Wait-free Programming for General Purpose Computations on Graphics Processors

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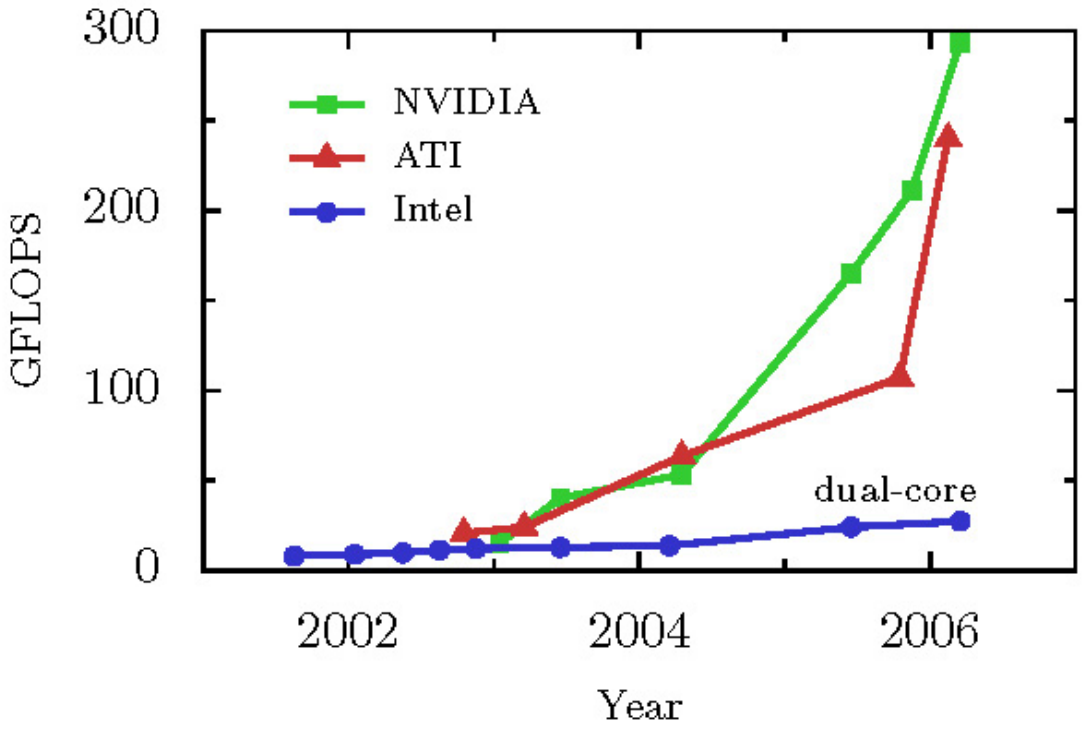
GPU: powerful and cheap



The chart is in *A Survey of General-Purpose Computation on Graphics Hardware* by J.D. Owens et al. [Computer Graphics Forum '07]

- GF 8800GTS 512
  - 624 GFLOPS
  - ~ $350
- Fastest supercomputer 1994 [top500.org]
  - 184 GFLOPS

⇒ GPGPU

- physics simulations,
- signal processing,
- geometric computing,
- databases
- etc.

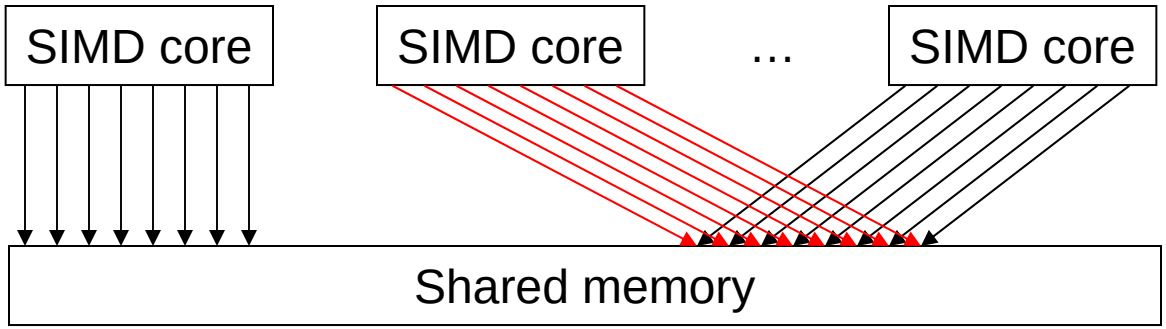
But …

- Lack of strong synchronization primitives
  - Pixels don't need to communicate

$\Rightarrow$ prevent GPU from being deployed more widely (e.g. conventional concurrent programming, lock-free/wait-free programming)

Can we construct strong synchronization mechanisms for GPU?

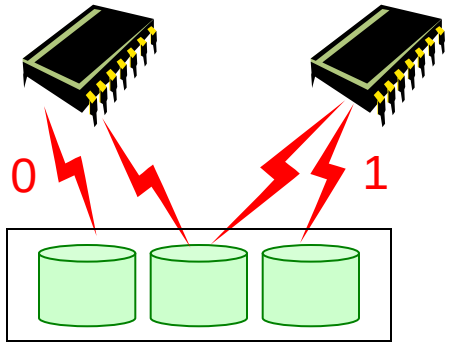
GPU Intrinsic features

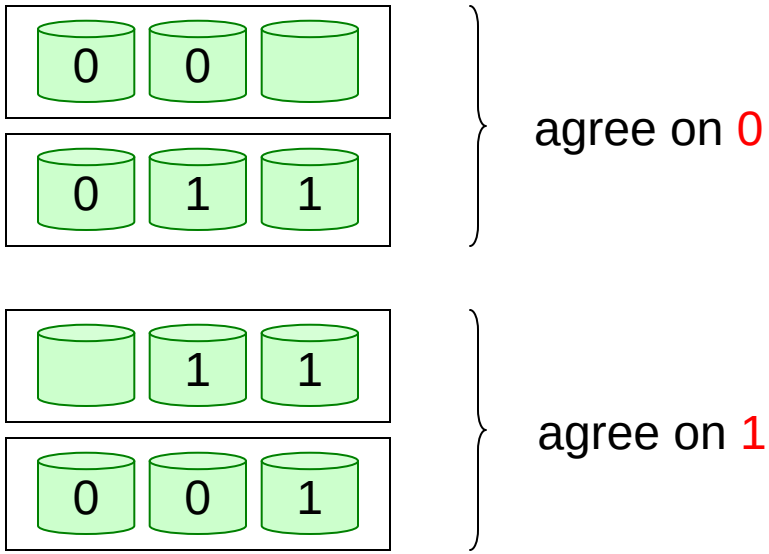


m-word assignment

Consensus using m-word assignment

- Wait-free (2m-2)-consensus [Herlihy, TOPLAS '91]
- Ex: 2-word assignment





short-lived consensus object !

Our main technical contribution

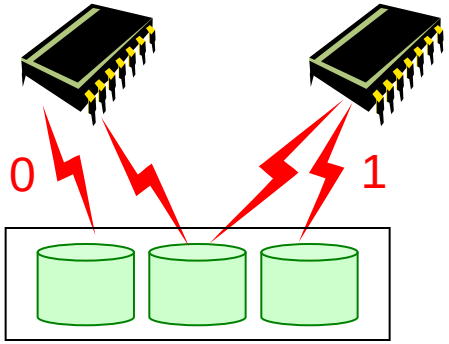
(2m-3)-resilient
long-lived
read-modify-write objects
using m-word assignment

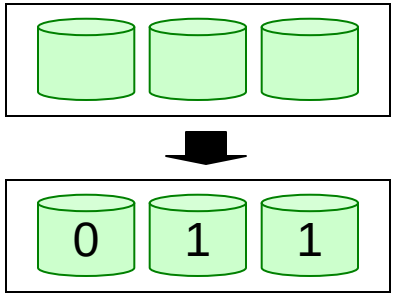
Road-map

- Wait-free long-lived consensus objects for (2m-2) processes.
- Wait-free long-lived read-modify-write (RMW) objects for (2m-2) processes
- (2m-3)-resilient long-lived RMW objects for any number of processes

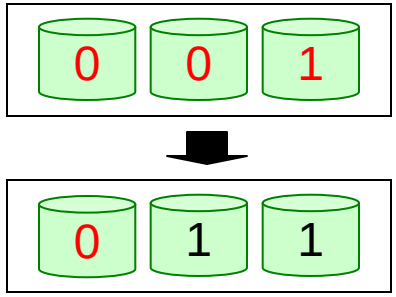
Wait-free long-lived (2m-2)-consensus (WF LLC)

WF LLC variables must be reusable





agree on 0



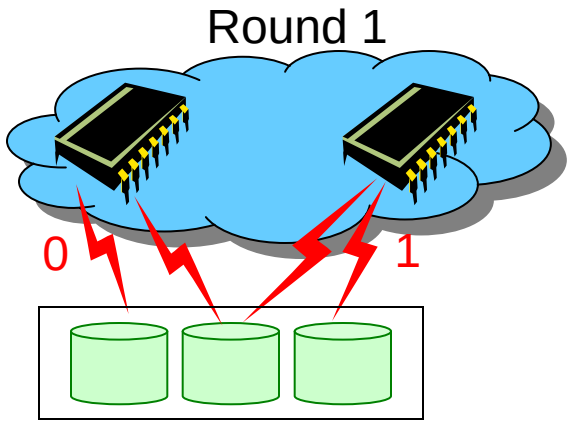
must agree on 1

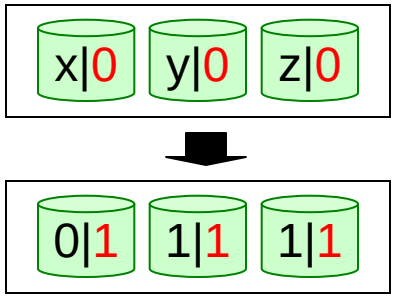
WF LLC: Key ideas

- Models:
  - each process p_i is associated with a round number
  - p_i gets a round number *r* only if round *(r-1)* has finished.

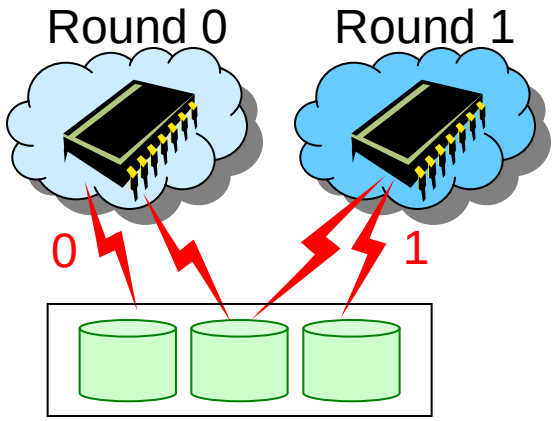
- WF LLC objects return
  - *nil* if p_i's round has finished
  - a value proposed in p_i's round.

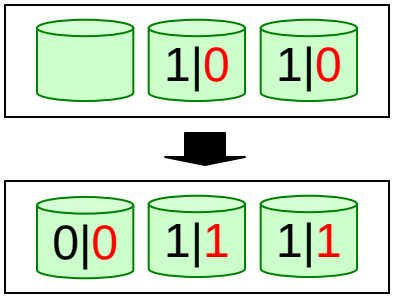
WF LLC: An illustration





agree on 0





- p_0 gets *nil*
- p_1 agrees on 1

WF LLC: Complexity

- Time complexity *O(N)*, where *N=(2m-2).*
  - vs. time complexity $O(N^2)$ of the WF *short-lived* consensus [TOPLAS '91].
  - Key idea: utilize the transitive property of the preceding order.
- Space complexity $O(N^2)$, the optimal.

Road-map

- Wait-free long-lived consensus objects for (2m-2) processes.
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Wait-free RMW for $N=(2m-2)$ (WF RMW)

```
function RMW(X, f)

atomically {
    temp ← X;
    X ← f(X);
    return( temp);
}
```

WF RMW: Key idea 1

- Model:
  - Each process p_i executes one function f_i on X at a time
- Use WF LLC
  - p_i locally executes the functions of concurrent processes on a copy of X in a certain order.
  - p_i's proposal = responses to these functions.
  - Invoke WF LLC to achieve an agreement on their proposal.

But …

Such proposals are too big to be stored in one word

- How to achieve an agreement for (2m-2) processes as the consensus object does?

WF RMW: Key idea 2

- p_i's proposal = reference to the buffer containing responses

- Key property of the buffer:
  - response to f_k is kept unchanged until p_k submits a new function.

WF RMW: Complexity

- Time complexity *O(N)*,
  - Each process invokes WF LLC at most 2 times to get a response
- Space complexity $O(N^2)$, the optimal.

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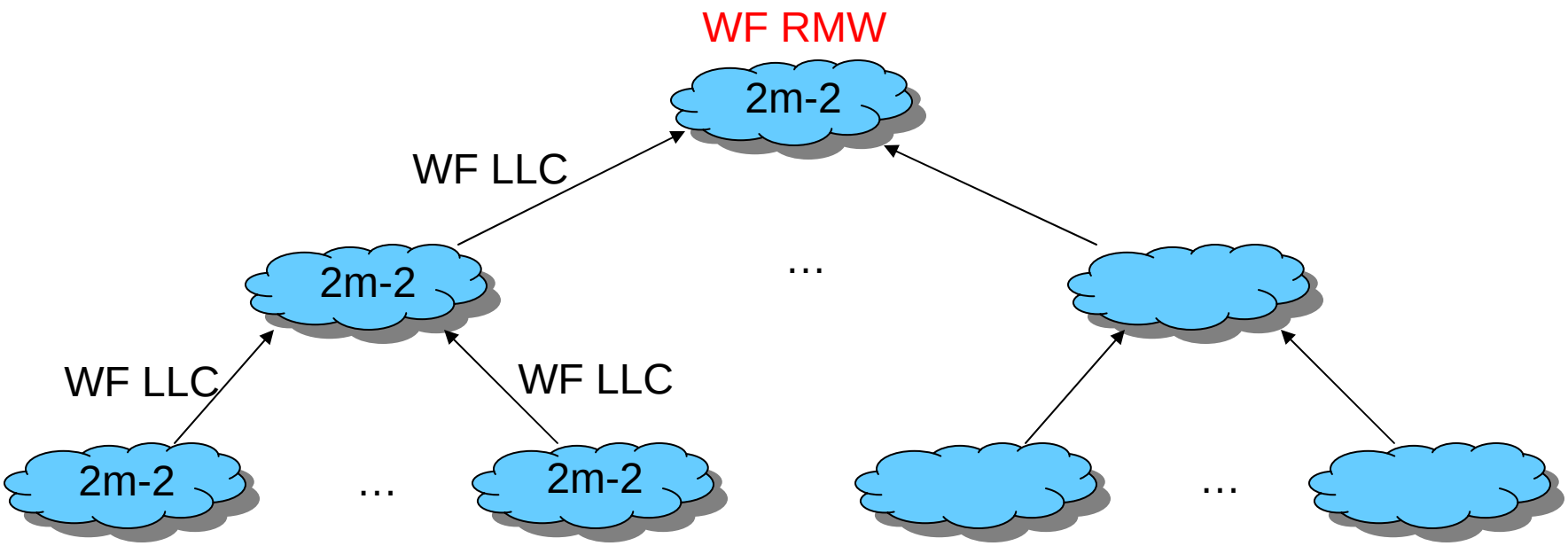
(2m-3)-resilient RMW

What if N > 2m-2?

WF LLC and WF RMW no longer work!

(2m-3)-resilient RMW: Key idea



- Balance tree with degree *(2m-2)*
- (2m-3)-resilient, the optimal [Chandra et al., SIAM J. Comput. '04]

Conclusions

- Design a set of universal synchronization objects for lock-free/wait-free programming on GPU
  - Wait-free long-lived (2m-2)-consensus using m-word assignment.
    - Time complexity: *O(N)* vs. $O(N^2)$ of the short-lived in [TOPLAS '91]
    - Space complexity: $O(N^2)$, the optimal.
  - Wait-free long-lived read-modify-write (RMW) objects for (2m-2) processes.
    - Time complexity *O(N)*.
    - Space complexity $O(N^2)$, the optimal.
  - (2m-3)-resilient long-lived RMW objects for any number of processes

Thank you for your attention!