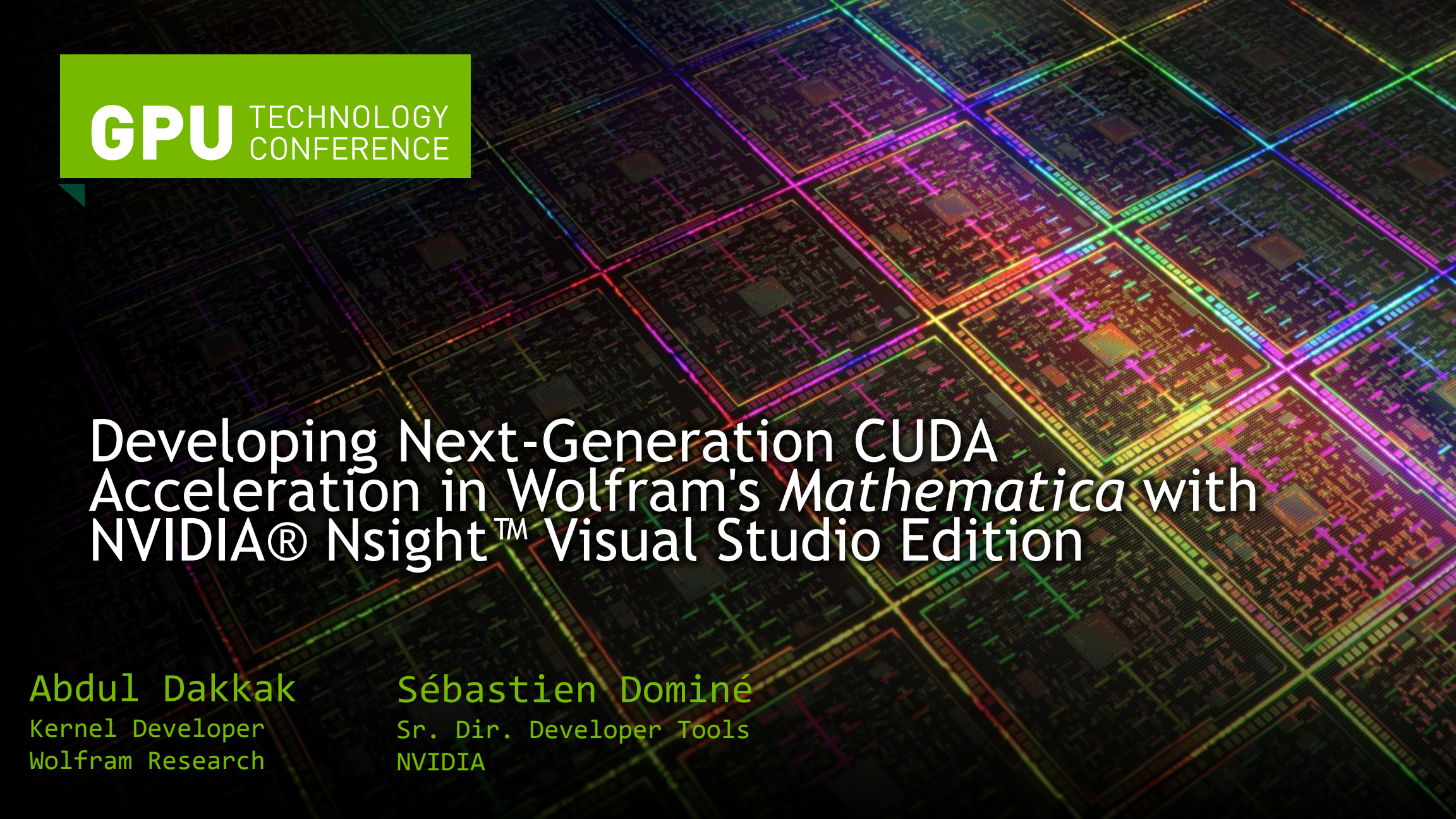
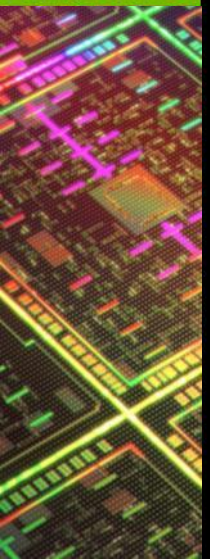


Developing Next-Generation CUDA Acceleration in Wolfram's *Mathematica* with NVIDIA® Nsight™ Visual Studio Edition

Abdul Dakkak
Kernel Developer
Wolfram Research

Sébastien Dominé
Sr. Dir. Developer Tools
NVIDIA



Agenda

- Nsight Visual Studio Edition Update
- CUDA Development in Wolfram's *Mathematica*
- The future of Nsight Visual Studio Edition
- Conclusion

GPU TECHNOLOGY CONFERENCE

NVIDIA® Nsight™ Visual Studio Edition

Software Development Platform for GPU and CPU

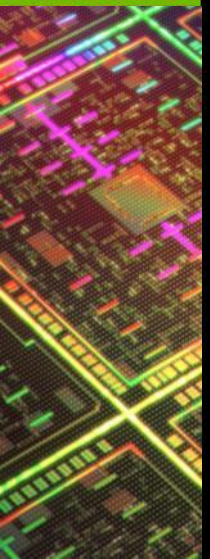
Microsoft® Visual Studio®
PARTNER

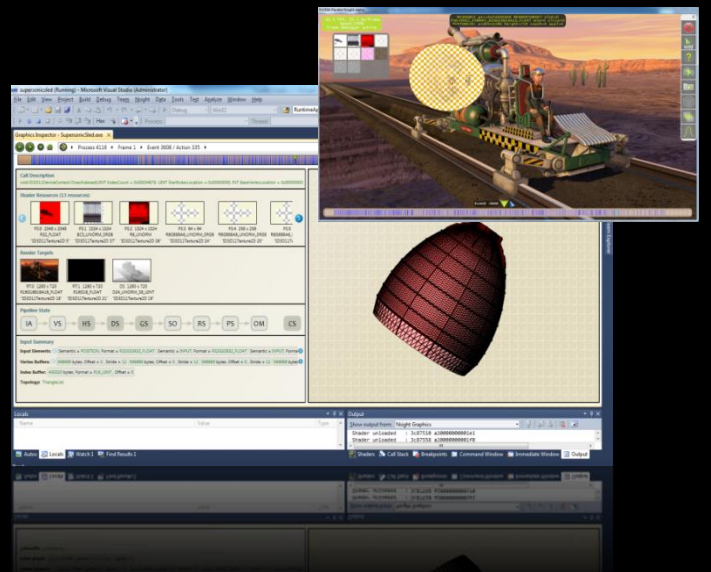
GPU TECHNOLOGY CONFERENCE

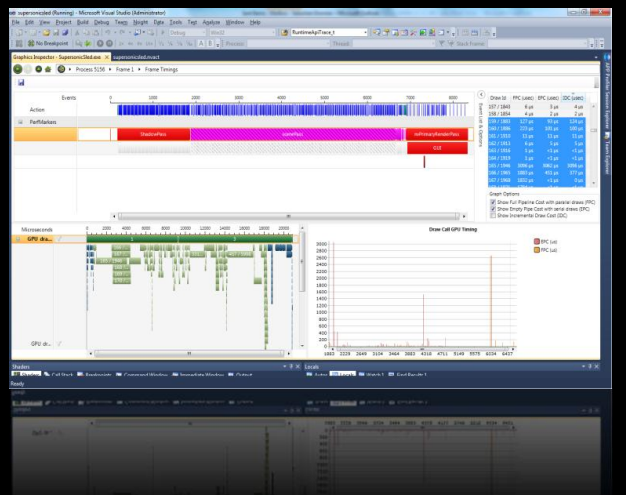
Nsight Visual Studio Edition

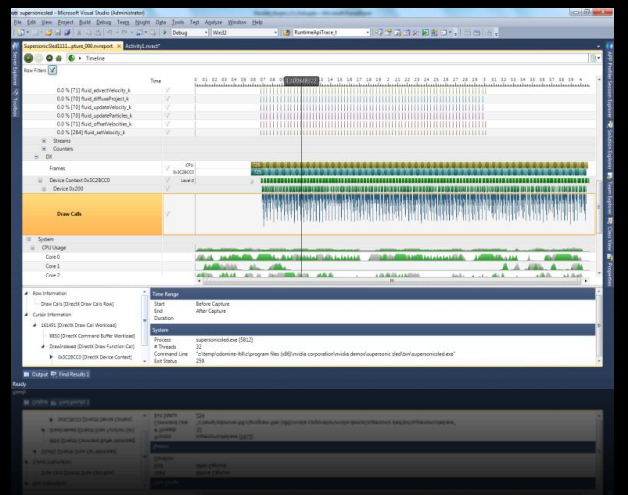
for Graphics Developers

- Frame debugger for Direct3D
- HLSL Shader debugger
- Frame profiler for Direct3D
- Application and system trace







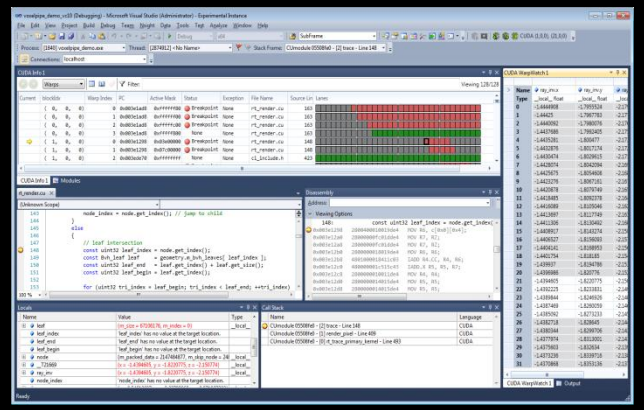


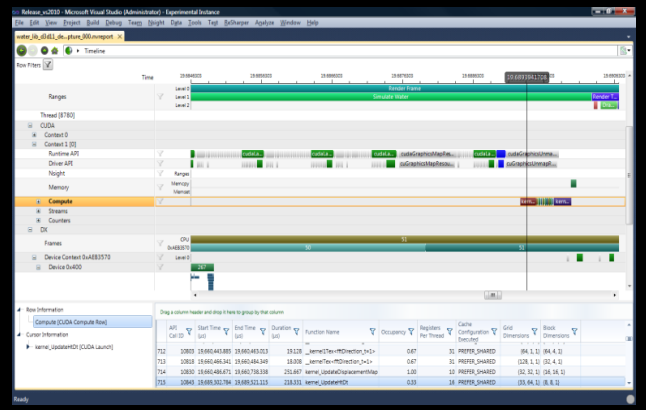
GPU TECHNOLOGY CONFERENCE

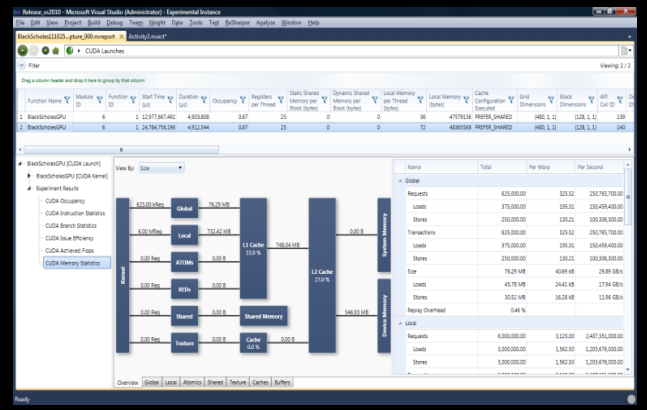
Nsight Visual Studio Edition

for CUDA® Developers

- CUDA debugger
- CUDA memory checker
- Application and system trace
- CUDA profiler



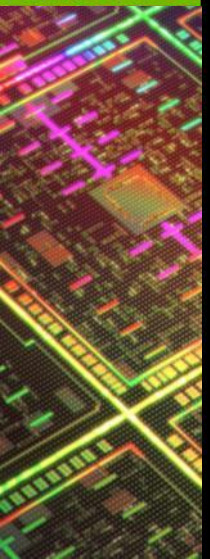




New in Nsight Visual Studio Edition 2.2

- Kepler architecture support
- Fully featured on single GPU systems
  - Local CUDA Debugging
  - CUDA memory checker
- Warp freeze/thaw run-control
- Debug Kernel without symbols
  SASS and PTX
- New Analysis summary page

```
Address: 0x0001db78
Viewing Options
0x0001db28  @P0 BRA 0x738; # Target=0x0001db38
0x0001db30  STS.S [R25], RZ;
0x0001db38  MOV R4, R21;
0x0001db40  MOV R7, R24;
0x0001db48  CAL 0x1b88; # Target=0x0001ef88
0x0001db50  STS.S [R25], R4;
0x0001db58  IADD R19, R19, c[0x0][0x8];
0x0001db60  ISETP.LT.U32.AND P0, pt, R19, R18, pt;
0x0001db68  @P0 BRA 0x440; # Target=0x0001d840
0x0001db70  IMAD.U32.U32.S RZ, R1, RZ, RZ;
0x0001db78  BAR.RED.POPC RZ, RZ;
0x0001db80  LD R4, [R2+0x420c];
0x0001db88  LD R5, [R2+0x4204];
0x0001db90  LD R0, [R2+0x4208];
0x0001db98  LD R3, [R2+0x4200];
0x0001dba0  SSY 0x18b0;
0x0001dba8  FMNMX R25, R5, R4, !pt;
0x0001dbb0  FMNMX R26, R3, R0, !pt;
0x0001dbb8  F2F.CEIL R0, R25;
```

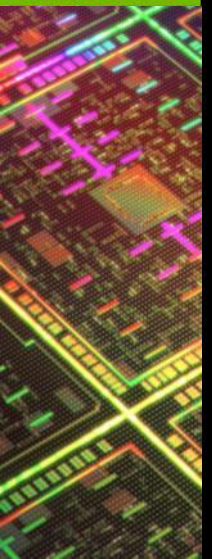


What is *Mathematica*?

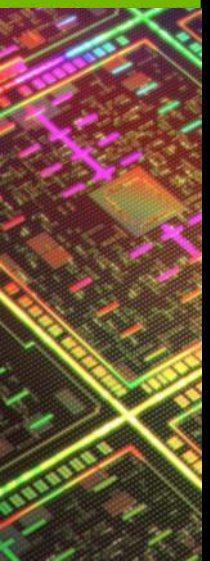
- Computational Engine
- Functional, pattern based, procedural, … — everything is data
- Covers Many Domains All in One Package — no need for extensions and toolkits

Structure of *Mathematica* Code Base

- Mainly written in C and Mathematica
- Some bits are written in Java
- A separation between the frontend and the kernel into different processes
- Uses and loads external libraries on demand for certain operations
- Has a linking mechanism that allows loading C, Java, .Net, and Python code into the system
- *CUDALink* is one of those linking mechanisms



Mathematica Frontend and Kernel



Mathematica Kernel

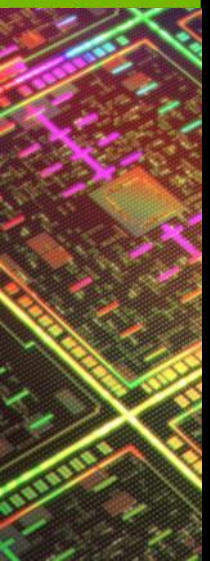
All computation happens in the kernel

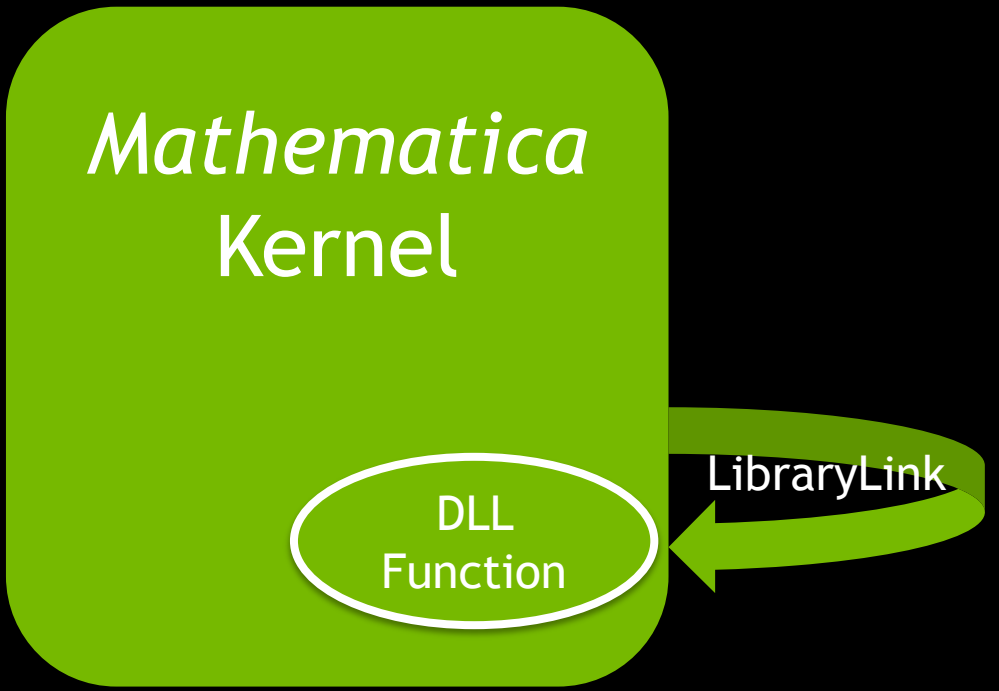
MathLink

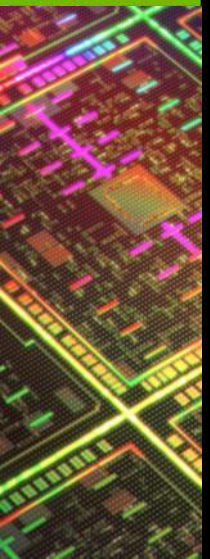
Mathematica Frontend

All GUI and visualization happens here

Mathematica Linking Mechanism



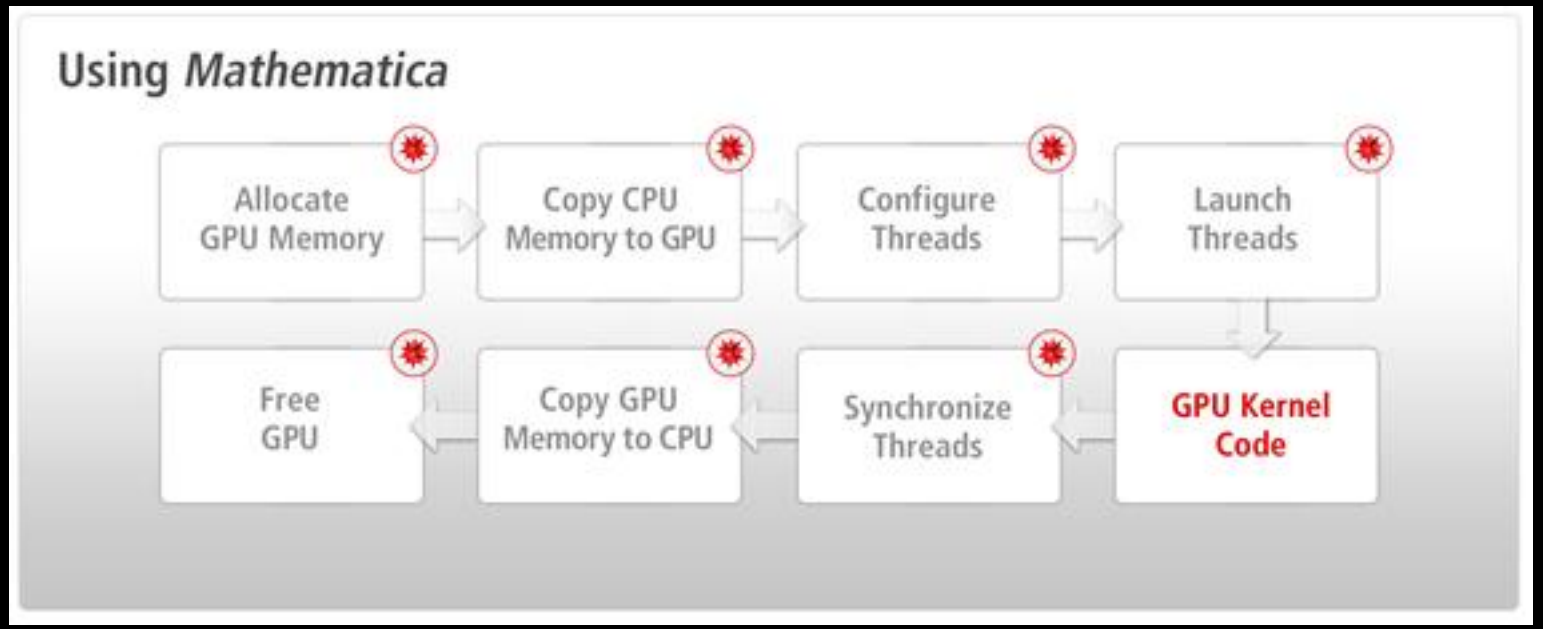




What is *CUDALink*?

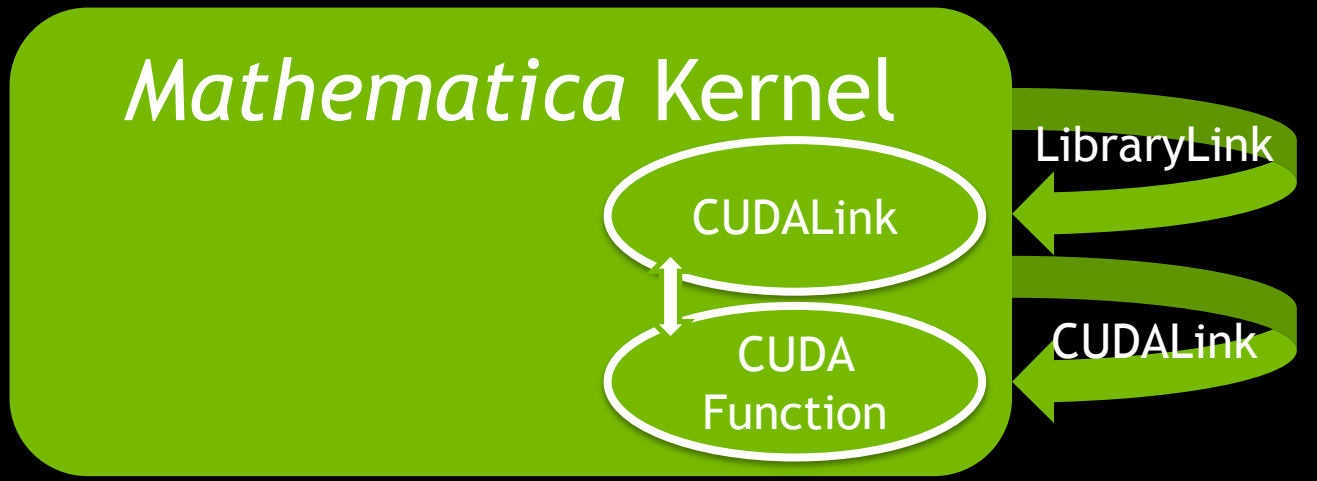
- A way to load CUDA programs into *Mathematica*
- Handles all the trivial, repetitive, and sometime error prone host code that developers have to write
- Allows CUDA programs to benefit from *Mathematica*'s features and vice versa

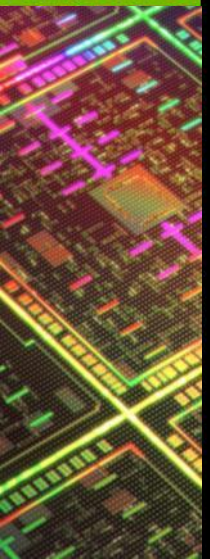
What is *CUDALink*?



Structure of *CUDALink*

- Written in C, CUDA, and *Mathematica*
- Uses NVIDIA libraries such as CUBLAS, CUFFT, CURAND, and Thrust
- Loaded as an external library by the main *Mathematica* kernel

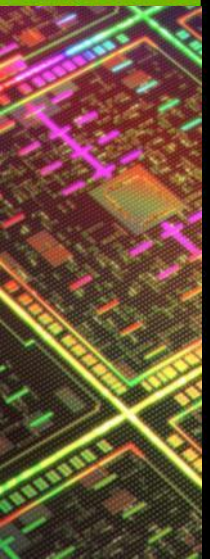


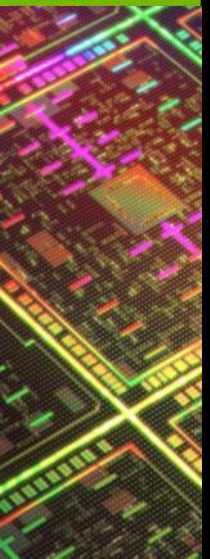


Demo: *CUDALink* Usage

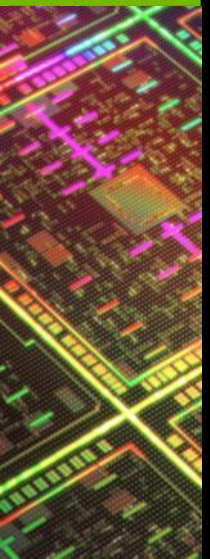
Challenges While Developing *CUDALink*

- Initially, lack of Nsight and **printf**
- The initial hardware requirements for Nsight were not easy to configure (QA, for example, did not have this setup)
- Large code base means that you cannot debug the entire CUDA code base

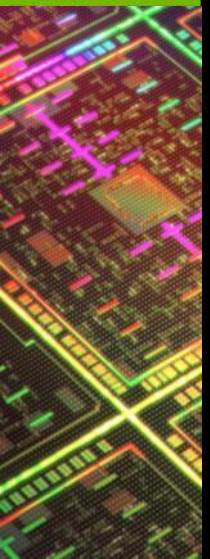




Demo: Attaching the CUDA Debugger to a *Mathematica* Process

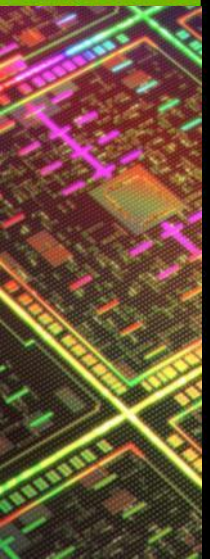


Demo: Profiling the CUDA Code with Nsight



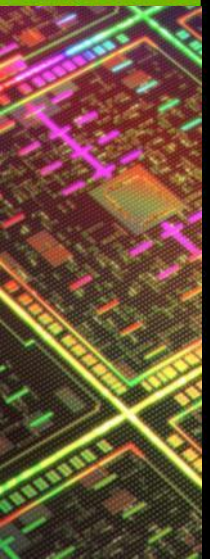
Previous Development Workflow

- Write implementation in C
- Port implementation into CUDA
- Scratch head if something does not work
- Optimize based on knowledge of the hardware
- Write tests to make sure things continue to work



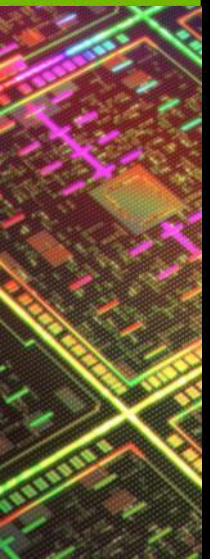
Current Development Workflow

- Write implementation in CUDA
- Debug CUDA implementation
- Memory check CUDA implementation
- Optimize the implementation based on what the profiler tells you



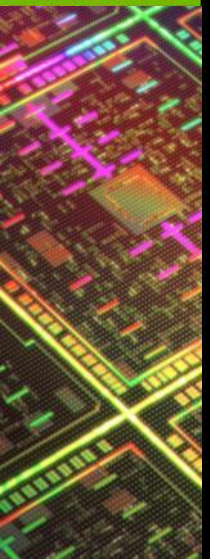
Pitfalls and Experiences

- A small change in the way we develop CUDA code — the "old school" way of debugging and profiling
- Initial setup challenges were answered by the documentation pages
- Enhanced and accelerated our development and QA process



Wish List

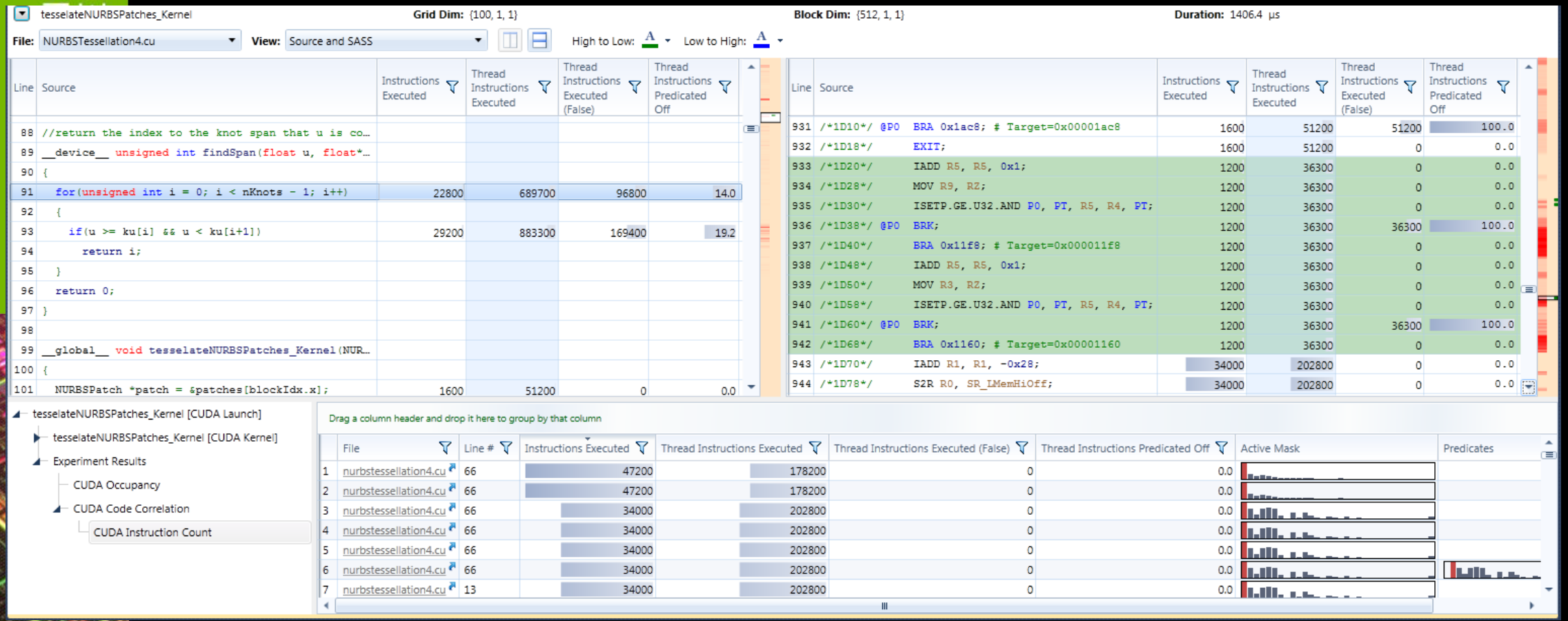
- Hard to debug large CUDA files
- Live variable range is short during debugging
- As CUDA projects get larger: the compilation process gets slower, debugging get harder, and the release binary size gets larger
- Run static analysis without writing the host code
- Attach debugger to a CUDA function without host code symbols

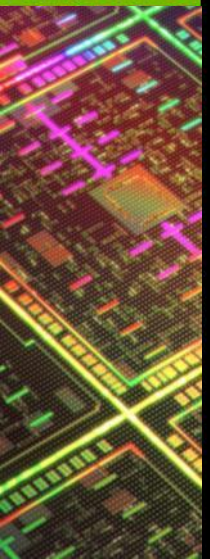


The Future for Nsight Visual Studio Edition

- CUDA 5.0 and dynamic kernel debugging
- Support for debugging GPU object linking
- Performance Bottleneck w/ Source code correlation
- Kernel Performance Limiter Analysis
- System trace File I/O

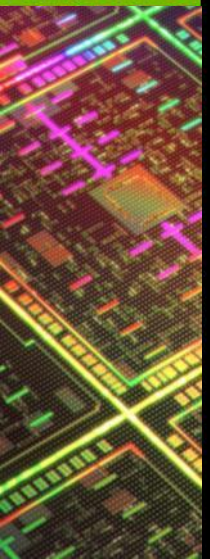
Profiling with source code correlation





Conclusion

- Full-featured CUDA development on a single GPU
- Advanced CUDA debugging with more control
  - Attach to process
  - CUDA Info and parallel warp pages
- System trace for finding where to focus optimization effort
- Powerful profiling experiments for accurate performance characterization



Mathematica Presentations

- *Mathematica* as a Practical Platform for GPU-Accelerated Finance: Wednesday 5:00PM (S0100)
- GPU Based Numerical Methods in *Mathematica*: Thursday 14:30 (S0106)

Nsight Visual Studio Edition@GTC'12

- Download

  http://developer.nvidia.com/nvidia-nsight

- NVIDIA Nsight Visual Studio Edition Trainings
  - Debugging: Tue:2-3pm, 5-6pm - Wed: 2-3pm - Thu: 9-10am, 4-5pm
  - Profiling: Tue:3-4pm – Wed: 9-10am, 4-5pm – Thu: 2-3pm
- Nsight Lab
  - Tue: 4-5pm – Wed: 10-11am, 3-4pm, 5-6pm - Thu: 10-11am, 3-4pm
- Nsight Visual Studio Edition@NVIDIA Booth/Exhibition Hall
  - Tue,Wed: 12-2pm, 6-8pm – Thu: 12-2pm