T4: A Highly Threaded Server-on-a-Chip with Native Support for Heterogeneous Computing

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Agenda

- T4 Overview
- S3 Core
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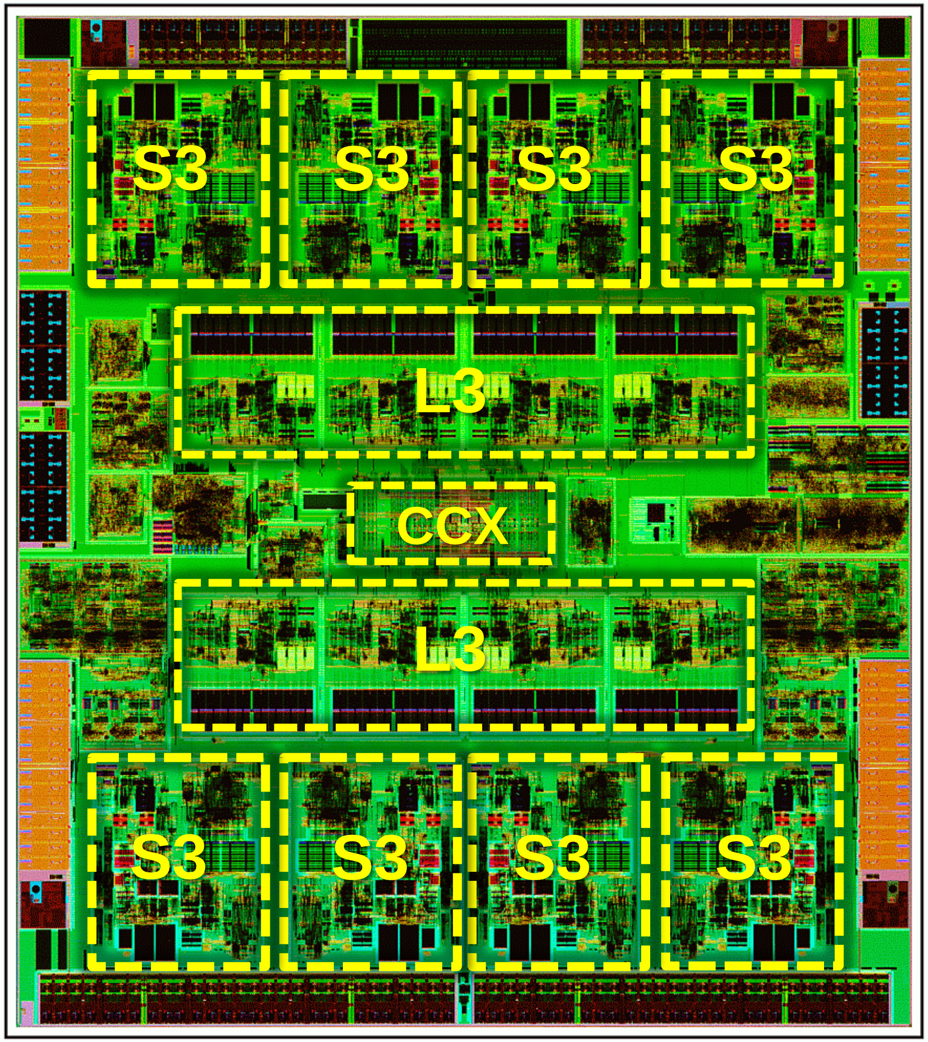
    - Block Diagram
    - Pipeline
- T4 Performance
- Dynamic Threading
- Crypto
    - Overview
    - Block Diagram
    - Performance
- Summary

T4 Design Objectives

- Optimize Software and Hardware for Oracle Workloads and Engineered Systems
  - Extend SPARC ISA
- Performance
  - Much better singlethread performance vs T3
  - Double T3's per thread throughput performance
  - Enhance overall crypto performance vs T3
- Compatibility
  - Maintain SPARC V9 and CMT model compatibility
  - Maintain current T3 system scalability
- Reliability
  - Extend T3's RAS capabilities

Sun ORACLE | SPARC T-SERIES

T4 Chip Overview



- 8 SPARC S3 cores
  - 8 threads each
- Shared 4 MB L3
  - 8-banks
  - 16-way associative
- Two dual-channel DDR3-1066 memory controllers
- Two PCI-Express x8 2.0 ports
- Two 10G Ethernet ports
- TSMC
  - 40 nm
  - ~855 million transistors

S3 Core Overview

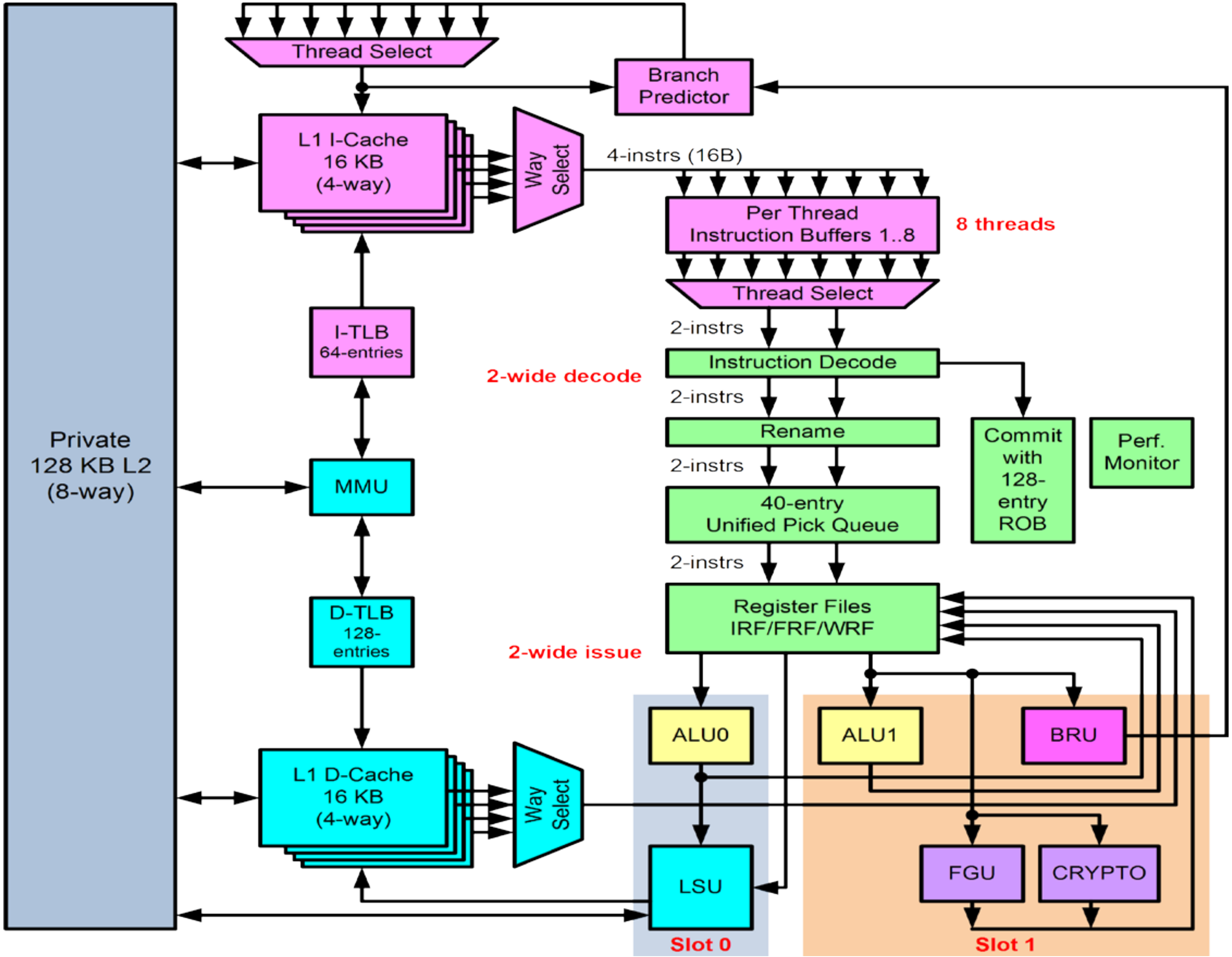
- Out-of-order
- Dual-issue
- Dynamically threaded
- Balanced pipeline design
  - Singlethread performance
    - Estimate ~5X S2's SPECint2006* performance
    - Estimate ~7X S2's SPECfp2006* performance
  - Throughput performance
    - ~2X S2's per thread throughput performance
- High frequency, deep pipeline
  - 16 stage integer pipe
  - 3+ GHz

*SPEC, SPECfp, SPECint are registered trademarks of the Standard Performance Evaluation Corporation. Estimates as of 8/18/2011, see www.spec.org for more about SPEC.

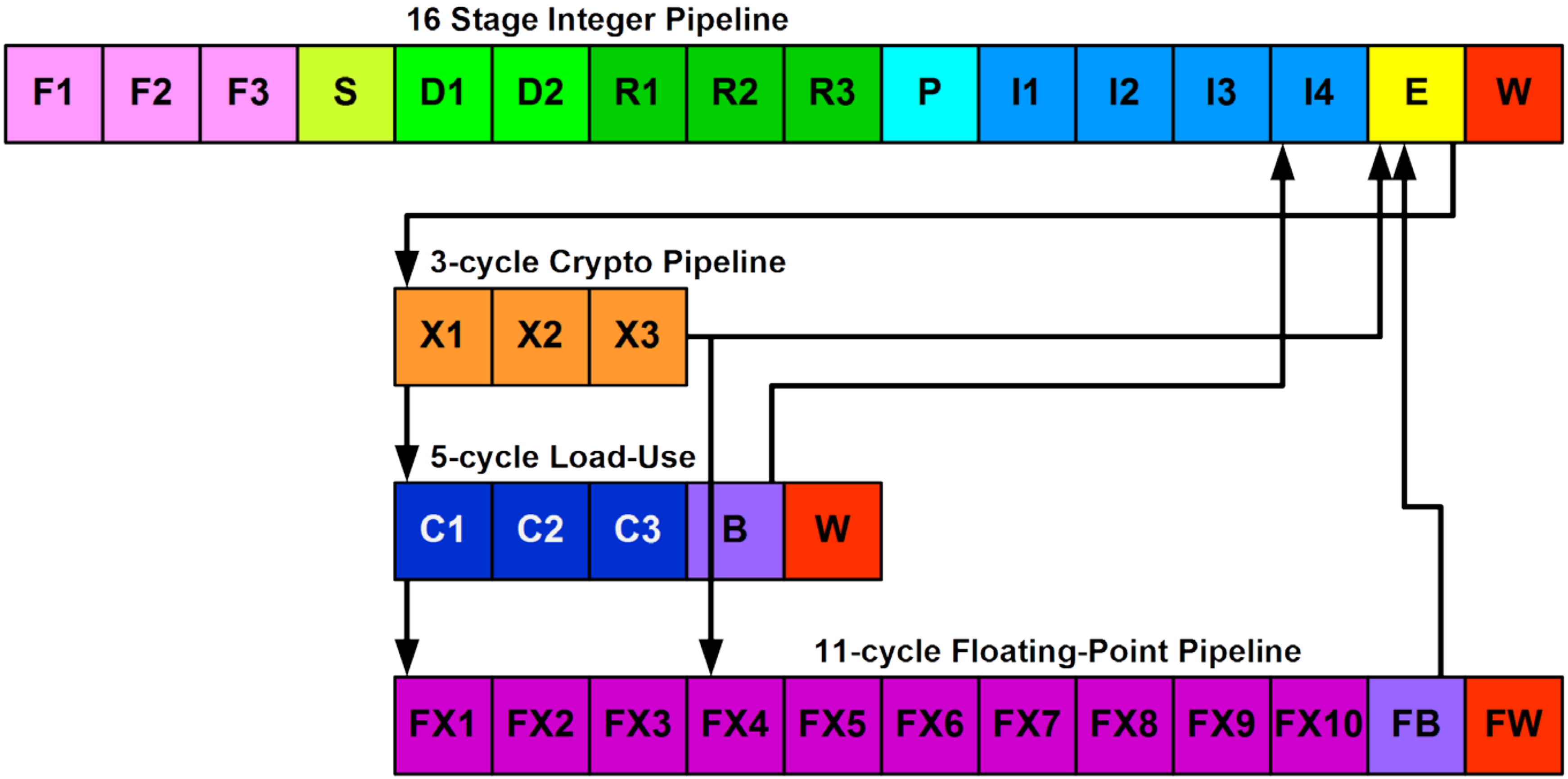
S3 Core Overview

- Extensive branch prediction
  - Perceptron direction predictor
  - Return Stack to predict return addresses
  - Far and Indirect target predictors
  - BTC to reduce taken branch penalty
- Hardware / Software optimizations for Oracle applications
  - User level crypto instructions
  - PAUSE instruction
  - Fused compare-branch instruction
- HW prefetchers
  - Instruction cache sequential line prefetcher
  - Data cache stride based prefetcher
- 16 KB, 4-way, L1 instruction and data cache
- 128 KB, 8-way, unified private L2 cache

S3 Core Block Diagram



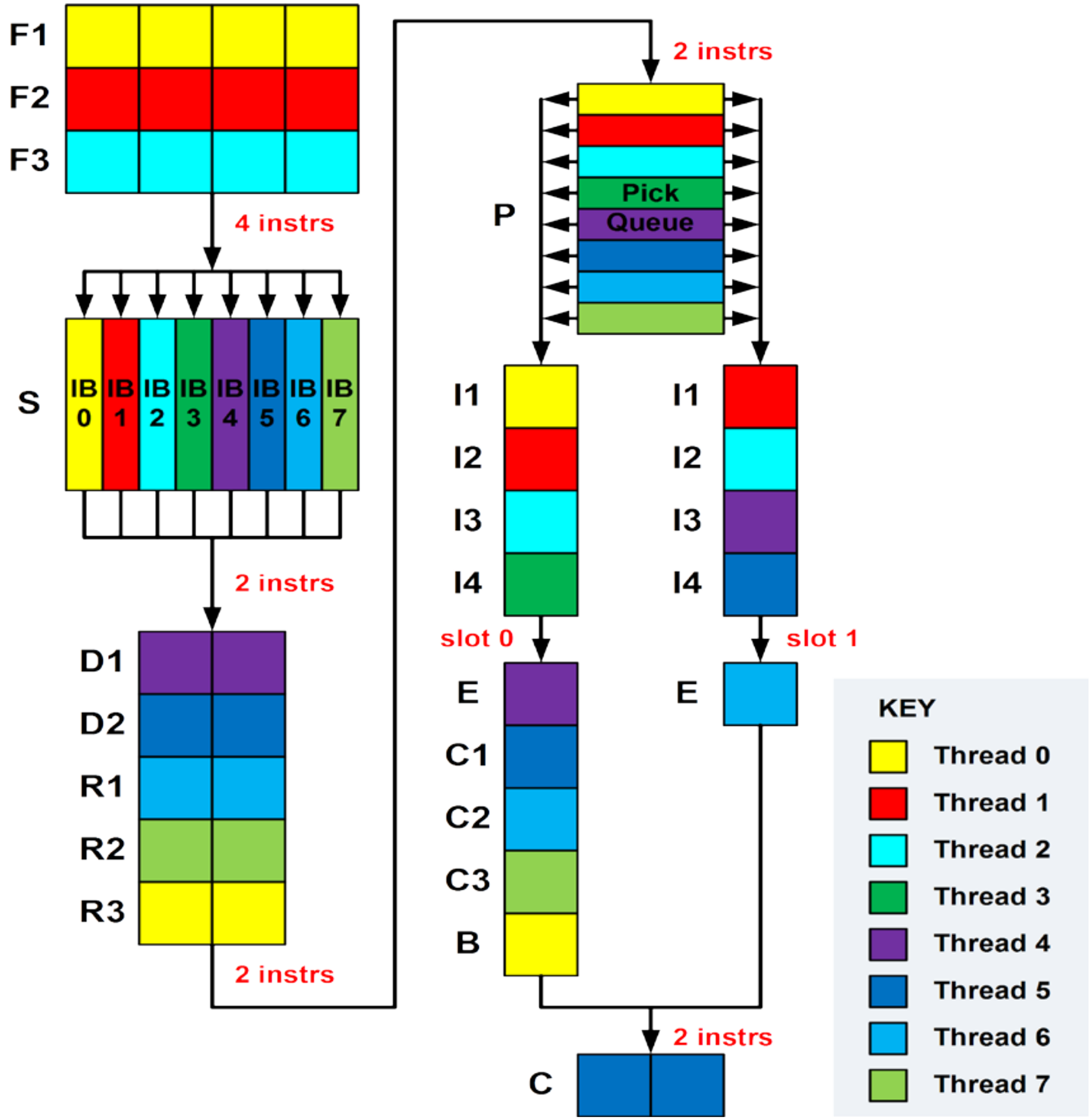
S3 Core Pipeline



Pipeline Key

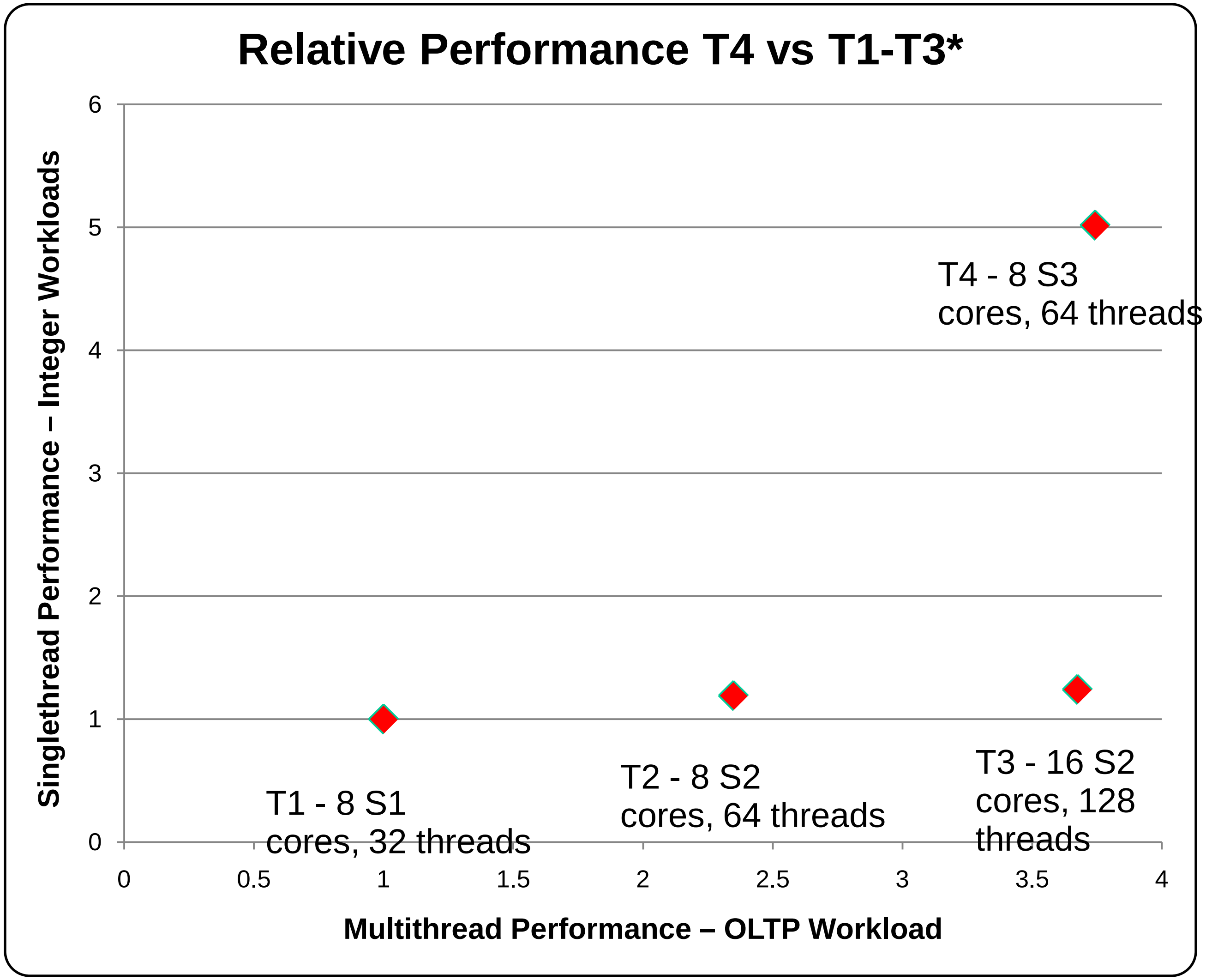
F	Fetch	R	Rename	E	Execute	B	Bypass	FX	Floating-point execute
S	Select	P	Pick	W	Write-back	X	Crypto execute	FB	Floating-point bypass
D	Decode	I	Issue	C	Data-cache			FW	Floating-point writeback

Threaded S3 Core Pipeline View



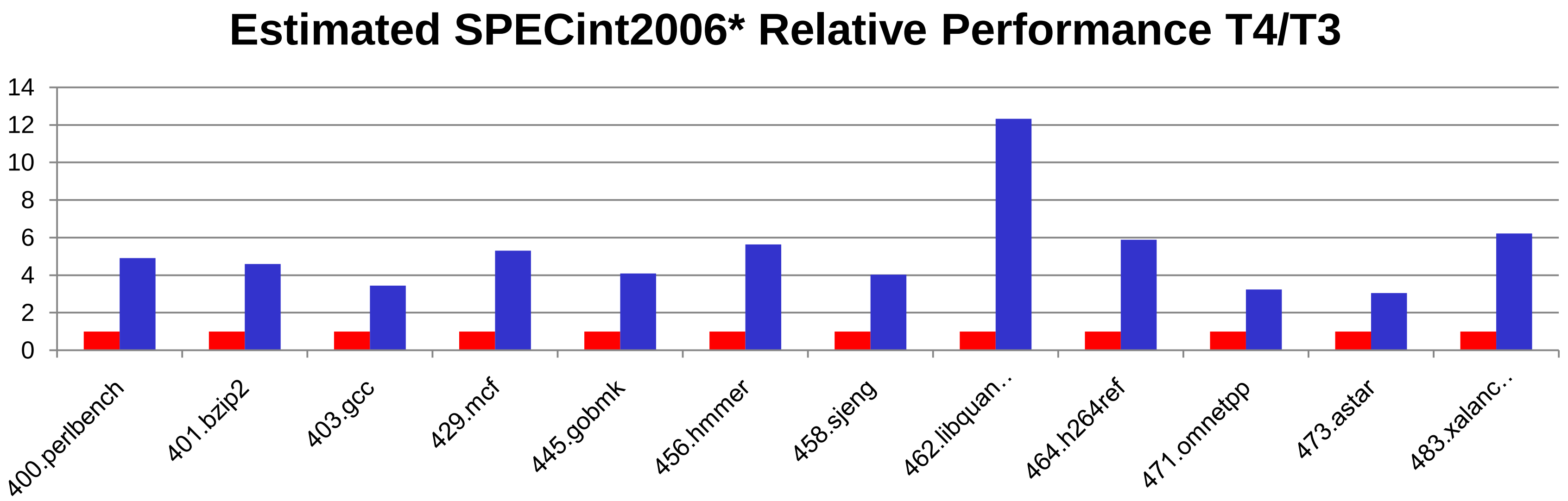
- Before Pick
  - Only 1 thread per pipe stage
- Pick to Commit
  - Multiple threads per pipe stage
- Commit
  - Only 1 thread per pipe stage

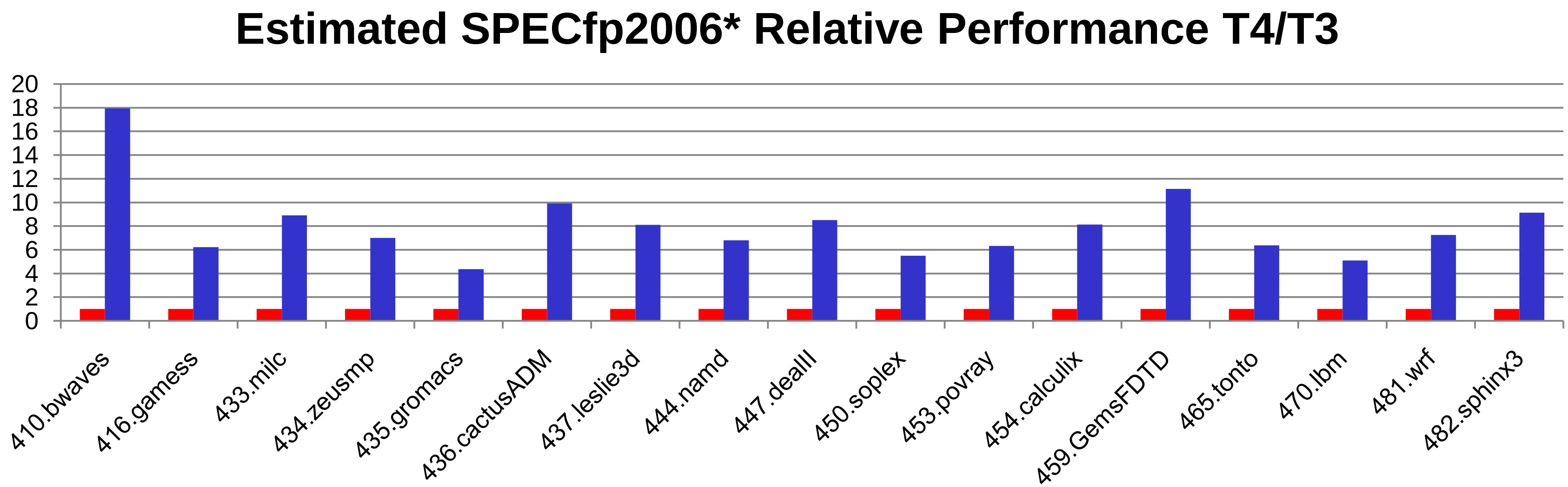
T4 Relative Performance



*All performance estimates are relative to T1 performance.

T4 Relative Performance





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Dynamic Threading

- Many of the resources on S3 are shared between threads
  - Load-buffers, store-buffers, pick-queue, working-register-file, reorder-buffer, etc.
- Thread sharing of resources
  - Static resource allocation
    - Not optimal for heterogeneous workloads
  - Dynamic resource allocation
    - Better for heterogeneous workloads
    - Improves overall application scaling
    - Resources are dynamically configured between threads each cycle
      - No synchronization required

Dynamic Threading – Thread Hogs

- Thread hog definition
  - A thread which fails to release its shared resources in a timely fashion
- Thread hog mitigation using watermarks
  - High and low watermarks defined for each shared resource
    - High watermark reached by allocation
    - Low watermark reached by deallocation
  - Upon reaching high watermark, thread resource allocation stalls
  - Thread resource allocation remains stalled until low watermark is reached

Dynamic Threading – Thread Hogs

- Thread hog mitigation using rate of deallocation
  - Pick Queue (PQ) mitigation technique
    - PQ is most critical shared resource on S3
  - Threads are expected to deallocate PQ entries in a timely fashion
    - If not, thread is considered a PQ thread hog
  - If thread is a PQ thread hog
    - PQ resource available to thread is reduced and made available to other threads
    - If hogging behavior continues, PQ resource is further reduced and made available to other threads
    - If thread deallocates PQ entries in a timely fashion, PQ resource is increased

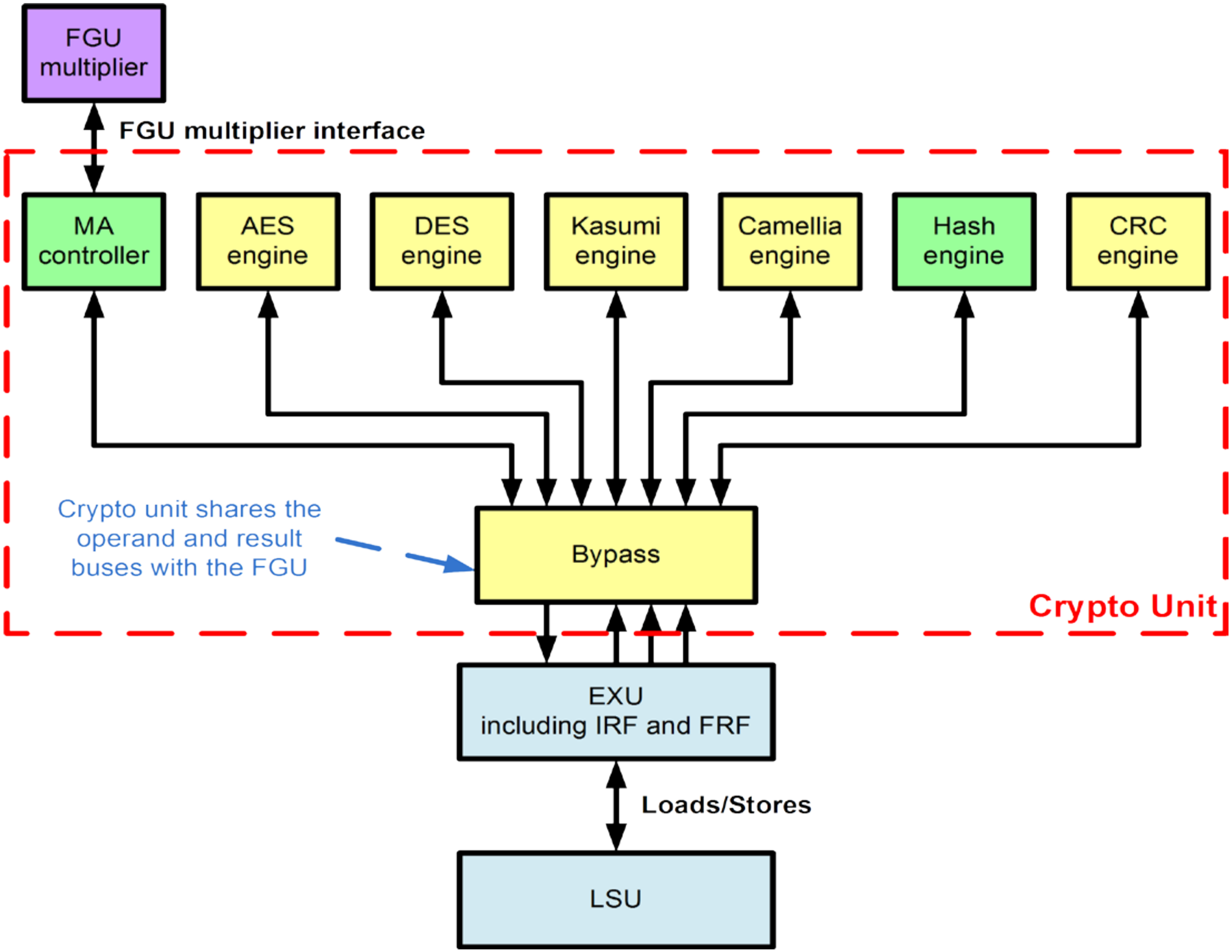
Dynamic Threading – Thread Hogs

- Thread hog mitigation using flushes
  - Flush on L3 miss
    - When a load misses the L3, flush the thread
    - Flushing releases any allocated shared resources for that thread
  - Load/Store timeout
    - Some events are not covered by other thread hog mitigation policies
      - Load that RAWs to a previous store that misses the L3
    - Flush any load/store that is the oldest and does not commit for N cycles
  - Flush after IO
    - Flush thread after an IO access reaches Commit

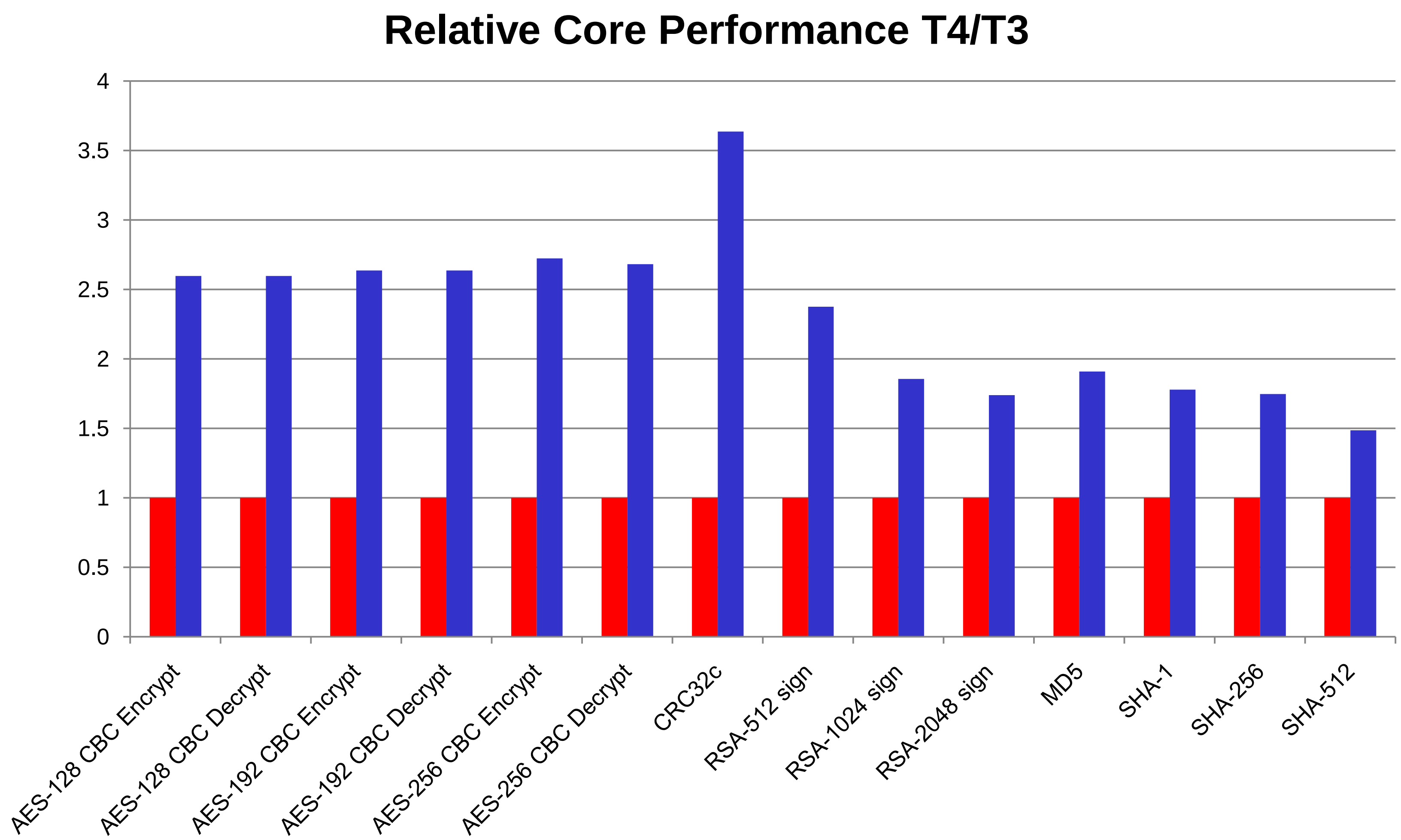
Crypto Overview

- Crypto programmed via user instructions
- Instructions are either “in-pipe” or “out-of-pipe”
  - “in-pipe” set supports 3 cycle internal latency
    - AES, DES, Kasumi, Camellia, CRC32c
  - “out-of-pipe” set has long latency
    - MD5, SHA-1, SHA-256, SHA-512, MPMUL, MONTMUL, MONTSQR
- MPMUL, MONTMUL, MONTSQR have separate state machine
  - Stall Pick Queue to inject crypto multiplies
  - Fairness heuristic between crypto and non-crypto threads

Crypto Unit Block Diagram



Crypto Relative Performance



Summary

- Next-generation processor for Oracle servers
  - Significantly improved per thread throughput performance
  - Much better singlethread performance
- Dynamic threading
  - Better for heterogeneous workloads
  - Improves overall application scaling
- Excellent overall crypto performance
  - Enables transparent encryption across Oracle software stack

Glossary

- SPC – SPARC core
- CCX – crossbar
- BTC – branch target cache
- IRF – integer register file
- WRF – working register file
- FRF – floating-point register file
- FGU – floating-point / graphics unit
- IB – instruction buffer