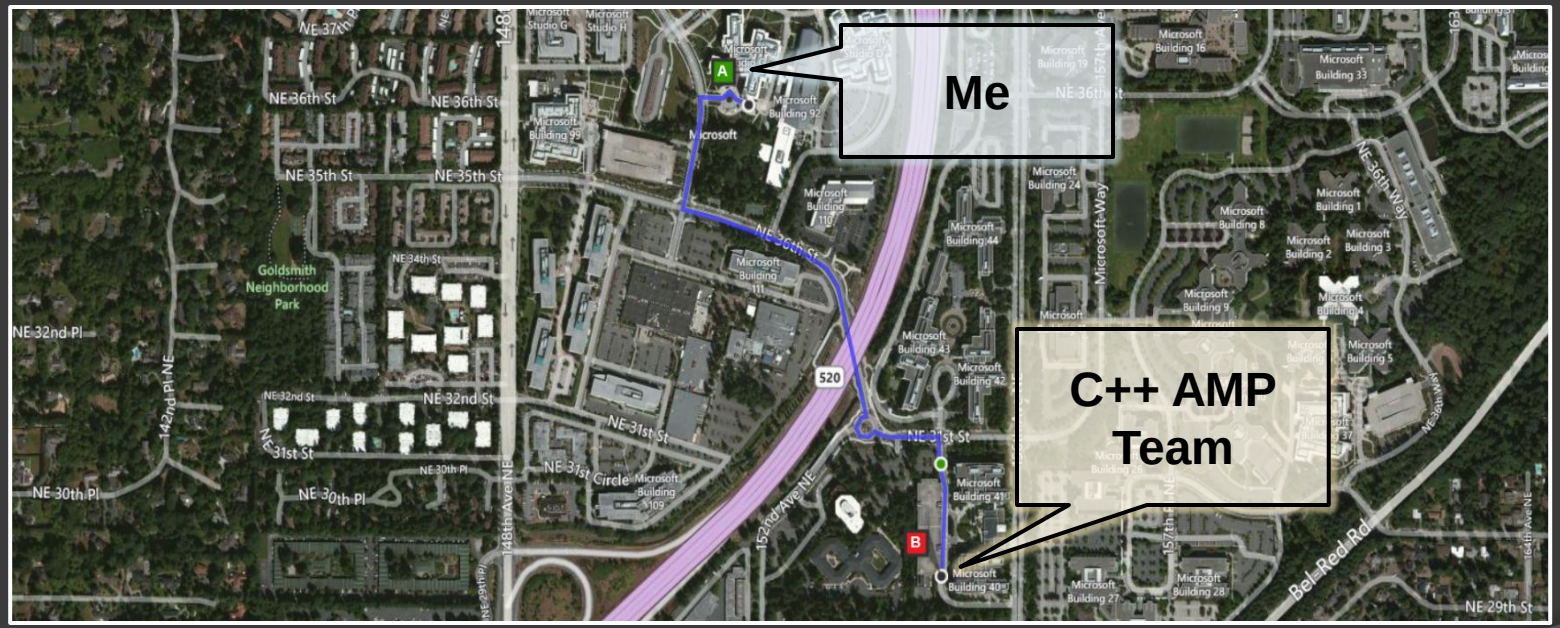
Ade Miller

AN OVERVIEW OF ACCELERATED PARALLELISM WITH C++ AMP

I'm NOT on the C++ AMP Team



I Just wrote the book

For Fun Not Money

What's it all about? …

Introduction

What About The Future?

- CPUs and GPUs coming closer together…
  - …rapidly evolving space

- C++ AMP is designed as a mainstream solution for data parallel kernels.

  Not only for today, but also for tomorrow.

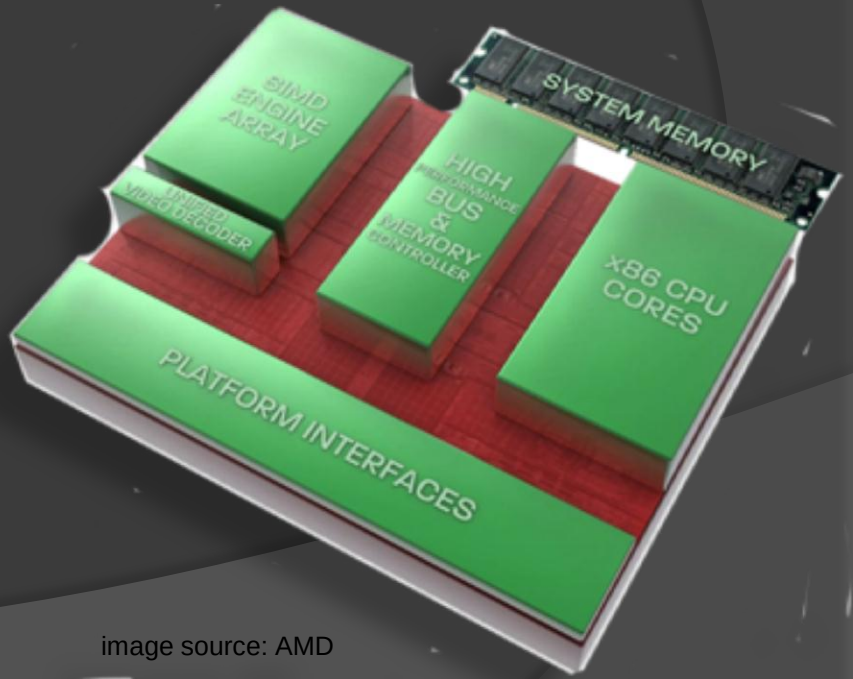


image source: AMD

C++ AMP Platforms Goal

(not current reality)

- Windows Azure
- Windows Desktop
- Windows Server
- Windows HPC Server
- Windows Phone
- Windows RT
- Windows Embedded
- Xbox

C++ AMP

- STL-like library for multidimensional data
- Part of Visual C++
- Visual Studio integration
- Microsoft's implementation builds on Direct3D
- An open specification
  - Intel's Shevlin Park project implements a POC of C++ AMP on top of OpenCL

Portability

- Target GPUs with DirectX 11 drivers
  - NVIDIA GPUs
  - AMD GPUs (and APUs)
  - Intel GPUs (Ivy Bridge and later)
  - ARM GPUs from various IHVs (soon, e.g. see Mali design)
- Fallback to CPU when no capable GPU present
  - AMD and Intel CPUs (multi-core and SSE)
  - ARM CPUs (multi-core and NEON)
- Windows
  - HPC Server, Server, Desktop, Tablets (x86 and ARM)
- Other platforms/hardware through open specification

Performance

- Much faster than CPU multi-core solutions
  - Many samples in the book and online
- Comparable with other GPU approaches

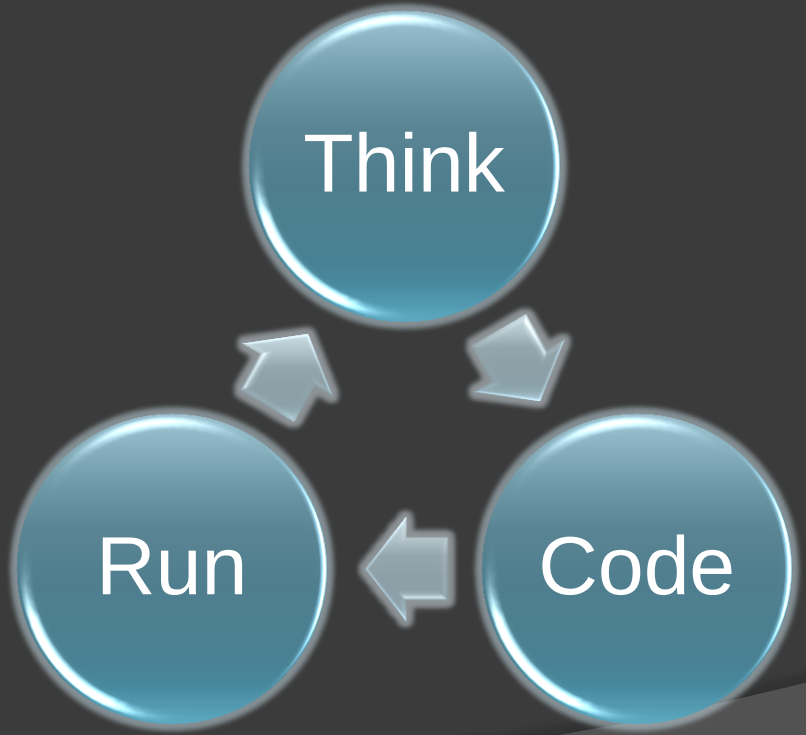
Productivity

- Elements of productivity typically forgotten
  - Acquisition, Support, Deployment
- Lower the barrier to entry AND write less lines of code
  - Blur the line between “host” and “device”
    - One compiler for both, one code file for both, one outer function for both
    - Don’t have to manage data transfers explicitly
    - Don’t have to learn about accelerators until you need to…
  - Don’t have to learn about thread groups/blocks until you need to
    - …and then it is a seamless addition to learn and use
  - C++ AMP is modern C++!
    - No explicit resource management, No stateless global functions, No raw memory pointers, use of lambdas at the API surface

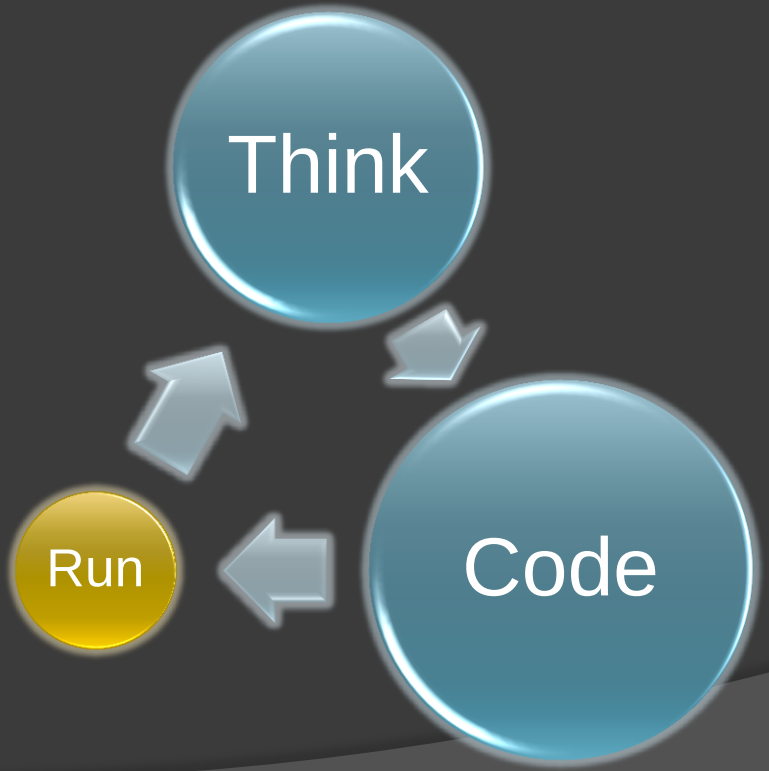
We’re developers so let’s focus on…

Productivity

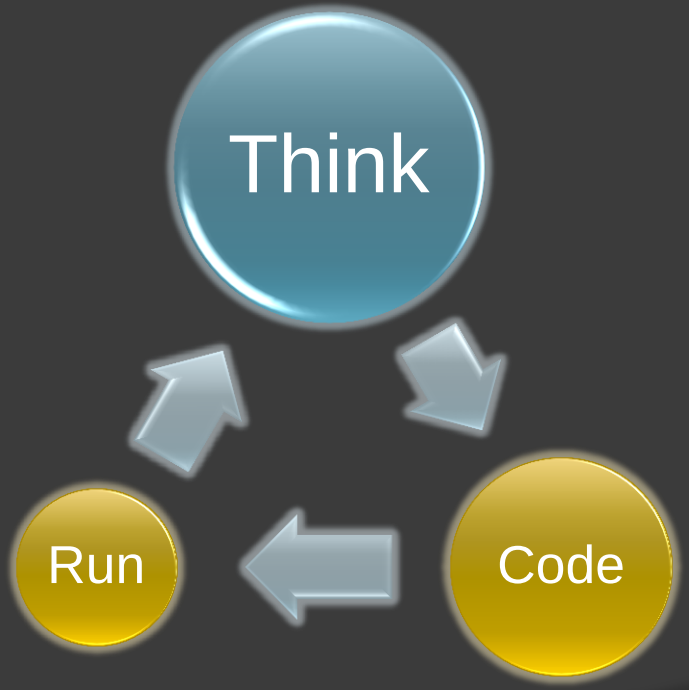
Improving Time to Insight



Improving Time to Insight



Improving Time to Insight



C++ AMP in five (ish) minutes…

The Quick Tour

Containers

`array<T, N>`

`array_view<T, N>`

Container descriptors

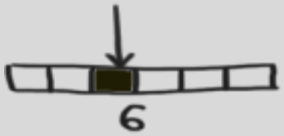
`index<N>`

`extent<N>`

extent<N> and index<N>

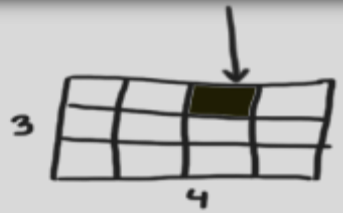
- **`index<N>`** - an N-dimensional point
- **`extent<N>`** - size of an N-dimensional space

```
index<1> i(2);
```



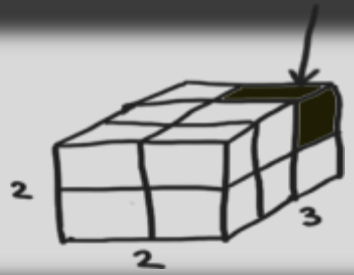

```
extent<1> e(6);
```

```
index<2> i(0,2);
```




```
extent<2> e(3,4);
```

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




```
extent<3> e(3,2,2);
```

- rank N can be any number <=128

array<T, N>

- Multi-dimensional array of rank N with element type T
- Container whose storage lives on a specific accelerator
- Capture by reference [&] in the lambda
- Explicit copy

```
vector<int> vec(8 * 12);
extent<2> ext(8, 12);
array<int, 2> arr(ext);
copy(vec.begin(), vec.end(), arr);
```

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)
- Nearly identical interface to array_view<T, N>

```
std::vector<int> vec(2 * 5);
extent<2> ext(2, 5);
array_view<int, 2> arr(ext, vec);
```

Keyword: restrict(. . .)

- Applies to functions (including lambdas)
- restrict(…) informs the compiler to enforce language restrictions
  - e.g., target-specific restrictions, optimizations, special code-gen
- In 1st release only implements two options:
  - cpu – the implicit default
  - amp – checks that the function conforms to C++ AMP restrictions

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[1]
  - structs & arrays of these types
- Pointers and References
  - Lambdas cannot capture by reference[1], 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

Algorithm(s)

parallel_for_each

- Executes the kernel for each point in the extent
- As-if synchronous in terms of visible side-effects

```
std::vector<int> arr(100000);
array_view<int, 1> arr_av(input.size(), input);
parallel_for_each(arr_av.extent, [ ](index<N> idx)
  restrict(amp)
{
  // kernel code ...
});
```

Hello World

```
#include <ppl.h>
using namespace concurrency;

static float Func(float val)
{ ... }

std::vector<float> arr(10000);
std::iota(begin(arr), end(arr), 1.0f);

parallel_for_each(begin(arr), end(arr),
  [=](float& v)
{
  v = Func(v);
});
```

Library header and namespace

PPL parallel execution

C++11 Lambda function

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

static float Func(float val) restrict(cpu, amp)
{ ... }

// Initialize arr ...
array_view<float> arr_av(arr.size(), arr);

parallel_for_each(arr_av.extent, [=](index<1> idx) restrict(amp)
{
  arr_av[idx] = Func(arr_av[idx]);
});

for(int i = 0; i < arr_av.extent[0]; ++i)
  std::cout << arr_av[i] << std::endl;
```

Library header and namespace

Target CPU & GPU with `restrict` keyword

Thread index

Target GPU

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

static float Func(float val) restrict(cpu, amp)
{ ... }

// Initialize arr ...
array_view<float> arr_av(arr.size(), arr);

parallel_for_each(arr_av.extent, [=](index<1> idx) restrict(amp)
{
  arr_av[idx] = Func(arr_av[idx]);
});

for(int i = 0; i < arr_av.extent[0]; ++i)
  std::cout << arr_av[i] << std::endl;
```

Wrap data (no copy)

Loop bounds

Copy to GPU on demand

Copy to CPU

Using Tiled Memory to

Improve Performance

Keyword: tile_static

- The tile_static storage class
  - Second addition to the C++ language
  - Reflects hardware memory hierarchy

- Within the tiled parallel_for_each lambda use
  - tile_static for local variables
    - indicates that the variable is allocated in fast cache memory
      - i.e. shared by each thread in a tile of threads
    - only applicable in restrict(amp) functions

"Untiled" GPU

Don't copy input, `arr` out

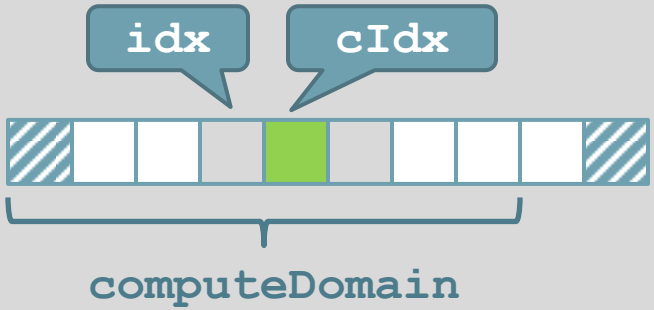
```
array_view<const float> arr_av(arr.size(), arr);
std::vector<float> avg(arr.size() - 2);
array_view<float> avg_av(avg.size(), avg);extent<1>

avg_av.discard_data();
parallel_for_each(avg_av.extent, [=](index<1> idx)
  restrict(amp)
{
  const int cIdx = idx[0] + 1;

  avg_av[cIdx - 1] = (arr_av[idx] +
      arr_av[idx + 1] +
      arr_av[idx + 2]) / 3;
});
```

Don't copy result, `avg` in

Number of threads

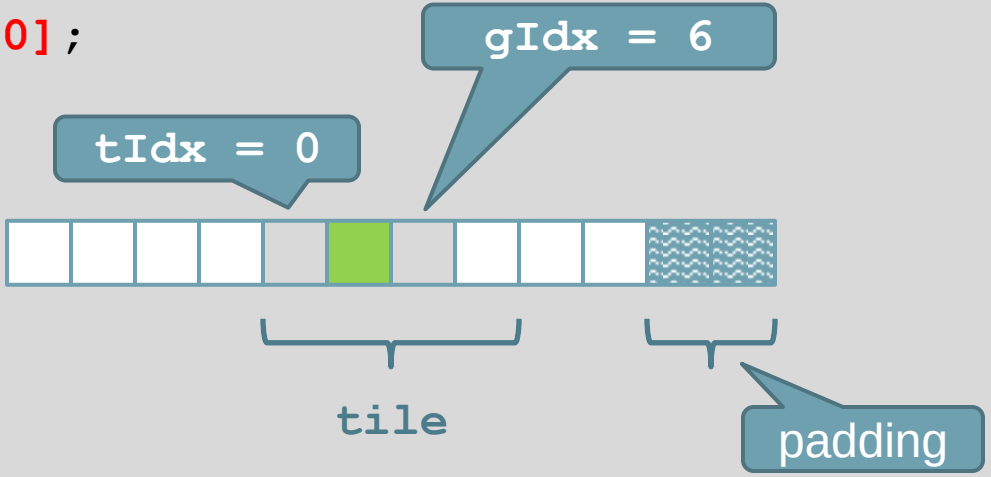


```
static const int tileSize = 4; // 256
tiled_extent<tileSize> computeDomain = avg_av.extent;
computeDomain = computeDomain.pad();

parallel_for_each(computeDomain,
  [=](tiled_index<tileSize> idx) restrict(amp)
{
  const int gIdx = idx.global[0];
  const int tIdx = idx.local[0];

  // ...
});
```

Tiled extent padded to tile size



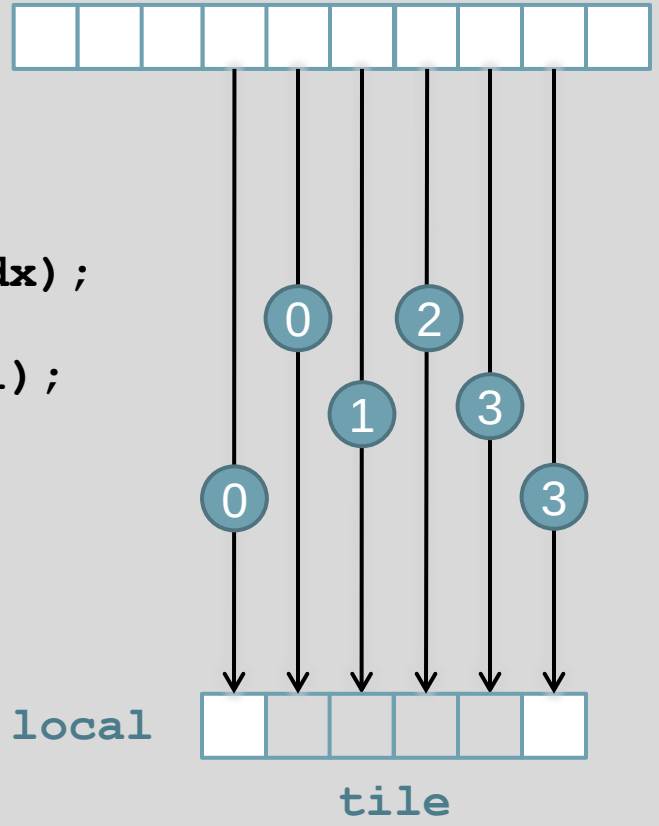
```
parallel_for_each(computeDomain,
  [=](tiled_index<tileSize> idx) restrict(amp)
{
  const int gIdx = idx.global[0];
  const int tIdx = idx.local[0];

  tile_static float local[tileSize + 2];

  local[tIdx + 1] = PaddedRead(arr_av, gIdx);
  if (tIdx == 0)
    local[0] = PaddedRead(arr_av, gIdx - 1);
  if (tIdx == (tileSize - 1))
    local[tileSize + 1] =
      PaddedRead(arr_av, gIdx + 1);

  idx.barrier.wait();
  // ...
});
```

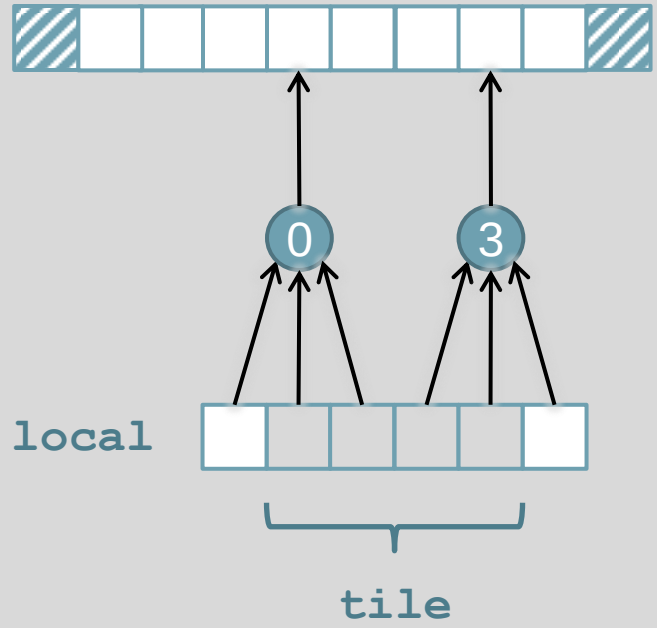
Wait for all data to be copied to `local`



```
parallel_for_each(computeDomain,
   [=](tiled_index<tileSize> idx) restrict(amp)
{
   const int gIdx = idx.global[0];
   const int tIdx = idx.local[0];

   // ...

   float val = (local[tIdx] +
     local[tIdx + 1] +
     local[tIdx + 2]) / 3;
   PaddedWrite(avg_av, gIdx - 1, val);
});
```



```
template <typename T>
T PaddedRead(const array_view<const T, 1>& A, int idx)
restrict(cpu, amp)
{
  return A.extent.contains(index<1>(idx)) ? A[idx] : T();
}

template <typename T>
void PaddedWrite(const array_view<T, 1>& A, int idx, T val)
restrict(cpu, amp)
{
  if (A.extent.contains(index<1>(idx))) A[idx] = val;
}
```

Is `idx` within the extent?

Usual Performance Rules Apply

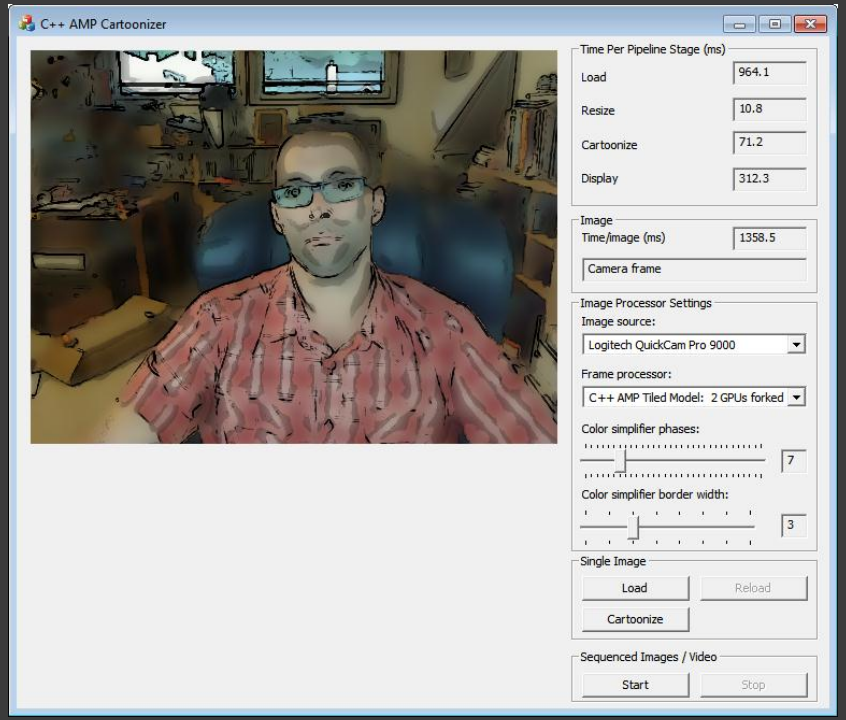
- Measure and understand your goals
- Consider your whole algorithm
- Use off the shelf libraries – C++ AMP Algorithms Library

- Minimize or overlap memory transfers to and from the GPU
- Coalesce global memory accesses
- Take Advantage of tile_static (local memory)
- Avoid bank conflicts in tile_static memory
- Avoid branching within kernels

Using GPUs and CPUs together

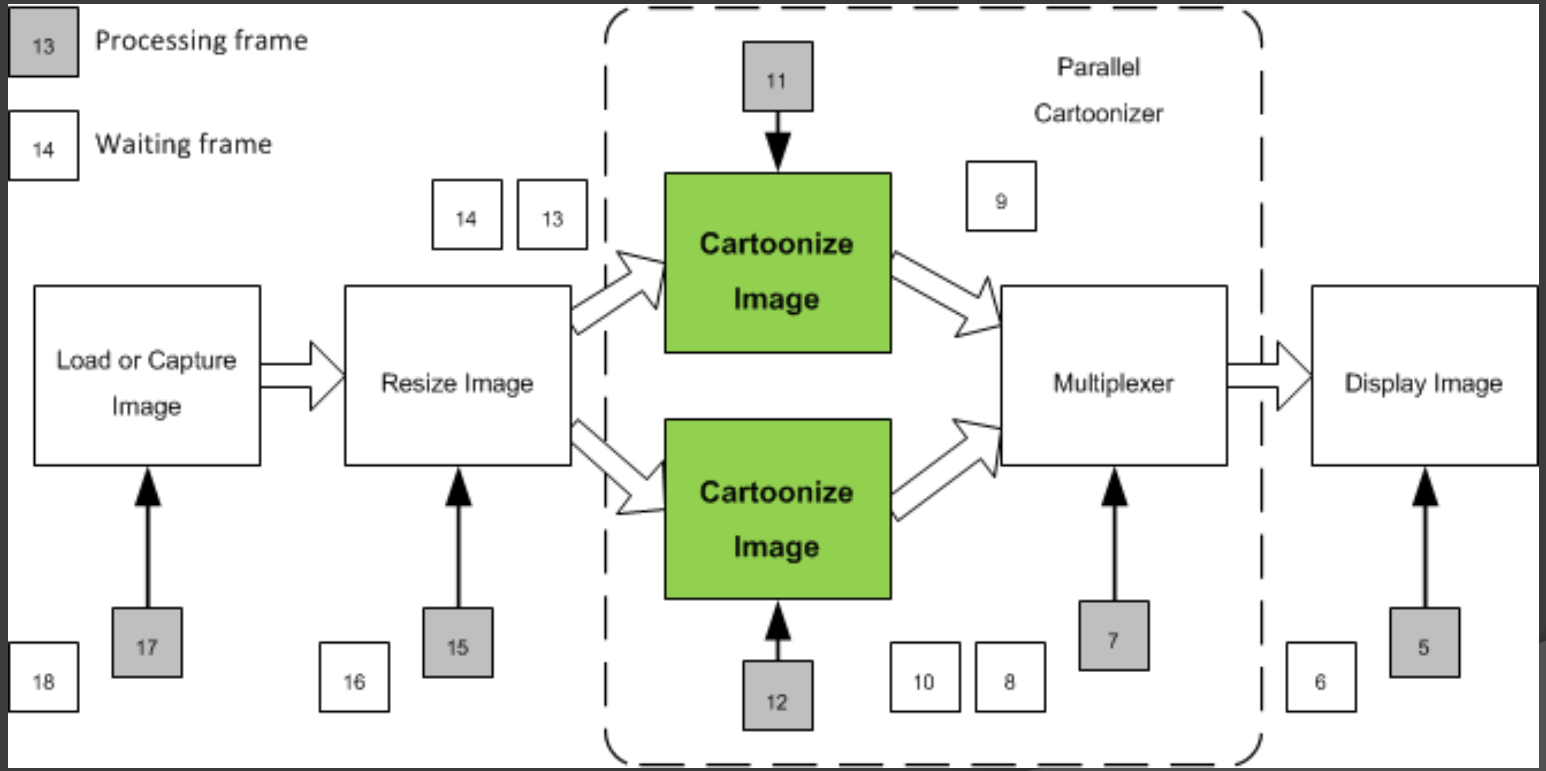
Braided Parallelism

Cartoonizer Demo



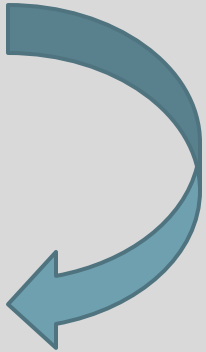
- Real time video processing on multiple GPUs
- Edge detection and color smoothing
- Pipelined approach using both CPU and GPU at different stages

Video Processing Pipeline



CPU

```
parallel_for_each(begin(m_processors), end(m_processors),
  [=](std::shared_ptr<IFrameProcessor>& proc)
{
  ImageInfoPtr pInfo = nullptr;
  do
  {
    pInfo = receive(m_inputBuffer);
    CartoonizeImage(pInfo, proc, ...);
    asend(..., pInfo);
  }
  while (nullptr != pInfo);
});
```



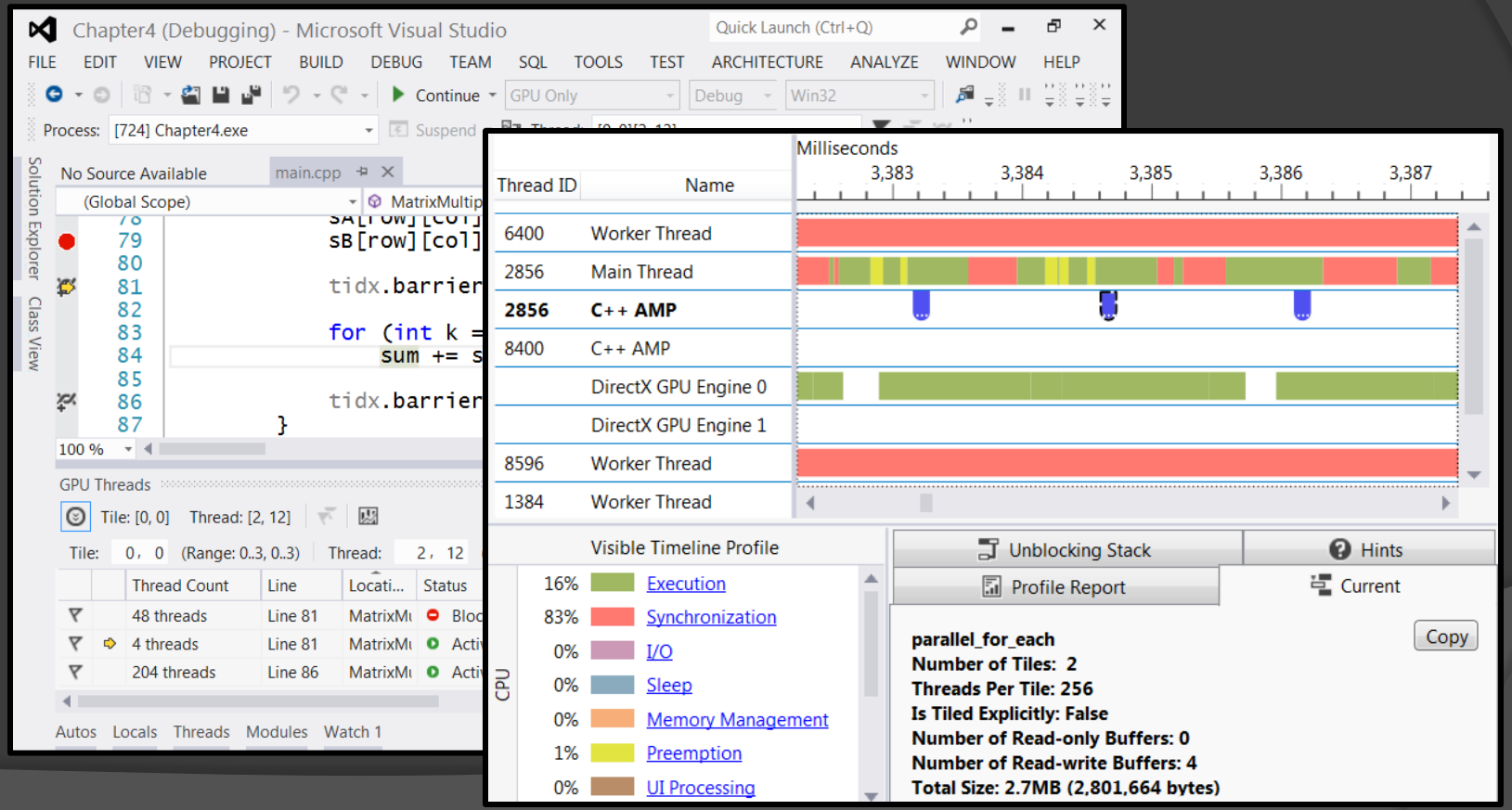
GPU

```
extent<2> computeDomain( ... );
parallel_for_each(computeDomain,
  [=, &srcFrame, &destFrame](index<2> idx) restrict(amp)
{
  SimplifyIndex(srcFrame, destFrame, idx, ...);
});
```

C++ AMP Tools

- Visual Studio 2012
  - Visual C++ with C+11 support
  - CPU and GPU Debugger
  - CPU and GPU Profiler
  - IDE support; Intellisense

Visual Studio IDE



Learn C++ AMP...

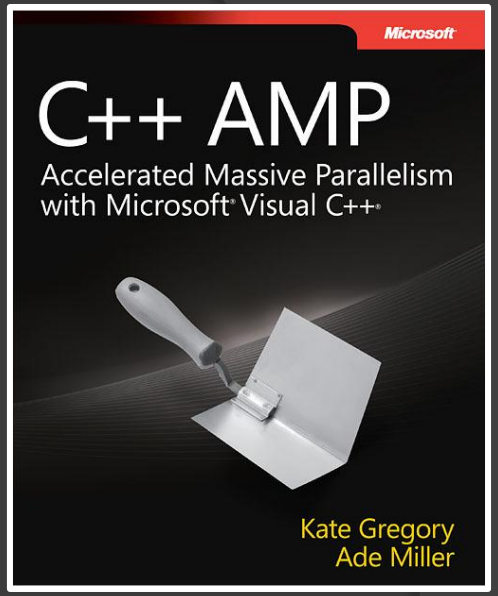
Book / Source Code / Blogs:

http://www.gregcons.com/cppamp

Courses:

http://www.acceleware.com/

- Apr 23 - C++ AMP in Seattle, WA
- Sep 10 - C++ AMP in Boston, MA



More C++ AMP

C++ AMP Team Blog
http://blogs.msdn.com/b/nativeconcurrency/

C++ AMP Forum

http://social.msdn.microsoft.com/Forums/en-US/parallelcppnative/threads

Open Specification:
http://blogs.msdn.com/b/nativeconcurrency/archive/2012/02/03/c-amp-open-spec-published.aspx

Questions?