Timescale Stream Statistics for Hierarchical Management

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Implications of the datacenter’s shifting center.

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Non-Volatile Storage

“The arrival of high-speed, non-volatile storage … is likely the most significant architectural change that datacenter and software designers will face in the foreseeable future.”
Hierarchical Cache Memory

- **Science**
  - nothing travels faster than light
    - the faster the access, the smaller the data capacity
- **Engineering**
  - speed, size and cost
    - no single technology can satisfy all demands
  - e.g. SCM mentioned in the CACM article
- **Programmability**
  - automatic, transparent, modular, efficient, portable
  - efficient sharing of fast/local memory
- **Uses**
  - CPU/GPU caches, virtual memory
  - software cache, e.g. Memcached, Redis
### Summary Table

<table>
<thead>
<tr>
<th>GPU</th>
<th>G80</th>
<th>GT200</th>
<th>Fermi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transistors</td>
<td>681 million</td>
<td>1.4 billion</td>
<td>3.0 billion</td>
</tr>
<tr>
<td>CUDA Cores</td>
<td>128</td>
<td>240</td>
<td>512</td>
</tr>
<tr>
<td>Double Precision Floating Point Capability</td>
<td>None</td>
<td>30 FMA ops / clock</td>
<td>256 FMA ops / clock</td>
</tr>
<tr>
<td>Single Precision Floating Point Capability</td>
<td>128 MAD ops/clock</td>
<td>240 MAD ops / clock</td>
<td>512 FMA ops / clock</td>
</tr>
<tr>
<td>Special Function Units (SFUs) / SM</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Warp schedulers (per SM)</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Shared Memory (per SM)</td>
<td>16 KB</td>
<td>16 KB</td>
<td>Configurable 48 KB or 16 KB</td>
</tr>
<tr>
<td>L1 Cache (per SM)</td>
<td>None</td>
<td>None</td>
<td>Configurable 16 KB or 48 KB</td>
</tr>
<tr>
<td>L2 Cache</td>
<td>None</td>
<td>None</td>
<td>768 KB</td>
</tr>
<tr>
<td>ECC Memory Support</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Concurrent Kernels</td>
<td>No</td>
<td>No</td>
<td>Up to 16</td>
</tr>
<tr>
<td>Load/Store Address Width</td>
<td>32-bit</td>
<td>32-bit</td>
<td>64-bit</td>
</tr>
</tbody>
</table>
What is Locality?
“During any interval of execution, a program favors a subset of its pages, and this set of favored pages changes slowly” -- Peter Denning

- locality analysis is a streaming problem
- too many data points, unusable for optimization
Locality Theory

- Since 1960s
  - working-set theory [Denning 1968]
  - stack simulation [Mattson et al. 1970]
- Since 1999
  - reuse distance (i.e. LRU stack distance)
  - 5 dimensions of locality [TOPLAS‘09]
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  - HPCToolkit by Mellor-Crummey et al. at Rice [CCPE‘10]
    - not composable, unable to derive shared-cache performance
- Since 2008
  - footprint — timescale statistics
Timescale Stream Statistics

• A stream
  • “a possibly unbounded sequence of events” [Stream workshop 2015]
  • a time window or interval
  • a timescale \( x \) is a length of time
  • \( f(x) \) is the average behavior of all windows of length \( x \)
    • a function for all non-negative \( x \)

• Peak temperature variation \( pv(x) \)
  • each window has a peak variation
  • \( pv(x) \) is the average of all windows of length \( x \)
    • e.g. a week time or a month time
  • avoid data bias
    • e.g. if we were to measure just calendar weeks/months
Timescale Locality

- Footprint $fp(x)$
  - working-set size (WSS): the amount data accessed in a window
  - $fp(x)$: average WSS of all length $x$ windows

- Theoretical properties (selected)
  - composable
  - miss ratio is the increase of footprint
  - concavity [ASPLOS’13]
    - (computed) miss ratio is monotone
  - linear time measurement [PACT’11]
    - real-time sampling [CCGrid’15]
  - A function is worth a thousand pictures
Theory is for Optimization

• Key-value store Memcached [USENIX’15]
  • DRAM as cache for database
  • optimization vs. heuristics by Facebook and Twitter
    • faster steadystate/convergence on a Facebook test set
  • monotonicity: no Belady anomaly
• Concurrent memory allocation [see white paper]
  • optimization vs. Google’s tcmalloc
    • 26% higher throughput 64-thread MongoDB
  • consistency: intermediate steps order insensitive
• Storage cache [Wires/Warfield et al. OSDI’14]
  • independent validation of footprint theory
• Other theories
  • optimal data placement [PLDI’04, POPL’06, POPL’16]
  • optimal collaborative caching [LCPC’08, ISMM’11/12/13]
Summary: Locality Theory/Optimization

- **Locality theory**
  - partly a streaming problem/solution
  - equivalent* definitions of locality
    - reuse distance, footprint, working set, miss ratio curve

- **Possible uses in a streaming system**
  - Nathan’s IPPD
    - memory resource steering
  - timescale statistics
    - user decision support

- **A conjecture**
  - memory: hierarchical and shared
  - timescale stream statistics: optimal sharing of a hierarchy