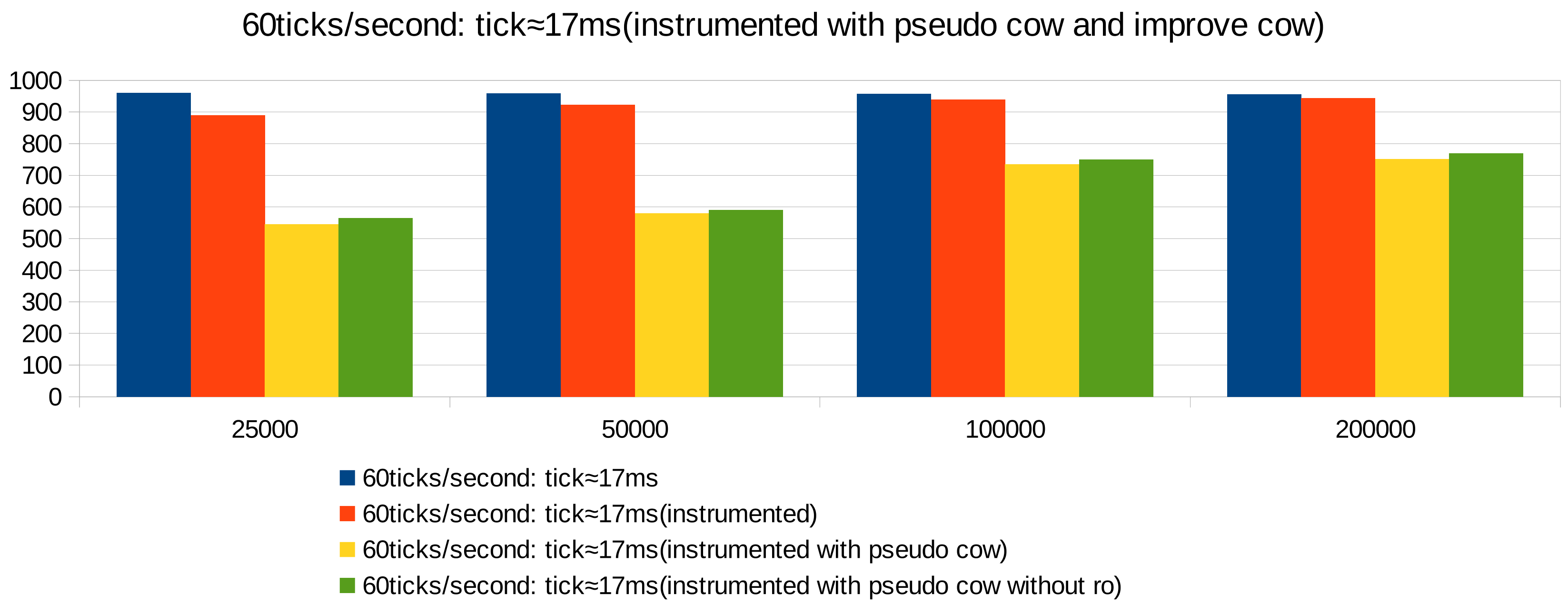
**Not so good!!! let's improve the algorithm.**

# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write without reset to Read Only)

- At the end of process quantum 0 (the first quantum):
  - All the process memory space is set to read-only,
  - current_ws_list is empty
- During each quantum :
  - The current working set (current_ws_list) of the process is increased when a page fault occurs; pages are then set to R/W.
- At the end of each quantum :
  - Only unmodified R/W pages are set back to read only and removed from current_ws_list.
  - Dirty bit of modified RW pages is reset

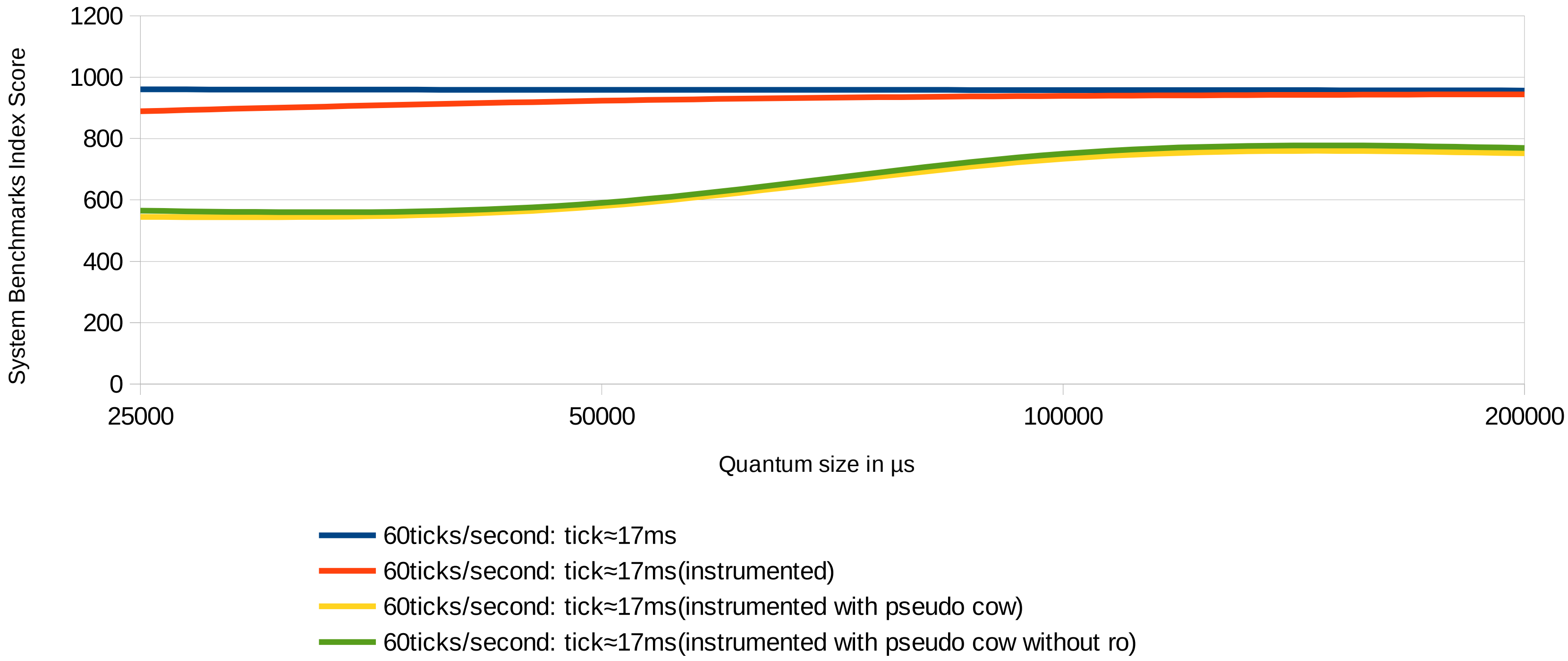
# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write without reset to Read only)(2)

## Long traditional tick



# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write without reset to Read only)(3)

## Zoom on variations with quantum size



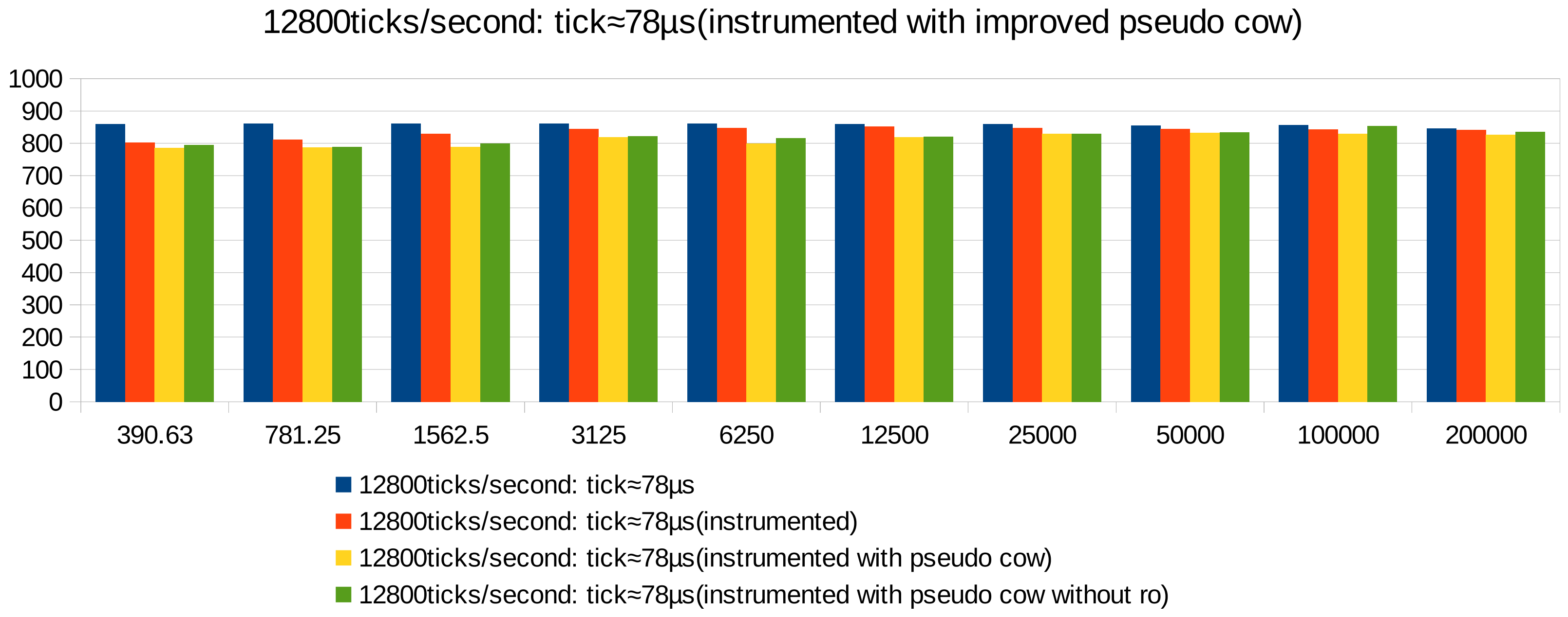

The improve copy-on-write cost is:

- 41.16% for smallest quantum size
- 19.59 % for highest quantum size

**Compare to the pseudo copy-on write algorithm there is some improvement. But the cost of frequent page fault remains high.**

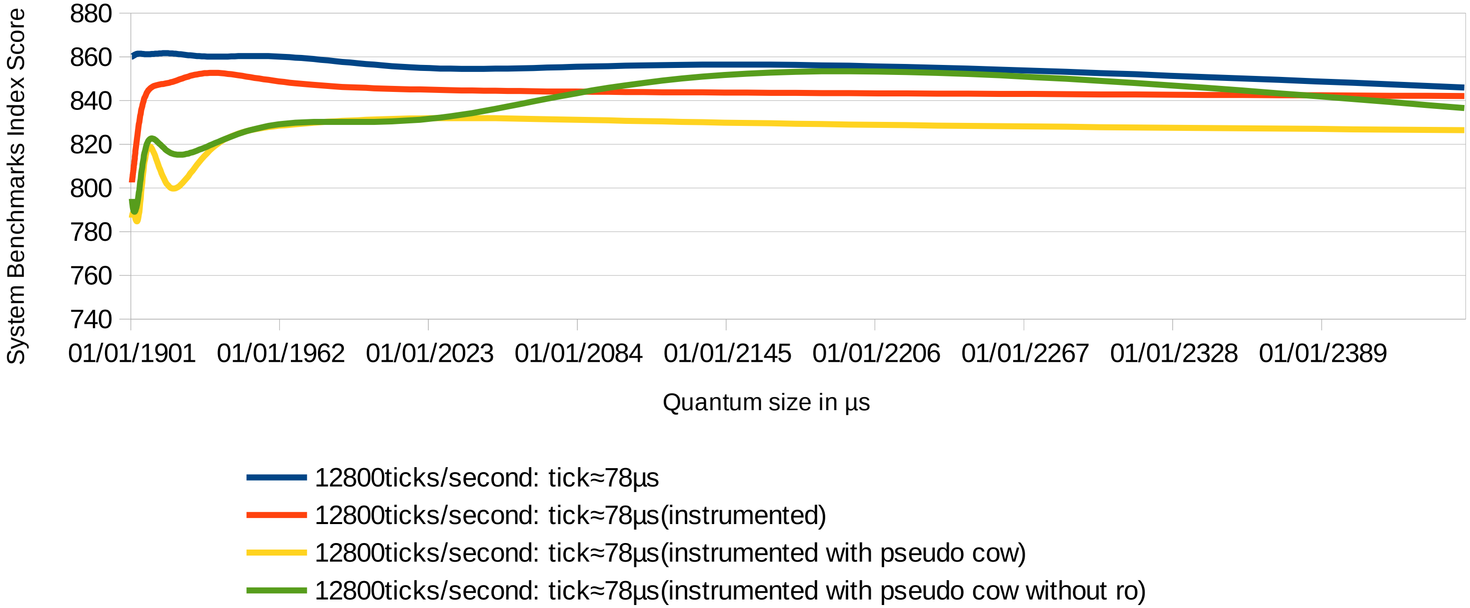
# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write without reset to Read only)(4)

## Short tick



# Evolution of the Index Score with the tick/second: with instrumentation (pseudo copy-on-write without reset to Read only)(5)

## Zoom on variations with quantum size

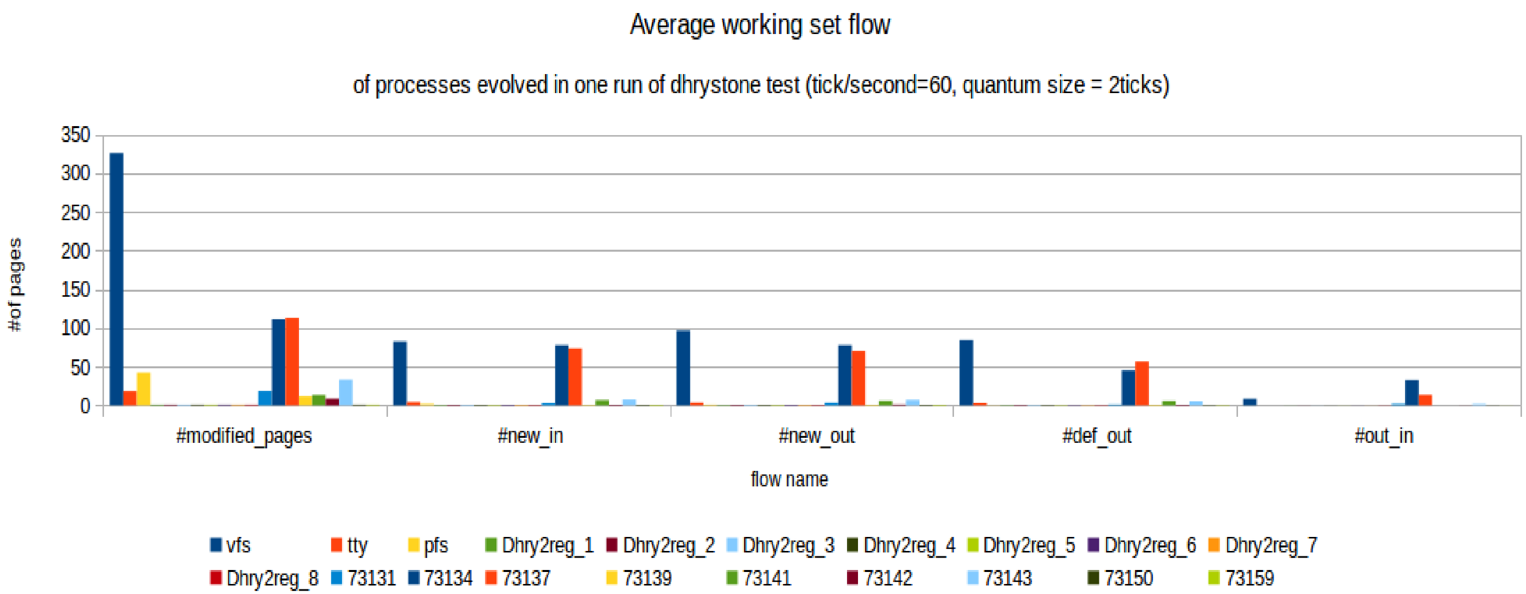



The improve copy-on-write cost is:

- 7.57% for smallest quantum size
- 1.11 % for highest quantum size

**The penalty was improved**

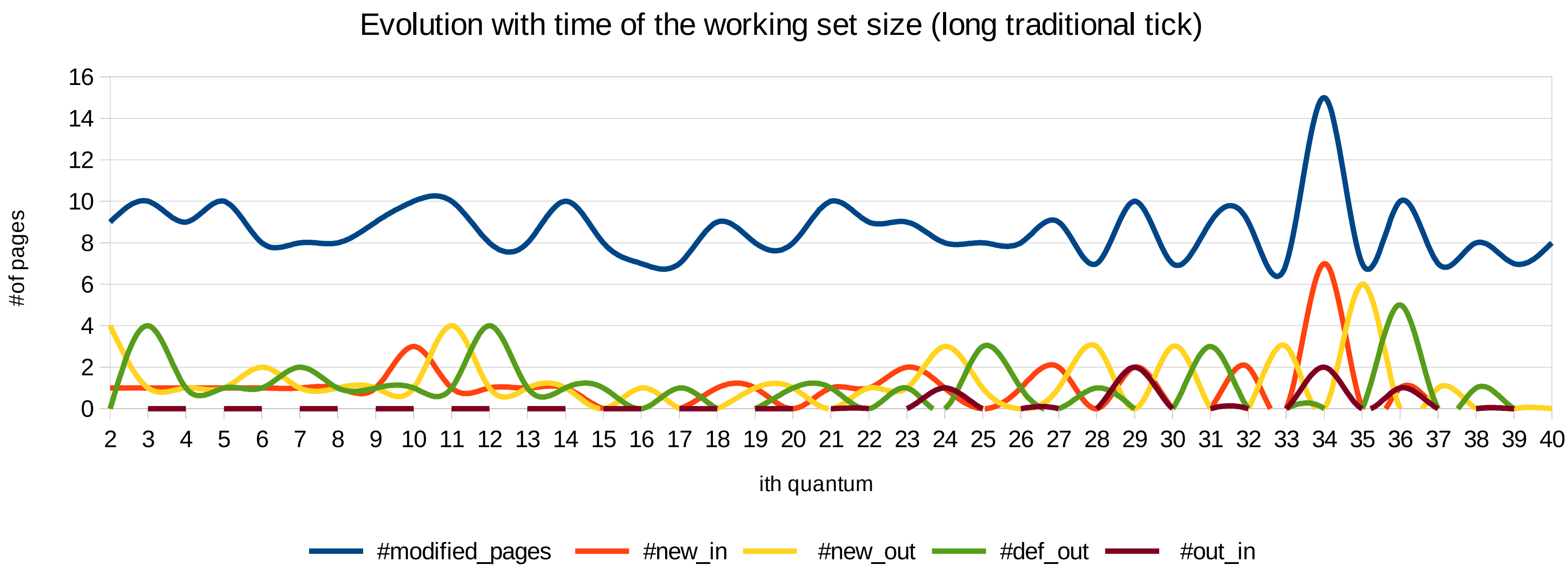
# Average parameters of working set evolution of a few processes



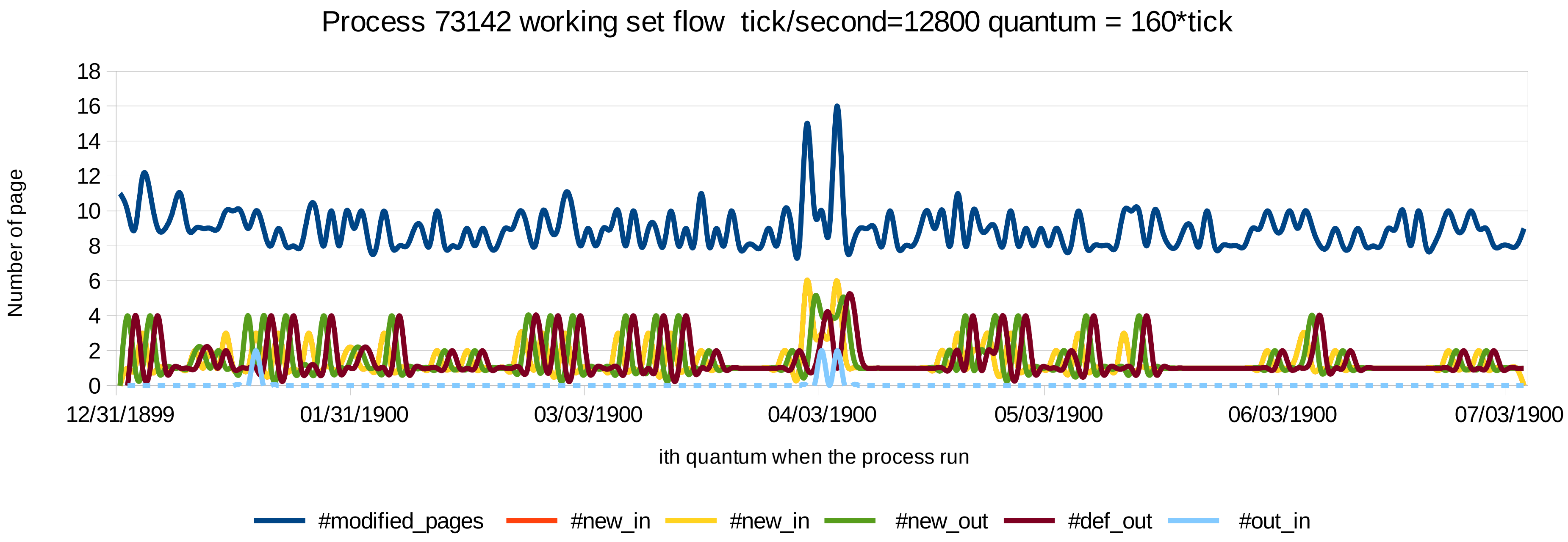

- The average number of pages in the working set is relatively low, around 100 pages for server processes and around 4 for dhrystone processes. Except the file system server, which has 300 pages as average.
- The working set size in relatively stable, considering the number of pages coming in the working set and the number of pages going out from the working set
- The number of pages going out and coming back again is also relatively low So the optimization algorithm to reduce the number of copy-on-write makes sense.

# Evaluation with time of the working set of process (73142)

## Long traditional tick



# Evaluation with  time of the working set of process (73142)



# Our real-time problem: the blended hardening technique (BHT)

# Protecting computers running in space environments (erg. satellites) against cosmic radiation effects

- SEU = bit flips caused by cosmic radiations
  = transient errors
- Hardening central memories or caches against direct effects of SEU is common (ECC/scrubbing)
- Hardening processors in hardware is more difficult and very expensive;
- pure software techniques can only reduce, not eliminate SEU effects
- Blended hardening is a mostly software solution using limited hardware features, either simple hardened hardware or side effects of classical hardware components

# Principle of Blended Hardening

- Hypotheses
  - SEU are “infrequent” events. For a short time interval (say 1ms) the probability of suffering from more than 1 SEU can be neglected
  - There is a “protected memory”, i.e. a memory area that is both hardened (immune to direct SEU effects) and immune to indirect ones (changes caused by a program made faulty because of a SEU)
- Principle:
  - divide the program in short “processing elements”; run each of them twice and compare the results: same: OK, proceed; different: restart the processing element.
  - This is OK because only one of the executions or the comparison can be made faulty by a SEU. If the single error occurs in the comparison it will just cause redoing a correct computation.

# Using BHT to protect user mode processes in the operating system

- Additional hypotheses:
  - The central memory is hardened against direct SEU effects
  - The MMU and the OS itself are assumed to be protected independently.
  - User processes only interact with the outside world through the OS.
  - External interrupts or exceptions do not change the memory state of hardened processes.
- Problems to solve:
  - Implementing “protected memory”
  - Dividing the process in atomic processing elements without any knowledge of the program

# Processing elements in user processes

- UPE = code executed (in user mode) between 2 system calls or limits of a time quantum:
  - starts after system call; ends at system call or timer trap (execution of system calls is not included in UPE)
  - has thus no direct interactions with the outside world; its execution is atomic and idempotent
  - is run twice in BHT
  - results of the two runs are compared
  - Results will be the same if no SEU
- Problems to solve:
  - Implementing “protected memory”
  - Replaying exactly the same processing element

# How to implement the protected memory concept using the MMU ?

- MMU can protect memory by restricting access
- Problem is to identify the “results” of the user space processing element (kernel PE are assumed to be protected otherwise).
- Solution: when starting a PE, set the whole process memory in RO mode and use copy on write: the result is the copied pages at the end of UPE execution.

# Replaying exactly the same processing element ?

- If UPE ends at system call: easy
- If UPE ends at time quantum:
  - hard: one must count the instructions and let the UPE run again for exactly the same number of instruction;
  - but feasible with modern processors

**Can it be done with MINIX without an unacceptable performance penalty ?**

# Conclusions

- Minix was a good choice
  - Code is clean and well documented
  - Micro-kernel architecture allows to handle some system functions as user processes.
  - It resists to changes to the clock rate and the time quantum.
- So far performance penalty looks acceptable but more tests will be necessary.

Questions ?

Comments ?