CS7960 L6 : I/O-Cache Oblivious + Parallel

Disk <---I/O---> RAM <--> CPU
N = size of problem
B = block size
M = size of memory
T = size of output
I/O = block move between disk + memory

Sorting N items:
 Theta((N/B) log_{M/B} (N/B)) << N log_2 N

Cache-Oblivious Algorithms

[Frigo, Leiserson, Prokop, Ramachandran '99]

 - design algorithms with good I/O efficiency without knowledge of M, B
 - sometimes don't know M,B
 - portable. Same code to different systems
 - holds for all levels of hierarchy simultaneously
 - does not work as well in practice.

Modeling assumptions
 * Ideal Cache : cache always flushes the block that will be used furthest in future
    - LRU performs within constant factor

* Full Associativity : any block can go anywhere in cache (not always true - maybe 8 places)
    - can be gotten around using hashing, in expectation, with constant overhead
* Tall Cache : M > B^2 (usually M > B^{1+a} for a > 0 constant ok).

Scanning:
  [N/B + 1]   I/Os
 - store elements in consecutive blocks of memory.

```
  ... | XXX [X | XXXX | XXXX | XXXX | XX] XX | ...
```

 - Extra 1 because may not hit boundary exactly.

Array reversal?
  [N/B + 1] I/Os   (two scans from opposite ends)

Divide and Conquer:
Divide into subproblems until size is <M (and Theta(M)) or <B (and Theta(B))

Median Finding:
 (A) Split D into N/5 sets of size 5 (adjacent)

(B) Find median of each set -> M
(C) Recursively compute median of M -> m
(D) Split D into L (l \in L < m) and R (r \in R >= m)
(E) Recur on L or R.

A : free
B : 2 scans | first on D, second records median to M
C : recursive call of size N/5
D : 3 scans | first on D, second and third records L and R
E : recursive call of size N(7/10)

T(N) = O(N/B + 1) + T(N/5) + T(7N/10) = O(N/B + 1)

Binary Search:
Theta(log N - log B)
- recall if we know M,B then Theta(log N/log B) = Theta(log_B N)

Merge Sort:
O((N/B) log_2 (N/B))
- recall if we know M,B then Theta((N/B) log_{M/B} (N/B))

- same can be achieved with variation of Quick Sort == Distribution Sort

or with "Funnel Sort" -- similar to merge sort but split N^{1/3} pieces
and merge N^{1/3} way with a "funnel"

Parallel External Memory

```
P1 - [M]  | |  [ D ]
P2 - [M]  |I|  [ I ]
P3 - [M]  |/|  [ S ]
...       |O|  [ K ]
Pp - [M]  | |  [   ]
```

- P CPUs.
- each CPU has private cache of size M
- block of size B
- P block transfers == 1 I/O   (one for each CPU)
- Block level CREW

Scanning
scan_P(N) = O(N/PB + log P) parallel I/Os
  if P <= N/(B log N) --> scan_P(N) = O(N/BP)

Sorting

```
sort_P(N) = O((N/PB) log_{M/B} (N/B))
parallel I/Os
  if P <= N/B^2
```

Parallel Disk Model (PDM) for External Memory

```
          | | - d1
          |I| - d2
P - [M] - |/| - d3
          |O| ....
          | | - dD
```

```
M << N,  1 <= DB <= M/2  (often M^2)
```

Assume transfers are synchronous, although faster otherwise.

[Vitter + Schriver '94]

sometimes ...

```
p1 - [M1] - | | - d1
p2 - [M2] - |I| - d2
p3 - [M3] - |/| - d3
 ...        |O| ....
pP - [MP] - | | - dD
```

Scanning: Theta(N/DB)

Sorting : Theta((N/DB) log_{M/B} (N/B))
Search : Theta(log_{DB} N)

Striping :

```
  ... | 111 | 222 | 333 | 444 | 555 | 666 |
777 | 888 | 999 | ...
  -->
D1  ... | 111 | 444 | 777 | ...
D2  ... | 222 | 555 | 888 | ...
D3  ... | 333 | 666 | 999 | ...
```

Usually extending regular EM algorithms to striped discs is sufficient
- a few new ideas needed...

How to stripe a single-disk queue?

TPIE : Templated Portable I/O Environment (formerly, Transparent Parallel I/O Environment)
http://www.madalgo.au.dk/Trac-tpie

What do you think?
- How useful is it?
- How would you change/extend the model?