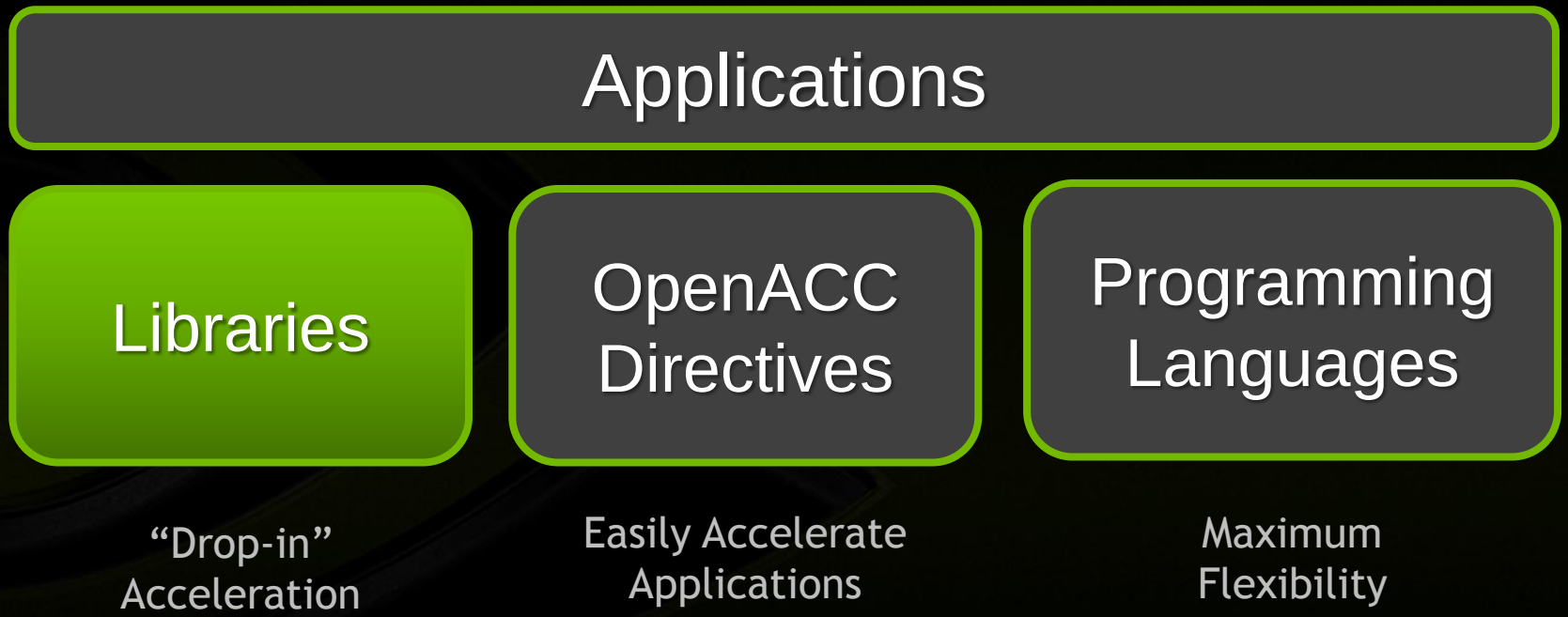
Fast GPU Development with CUDA Libraries

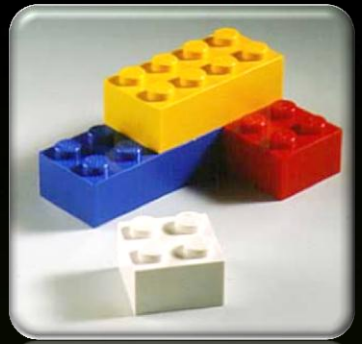
Levi Barnes

3 Ways to Accelerate Applications



NVIDIA CUDA Library Approach

- Provide basic building blocks
- Make them easy to use
- Make them fast



- Provides a quick path to GPU acceleration
- Enables developers to focus on their “secret sauce”
- Ideal for applications that use CPU libraries

CUDA Math Libraries

High performance math routines for your applications:

- **cuFFT – Fast Fourier Transforms Library**
- **cuBLAS – Complete BLAS Library**
- **cuSPARSE – Sparse Matrix Library**
- **cuRAND – Random Number Generation (RNG) Library**
- **NPP – Performance Primitives for Image & Video Processing**
- **Thrust – Templated C++ Parallel Algorithms & Data Structures**
- **math.h - C99 floating-point Library**

Included in the CUDA Toolkit

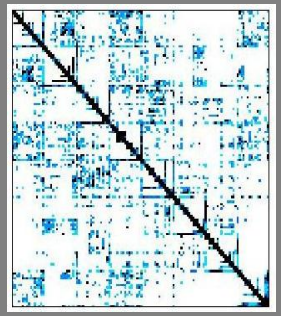
Free download @ www.nvidia.com/getcuda

Linear Algebra

Dense

cuBLAS

Sparse



cuSPARSE

Drop-In Acceleration

```
int N = 1 << 20;
```

```
// Perform SAXPY on 1M elements: y[]=a*x[]+y[]
saxpy(N, 2.0, d_x, 1, d_y, 1);
```

Drop-In Acceleration (Step 1)

```
int N = 1 << 20;
```

```
// Perform SAXPY on 1M elements: d_y[]=a*d_x[]+d_y[]
cublasSaxpy(N, 2.0, d_x, 1, d_y, 1);
```

Add “cublas” prefix and use device variables

Drop-In Acceleration (Step 2)

```
int N = 1 << 20;
cublasInit();
```

Initialize CUBLAS

```
// Perform SAXPY on 1M elements: d_y[]=a*d_x[]+d_y[]
cublasSaxpy(N, 2.0, d_x, 1, d_y, 1);
```

```
cublasShutdown();
```

Shut down CUBLAS

Drop-In Acceleration (Step 3)

```
int N = 1 << 20;
cublasInit();
cublasAlloc(N, sizeof(float), (void**)&d_x);
cublasAlloc(N, sizeof(float), (void*)&d_y);
```

Allocate device vectors

```
// Perform SAXPY on 1M elements: d_y[]=a*d_x[]+d_y[]
cublasSaxpy(N, 2.0, d_x, 1, d_y, 1);
```

```
cublasFree(d_x);
cublasFree(d_y);
cublasShutdown();
```

Deallocate device vectors

Drop-In Acceleration (Step 4)

```
int N = 1 << 20;
cublasInit();
cublasAlloc(N, sizeof(float), (void**)&d_x);
cublasAlloc(N, sizeof(float), (void**)&d_y);

cublasSetVector(N, sizeof(x[0]), x, 1, d_x, 1);
cublasSetVector(N, sizeof(y[0]), y, 1, d_y, 1);

// Perform SAXPY on 1M elements: d_y[]=a*d_x[]+d_y[]
cublasSaxpy(N, 2.0, d_x, 1, d_y, 1);

cublasGetVector(N, sizeof(y[0]), d_y, 1, y, 1);

cublasFree(d_x);
cublasFree(d_y);
cublasShutdown();
```

Transfer data to GPU

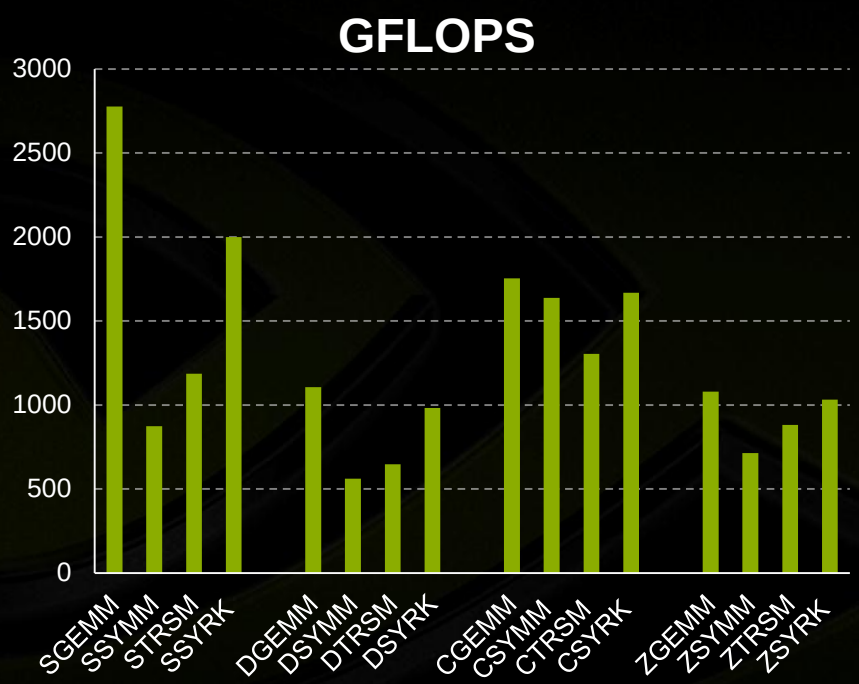
Read data back GPU

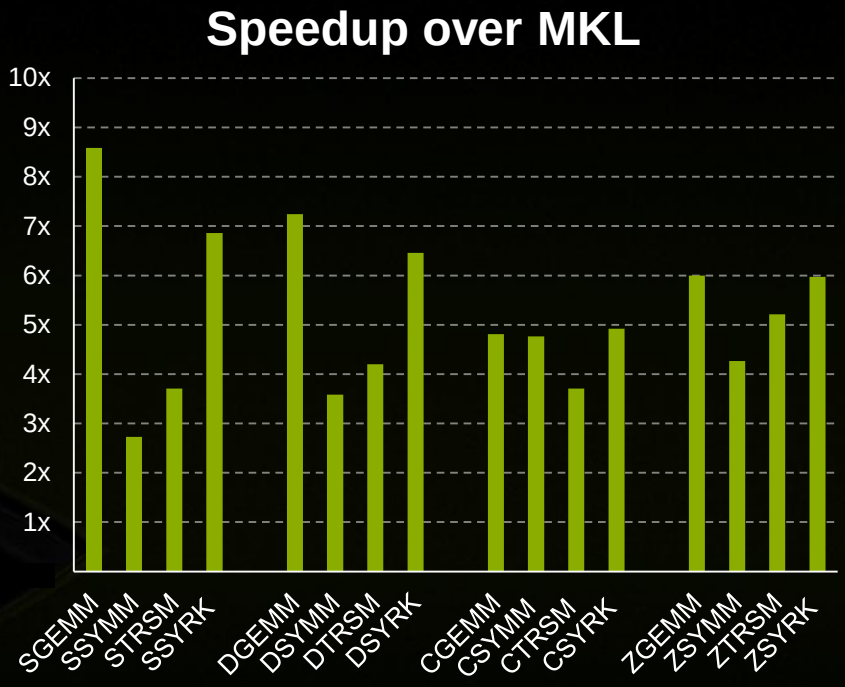
cuBLAS Interface

```
err = idamax(n, col, 1, size);

err = dscal(n, val, row, 1);

dgemm('N','N',m,n,k,A,m,
      B,k,0.0,C,m)
```

```
err = cublasIdamax(hdl, n, col, 1, size);

err = cublasDscal(hdl, n, val, row, 1);

cublasDgemm(hdl,'N','N',m,n,k,d_A,m,
      d_B,k,0.0,d_C,m)
```

cuBLAS Level 3: >1 TFLOPS double-precision





- MKL 10.3.6 on Intel SandyBridge E5-2687W @3.10GHz
- CUBLAS 5.0.30 on K20X, input and output data on device

GPU-Callable Libraries

New in CUDA 5.0

- **Call cuBLAS library function from GPU code**
- **Supported on K20 and K20x only**
- **Encourages third party libraries**

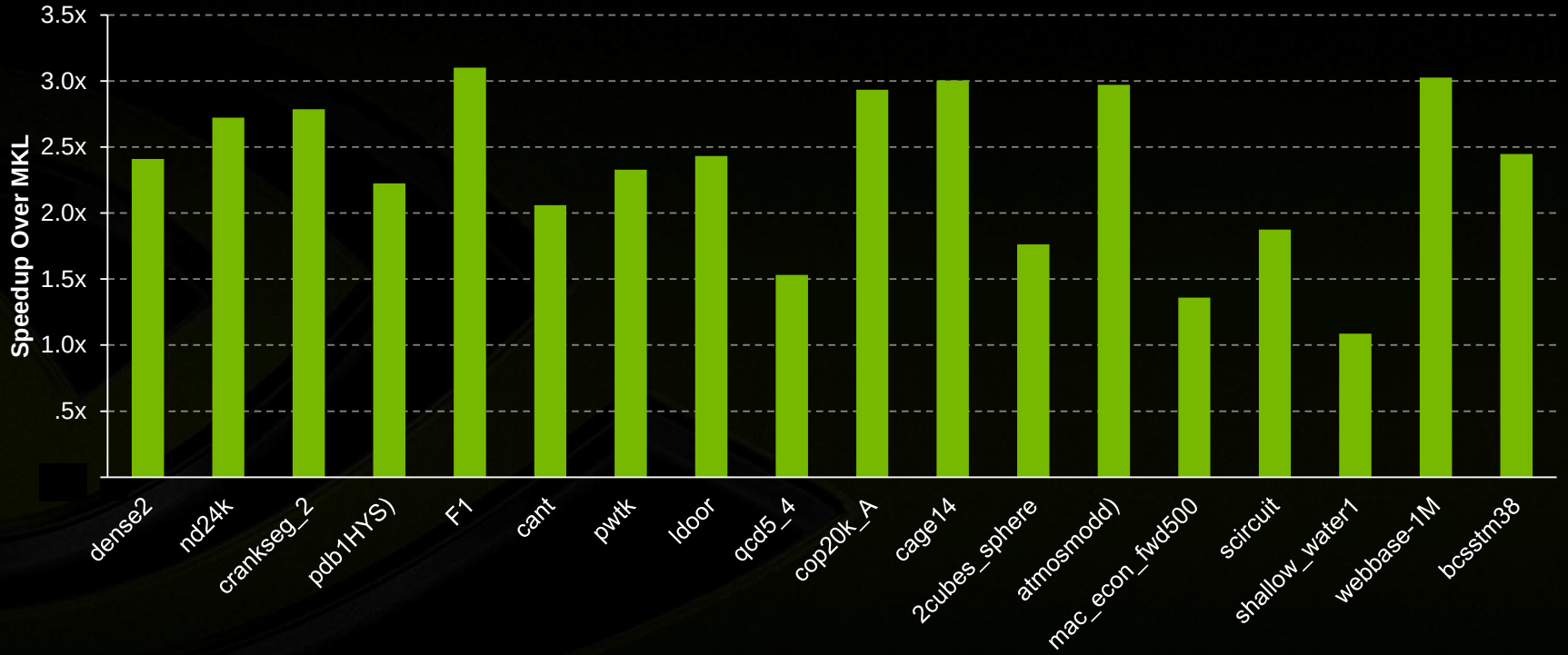
cuSPARSE Interface

```
mkl_dcsrmv(transa, m, k,
           alpha, descr,
           val, indx, pntrb, pntre,
           x, beta, y);
```

```
err = cusparseDcsrmv(hdl, transa, m, k,
                     nnz, alpha, desrc,
                     val, indx, col,
                     x, beta, y);
```

cuSPARSE performance

Sparse Matrix x Dense Vector

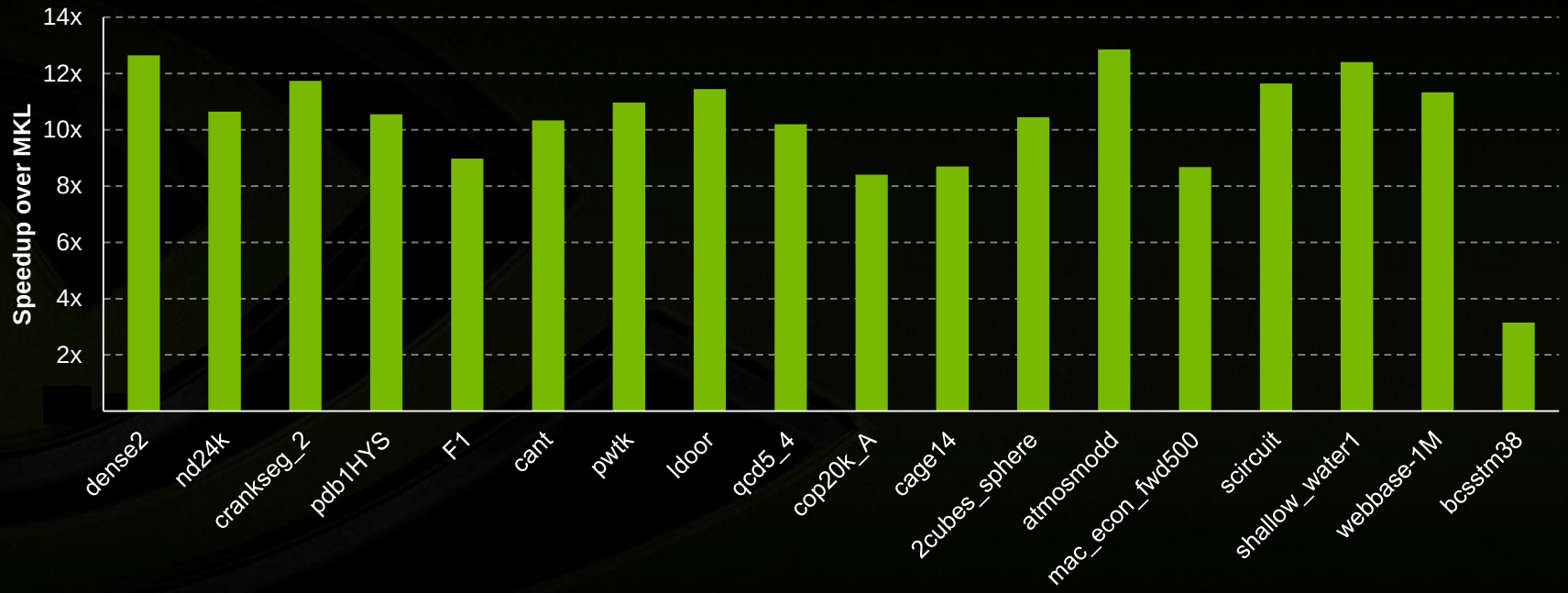


- Average of s/d/c/z routines
- cuSPARSE 5.0 on K20X, input and output data on device
- MKL 10.3.6 on Intel SandyBridge E5-2687W @ 3.10GHz

Performance may vary based on OS version and motherboard configuration

cuSPARSE: up to 12x Faster than MKL

Sparse Matrix x 6 Dense Vectors
(useful for block iterative solvers)



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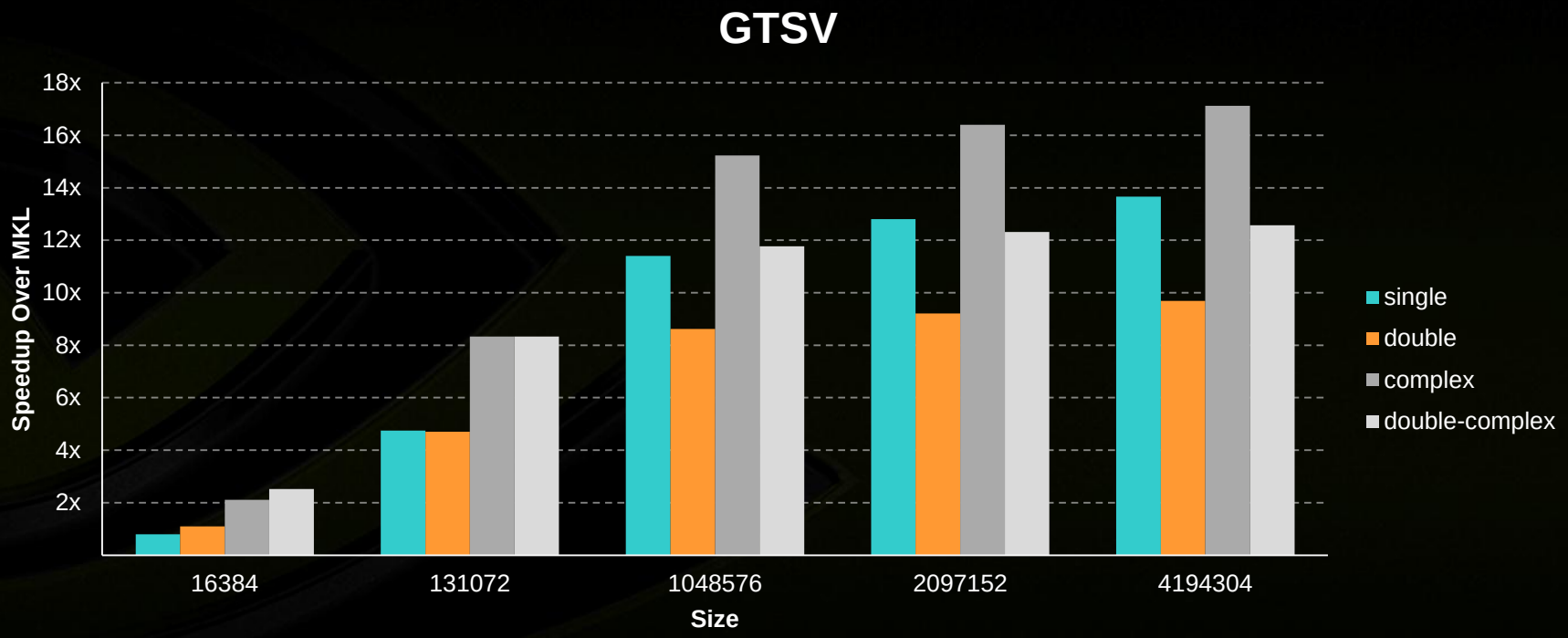
Tri-diagonal Solver Performance vs. MKL

Speedup for Tri-Diagonal solver (gtsv)



- cuSPARSE 5.0 on K20X, input and output data on device
- MKL 10.3.6 on Intel SandyBridge E5-2687W @ 3.10GHz

Performance may vary based on OS version and motherboard configuration

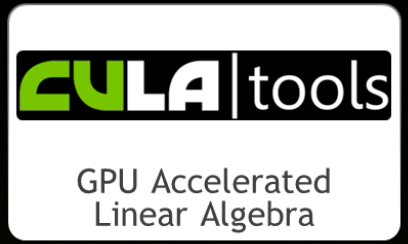
Different Approaches to Linear Algebra

- CULA tools (dense, sparse)
  - LAPACK based API
  - Solvers, Factorizations, Least Squares, SVD, Eigensolvers
  - Sparse: Krylov solvers, Preconditioners, support for various formats

```
culaSgetrf(M, N, A, LDA, IPIV, INFO)
```

- ArrayFire
  - Array container object
  - Solvers, Factorizations, SVD, Eigensolvers

```
array out = lu(A)
```



EM Photonics

AccelerEyes

Different Approaches to Linear Algebra (cont.)

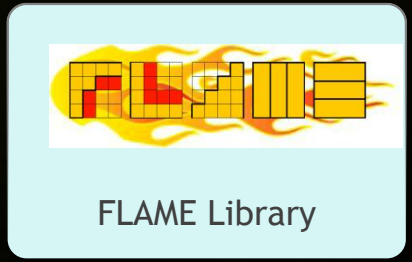
- MAGMA
  - LAPACK conforming API
  - Magma BLAS and LAPACK
  - High performance by utilizing both GPU and CPU

```
magma_sgetrf(M, N, A, LDA, IPIV, INFO)
```

ICL

- LibFlame
  - LAPACK compatibility interface
  - Infrastructure for rapid linear algebra algorithm development

```
FLASH_LU_piv(A, p)
```

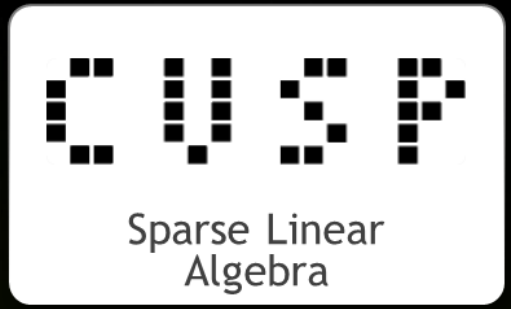


UT-Austin

Different Approaches to Linear Algebra (cont.)

- CUSP
  - Sparse matrix operations
  - Open source
  - Supports COO, CSR, ELL, DIA, hybrid, etc.
  - Solvers, monitors, preconditioners, etc.

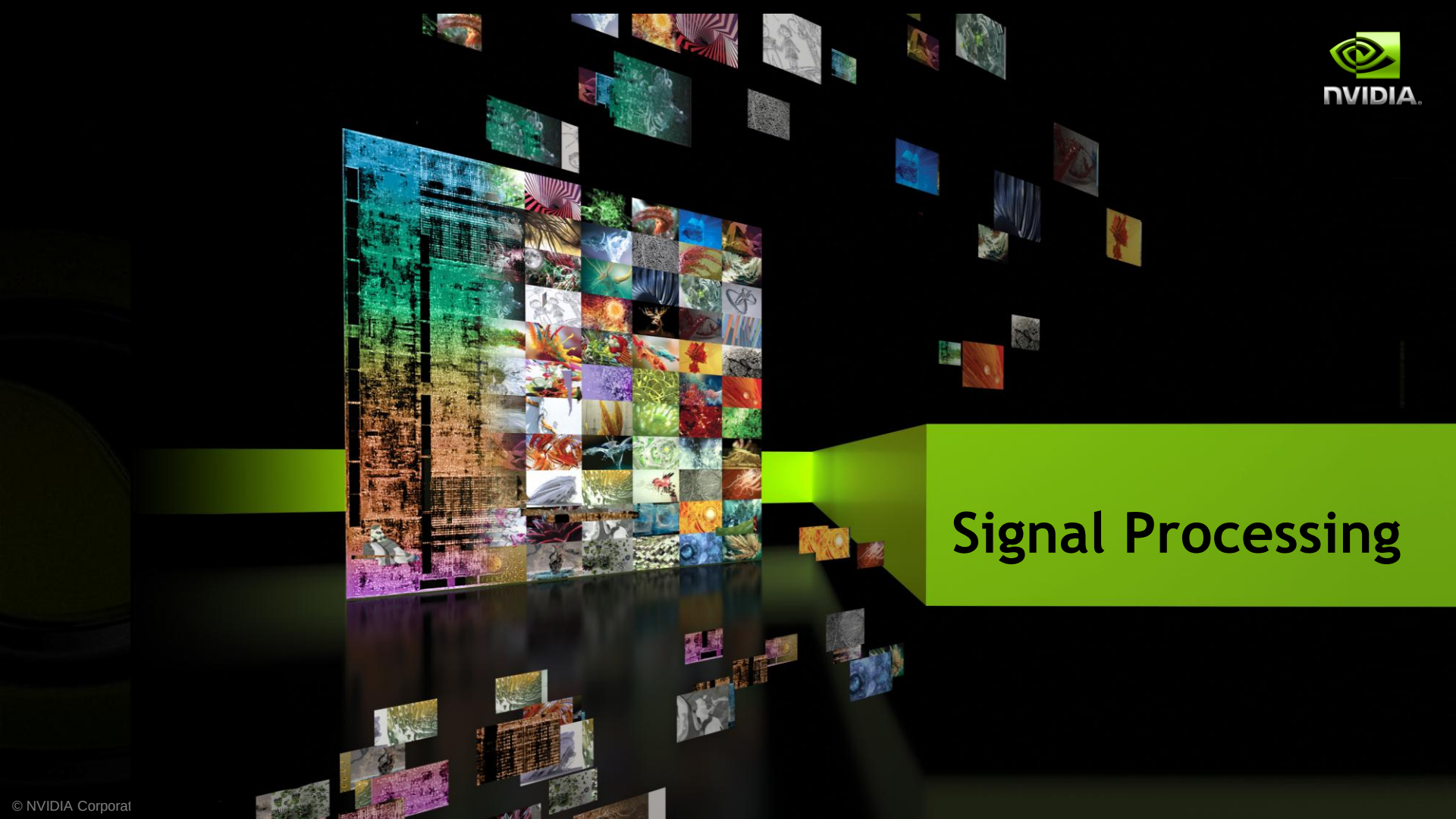
```
cusp::krylov::cg(A, x, b);
```



Toolkits are increasingly supporting GPUs

- PETSc
  - GPU support via extension to Vec and Mat classes
  - Partially dependent on CUSP
  - MPI parallel, GPU accelerated solvers

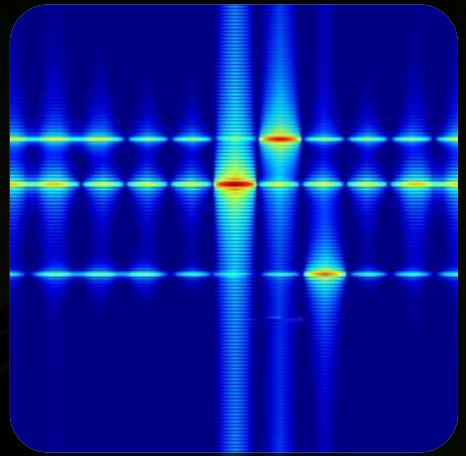
- Trilinos
  - GPU support in KOKKOS package
  - Used through vector class Tpetra
  - MPI parallel, GPU accelerated solvers



Common Tasks in Signal Processing

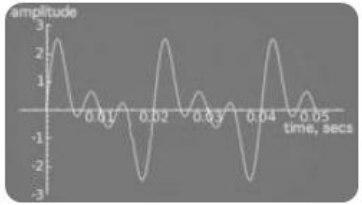
Filtering

Correlation



Segmentation

Libraries for GPU Accelerated Signal Processing



NVIDIA cuFFT

NVIDIA NPP

GPU VSIPL

Vector Signal Image Processing

MATLAB

Parallel Computing Toolbox

ArrayFire Matrix Computations

GPULib

GPU Accelerated Data Analysis

cuFFT

- Interface modeled after FFTW

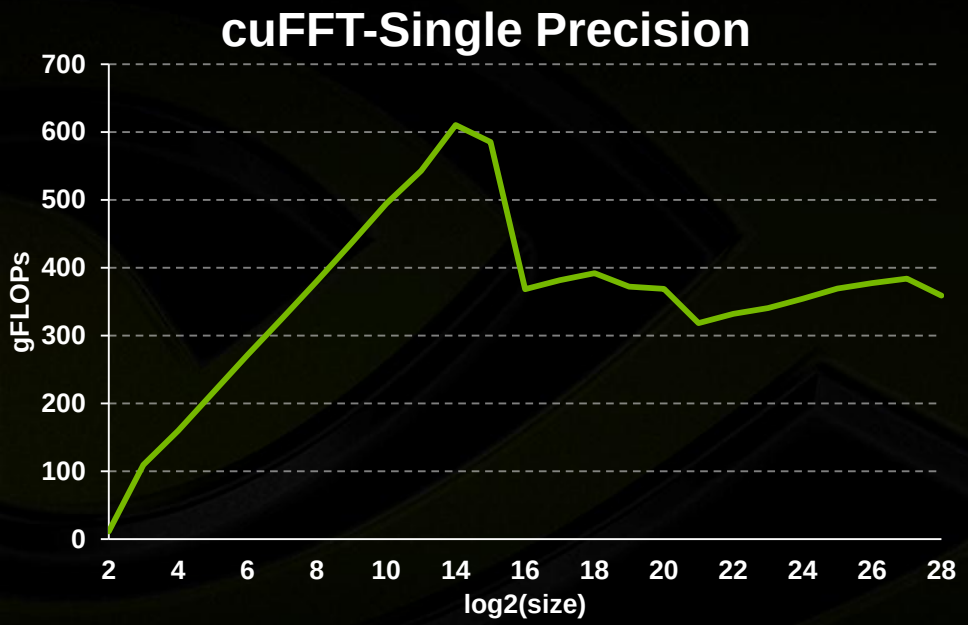
```
fftw_plan PlanA;

fftw_plan_dft_2d(N, M, &PlanA,
        data, data, FFT_FORWARD)

fftw_execute_dft(PlanA, data,
                 data);
```

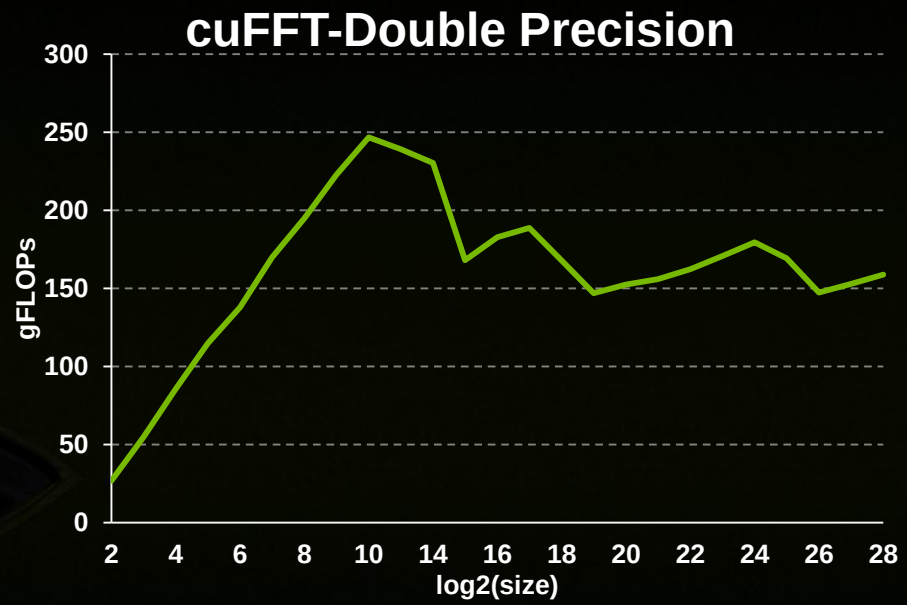
```
cufftPlan2d PlanA;

cufftCreatePlan(N, M, &PlanA, CUFFT_C2C);

cufftExecC2C(PlanA, d_data, d_data,
             CUFFT_FORWARD);
```

- Supports streams and batching (2 and 3-D, too!) for better performance

CUFFT: up to 600 GFLOPS

1D used in audio processing and as a foundation for 2D and 3D FFTs





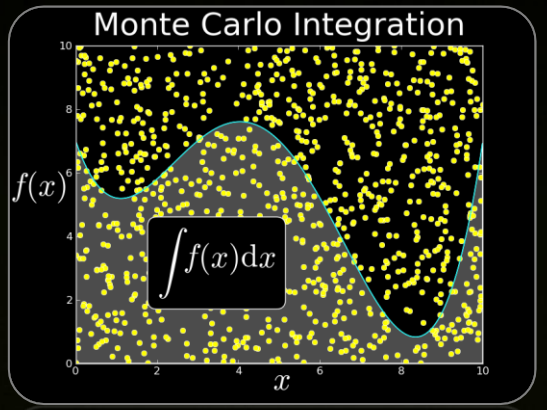
- CUFFT 5.0.30 on K20X, input and output data on device

NPP features a large set of functions

- Arithmetic and Logical Operations
  - Point-by-point ops, clamp, threshold, etc.
- Geometric transformations
  - Rotate, Warp, Interpolate
- Compression
  - jpeg de/compression
- Image processing
  - Filter, histogram, statistics

Random Number Generation on GPU

- Generating high quality random numbers in parallel is hard
  - Don’t do it yourself, use a library!
- Large suite of generators and distributions
  - XORWOW, MRG323ka, MTGP32, (scrambled) Sobol
  - uniform, normal, log-normal
  - Single and double precision



- Two APIs for cuRAND
  - Called from CPU: Ideal when generating large batches of RNGs on GPU
  - Called from GPU: Ideal when RNGs need to be generated inside a kernel

cuRAND: Host vs Device API

- CPU API

```
#include “curand.h”
curandCreateGenerator(&gen, CURAND_RNG_PSEUDO_DEFAULT);
curandGenerateUniform(gen, d_data, n);
```

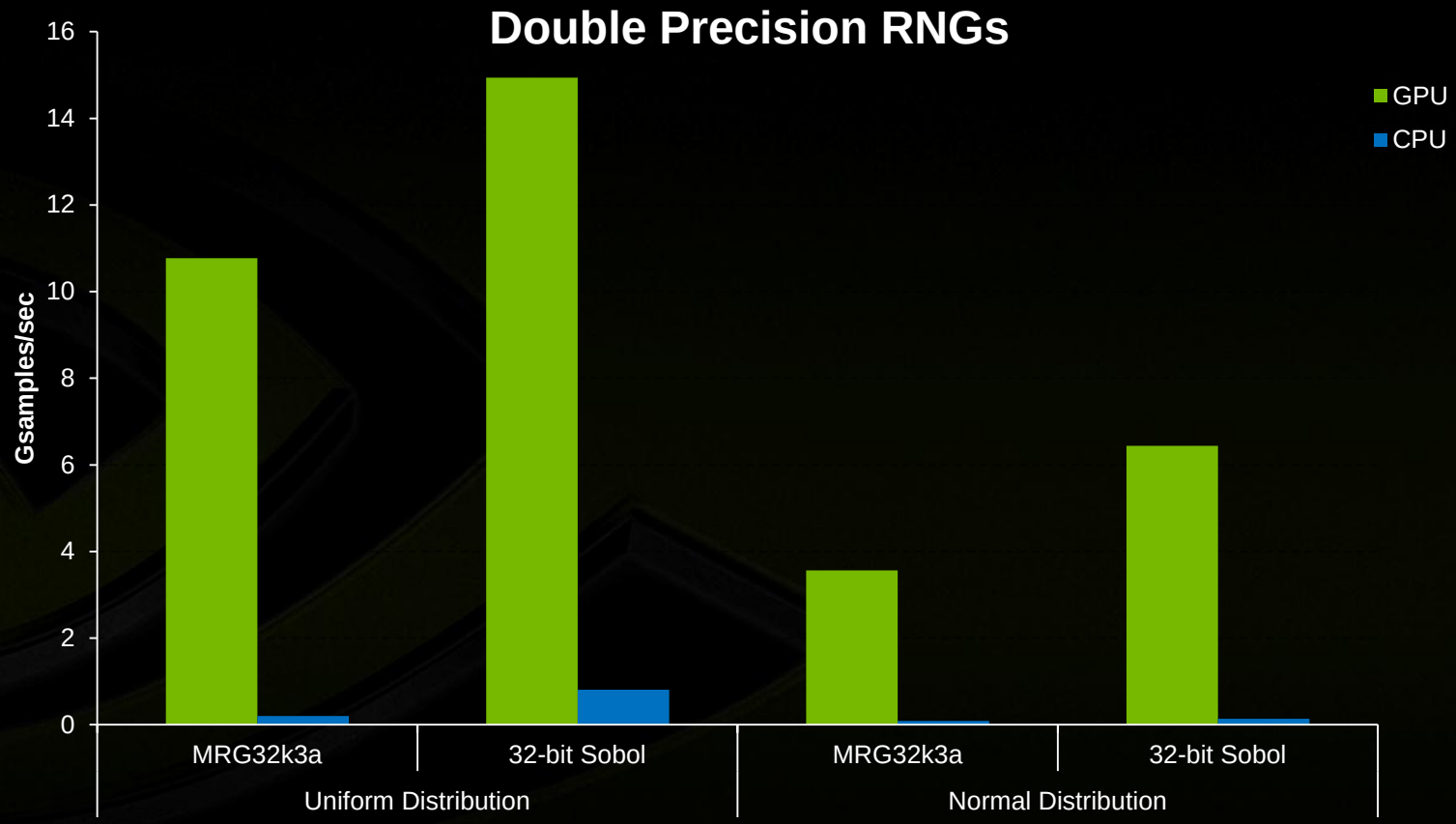
Generate set of random numbers at once

- GPU API

```
#include “curand_kernel.h”
__global__ void generate_kernel(curandState *state) {
        int id = threadIdx.x + blockIdx.x * 64;
        x = curand(&state[id]);
}
```

Generate random numbers per thread

cuRAND Performance



Thrust: STL-like CUDA Template Library

- **GPU(device) and CPU(host) vector class**

```
thrust::host_vector<float> H(10, 1.f);
thrust::device_vector<float> D = H;
```

- **Iterators**

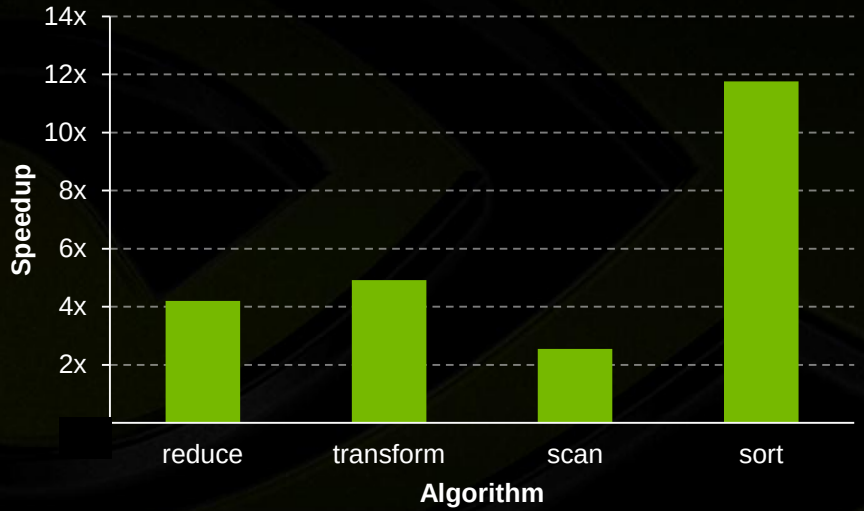
```
thrust::fill(D.begin(), D.begin()+5, 42.f);
float* raw_ptr = thrust::raw_pointer_cast(D);
```

- **Algorithms**
  - **Sort, reduce, transformation, scan, ..**

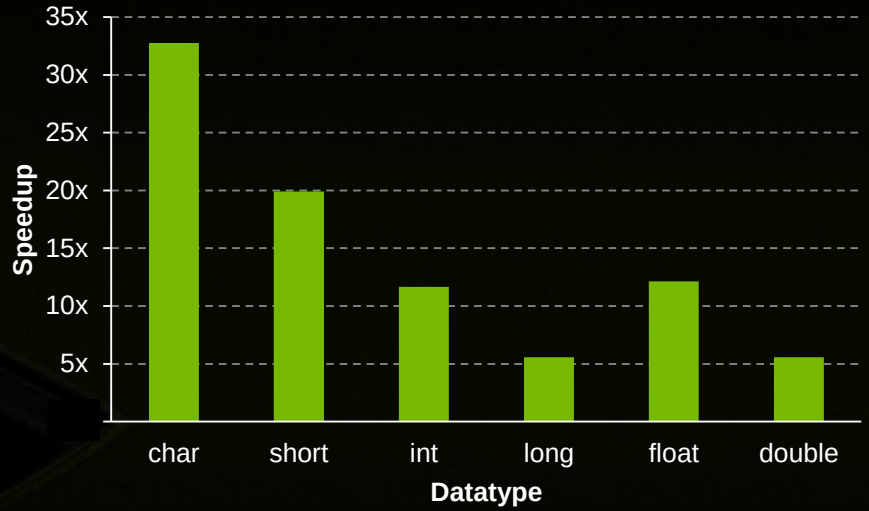
```
thrust::transform(D1.begin(), D1.end(), D2.begin(), D2.end(),
thrust::plus<float>());   // D2 = D1 + D2
```

Thrust Performance

Various Algorithms (32M int.) Speedup over TBB



Sort (32M samples) Speedup over TBB



- Thrust 5.0 on K20X, input and output data on device
- TBB 4.1 on Intel SandyBridge E5-2687W @3.10GHz

Performance may vary based on OS version and motherboard configuration

math.h: C99 floating-point library + extras

CUDA math.h is industry proven, high performance, accurate

- Basic: +, *, /, 1/, sqrt, FMA (all IEEE-754 accurate for float, double, all rounding modes)
- 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, cospi, erfinv, erfcinv, ...

- New in CUDA 5.0
  - sincospi[f]() and normcdf[inv][f]()
  - sin(), cos() and erfcinvf() more accurate and faster
  - Full list of new features and optimizations:

    http://docs.nvidia.com/cuda/cuda-toolkit-release-notes/index.html#math

    http://docs.nvidia.com/cuda/cuda-toolkit-release-notes/index.html#math-performance-improvements

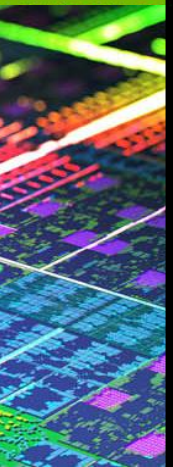
CUDA libs with OpenACC

```
cufftExecPlan(plan, d_signal, d_signal)
…
#pragma acc data deviceptr(d_signal)
#pragma acc loop independent
for(i=0; i<n; i++) d_signal[i] = 2 * d_signal[i];
```

Explore the CUDA (Libraries) Ecosystem

- **CUDA Tools and Ecosystem described in detail on NVIDIA Developer Zone:**

developer.nvidia.com/cuda-tools-ecosystem



GPU Technology Conference 2013
The Premier Event in Accelerated Computing

- Four days – March 18-21, San Jose, CA
- 300+ sessions
- 100+ research posters
- Networking opportunities with experts & colleagues from 40+ countries

It's everything you want to know about accelerated computing -- all in one place!

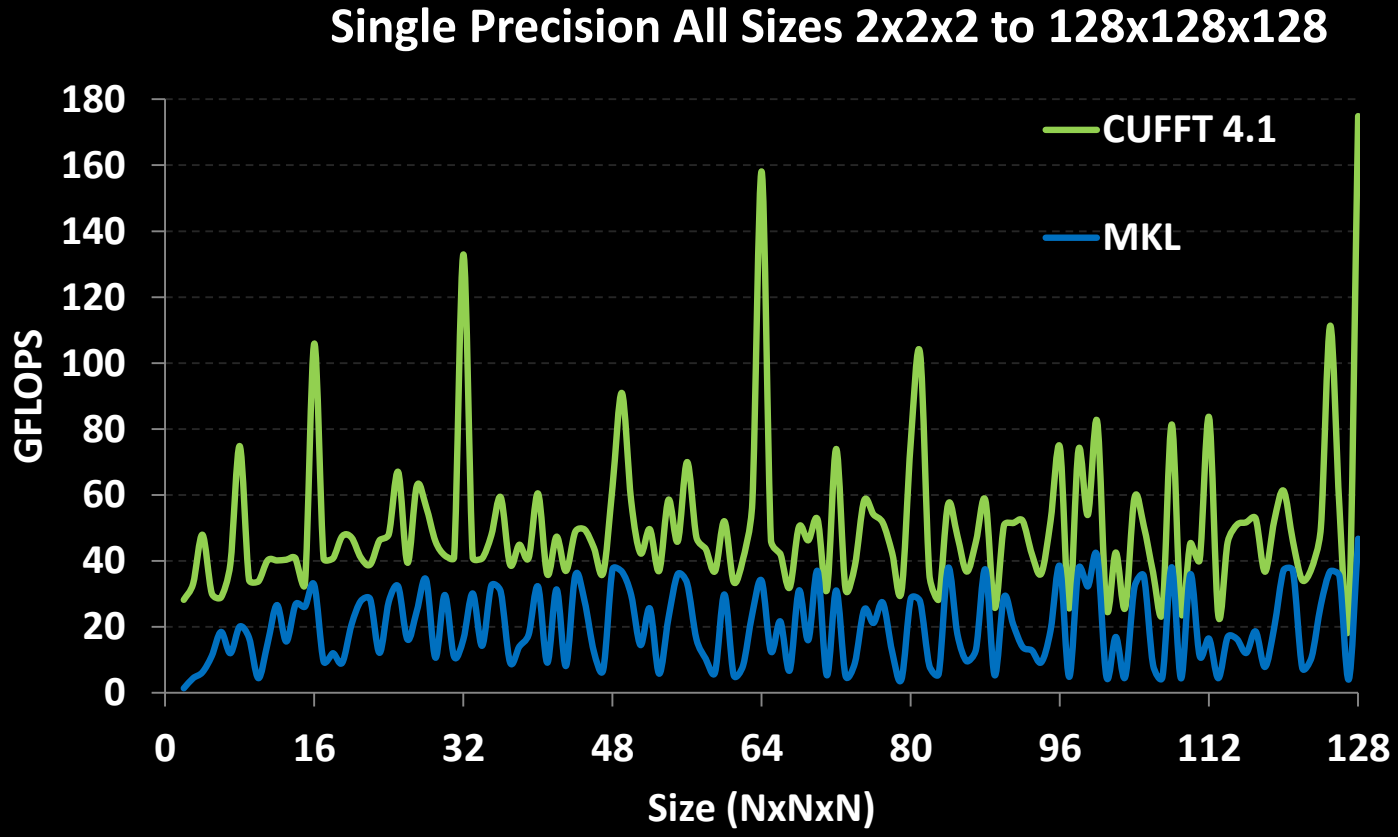
Visit www.nvidia.com/gtc-compute for more info.

Summary

- CUDA libraries offer high performance for minimal effort
- Robust community of 3rd party libraries
- Familiar interfaces make porting legacy code easy (“drop-in”)
- Enables focus on core IP


Thank you
NVIDIA

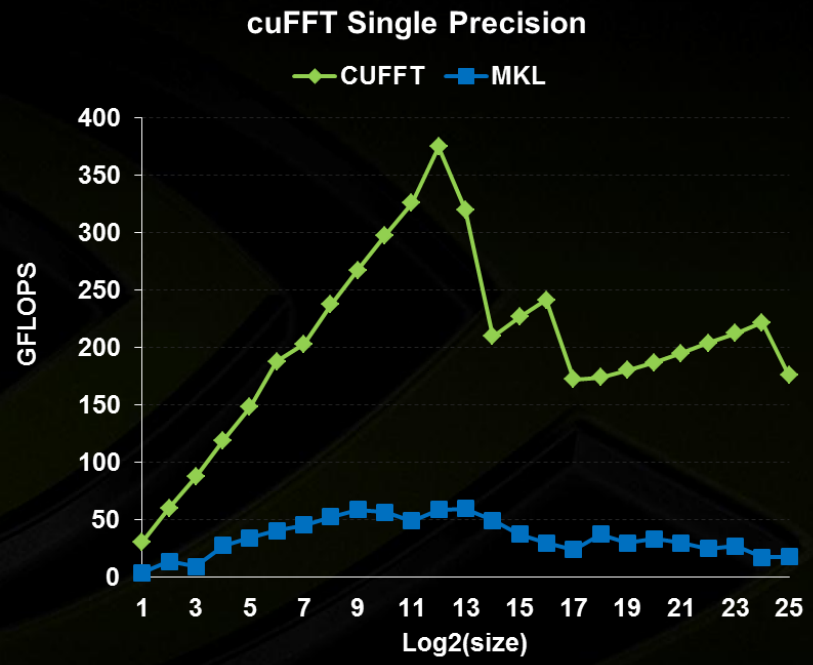
Optimized 3D transforms

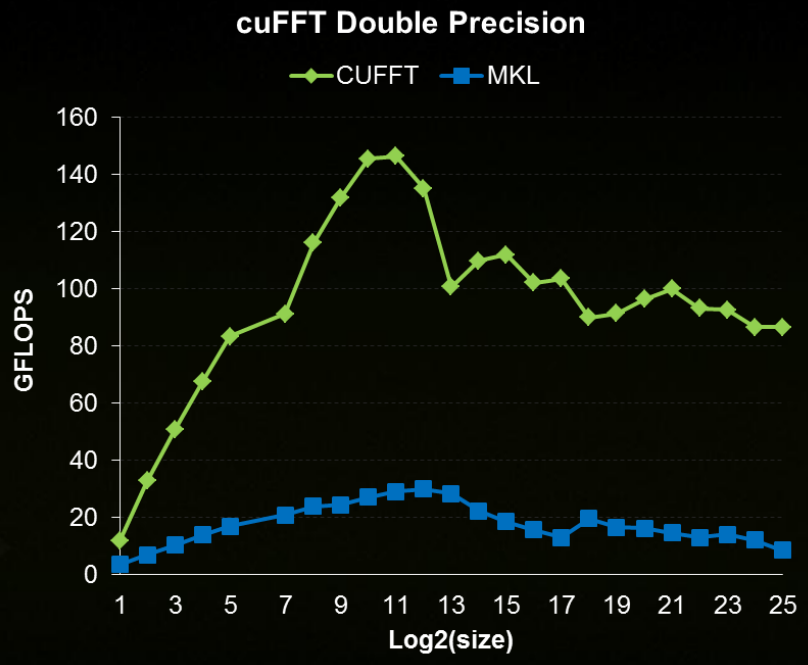


Performance may vary based on OS version and motherboard configuration

- cuFFT 4.1 on Tesla M2090, ECC on
- MKL 10.2.3, TYAN FT72-B7015 Xeon x5680 Six-Core @ 3.33 GHz

cuFFT Performance -1D





Performance may vary based on OS version and motherboard configuration

- Measured on sizes that are exactly powers-of-2
- cuFFT 4.1 on Tesla M2090, ECC on
- MKL 10.2.3, TYAN FT72-B7015 Xeon x5680 Six-Core @ 3.33 GHz