NVIDIA CUDA Libraries

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San Jose Convention Center| Sept 22, 2010

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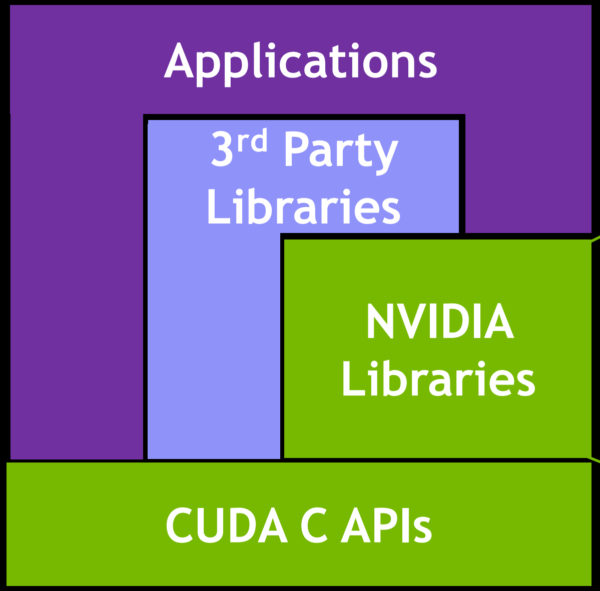
NVIDIA CUDA Libraries



- CUFFT
- CUBLAS
- CUSPARSE (Separate talk: Th 11AM)
- math.h
- CURAND
- NPP
- Thrust (Separate talks: Th 11AM, Th 2PM)
- CUSP

Goal: World Class Performance

- Accelerate building blocks required by algorithms widely used in GPU computing
  - Our team consists of algorithm experts and CUDA experts
- Heavily optimize the most commonly used routines
- Support all CUDA-capable hardware
  - Optimized libraries with hardware launch
- Incorporate best practices from the field
  - Published papers, open source software, academic partners, etc.

Further information

- http://www.nvidia.com/getcuda
- Questions can be posted to the "CUDA Programming and Development" Forum
  - http://forums.nvidia.com/index.php?showforum=71
- Directly approach our CUDA Library engineers right after this talk

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CUFFT Library

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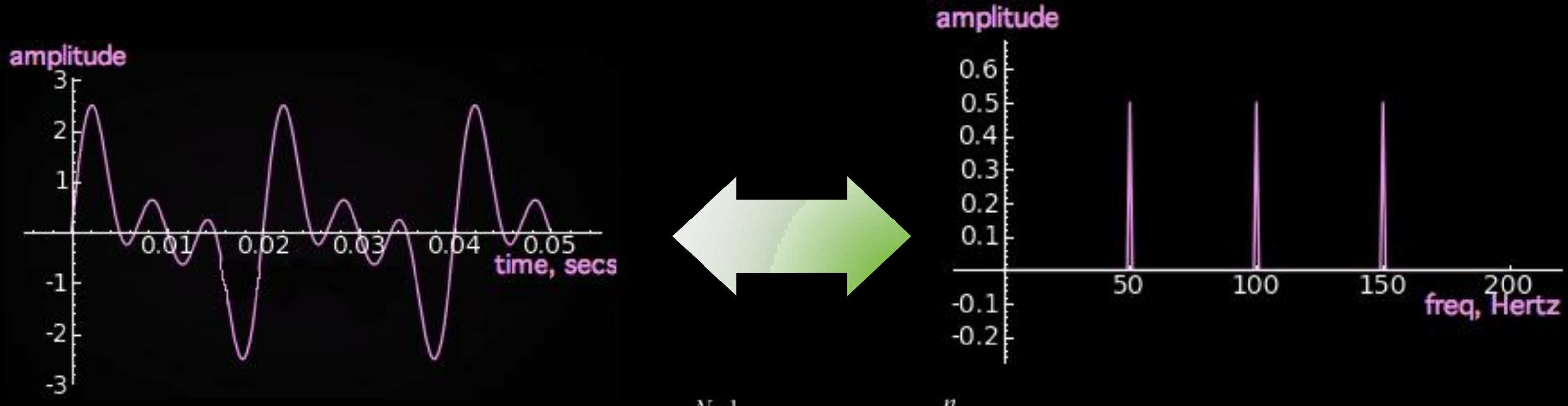
Introduction

NVIDIA CUDA Fast Fourier Transform Library is a GPU based FFT library computing parallel FFTs on NVIDIA GPUs.



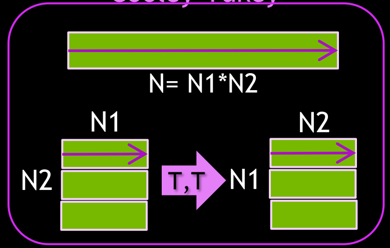
$$F(x) = \sum_{n=0}^{N-1} f(n) e^{-j2\pi(x\frac{n}{N})}$$

$$f(n) = \frac{1}{N} \sum_{n=0}^{N-1} F(x) e^{j2\pi(x\frac{n}{N})}$$

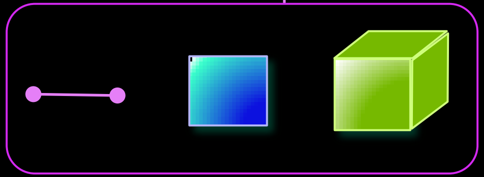
CUFFT Library Features

- Algorithms based on Cooley-Tukey and Bluestein
- Simple interface similar to FFTW
- Streamed asynchronous execution
- 1D, 2D and 3D transforms of complex and real data
- Double precision (DP) transforms
- 1D transform sizes up to 128 million elements
- Batch execution for doing multiple transforms
- In-place and out-of-place transforms

Cooley-Tukey



1D-2D-3D Complex/Real



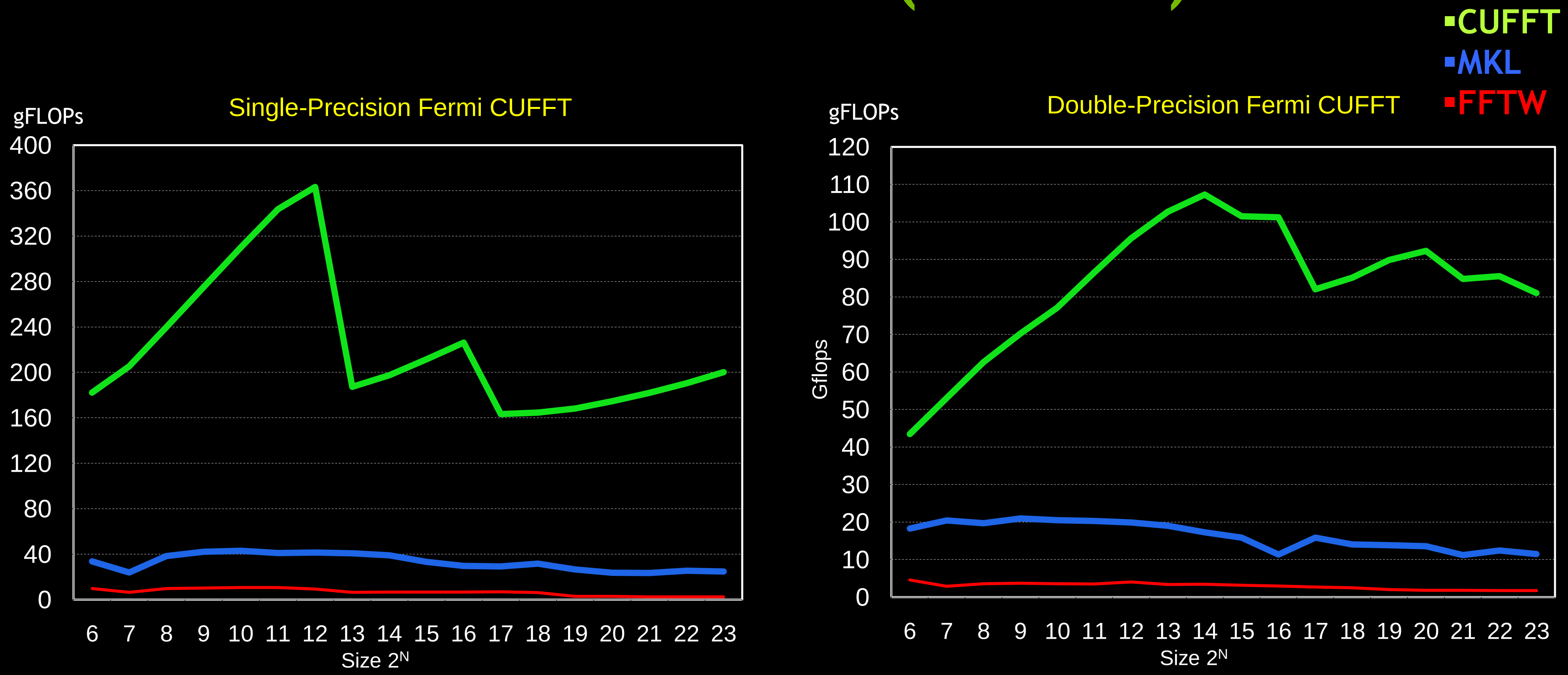
Use CUFFT in 3 easy steps

Step 1 –Allocate space on GPU memory

Step 2 – Create plan specifying transform configuration like the size and type (real, complex, 1D, 2D and so on).

Step 3 –Execute the plan as many times as required, providing the pointer to the GPU data created in Step 1.

Performance of Radix-2 (ECC on)



- Up to 8.8x performance advantage over MKL in both single- and double-precision

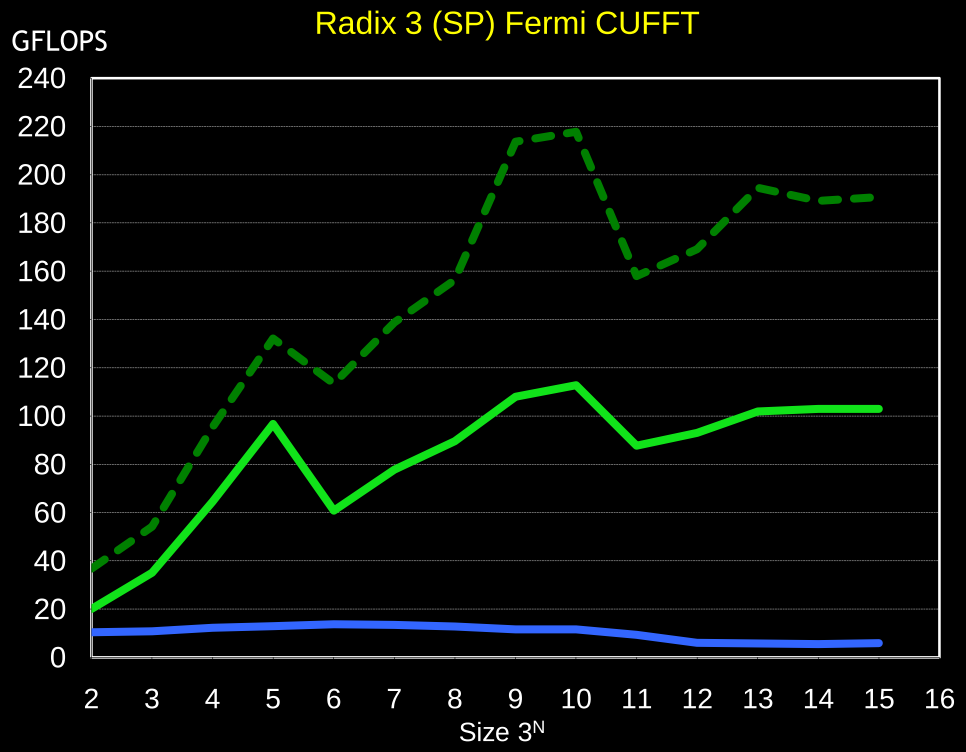
* MKL 10.1r1 on quad-Corei7 Nehalem @ 3.07GHz
* FFTW single-thread on same CPU
* CUFFT on Fermi C2050

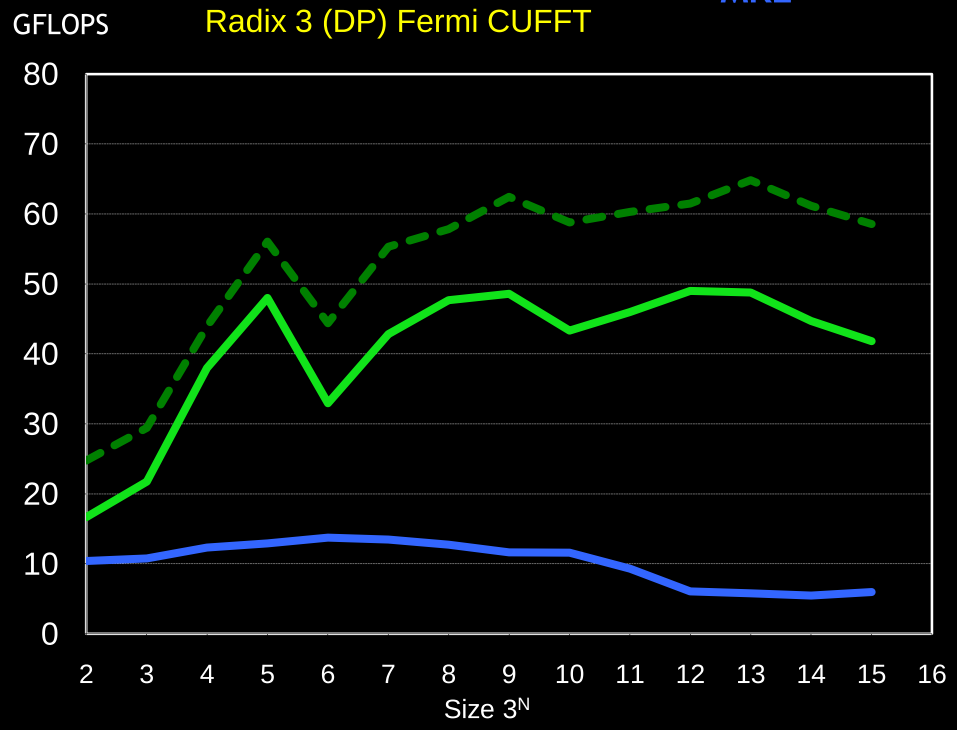
New in 3.2 Release

- Optimized performance of Radix-3, -5, and -7
  - Hence, acceleration of sizes $(2^a \cdot 3^b \cdot 5^c \cdot 7^d)$
- Bluestein algorithm improves performance and accuracy for large prime transform sizes
  - Up to 100,000x improvement in accuracy for large prime transforms
  - Motivated by customer request
- Support large batches up to the available GPU memory
  - i.e., up to 6GB on C2070

Radix-3 Performance in 3.2

-- CUFFT (ECC off)
▪ CUFFT (ECC on)
▪ MKL





- Up to 18x for single-precision and up to 15x for double-precision
- Similar acceleration for radix-5 and -7

* MKL 10.1r1 on quad-Corei7 Nehalem @ 3.07GHz
* FFTW single-thread on same CPU
* CUFFT on Fermi C2050

Future Releases of CUFFT

?

Multi-GPU scaling ?

Further performance improvements ?

. . .

Suggestions?

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CUBLAS Library

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Cublas Features

- Implementation of BLAS (Basic Linear Algebra Subprograms)
- CUBLAS first release in Toolkit2.0 in 2008
- Divided in three categories
  - Level1 (vector,vector):
    - AXPY : y = alpha.x + y
    - DOT : dot = x.y
  - Level 2(matrix,vector),
    - Vector multiplication by a General Matrix : GEMV
    - Triangular solver : TRSV
  - Level3(matrix,matrix)
    - General Matrix Multiplication : GEMM
    - Triangular Solver : TRSM

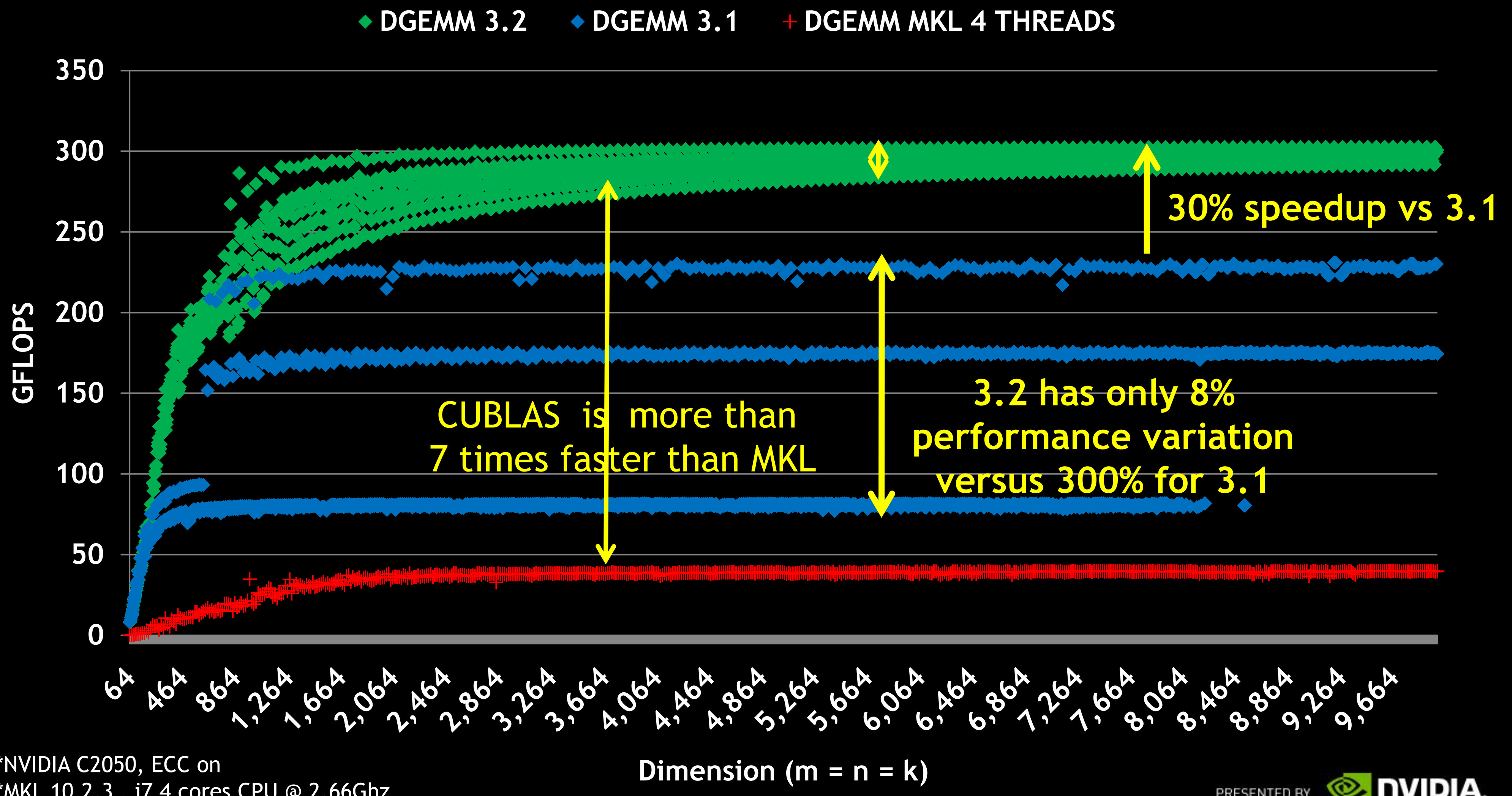
Cublas Features

- Support of 4 types :
  - Float, Double, Complex, Double Complex
  - Respective Prefixes : S, D, C, Z
- Example: SGEMM
  - S: single precision (float)
  - GE: general
  - M: multiplication
  - M: matrix output
- Contains 152 routines : S(37),D(37),C(41),Z(41)

CUBLAS Applications

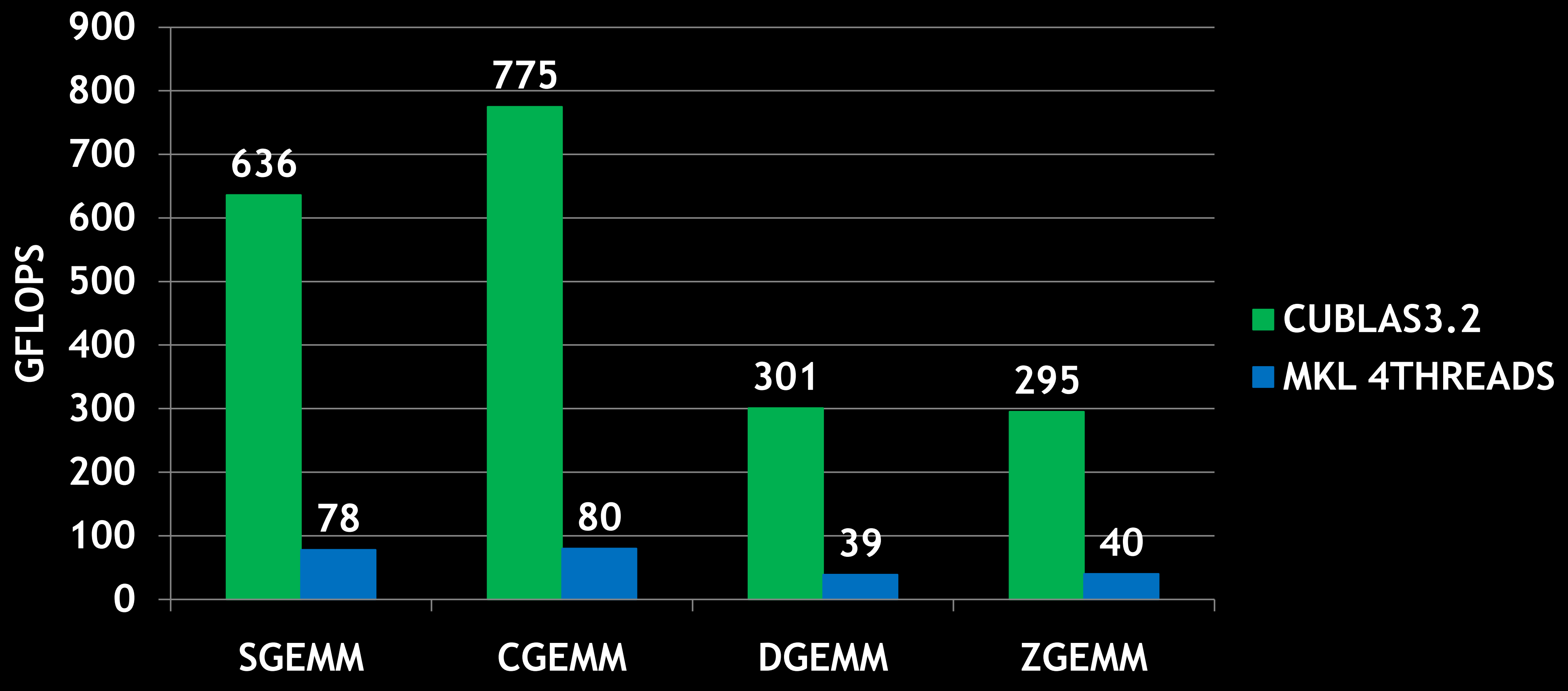
- Building block for CUDA port of LAPACK
  - CULA from EM Photonics
  - MAGMA from University of Tennessee
- MATLAB acceleration
  - Parallel Computing Toolbox from The Mathworks
  - Jacket from AccelerEyes
- ANSYS, CAE simulation software
- LS-DYNA, developed by Livermore Software Technology, FEA simulation

CUBLAS DGEMM Performance



*NVIDIA C2050, ECC on
*MKL 10.2.3 , i7 4 cores CPU @ 2.66Ghz

Performance GEMM summary



*NVIDIA C2050, ECC on
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Future plan

- Optimize TRSM, SYMM
- BLAS1 results returned in Device memory
- Scalar parameters alpha/beta passed by reference, residing on host or device memory.

- Looking for feedback on
  - Workloads that don't fit within a single GPU
  - Workloads that operate on small matrices

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CUDA math.h Library

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Features

math.h is industry proven, high performance, high accuracy

- C99 compatible math library, plus extras
- Basic ops: x+y, x*y, x/y, 1/x, sqrt(x), FMA (IEEE-754 accurate in single, double)
- Exponentials: exp, exp2, log, log2, log10, ...
- Trigonometry: sin, cos, tan, asin, acos, atan2, sinh, cosh, asinh, acosh, ...
- Special functions: lgamma, tgamma, erf, erfc
- Utility: fmod, remquo, modf, trunc, round, ceil, floor, fabs, ...
- Extras: rsqrt, rcbrt, exp10, sinpi, sincos, erfinv, erfcinv, ...

Improvements

- Continuous enhancements to performance and accuracy
- Changes based on customer feedback

CUDA 3.1 erfinvf (single precision)

accuracy

5.43 ulp → 2.69 ulp

performance

1.7x faster than CUDA 3.0

$$\mathrm{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

CUDA 3.2 1/x (double precision)

performance

1.8x faster than CUDA 3.1

CURAND Library

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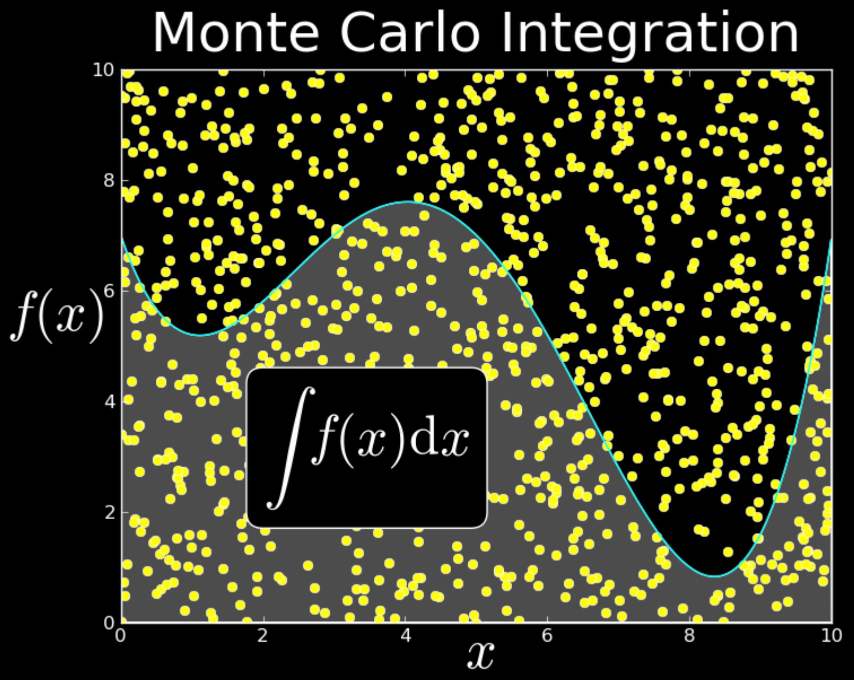
CURAND

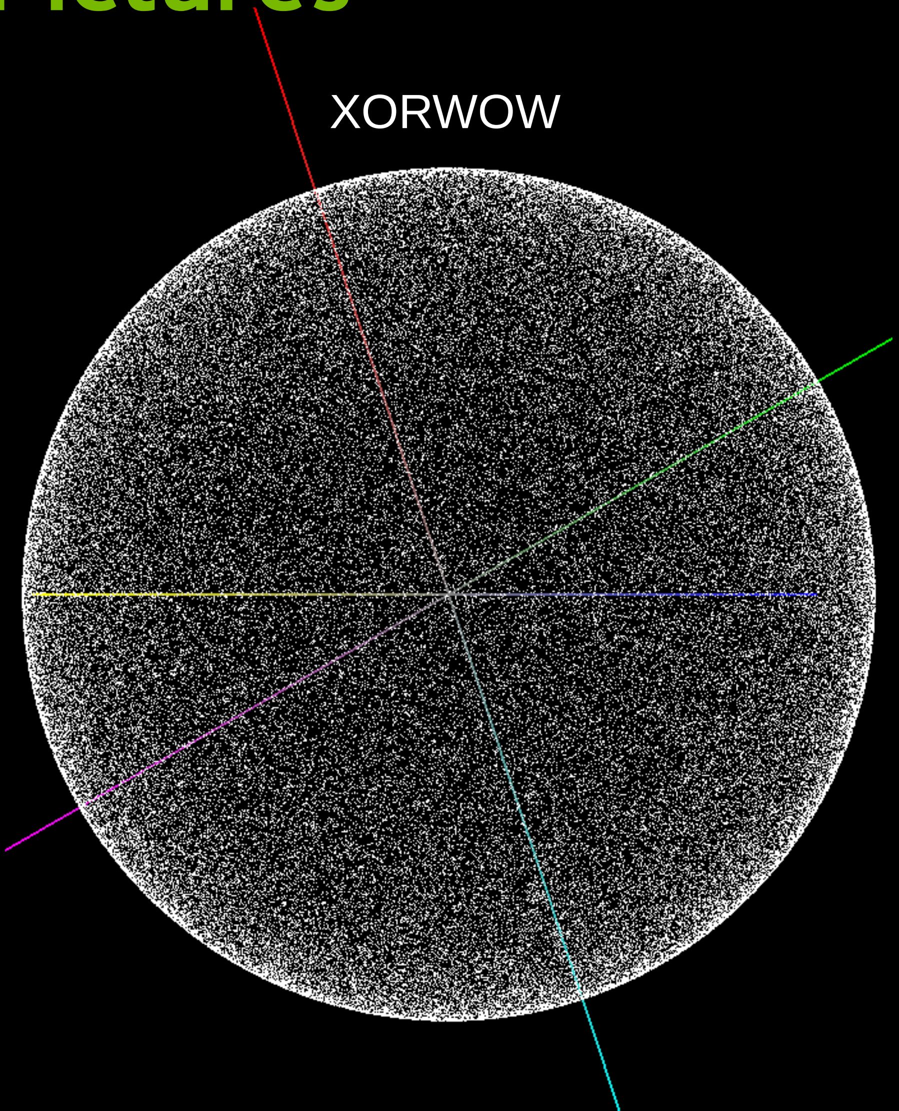
- New library for random number generation (CUDA 3.2)
- Applications
  - Physical sciences
    - particle physics
    - physical chemistry
  - Finance
    - risk analysis
    - derivatives pricing

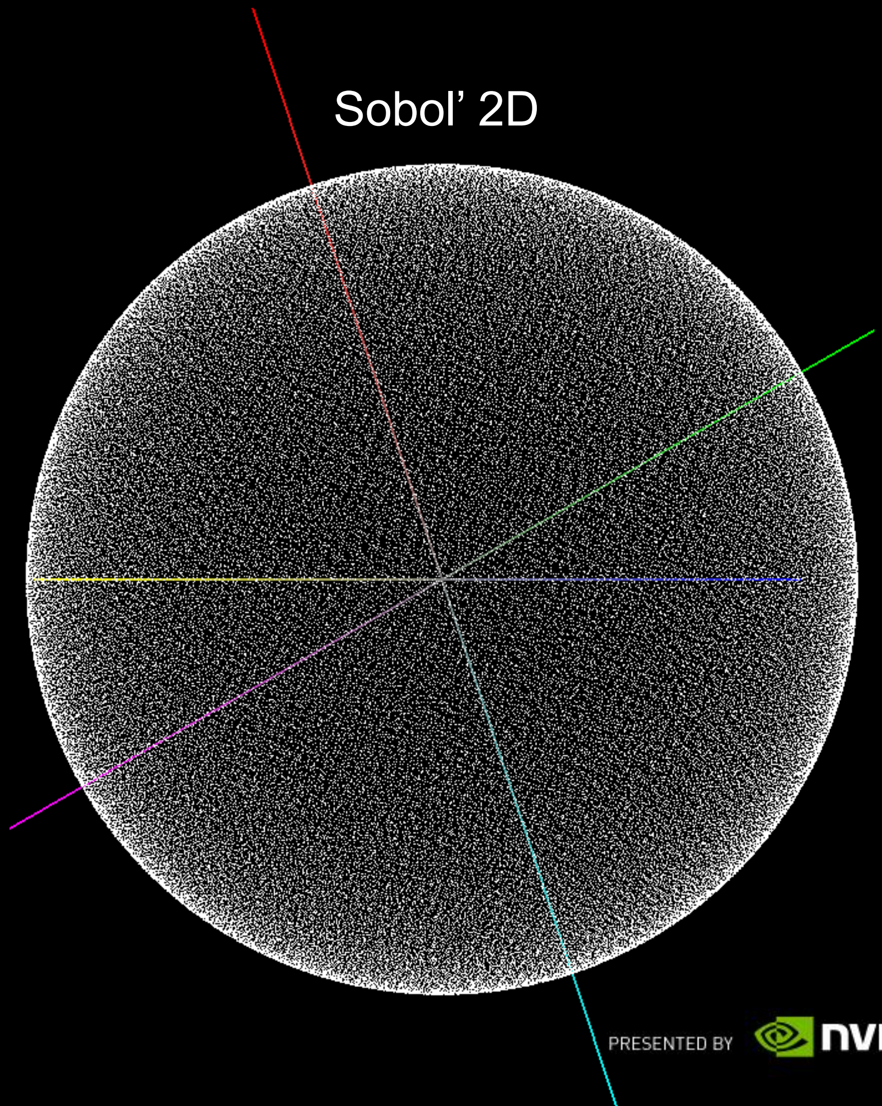


Features

- Library interface
  - Pseudorandom generation
  - Quasirandom generation
  - Bits, uniform, normal, floats, doubles
- Kernel interface
  - Inline generation, avoid memory altogether

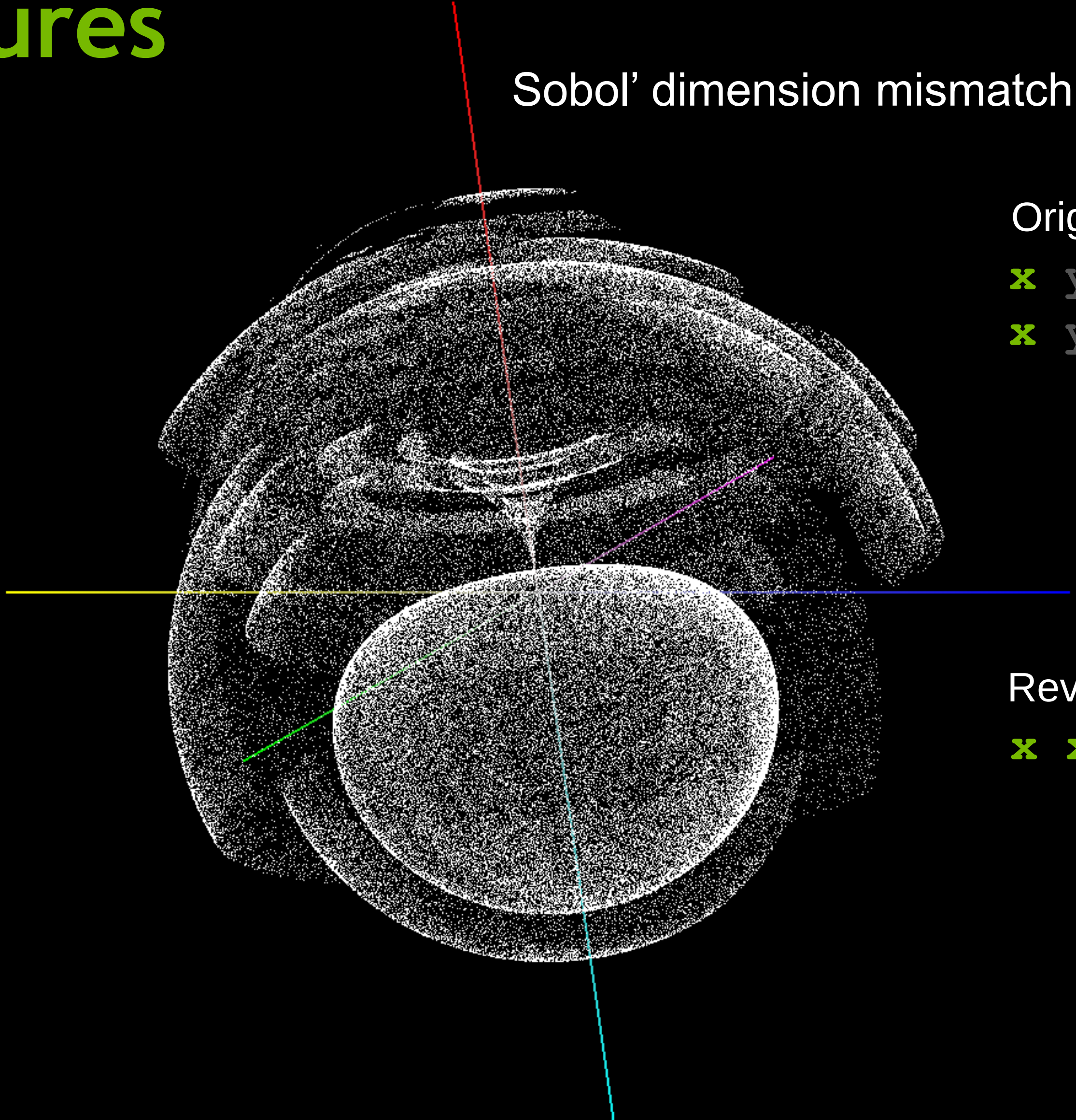
Pictures





Pictures

Sobol' dimension mismatch



Original memory layout

`x y x y x y x y x y x y`

`x y z x y z x y z x y z`

Revised memory layout

`x x x x x x y y y y y y`

XORWOW Pseudorandom Number Generator

Single thread

```
t = (x ^ (x >> 2));
x = y;
y = z;
z = w;
w = v;
v = (v ^ (v << 4)) ^
    (t ^ (t << 1));
d += 362437;
return d + v;
```

$$\begin{bmatrix} 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \mathrm{x}\langle 0 \rangle \\ \mathrm{x}\langle 1 \rangle \\ \mathrm{x}\langle 2 \rangle \\ \mathrm{x}\langle 3 \rangle \\ \mathrm{x}\langle 4 \rangle \end{bmatrix}$$

$$f^n(x) = A^n x$$

$$A^n \text{ is } O(\log n)$$

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XORWOW Pseudorandom Number Generator

Parallel threads

$$
\text{4096 threads} \left\{
\begin{array}{ccccc}
f^{0}(s_0) & \longrightarrow & f^{1}(s_0) & \longrightarrow & \ldots \\
f^{2^{1\cdot 67}}(s_0) & \longrightarrow & f^{2^{1\cdot 67}+1}(s_0) & \longrightarrow & \ldots \\
f^{2^{2\cdot 67}}(s_0) & \longrightarrow & f^{2^{2\cdot 67}+1}(s_0) & \longrightarrow & \ldots \\
\vdots & & \vdots & & \\
f^{2^{4095\cdot 67}}(s_0) & \longrightarrow & f^{2^{4095\cdot 67}+1}(s_0) & \longrightarrow & \ldots
\end{array}
\right.
$$

Customer Feedback To Drive New Features

Which ones do you want?

- More base generators
  - LCG, Mersenne Twister, rand48, ...
  - XOR-256

What's useful?

- More distributions
  - Log-normal, exponential, binomial, ...
- Performance optimizations

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NPP Library

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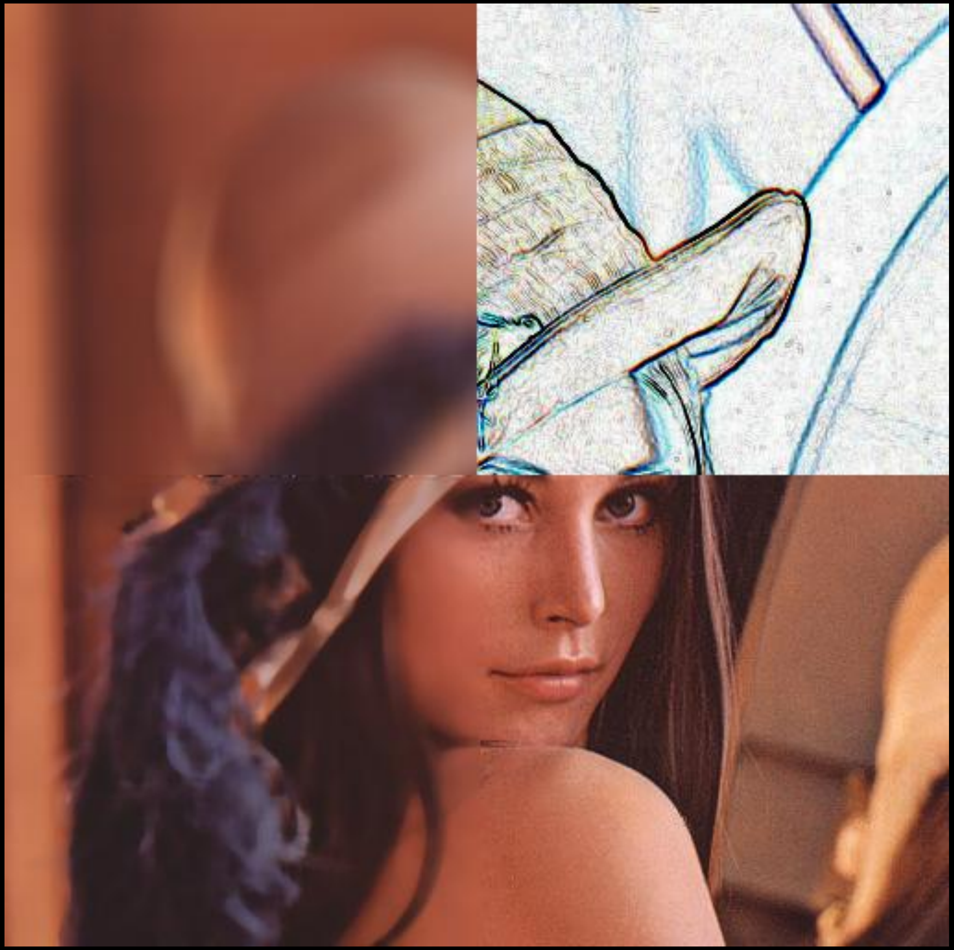
NVIDIA Performance Primitives (NPP)

- What is NPP?
- Performance
- Applications
- Roadmap



What is NPP?

- C library of functions (primitives)
  - well optimized
  - low level API:
    - easy integration into existing code
    - algorithmic building blocks
  - actual operations execute on CUDA GPUs
- Approximately 350 image processing functions
- Approximately 100 signal processing functions

Image Processing Primitives

- Data exchange & initialization
  - Set, Convert, CopyConstBorder, Copy, Transpose, SwapChannels
- Arithmetic & Logical Ops
  - Add, Sub, Mul, Div, AbsDiff
- Threshold & Compare Ops
  - Threshold, Compare
- Color Conversion
  - RGB To YCbCr (& vice versa), ColorTwist, LUT_Linear
- Filter Functions
  - FilterBox, Row, Column, Max, Min, Dilate, Erode, SumWindowColumn/Row
- Geometry Transforms
  - Resize , Mirror, WarpAffine/Back/Quad, WarpPerspective/Back/Quad
- Statistics
  - Mean, StdDev, NormDiff, MinMax, Histogram, SqrIntegral, RectStdDev
- Segmentation
  - Graph Cut

NPP Performance

- NPP vs highly optimized Intel CPU code (IPP)
- Majority of primitives 5x to 10x faster
- Up to 40x speedups
- HW:
  - GPU: NVIDIA Tesla C2050
  - CPU: Dual Socket Core™ i7 920 @ 2.67GHz

Applications

- NPP’s image processing primitives accelerate video or still-image processing tasks.

- AccelerEyes’ Matlab Plug-in:
  - “Jacket 1.4 provides direct access to the NVIDIA Performance Primitives or NPP enabling new Image Processing functionality such as ERODE and DILATE.”

NPP Roadmap

- NPP releases in lockstep with CUDA Toolkit:
  - grow number of primitives (data initialization, conversion, arithmetic, …)
  - complete support for all data types and broad set of image-channel configurations
  - Asynchronous operation support
- NPP 3.2 adds 167 new functions:
  - Mostly data-initialization/transfer and arithmetic
  - New basic signal processing

Additional Information

- On the web:
  - `developer.nvidia.com/npp`
- Feature requests:
  - `npp@nvidia.com`

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THANK YOU

Q&A Session