C++ AMP:
Accelerated Massive Parallelism in Visual C++

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C++ is the language for performance

- If you need speed at runtime, you use C++
- Frameworks and libraries can make your code faster
  - Eg PPL: use all the CPU cores
  - With little or no change to your logic and code
- Experienced C++ developers are productive in C++
  - Don’t want to go back to C or C-like language
  - Enjoy the tool support in Visual Studio
- Many C++ developers value portability
  - Write standard C++, compile with anything
  - Use portable libraries, run anywhere
  - Even in all-Microsoft universe, simple deployment is important

Demo

Cartoonizer

What is C++ AMP?

- Accelerated Massive Parallelism
  - Run your calculations on one or more accelerators
    - Today, GPU is the accelerator you use
    - Eventually: other kinds of accelerators
- Write your whole application in C++
  - Not a “C-like” language or a separate resource you link in
  - Use Visual Studio and familiar tools
  - Speed up 20x, 50x, or more
- Basically a library
  - Comes with Visual Studio 2012 and 2013, included in vcredist
  - Spec is open – other platforms/compilers can implement it too

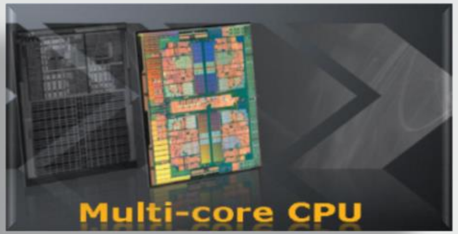
Agenda

- Why? Hardware Review
- C++ AMP Fundamentals
- A Few Details
- Debugging and Visualizing
- Call to Action

Wait, Why?

- Until 2005 “Free Lunch”
  - Clock speed increased every year
  - Single threaded performance increased every year
  - Apps got faster for free
- After 2005 “No More Free Lunch”
  - Clock speeds are not increasing that fast anymore
  - Instead, CPU’s get more powerful every year by adding more cores
  - Single threaded performance is now increasing much slower If at all
- Want to get faster?
  - Use more cores

CPUs vs GPUs today



CPU

- Low memory bandwidth
- Higher power consumption
- Medium level of parallelism
- Deep execution pipelines
- Random accesses
- Supports general code
- Mainstream programming

GPU

- High memory bandwidth
- Lower power consumption
- High level of parallelism
- Shallow execution pipelines
- Sequential accesses
- Supports data-parallel code
- Niche programming
  Mainstream programming with C++ AMP

images source: AMD

CPU Parallelism

- Vectorization (SIMD, SSE, AVX, …)
  - Visual Studio 2012 and 2013 can auto-vectorize and auto-parallelize your loops
- Multithreading:
  - Microsoft PPL (Parallel Patterns Library)
  - Intel TBB (Threading Building Blocks) (compatible interface with PPL)

.

GPU Parallelism

- **CUDA**: If you want to optimally use NVidia GPUs
- **OpenCL** : If you want to optimally use AMD GPUs
- **DirectCompute**: Uses HLSL, looks like C
- All are C-like, not truly C++
  - no type safety, genericity, …
  - only CUDA is becoming similar to C++
- **Hard**
  - **need to learn multiple technologies to optimally target multiple devices…**

Speed Changes Everything

- 2-3x faster is “just faster”
  - Do a little more, wait a little less
  - Doesn’t change how users really work
- 5-10x faster is “significant”
  - Worth upgrading
  - Worth re-writing (parts of) your applications
- 100x+ faster is “fundamentally different”
  - Worth considering a new platform
  - Worth re-architecting your applications
  - Makes completely new applications possible

C++ AMP

- Vendor independent (NVidia, AMD, …)
- Abstracts “accelerators” (GPU’s, APU’s, …)
- Only requirement: DirectX 11
  - Fallback to WARP if no hardware GPU’s available
- Future support for other accelerators
  - FPGA’s, off-site cloud computing…
- Support heterogeneous mix of accelerators!
  - Example: both an NVidia **and** AMD GPU in your system splitting a workload

C++ AMP is fundamentally a library

- Comes with Visual C++ 2012 and 2013
- `#include <amp.h>`
- Namespace: `concurrency`
- New classes:
  - array, array_view
  - extent, index
  - accelerator, accelerator_view
- New function(s): `parallel_for_each()`
- New (use of) keyword: `restrict`
  - Asks compiler to check your code is ok for GPU (DirectX)

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parallel_for_each

- Entry point to the library
- Takes number (and shape) of threads needed
- Takes function or lambda to be done by each thread
  - Must be restrict(amp)
  - Lambda must capture everything by value, except `concurrency::array` objects
- Sends the work to the accelerator
  - Scheduling etc handled there
- Returns – no blocking/waiting

Hello World: Array Addition

```cpp
void AddArrays(int n, int * pA, int * pB,
int * pSum)
{
    for (int i=0; i<n; i++)
    {
        pSum[i] = pA[i] + pB[i];
    }
}
```

```cpp
#include <amp.h>
using namespace concurrency;

void AddArrays(int n, int * pA, int * pB, int * pSum)
{
    array_view<int,1> a(n, pA);
    array_view<int,1> b(n, pB);
    array_view<int,1> sum(n, pSum);

    parallel_for_each(
        sum.extent,
        [=](index<1> i) restrict(amp)
        {
            sum[i] = a[i]+b[i];
        }
    );
}
```

Basic Elements of C++ AMP coding

array_view: wraps the data to operate on the accelerator

```
void AddArrays(int n, int * pA, int * pB, in
{
    array_view<int,1> a(n, pA);
    array_view<int,1> b(n, pB);
    array_view<int,1> sum(n, pSum);

    parallel_for_each(
        sum.extent,
        [=](index<1> i) restrict(amp)
        {
            sum[i] = a[i] + b[i];
        }
    );
```

parallel_for_each: execute the lambda on the accelerator once per thread

restrict(amp): tells the compiler to check that this code conforms to C++ AMP language restrictions

extent: the number and shape of threads to execute the lambda

array_view variables captured and associated data copied to accelerator (on demand)

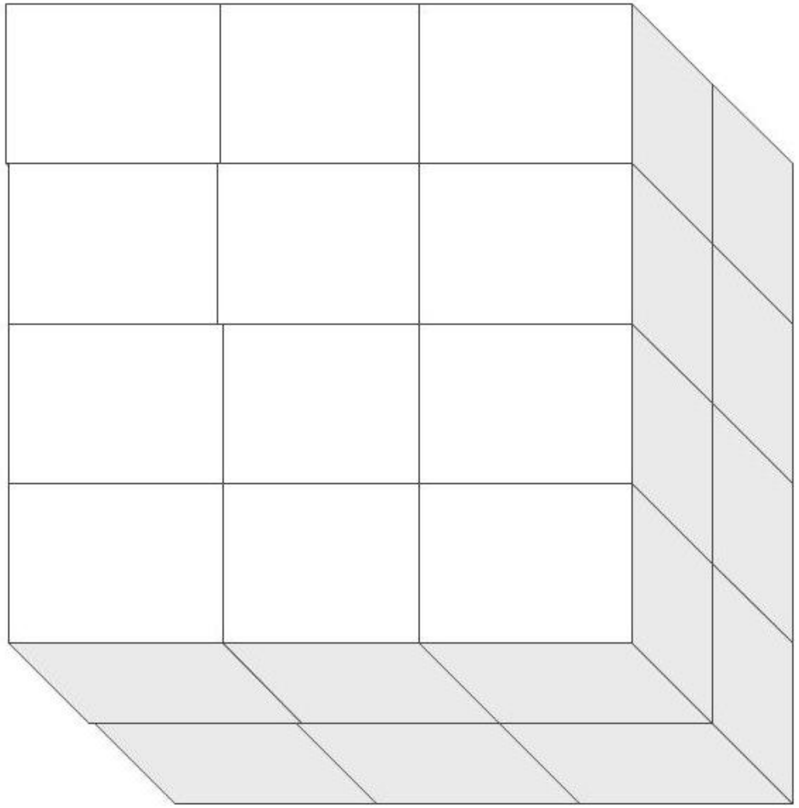
index: the thread ID that is running the lambda, used to index into data

The lambda

- Executes on the accelerator in parallel with whatever CPU code follows **parallel_for_each()** until a synchronization point is reached
- Synchronization:
  - Manually when calling **array_view::synchronize()**
    - Good idea, because you can handle exceptions gracefully
  - Automatically when CPU code uses structure wrapped by array_view
    - Not recommended, because you might lose error information if there is no try/catch block catching exceptions at that point
  - Automatically when array_view goes out of scope
    - Dangerous, errors will be ignored silently because destructors are not allowed to throw exceptions

extent<1> e(5);

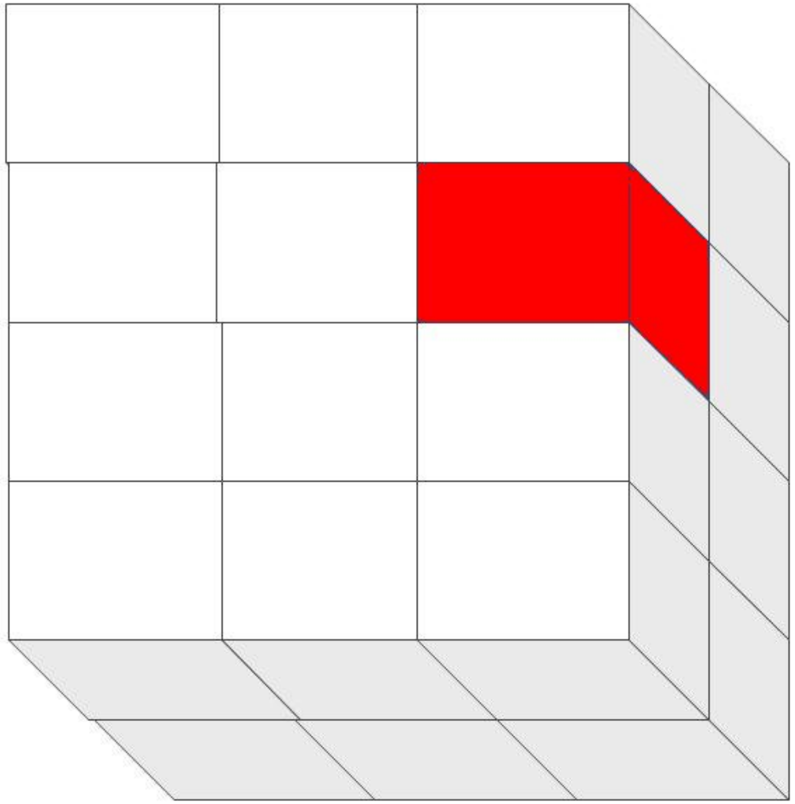
extent<2> f(2,4);



extent<3> g(2,4,3);

`index<1> i(3);`

`index<2> j(1,2);`

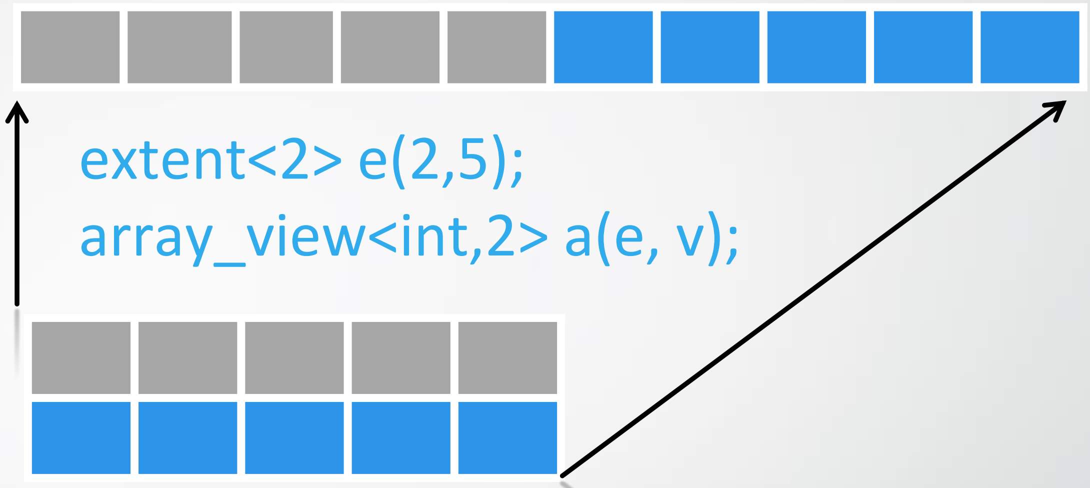


`index<3> k(0,1,2);`

array_view<T,N>

- View on existing data on the CPU or GPU
- Dense in least significant dimension
- Of element T and rank N
- Requires extent
- Rectangular
- Access anywhere (implicit sync)

```
vector<int> v(10);
```



```
extent<2> e(2,5);
array_view<int,2> a(e, v);
```

```
//above two lines can also be written
//array_view<int,2> a(2,5,v);

index<2> i(1,3);

int o = a[i]; // or a[i] = 16;
//or int o = a(1, 3);
```

array_view

- Read-only buffer:
  - **array_view<const int, 2> av(...);**
  - Only copies data from the CPU to the accelerator at the start, not back to the CPU at the end
- Write-only buffer:
  - **array_view<int, 2> av(...);**
    av.discard_data();
  - Only copies data from the accelerator to the CPU at the end, not to the accelerator at the start

Demo

Matrix Multiplication

Matrix Multiplication

W=4

M=2

A_{00}	A_{01}	A_{02}	A_{03}
A_{10}			

N=6

B_{00}	B_{01}	B_{02}	B_{03}	B_{04}	B_{05}
B_{10}					
B_{20}					
B_{30}					

$$C_{00} = A_{00} * B_{00} + A_{01} * B_{10}$$
$$+ A_{02} * B_{20} + A_{03} * B_{30}$$

N=6

M=2

C_{00}	C_{01}	C_{02}	C_{03}	C_{04}	C_{05}
C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}

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restrict(amp) restrictions

- Can only call other *restrict(amp)* functions
- All functions must be inlinable
- Only amp-supported types
  - int, unsigned int, float, double, bool
  - structs & arrays of these types
- Pointers and References
  - Lambdas cannot capture by reference, nor capture pointers
  - References and single-indirection pointers supported only as local variables and function arguments

restrict(amp) restrictions

- No
  - recursion
  - 'volatile'
  - virtual functions
  - pointers to functions
  - pointers to member functions
  - pointers in structs
  - pointers to pointers
  - bitfields
- No
  - goto or labeled statements
  - throw, try, catch
  - globals or statics
  - dynamic_cast or typeid
  - asm declarations
  - varargs
  - unsupported types
    - e.g. char, short, long double

restrict()

- restrict() is really part of the signature
  - Can differentiate overloads
- Compare:
  - float func1(float) restrict(cpu, amp);
    - Can run on both CPU and C++ AMP accelerators
  - float func2(float);
    - General code – not ok to call from `parallel_for_each`
  - float func2(float) restrict(amp);
    - AMP-specific code –ok to call from `parallel_for_each`

array<T,N>

- Multi-dimensional array of rank N with element T
- Container whose storage lives on a specific accelerator
- Capture by reference [&] in the lambda
- Explicit copy
- Nearly identical interface to array_view<T,N>

```
vector<int> v(8 * 12);
extent<2> e(8,12);
accelerator acc = ...
array<int,2> a(e,acc.default_view);
copy_async(v.begin(), v.end(), a);

parallel_for_each(e, [&](index<2> idx)
                              restrict(amp)
{
    a[idx] += 1;
});
copy(a, v.begin());
```

Tiling

- Rearrange algorithm to do the calculation in tiles
- Each thread in a tile shares a programmable cache
  - tile_static memory
  - Access 100x as fast as global memory
  - Excellent for algorithms that use each piece of information again and again
- Overload of parallel_for_each that takes a tiled extent

Race Conditions in the Cache

- Because a tile of threads shares the programmable cache, you must prevent race conditions
  - Tile barrier can ensure a wait
- Typical pattern:
  - Each thread does a share of the work to fill the cache
  - Then waits until all threads have done that work
  - Then uses the cache to calculate a share of the answer

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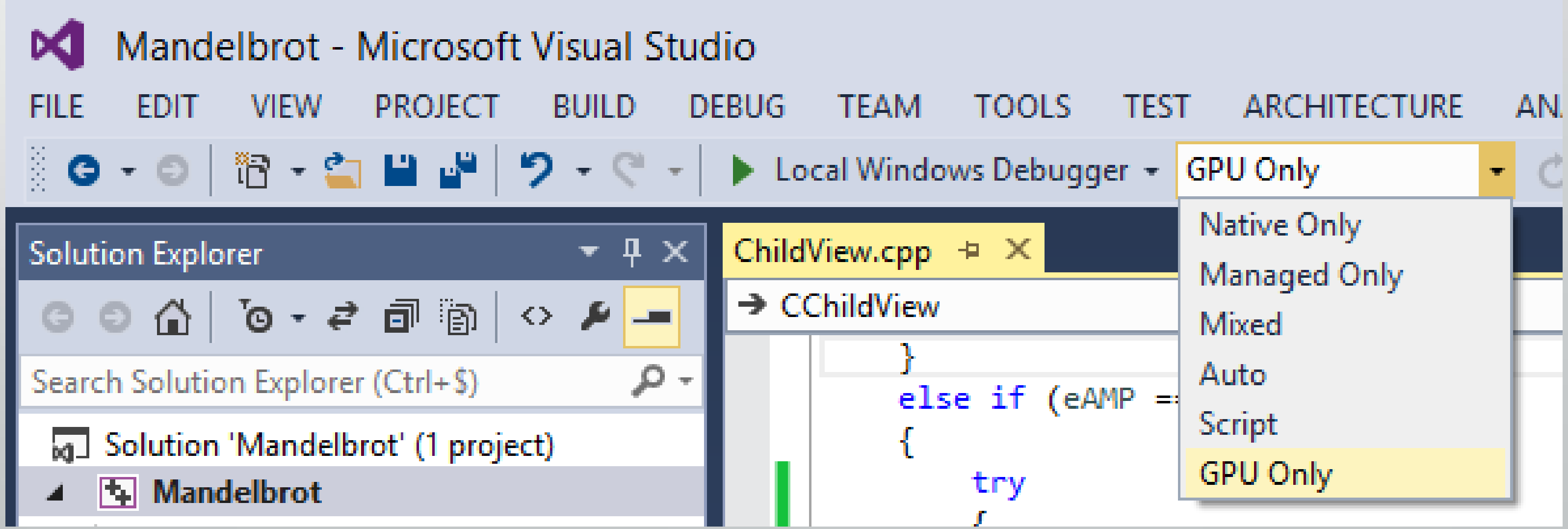
Visual Studio 2013 AMP Support

- Debugging
  - Everything you had before, plus:
  - GPU Threads
  - Parallel Stacks
  - Parallel Watch
- Visualizing

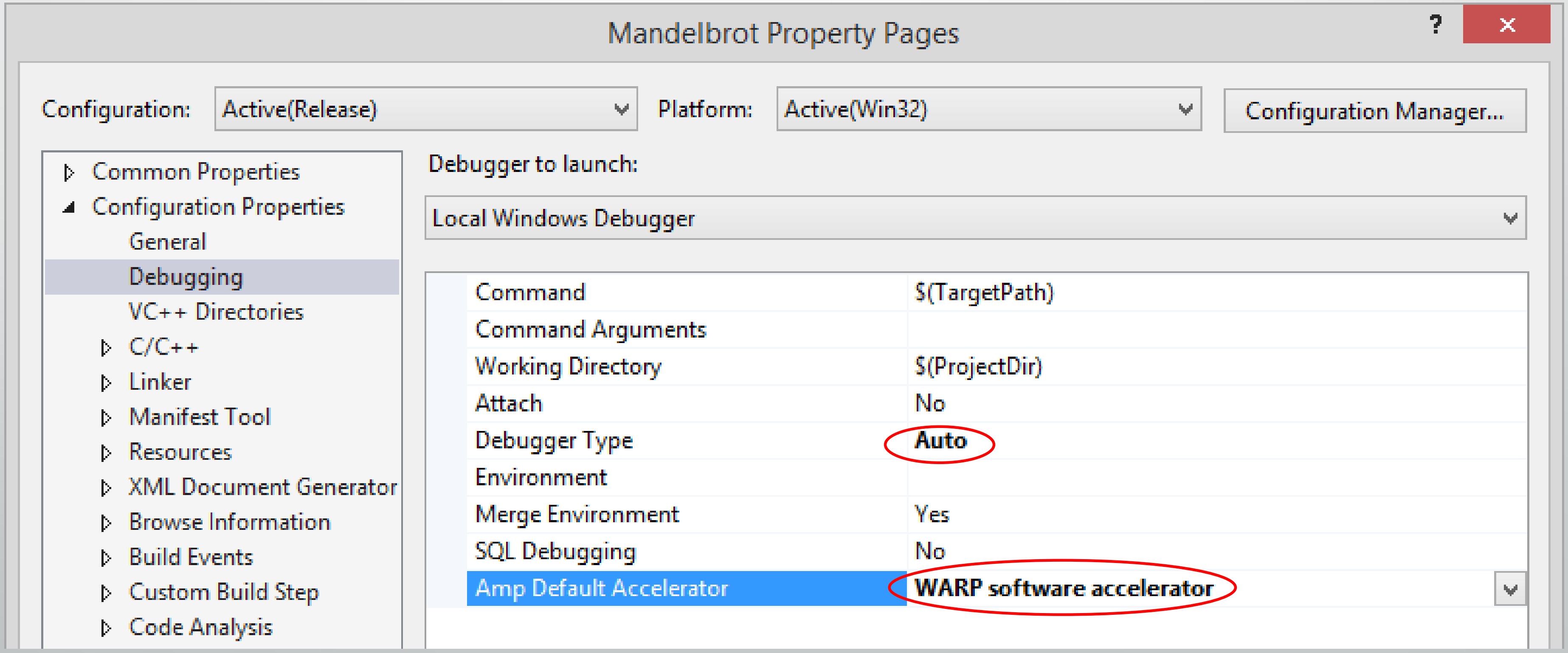
Debugging

- GPU breakpoints are supported
- On Windows 8 and 7, no CPU/GPU simultaneous debugging possible
- Choose the GPU Only debugging option

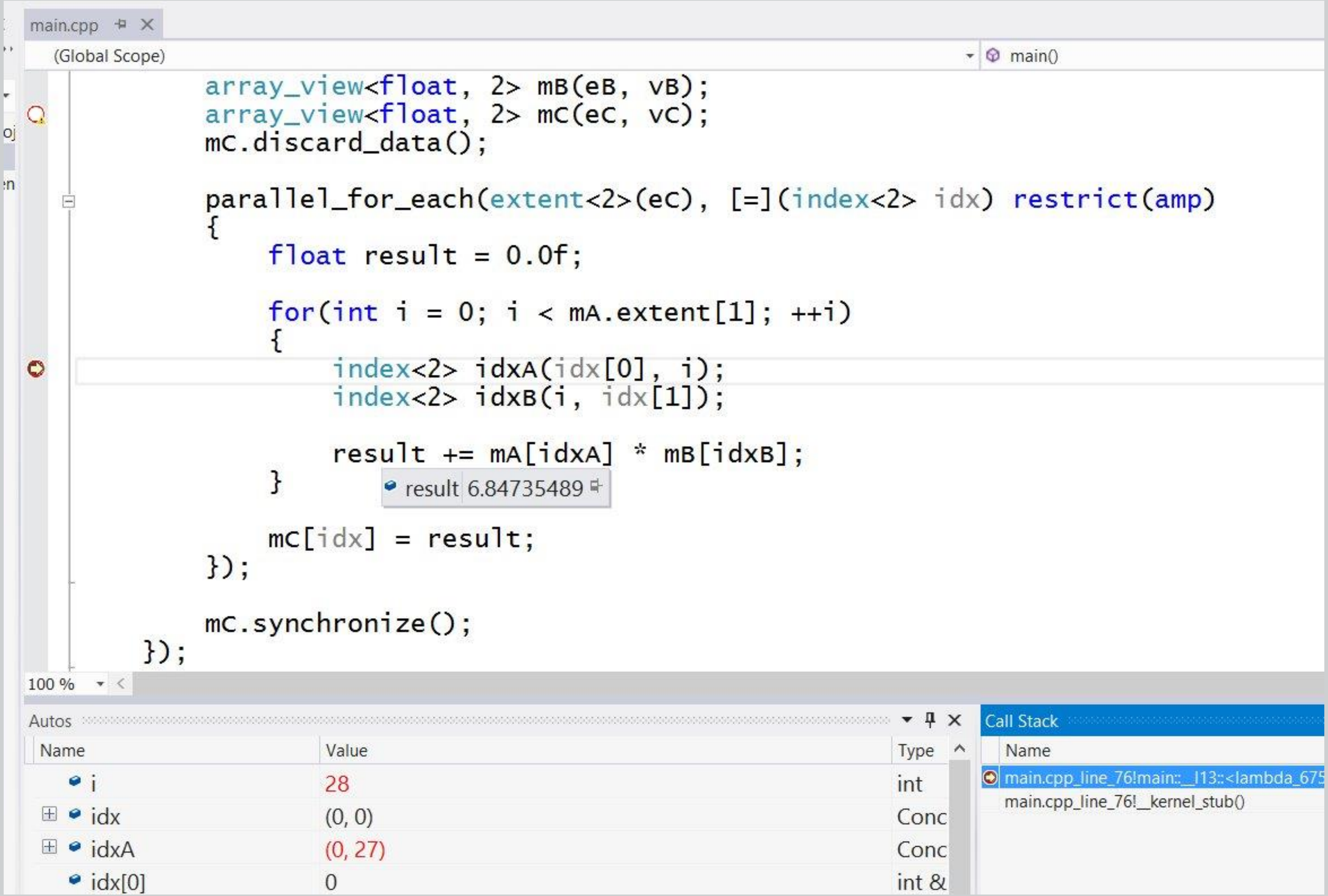


Debugging

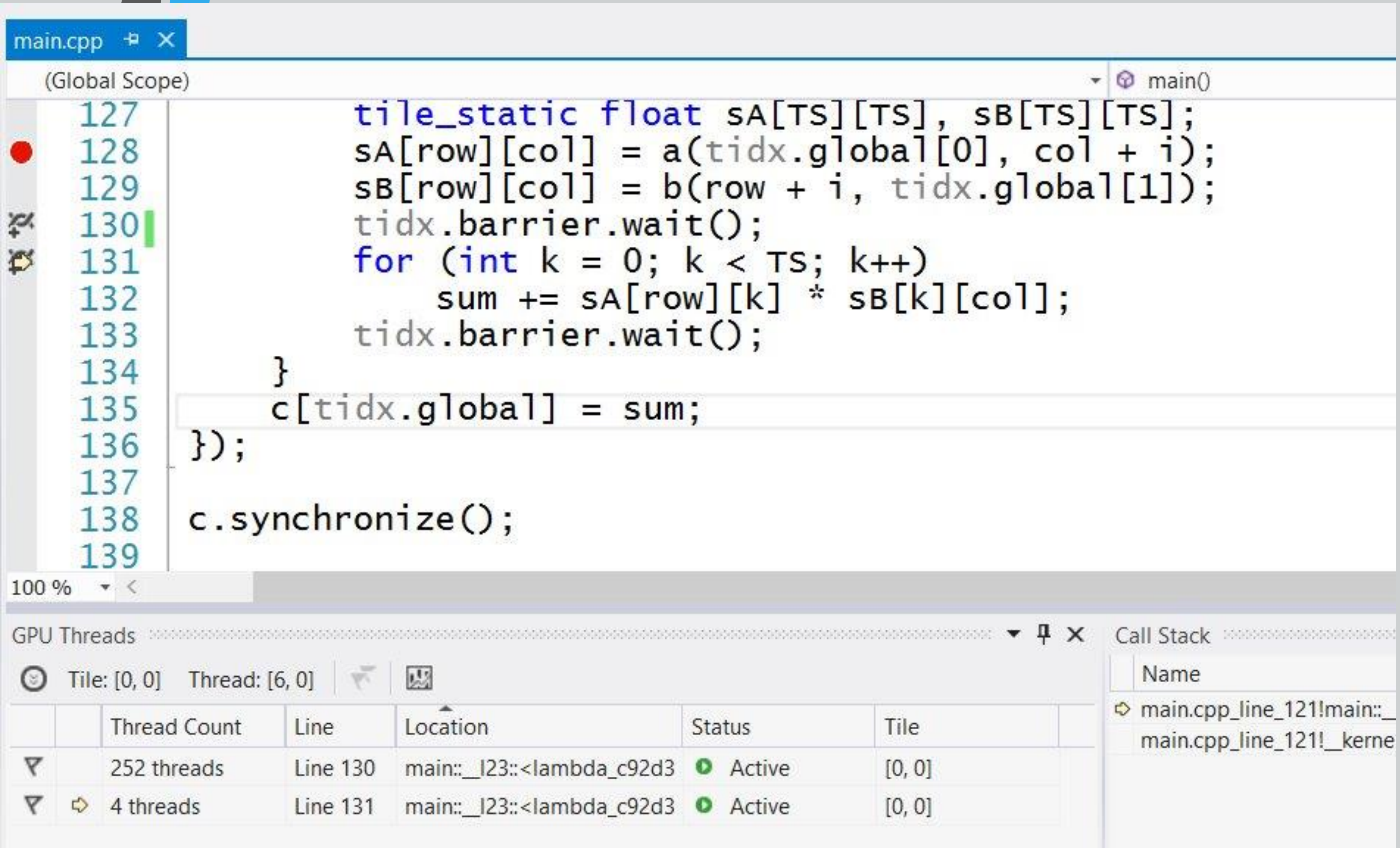
- Windows 8.1 and VC++2013 support simultaneous CPU/GPU debugging:
  - Uses the WARP accelerator



Values, Call Stacks, etc

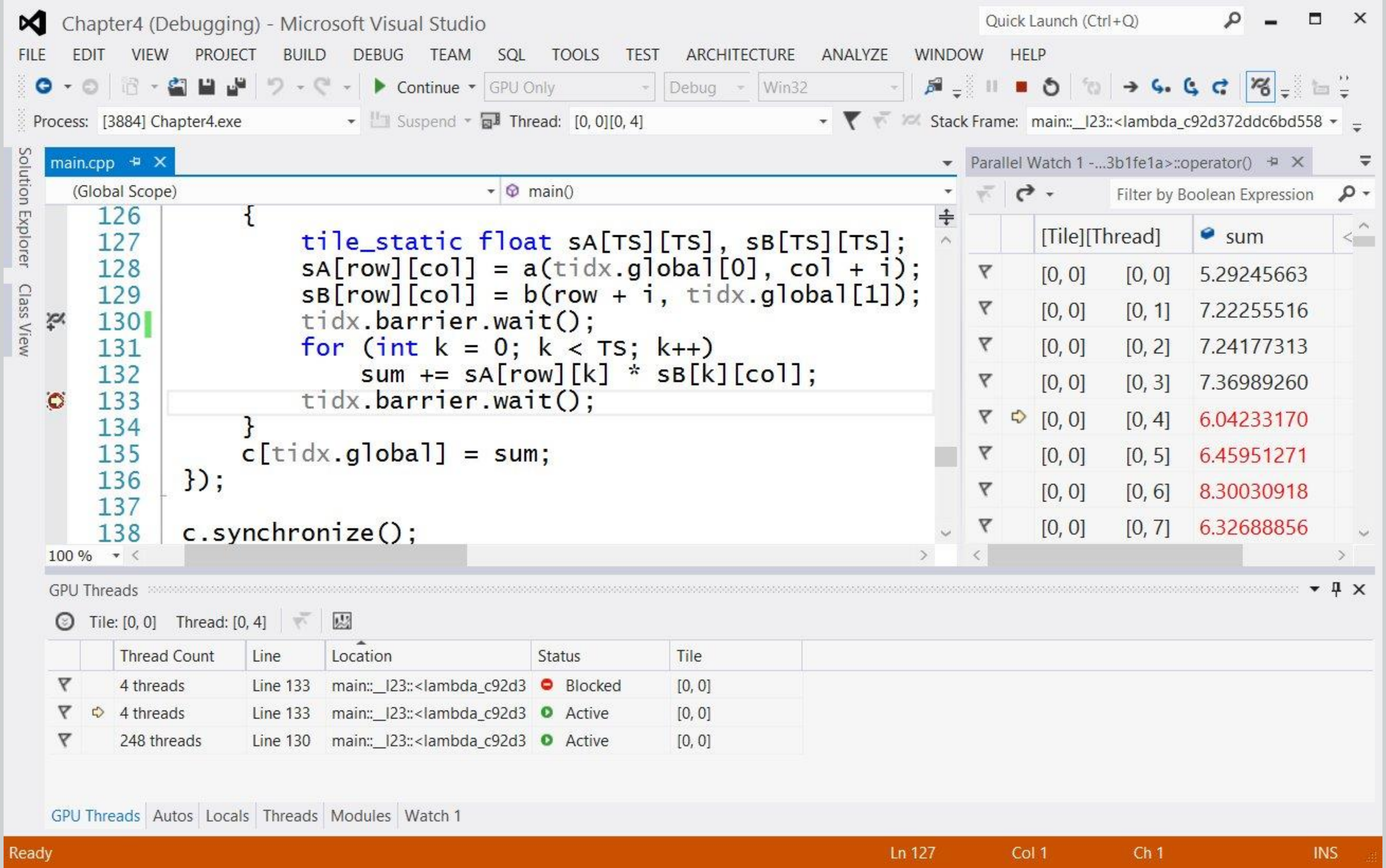


GPU Threads Window



- Shows progress through the calculation

Parallel Watch



- Shows values across multiple threads

And more!

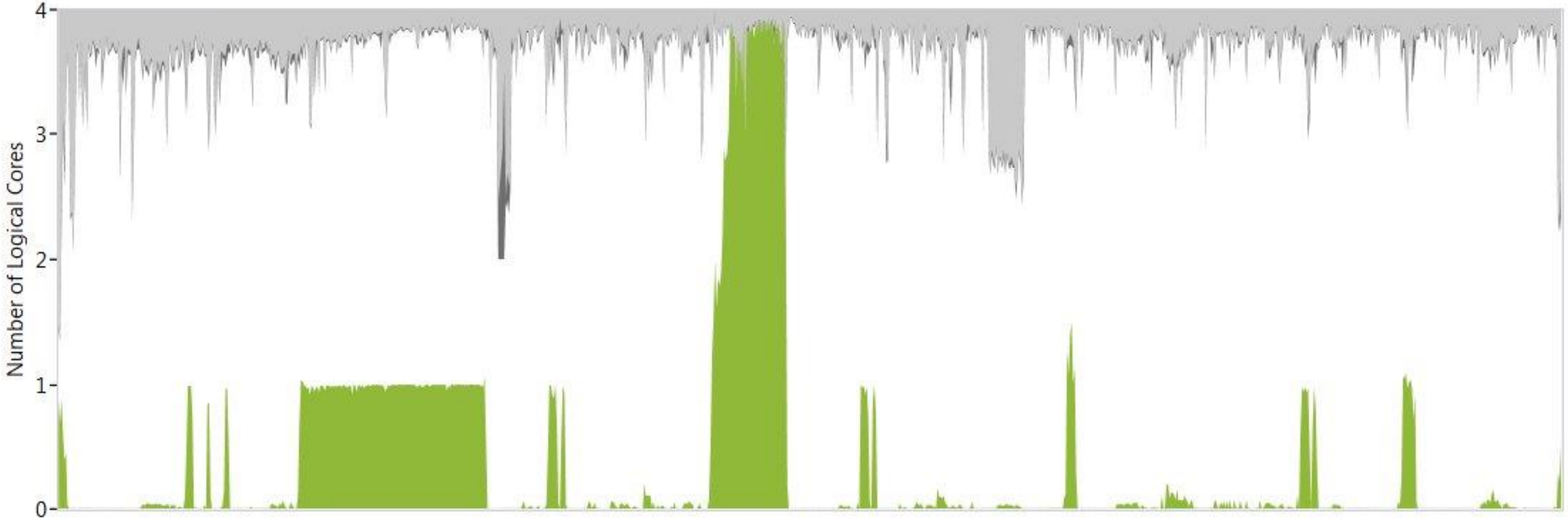
- Race Condition Detection
- Parallel Stacks
- Flagging, Filtering, and Grouping
- Freezing and Thawing
- Run Tile to Cursor

Concurrency Visualizer

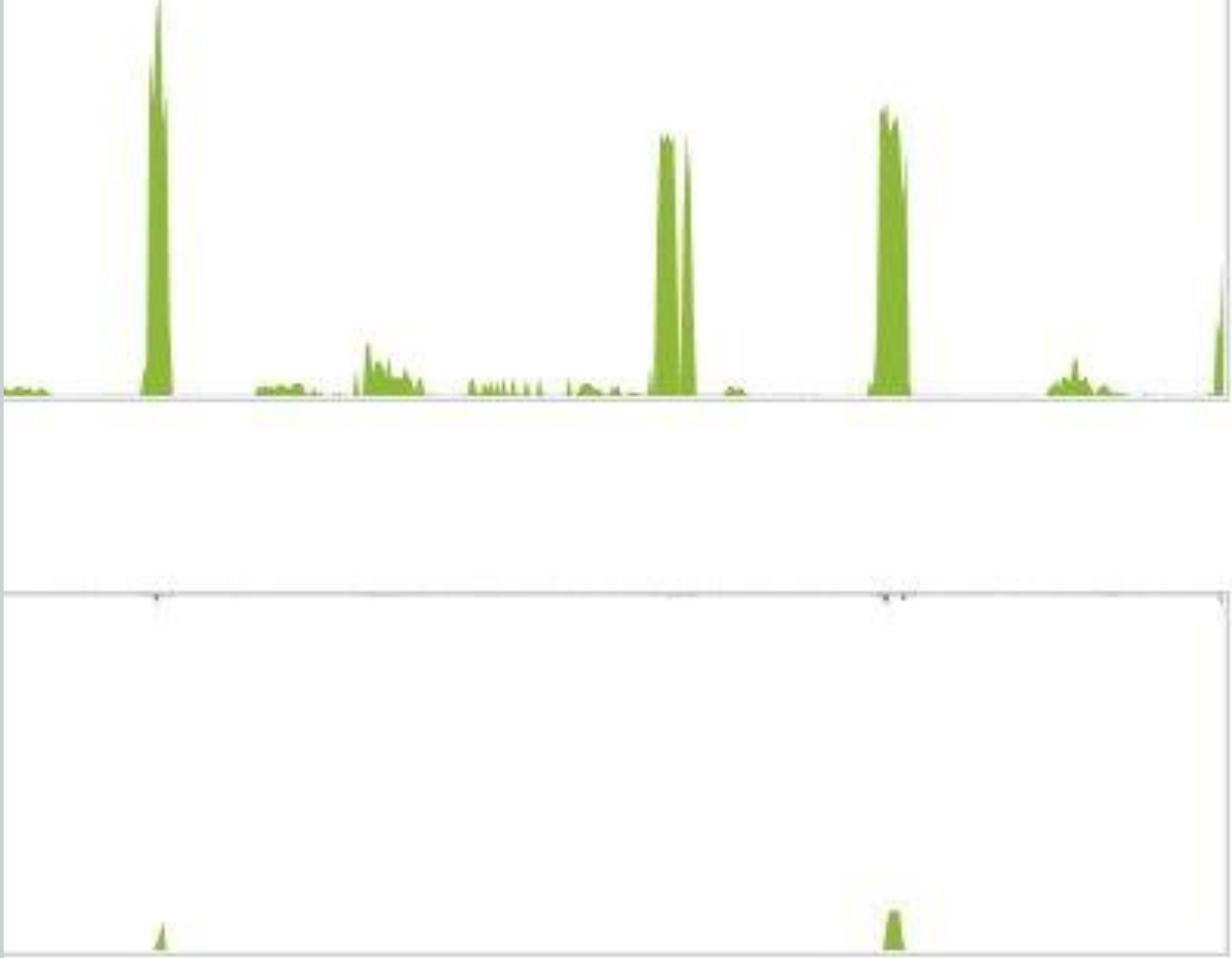
- Shows activity on CPU and GPU
- Can highlight relative times for specific parts of a calculation
- Or copy times to/from the accelerator

- Comes with Visual Studio 2012
- For Visual Studio 2013, shipped as a free extension
  - Search www.visualstudiogallery.com or use Extension Manager inside Visual Studio

CPU Utilization



GPU Activity (DirectX)



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C++ AMP is…

- C++
  - The language you know
  - Excellent productivity
  - The language you choose when performance matters
- Implemented as (mostly) a library
  - Variety of application types
- Well supported by Visual Studio
  - Debugger
  - Concurrency Visualizer
  - Everything else you already use
- Can be supported by other compilers and platforms
  - Open spec

Learn C++ AMP

- book http://www.gregcons.com/cppamp/
- training http://www.acceleware.com/cpp-amp-training
- videos http://channel9.msdn.com/Tags/c++-accelerated-massive-parallelism
- articles http://blogs.msdn.com/b/nativeconcurrency/archive/2012/04/05/c-amp-articles-in-msdn-magazine-april-issue.aspx
- samples http://blogs.msdn.com/b/nativeconcurrency/archive/2012/01/30/c-amp-sample-projects-for-download.aspx
- guides http://blogs.msdn.com/b/nativeconcurrency/archive/2012/04/11/c-amp-for-the-cuda-programmer.aspx
- spec http://blogs.msdn.com/b/nativeconcurrency/archive/2012/02/03/c-amp-open-spec-published.aspx
- forum http://social.msdn.microsoft.com/Forums/en/parallelcppnative/threads

http://blogs.msdn.com/nativeconcurrency/

Call to Action

- Get Visual Studio 2013
- Download some samples
- Play with debugger and other tools
- Try writing a C++ AMP application of your own
  - Console (command prompt)
  - Windows
  - Metro style for Windows 8
- Measure your performance and see the difference