The Influence of Environmental Parameters on Concurrency Fault Exposures

An Exploratory Study

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Outline

- Motivation
- Environmental parameters
- Multi-core systems: A case study
  - Experimental procedure
  - Data analysis
- Discussion
- Conclusion

Motivation

The Importance of Concurrency

- The advent of multicore systems
- The future trends in exploiting the power of multiple cores
- The software industry needs programmers capable of developing multi-threaded applications
- Developing parallel applications is harder than programming sequential code
- Testing concurrent programs is much harder than testing sequential applications
  - Parallel programs specifically those using threading can be non-deterministic

Motivation

Research Question

- Interleaving faults occur when there exists threads contentions that produce faulty behaviours
- Reproducing and debugging such systems might be very challenging
  - How to reproduce the interleaving defects
  - How to increase the frequency of interleaving faults occurring?

Motivation

Existing Techniques and Our Approach

- Existing programming solutions
  - Reproduce the faulty interleaving using programming commands (e.g. `yield` and `sleep`) (Eytani et al., 2007)
  - Model checking techniques (Stoller, 2002)
  - Statistical probabilistic techniques (Burckhardt et al, 2010)
- Our approach
  - An alternative view seeking influential environmental parameters that influence the frequency of interleaving faults occurring

Environmental Parameters

Classification of Possible Parameters

- Hardware parameters
- Software algorithms
- Concurrency defect types
- Concurrency levels

Environmental Parameters

Hardware Parameters

- Hardware architecture
- #cores
- Cache and buffer size
- CPU, memory, and bus interrupt speeds
  - Examples
    - Threads context switch when clock ticks
    - The time allocated for executing threads reaches its limit (memory speed)

Environmental Parameters

Hardware Parameters

- Core management technology
  - Dataflow-based
    - The task assignments are based on data-dependencies
  - Master-slave
    - A single core manages task assignments
- *CoolThreads*, *Hyperthreads*, and virtualizations

Environmental Parameters

Software Parameters

- Scheduling algorithms implemented by VM and OS
  - First-Come First-Served
  - Round Robin
  - Shortest-Job-First
  - Shortest Remaining Time
- Examples
  - Solaris OS – 60 threads priorities
  - Windows XP – 32 threads priorities
  - Linux 2.5 – 140 threads priorities

Environmental Parameters

Concurrency Defects Types

- Interleavings
- Deadlock
- Livelock
- Starvation
- Race condition
- Orphaned thread

Environmental Parameters

Concurrency Levels

- Number of threads
  - Direct relationship with complexity of execution of concurrent programs
- Needs for a model to determine the relationship between number of threads created and number of faults exhibited

Multicore Systems: A Case Study

Goal and Approach

- Goal
  - Study the effect of multicore systems on frequency of interleaving faults exhibitions
- Approach
  - A number of experiment on various computer systems offering multiple cores and with different threads implementations on a number of programs with known interleaving defects
  - Controlling the cores assigned to an application using Solaris containers

Multicore Systems: A Case Study

Computer Systems Used

- Sun Fire T1000
  - UltraSPARC T1 processor 1.2 GHz, 32 GB memory
  - Supporting 32 concurrent hardware threads
  - Suitable for:
    - Tightly coupled multi-threaded applications
    - Computational less expensive threads: serving more threads
- Sun SPARC Enterprise M3000
  - SPARC64 VII processor 2.75 GHz, 64 GB memory
  - Supporting eight concurrent hardware threads
  - Suitable for:
    - Single threaded workloads

Multicore Systems: A Case Study

Subject Programs Used

Program	NLOC	Fault Type
`bubble sort`	236	Data Race
`airline`	61	Data Race
`account`	119	Deadlock, Data Race
`deadlock`	95	Deadlock
`allocation vector`	163	No Lock

Developed and maintained by IBM Haifa

Multicore Systems: A Case Study

Generation of Solaris Containers

- Introduced by Solaris 10
- Resource management for applications using *projects*
  - Workload control
  - Security control by restricting access
- Generation
  1. k = number of CPUs
  2. For k in 1, 2, 4, 6, 8, 16
  3. `create (pset.max = k, pset.min=pset.max)`
- Monitor using `mpstat` command

Multicore Systems: A Case Study

Setup

- For T1000 machine:
  - Created 5 containers (projects)
    - One-CPU, Two-CPU, Four-CPU, Eight-CPU, Sixteen-CPU
- For M3000 machine:
  - Created 3 containers (projects)
    - One-CPU, Two-CPU, Four-CPU
- Commands used:
  - `poolcfg` : To create pools and processor sets
  - `projadd` : To create projects
  - `mpstate` : to monitor the assignment and utilization

Multicore Systems: A Case Study

Setup (con't)

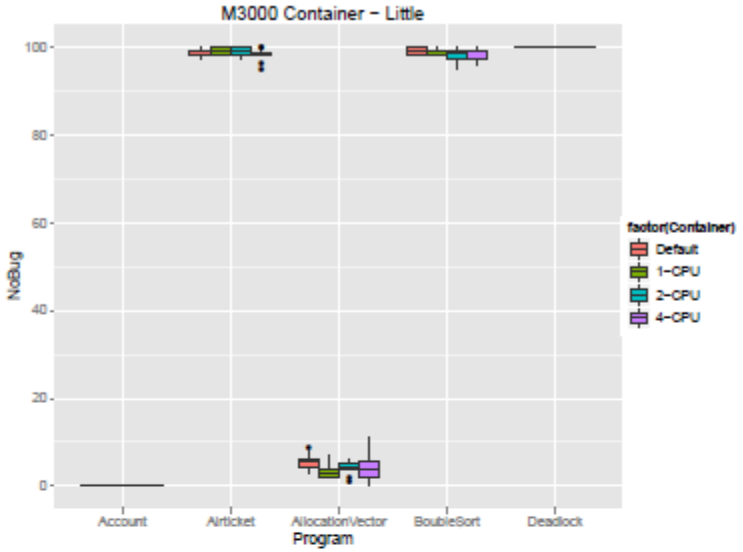
- Ran each benchmark for 100 times for each pair of:
  - <concurrency level, container>
- Count the number of times the interleaving fault exhibited
- Statistically compared the counted values for their significance
- Only two concurrency levels (little and lot) were considered

Multicore Systems: A Case Study

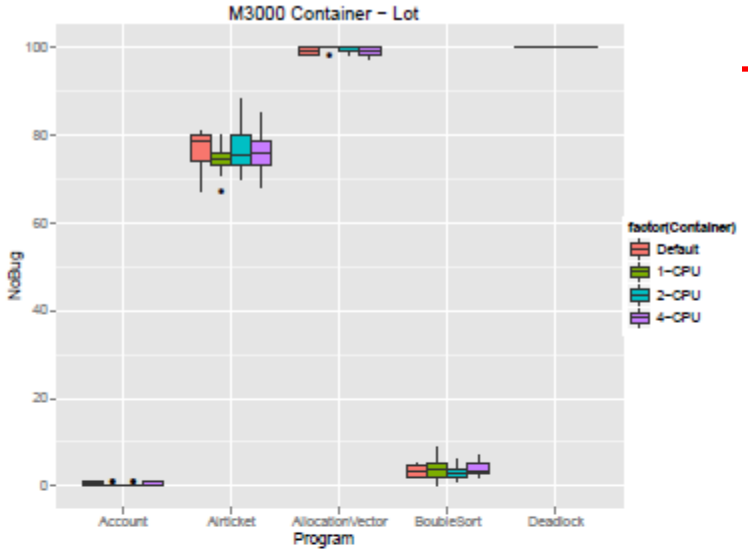
Data Analysis – The Mean Values of Defect Exposures

Program	M1000				T1000					
	Default	1-CPU	2-CPU	4-CPU	Default	1-CPU	2-CPU	4-CPU	8-CPU	16-CPU
a) Little Concurrency Level										
bubble sort	99.1	98.9	98.1	98.4	99.3	97	97.2	96.6	97.5	97
airline	98.7	98.9	98.8	98	99	99	99	99.2	99.4	99.1
account	0	0	0	0	0	0	0.1	0	0	0
deadLock	100	100	100	100	100	100	100	100	100	100
all. vector	5.5	3.5	4.2	4.1	3.1	1.6	2.4	2.4	2.1	1.9
b) Lot Concurrency Level										
bubble sort	3.4	3.9	3	4	7.7	6.4	5.4	5.9	5.8	6
airline	76.3	74.3	77	76.2	58.4	56.6	56.9	60.2	55.7	58.2
account	0.5	0.2	0.2	0.4	0.2	0.9	0.5	0.4	0.5	0.7
deadLock	100	100	100	100	100	100	100	100	100	100
all. vector	99	99.8	99.2	99	71.5	77	75.9	74.7	72.6	74.6

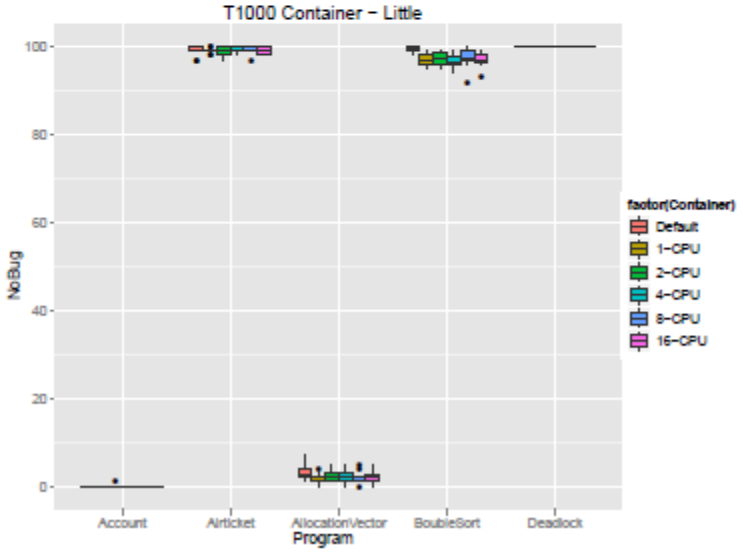
Multicore Systems: A Case Study



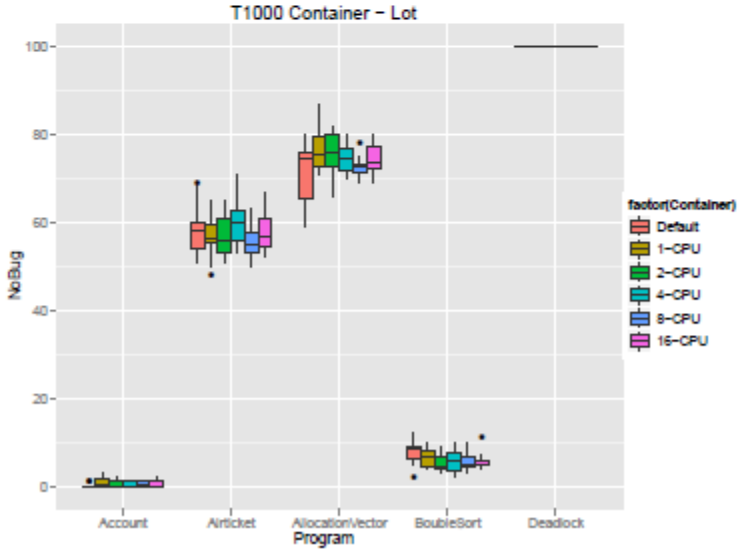
(a) M3000 - Concurrency Level:Little



(b) M3000 - Concurrency Level:Lot



(c) T1000 - Concurrency Level:Little



(d) T1000 - Concurrency Level:Lot

Multicore Systems: A Case Study

Data Analysis

Table 3: The p-values of the t-test performed on the number of faults exposed for the `lot` concurrency level on the T1000 computer system. D:Default, 1:1-CPU, 2:2-CPU, 4:4-CPU, 8:8-CPU, 16:16-CPU containers.

Containers	D	1	2	4	8	16
D	1	0.936	0.981	0.93	0.934	0.965
1	–	1	0.955	0.993	0.872	0.971
2	–	–	1	0.949	0.917	0.983
4	–	–	–	1	0.866	0.965
8	–	–	–	–	1	0.9
16	–	–	–	–	–	1

Discussion

Some Observations

- There is no evidence to believe that there is a dependency between number of cores and interleaving faults
- The number of threads influences the variance of fault exposures
- The concurrency level influences the variance of fault exposures
- The two computer systems had some effects on the frequencies of faults exhibited
  - Recall: two different threading mechanisms and architectures

Conclusion & Research Directions

- Identify environmental factors influencing the frequency of concurrency faults exhibitions
- A case study investigating the effect of multicore environment on concurrency faults
- The research is still in its early stages

Thank You

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