Communication-Avoiding QR for Computer Vision

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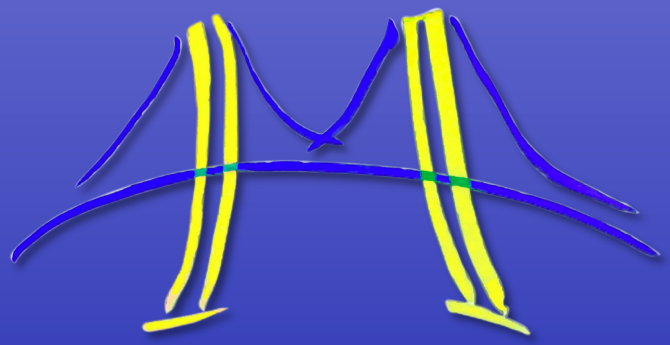
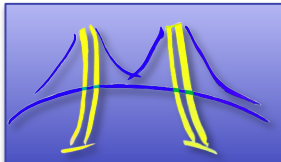




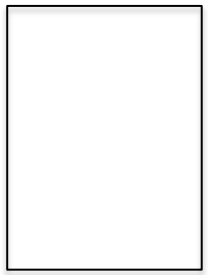
Introduction

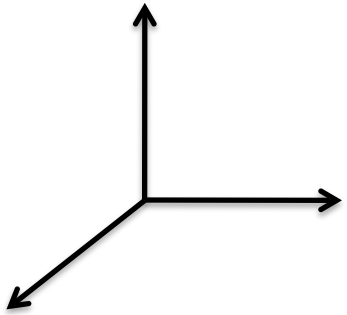
- The BEBOP group studies and designs cutting-edge parallel linear algebra algorithms
  - Communication-Avoiding QR
- The PALLAS group applies linear algebra to computer vision, to enable compelling applications
  - Robust video background subtraction
- Cutting-edge linear algebra enables cutting-edge computer vision!
  - (Cutting edge detection)

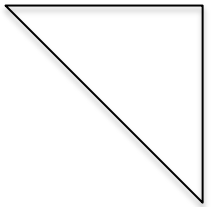
QR Decomposition

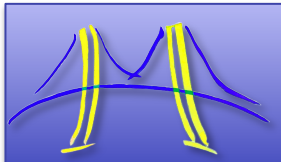
- Factor a matrix A into an orthogonal matrix Q, and an upper triangular matrix R

A = Q * R









Applications of QR

- Least squares → Linear Regression

```
>> [Q R] = qr(A, 0)
>> w = R\(Q'*b)
```

- Communication-avoiding Krylov methods → Sparse linear solvers
  - See Nick Knight's talk tomorrow
- Cleaning your room?

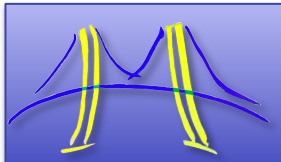
Cleaning Room with QR

After 30 QRs

After 70 QRs

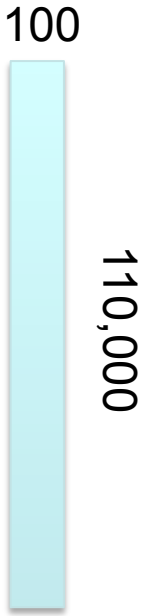
After 100 QRs

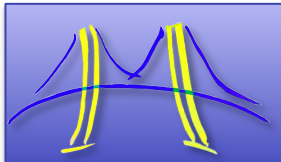
After 300 QRs



QR on Parallel Architectures

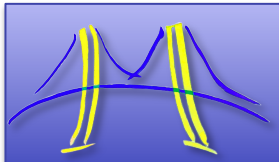
- "Isn't dense linear algebra on multicore/GPU a solved problem?"
  - NO!
- Consider QR decomposition of an entirely realistic tall-skinny matrix (e.g. 110000 x 100)
  - MAGMA (Fermi)
    - 12 Gflops. 0.9% of peak.
  - CULA (Fermi)
    - 5.1 Gflops. 0.4% of peak.
  - MKL (Dual Nehalem)
    - 15 Gflops. 10% of peak.





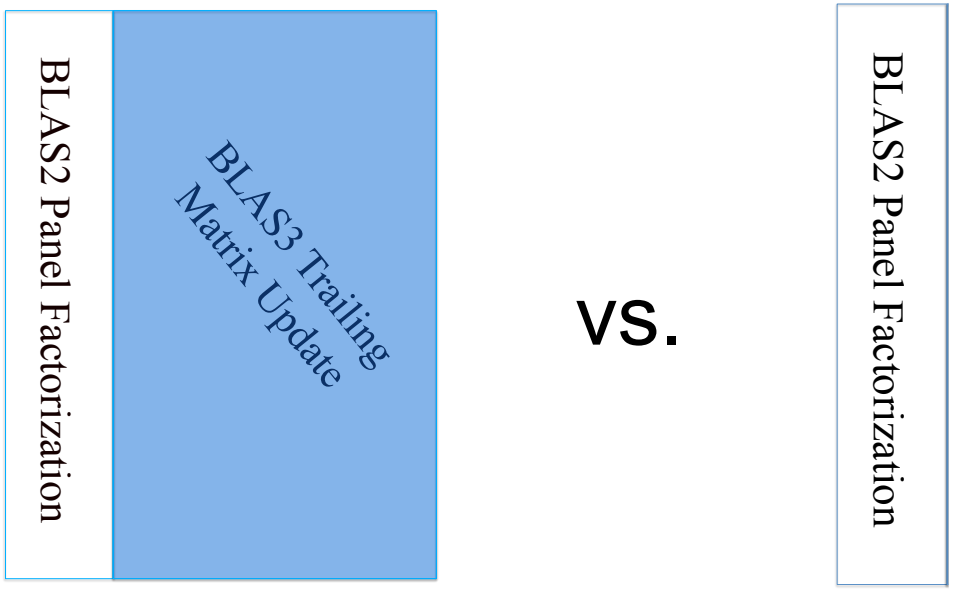
QR on Parallel Architectures

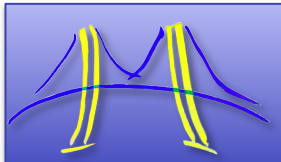
- Tall-skinny QR is actually common
  - Communication-avoiding Krylov methods
    - Dimension of sparse matrix (e.g. 1 million) x Number of steps (e.g. 10)
  - The “cleaning room” example (robust background subtraction)
    - Number of pixels (e.g. 110,000) x number of frames (e.g. 20)
  - Least squares
    - When the number of observations is much greater than the number of variables
    - e.g. Boston Housing Dataset is 506 houses x 14 variables



Householder Algorithm for QR

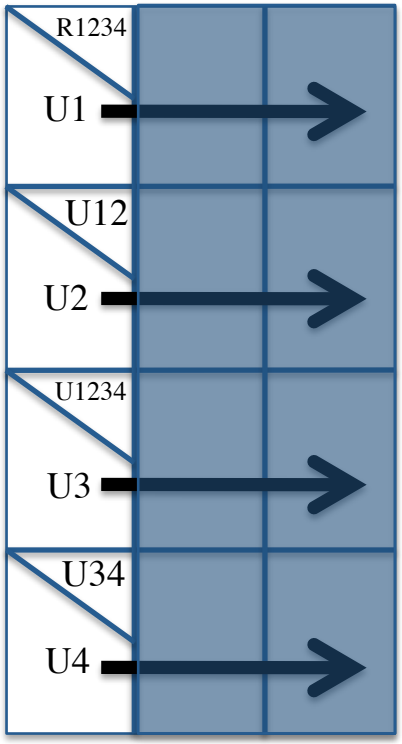
- Why is the tall-skinny case slow?
  - BLAS2 == Bandwidth Bound
  - "Communication" is heavy between DRAM and processor cores

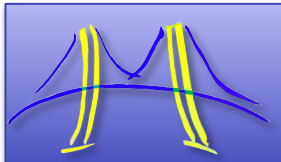




Communication-Avoiding QR

- Communication-Avoiding algorithm breaks the problem into small (cacheable) independent (parallel) problems
- Ideal for GPUs
- Communication-avoidance means fewer DRAM transfers
- Theoretically compute-bound



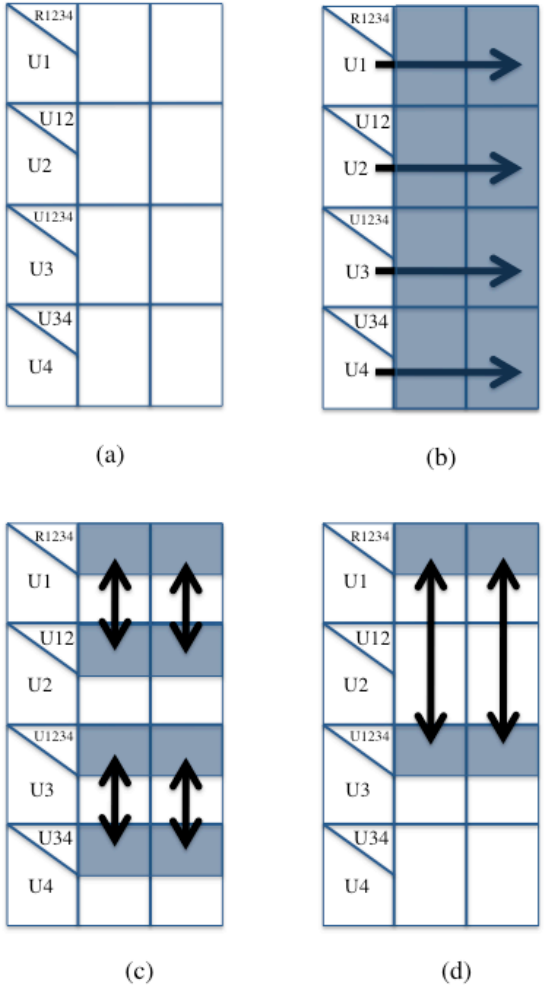


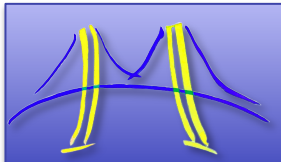
Why is this difficult on the GPU?

Must perform complete QRs within a thread block

Reduction tree must eliminate **irregular** triangles

Locations to be updated are **dispersed** throughout the matrix

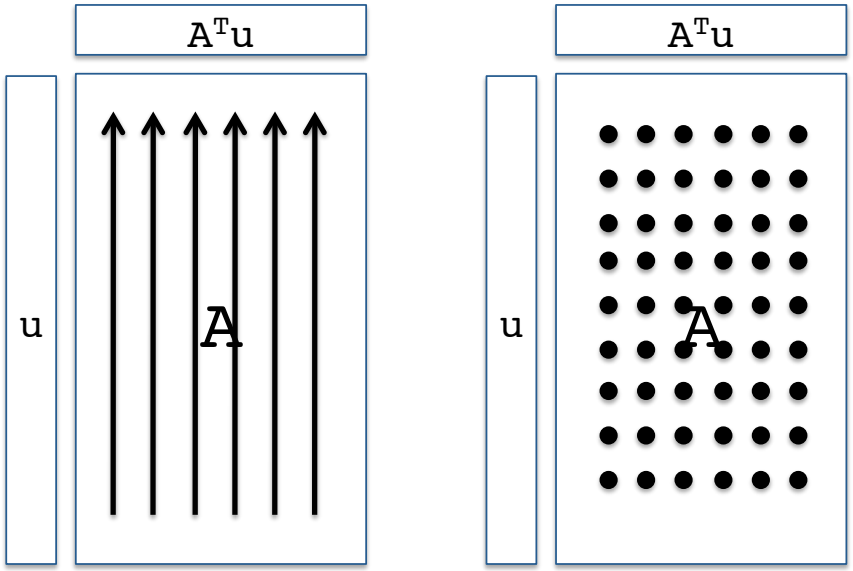




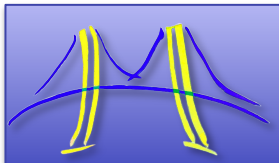
CAQR Autotuning

- Segmented reduction (matrix-vector multiply) and rank-1 update are the core computations
  - Referenced from all kernels
- Use this snippet to determine optimal block size

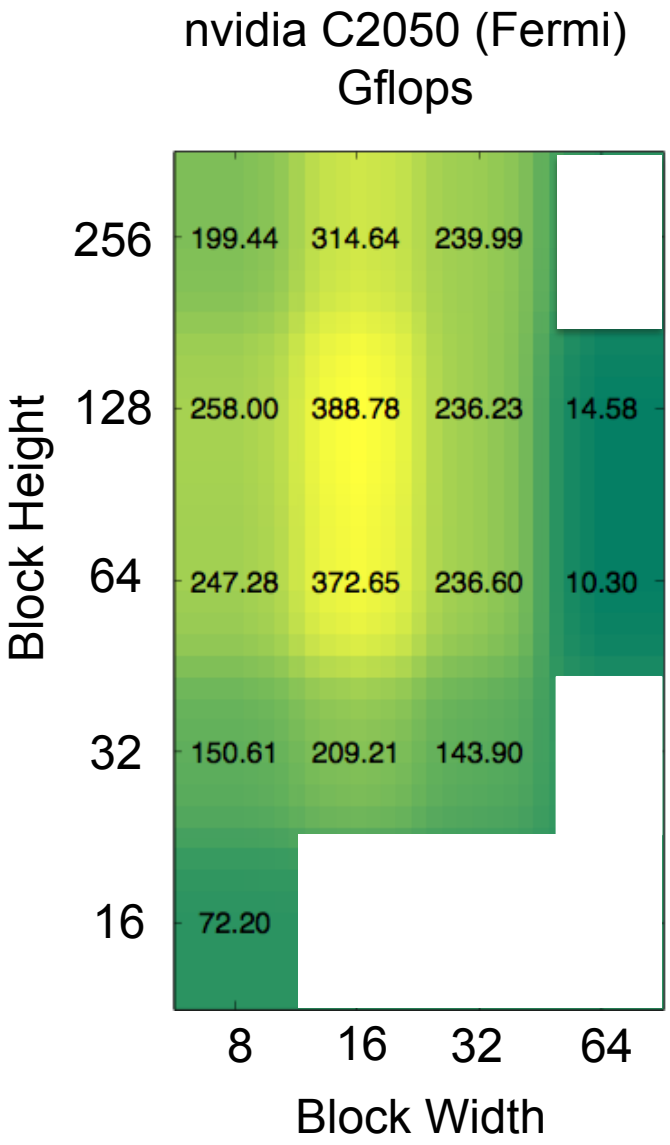
```
// For each Householder vector
 for(int j = 0 ; j < BLK_WIDTH; j++) {

   // Matrix-vector multiply
   real_t res = reduce(u_sh, col, av, tid_u, tid_l, tid);

   // Rank-1 update
   update(u_sh, col, res, tid_u);

   // Go to the next Householder vector
   u_sh += BLK_HEIGHT;
 }
```

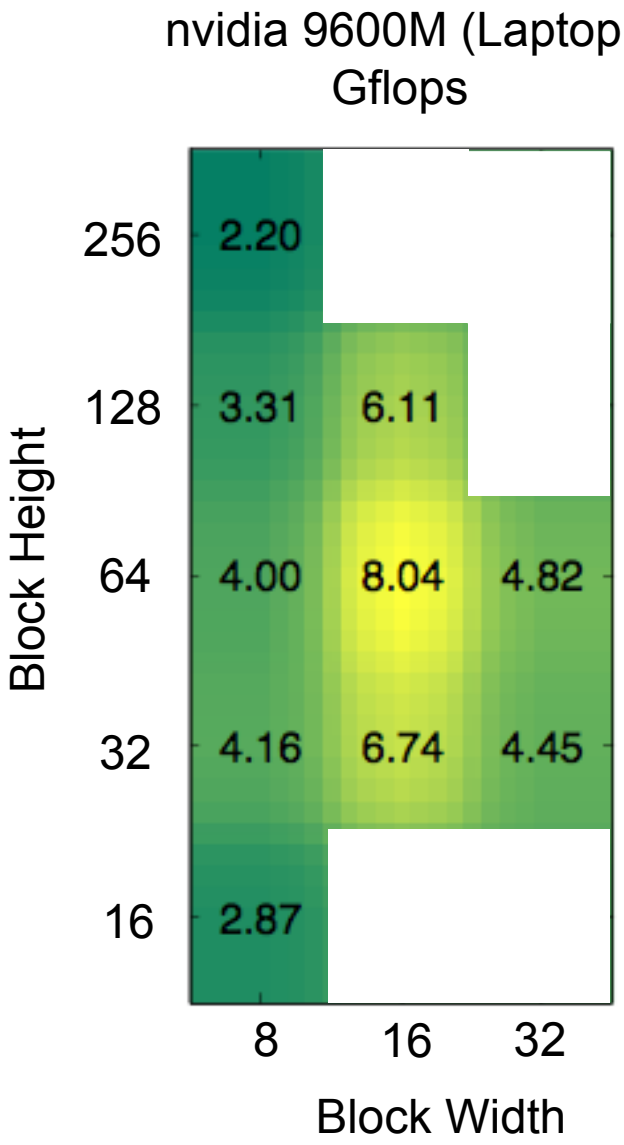


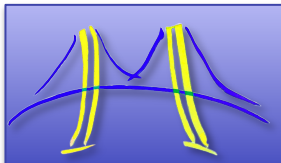
(a) (b)



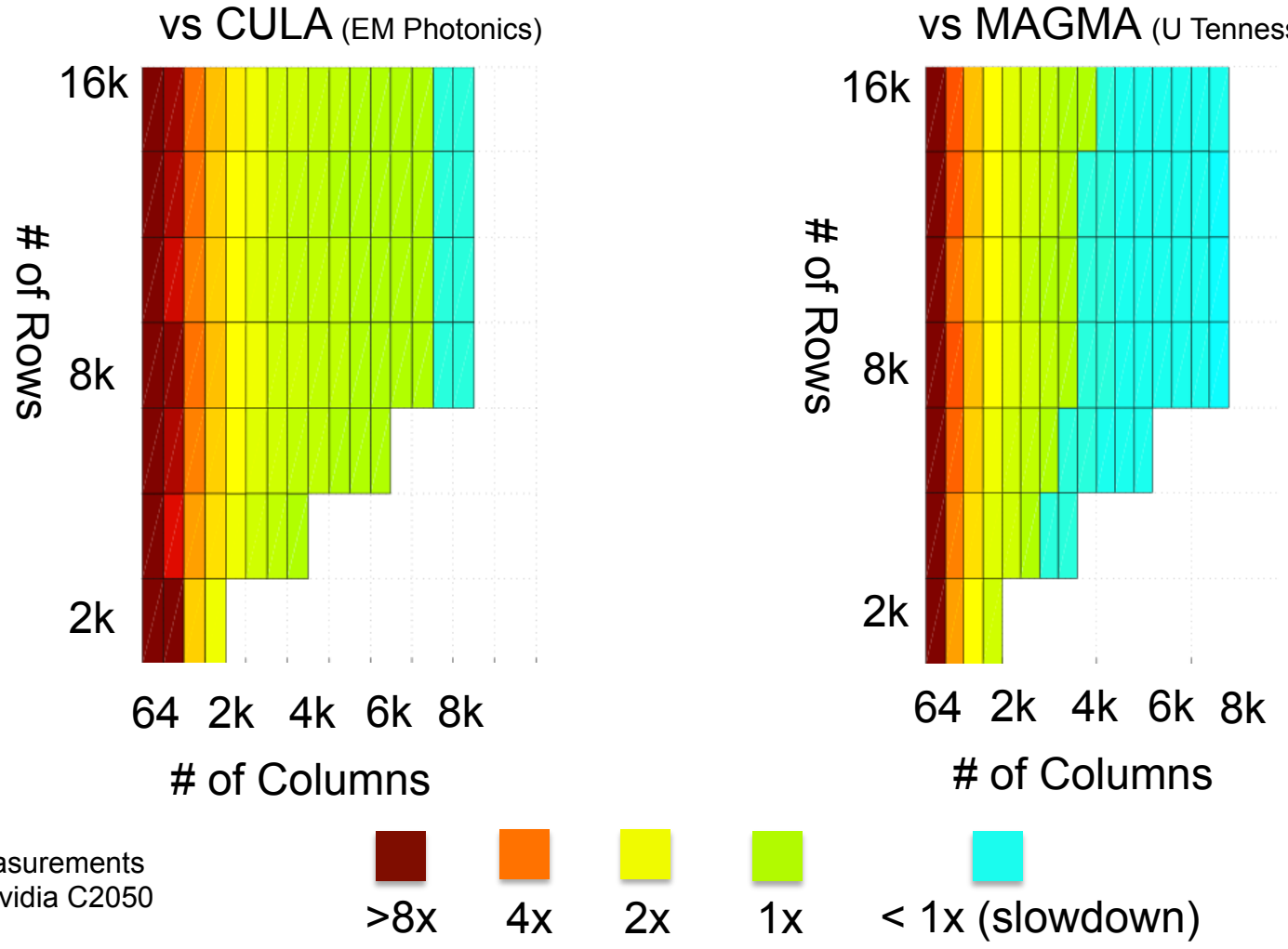
CAQR Autotuning



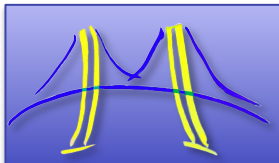




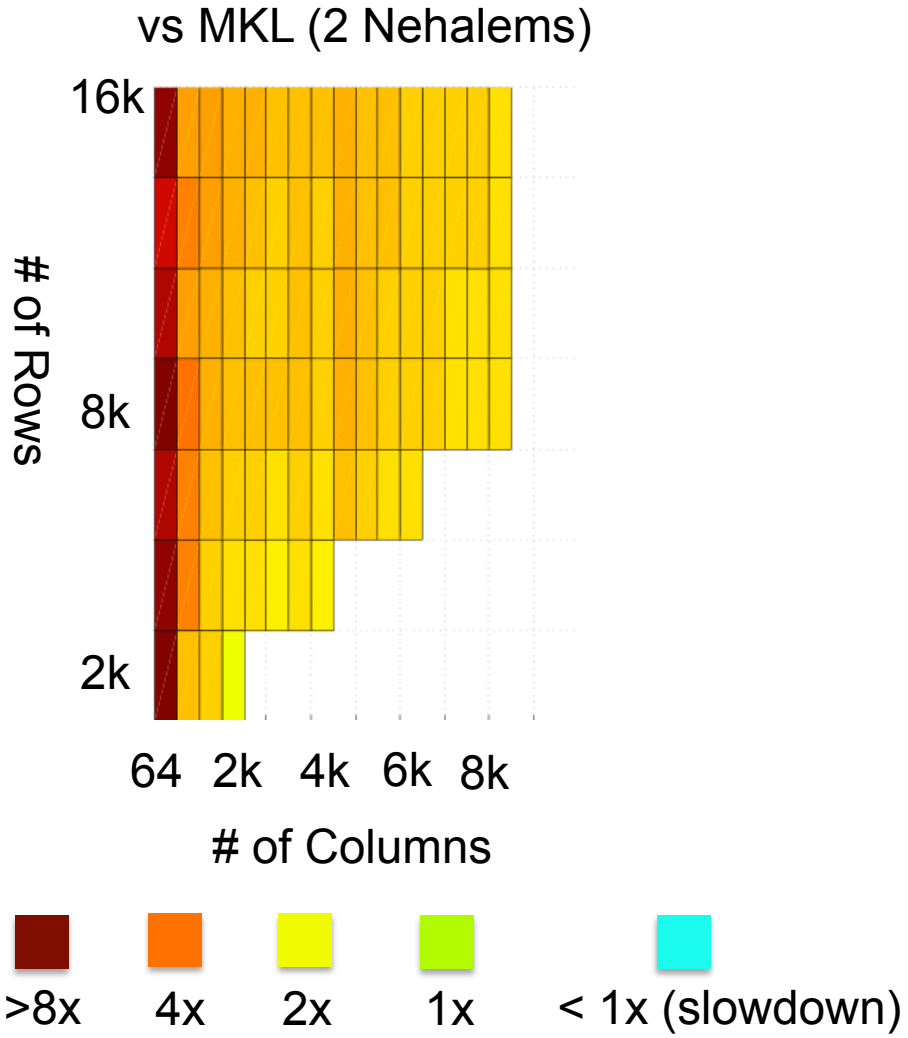
CAQR Speedup vs GPU Libraries



”Communication-Avoiding QR for GPUs" Anderson, Ballard, Demmel, Keutzer IEEE International Parallel & Distributed Processing Symposium, 2011



CAQR Speedup vs MKL



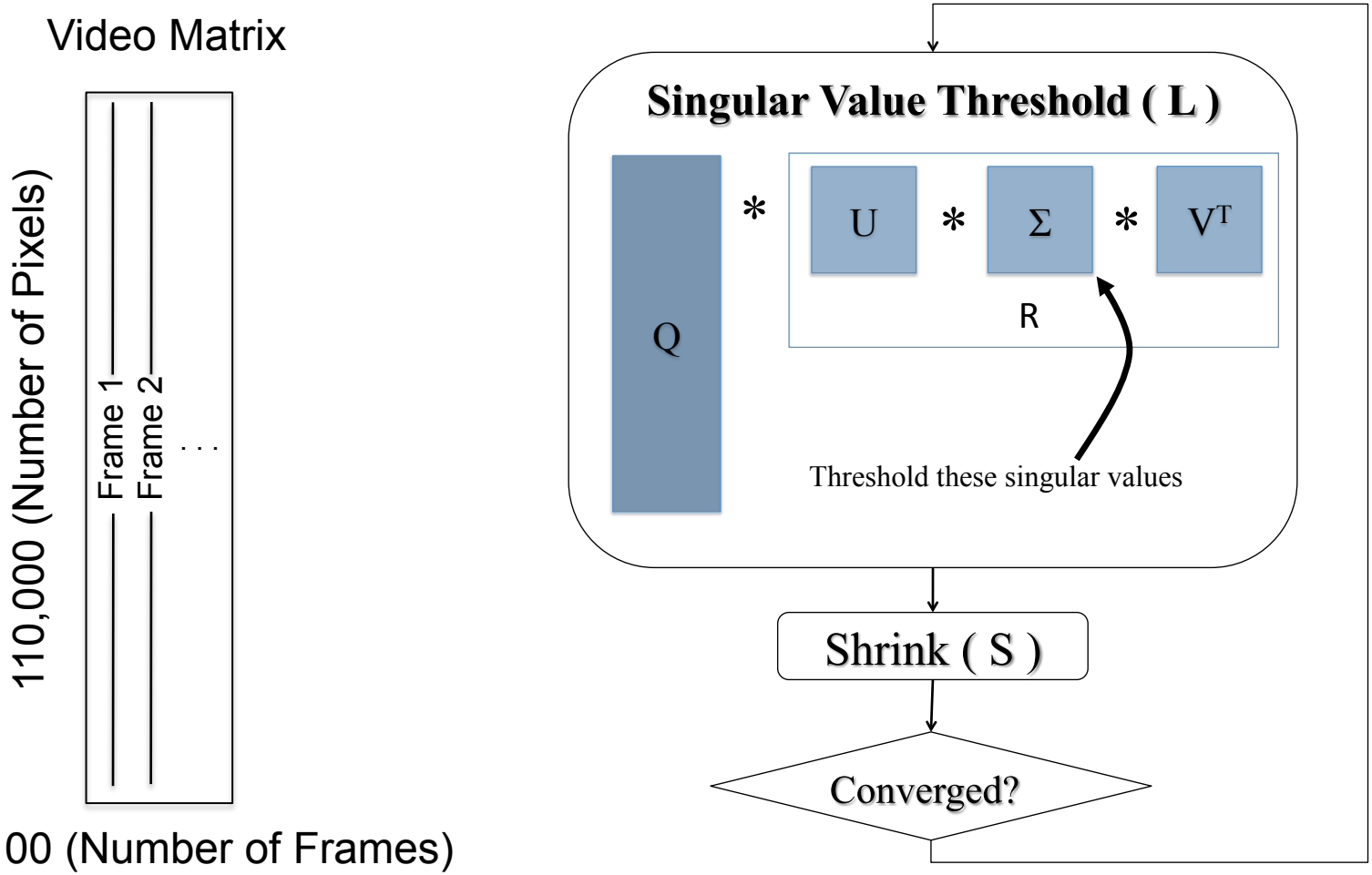
”Communication-Avoiding QR for GPUs" Anderson, Ballard, Demmel, Keutzer IEEE International Parallel & Distributed Processing Symposium, 2011

Robust Background Subtraction

- Decompose a video into a low-rank component (background) and a sparse component (foreground)
- Background is the *principal component*

From “Robust Principal Component Analysis?” by Emmanuel Candes et al

Robust Background Subtraction



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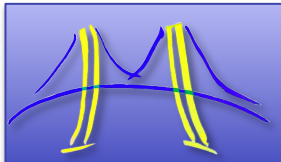
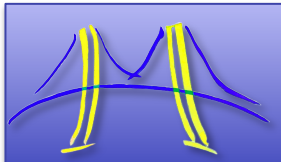


Robust Background Subtraction

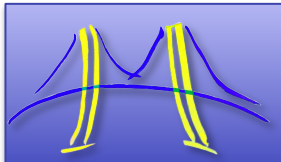
SVD type	Number of Iterations/Sec.
MKL SVD (4 cores)	0.9
BLAS2 QR (GTX480)	8.7
CAQR (GTX480)	27.0

- Tech Transfer: Others are using our QR software
  - *Y. Dong, G. N. DeSouza. "Adaptive learning of multi-subspace for foreground detection under illumination changes". Journal of Computer Vision and Image Understanding, 2010.* (Not in paper, but in future public releases)
  - Planning to integrate into Trilinos large-scale linear algebra library (Sandia)
  - Planning to integrate into MAGMA (U Tennessee)



Summary

- QR Decomposition is very useful
  - Least Squares, Communication-avoiding Krylov methods, surveillance video
- Communication-Avoiding QR is a great fit for GPU/ Multicore
  - Especially for tall-skinny matrices
  - Up to 13x faster than other **parallel** libraries
- Tall-skinny QR is at the core of robust video background subtraction
  - 30x speedup (parallel vs. parallel) for computer vision
- See our upcoming paper "Communication-Avoiding QR for GPUs" in IPDPS 2011



Thank You

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- Grey Ballard
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- Jim Demmel
- Kurt Keutzer
- This is just one small piece. See Nick Knight's talk tomorrow for more on Communication-Avoiding algorithms