Heterogeneous Parallelism at Microsoft

Herb Sutter

1975-2005

Put a **computer** on every desk, in every home, in every pocket.

The free lunch is so over

2005-2011

Put a **parallel supercomputer** on every desk, in every home, in every pocket.

Welcome to the jungle

2011-201x

Put a **heterogeneous supercomputer** on every desk, in every home, in every pocket.

mainstream, *df.*:

commercially available to millions

commercially affordable for millions

commercially programmable by millions

note: everything in "the mainstream" starts out in "the exotic"

GUIs ✓ *objects* ✓ *parallelism* ✓

mainstream trends

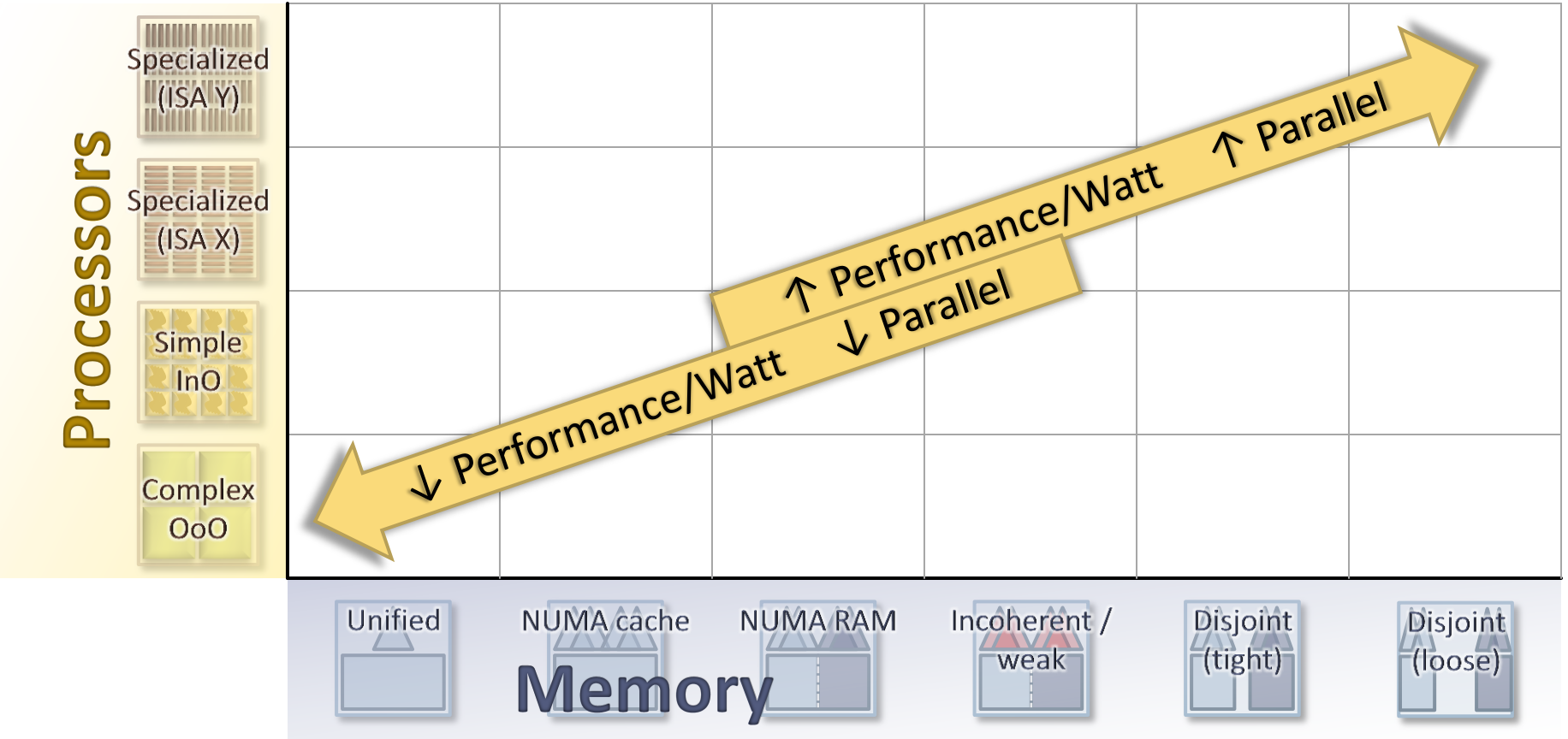
multicore CPUs

GPGPU

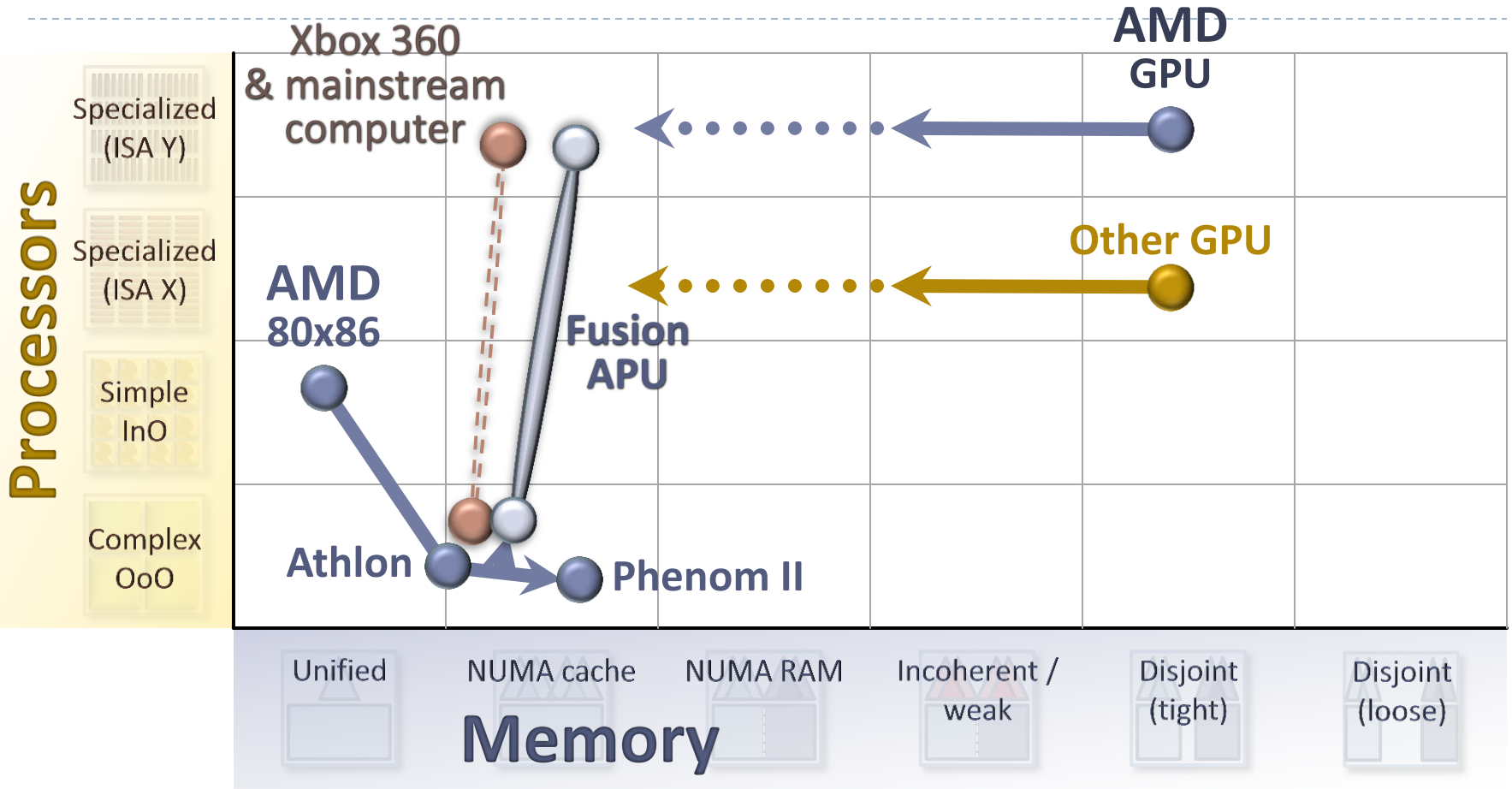
cloud IaaS/HaaS

Heterogeneous parallel computing

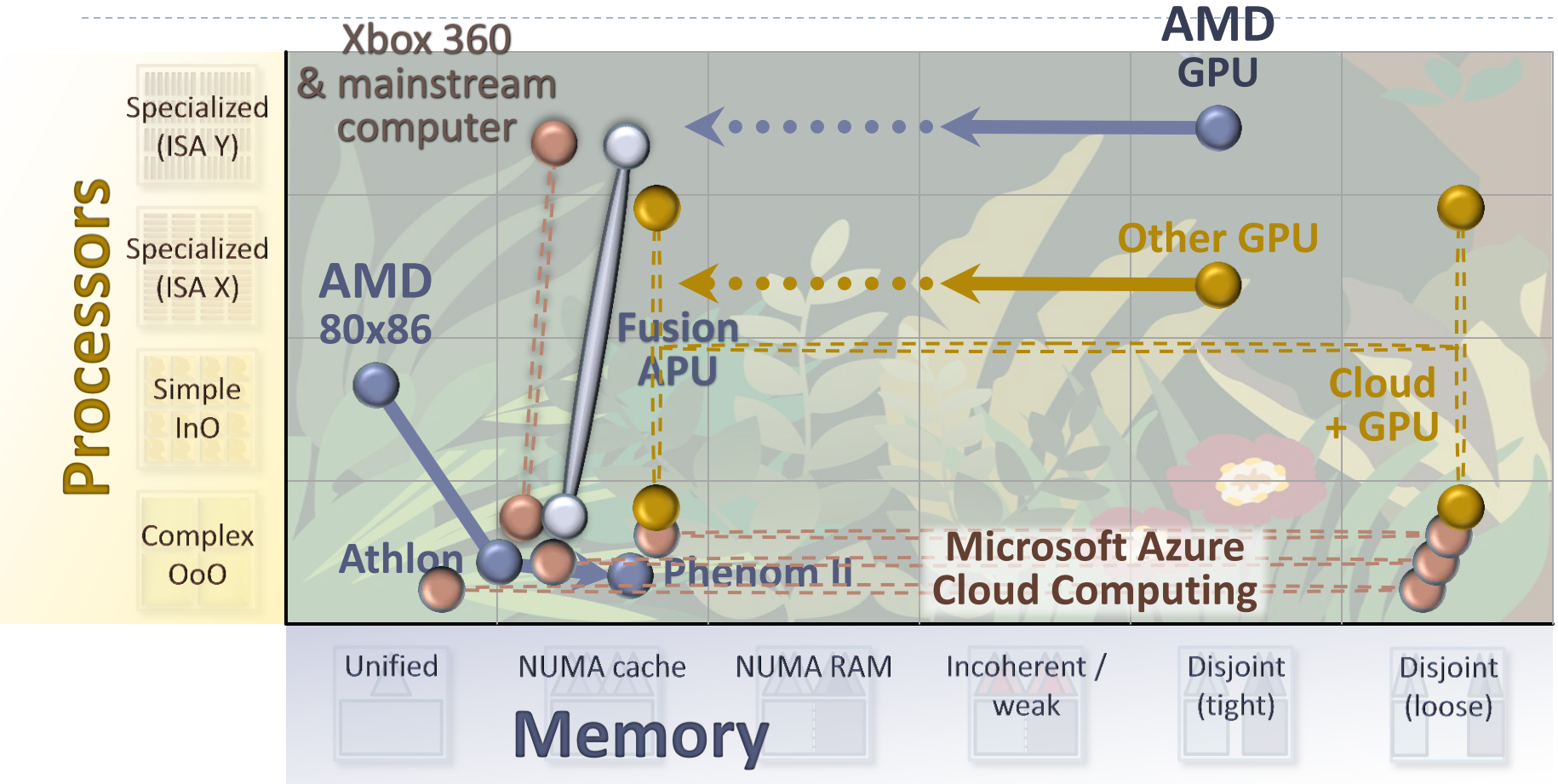
Charting the Landscape



Hardware


Xbox 360
& mainstream
computer
AMD
GPU
Other GPU
AMD
80x86
Fusion
APU
Athlon
Phenom II
Processors
Specialized
(ISA Y)
Specialized
(ISA X)
Simple
InO
Complex
OoO
Unified
NUMA cache
NUMA RAM
Incoherent /
weak
Disjoint
(tight)
Disjoint
(loose)
Memory

Hardware


Processors
Specialized (ISA Y)
Specialized (ISA X)
Simple InO
Complex OoO
Xbox 360 & mainstream computer
AMD GPU
Other GPU
AMD 80x86
Fusion APU
Cloud + GPU
Athlon
Phenom II
Microsoft Azure Cloud Computing
Unified
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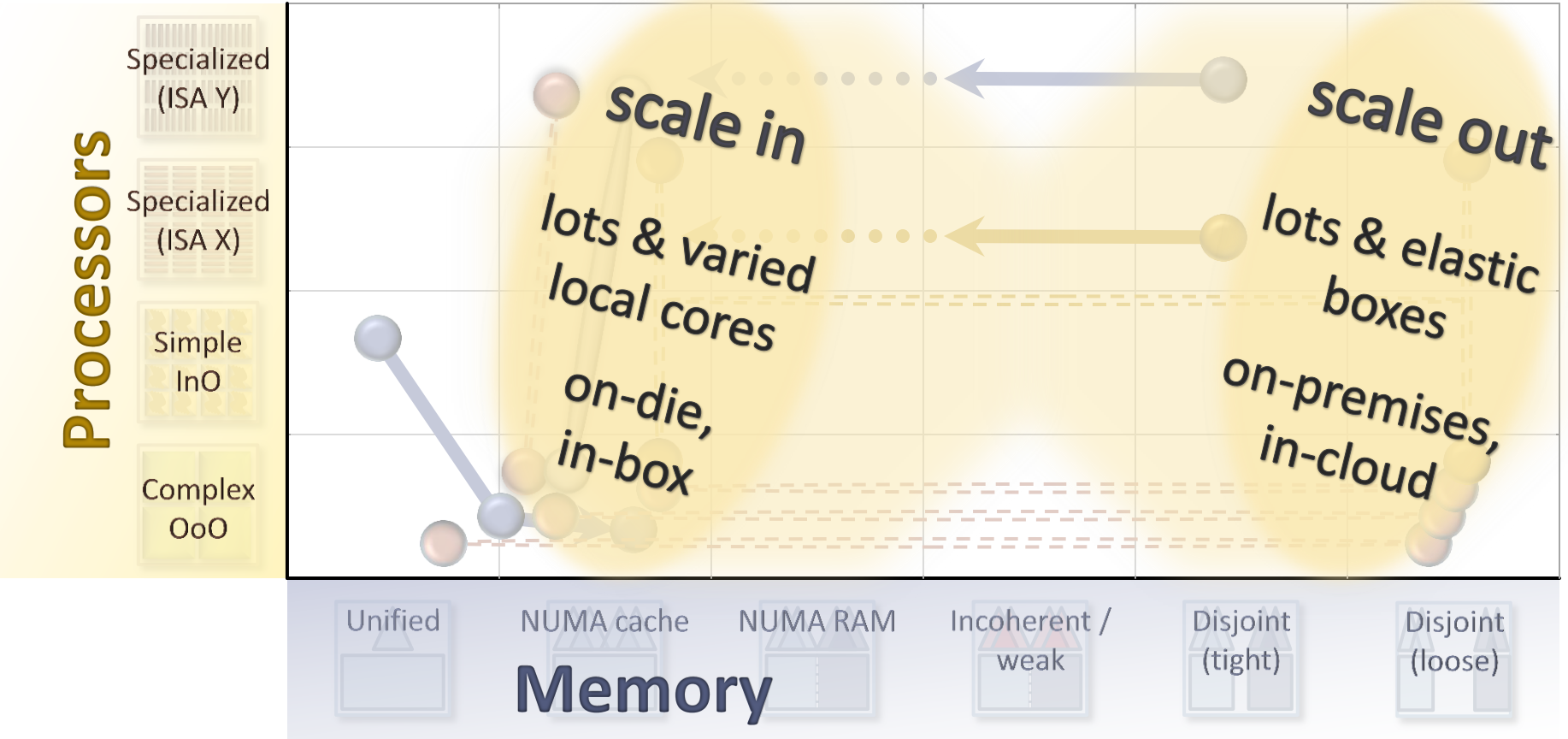
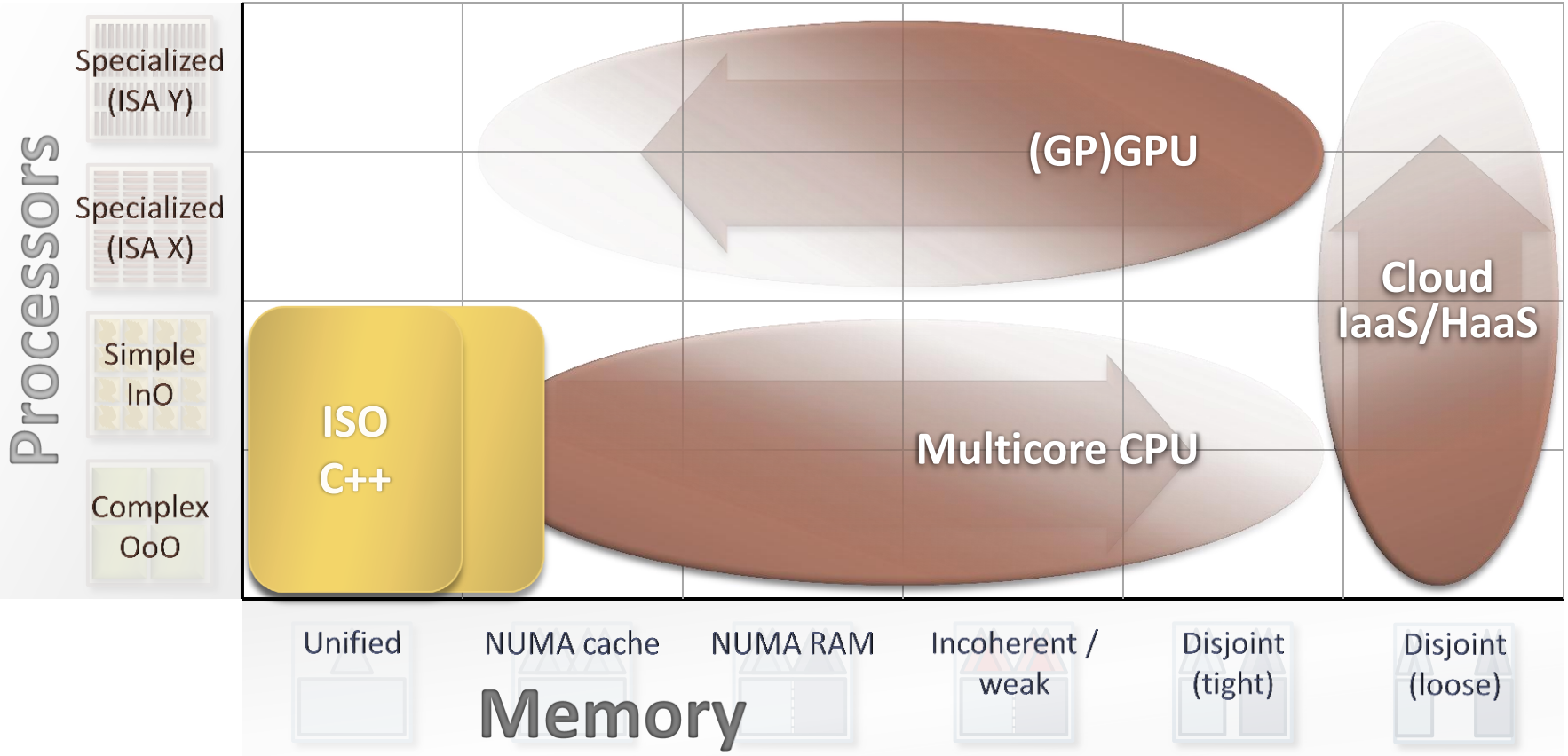
Hardware Evolution



Programming Models & Languages



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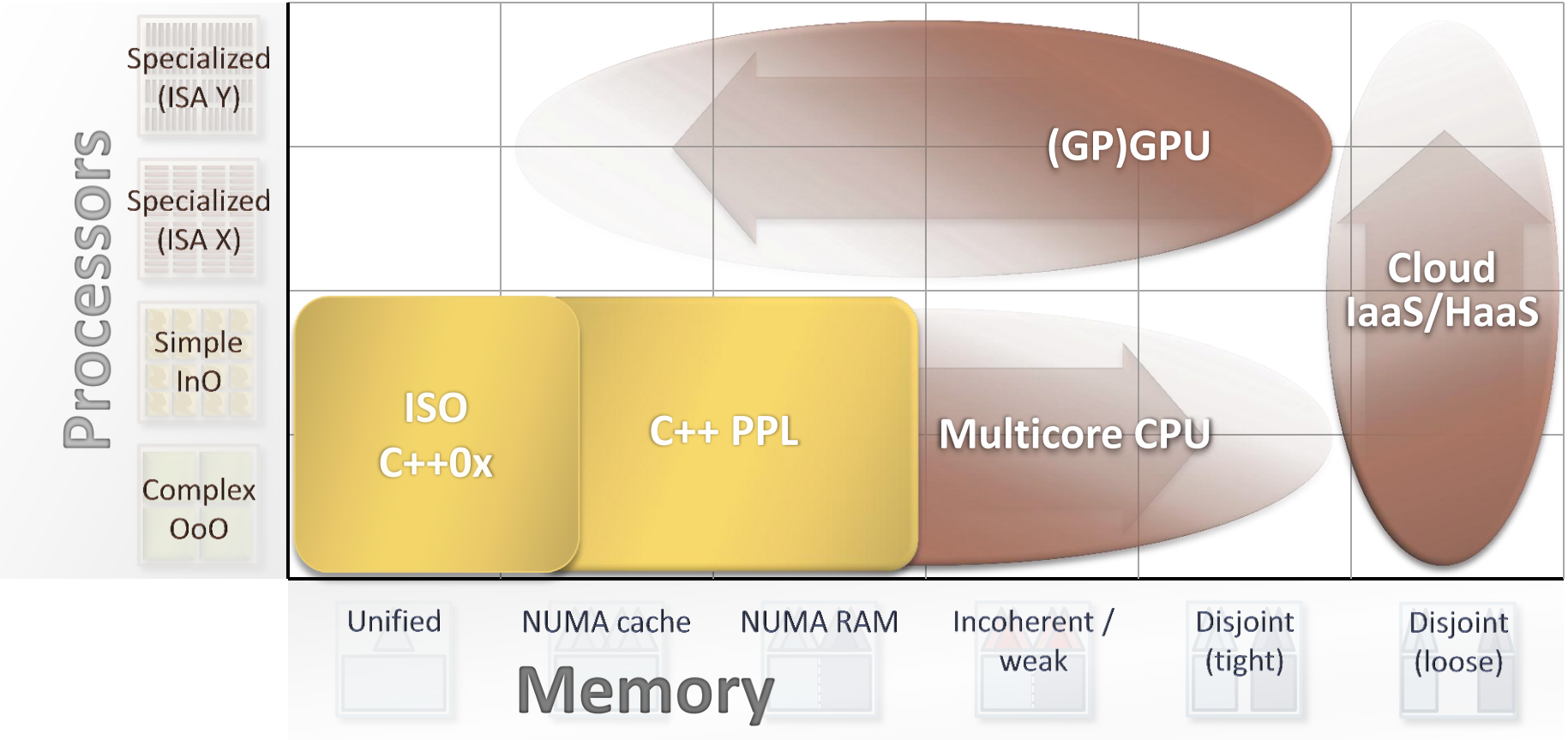
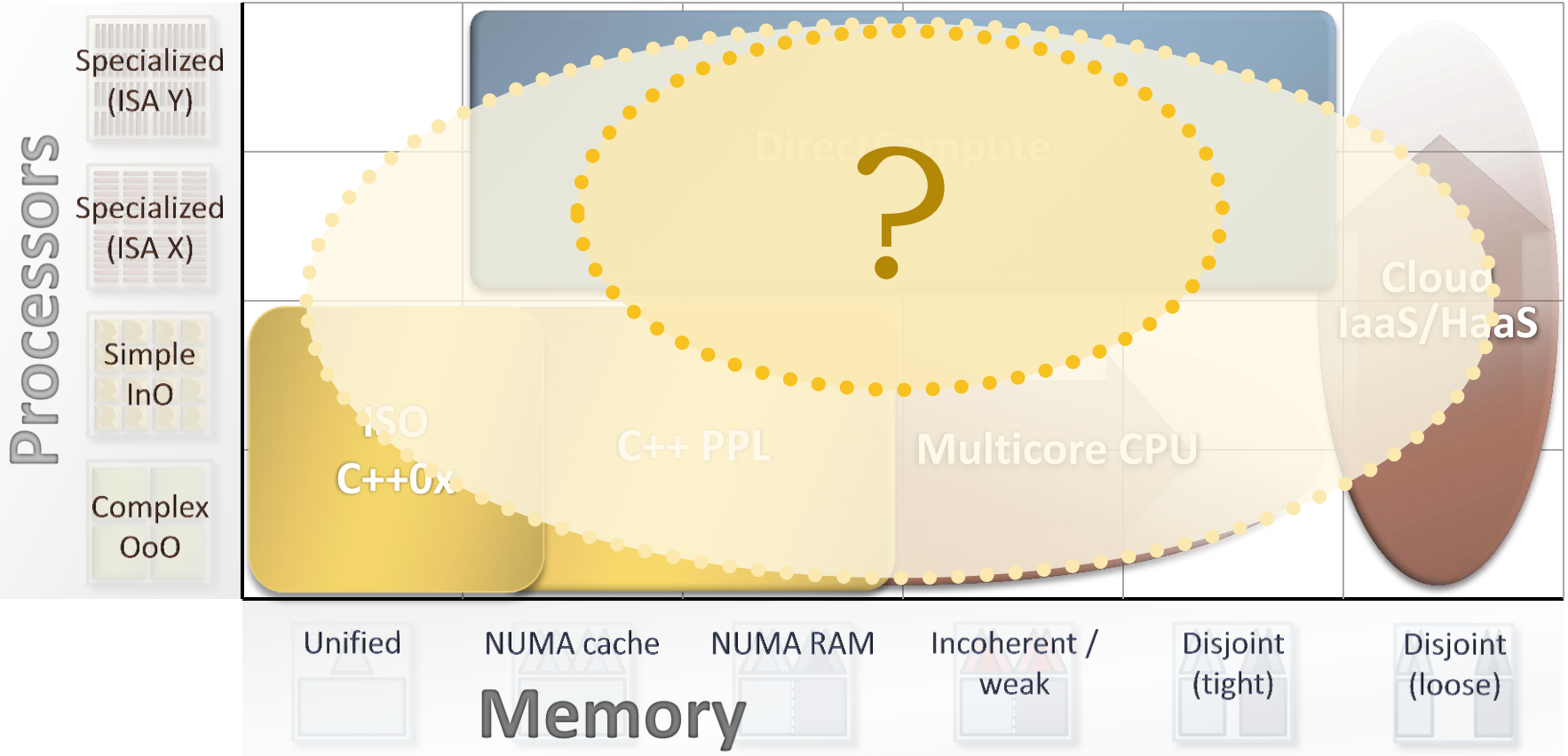
C++ the Clear Winner In Google's Language Performance Tests
Google has released a research paper that suggests C++ is the best-performing programming language in the market.
The internet giant implemented a compact algorithm in four languages – C++, Java, Scala and its own programming language Go – and then benchmarked results to find "factors of difference".
"We find that in terms of performance, C++ wins out by a large margin," the paper says.
Further reading
› Surge in C++ demand

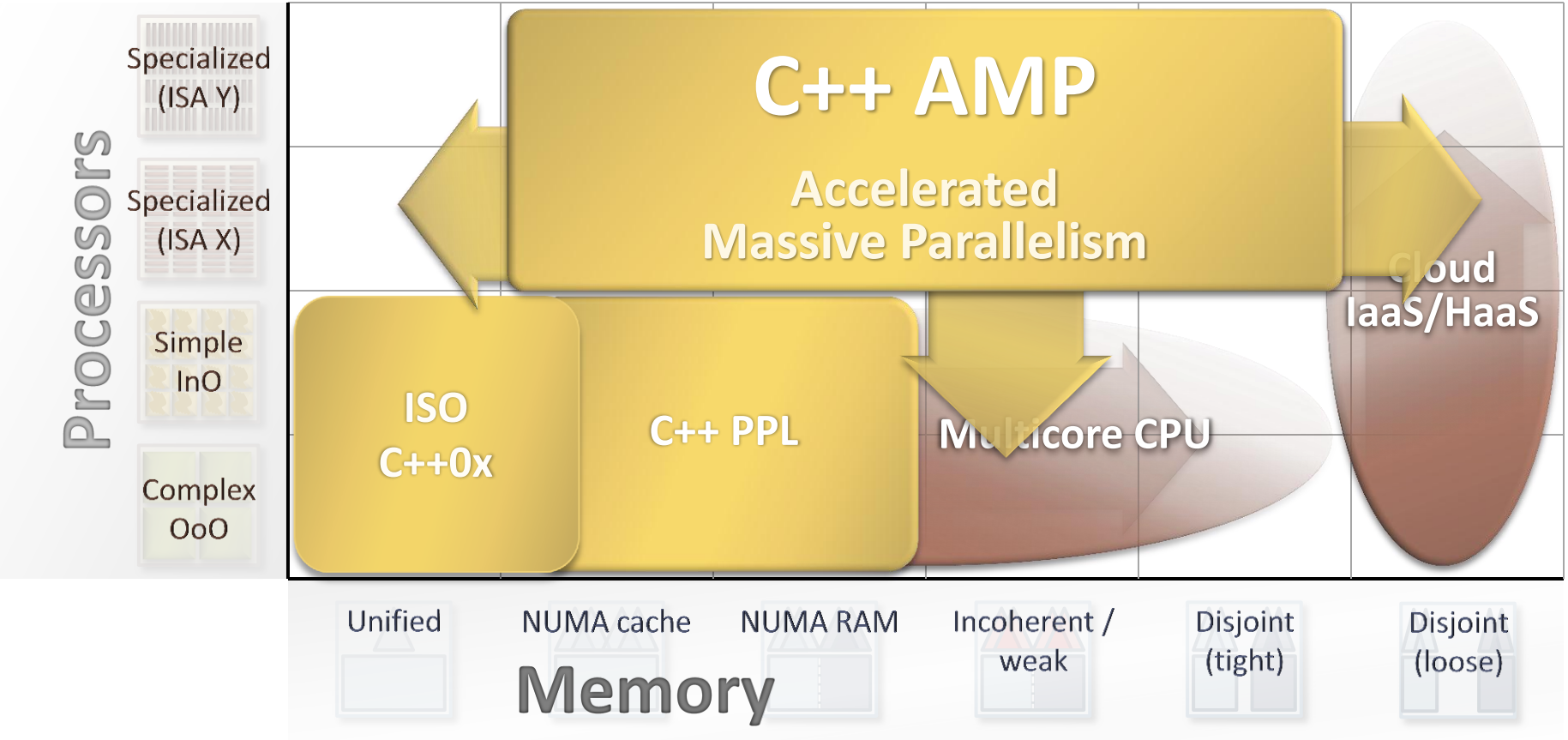
Programming Models & Languages



Programming Models & Languages



Programming Models & Languages



Matrix Multiply

Convert this (serial loop nest)

```
void MatrixMult( float* C, const vector<float>& A,  const vector<float>& B,
                 int M, int N, int W )
{
  for (int y = 0; y < M; y++)
    for (int x = 0; x < N; x++) {
      float sum = 0;
      for(int i = 0; i < W; i++)
        sum += A[y*W + i] * B[i*N + x];
      C[y*N + x] = sum;
    }
}
```

Matrix Multiply

Convert this (serial loop nest)

```
void Mat

{
  for (int
    for (ir
      floa
      for(
        su
      C[y*
    }
}
```

… to this (parallel loop, CPU or GPU)

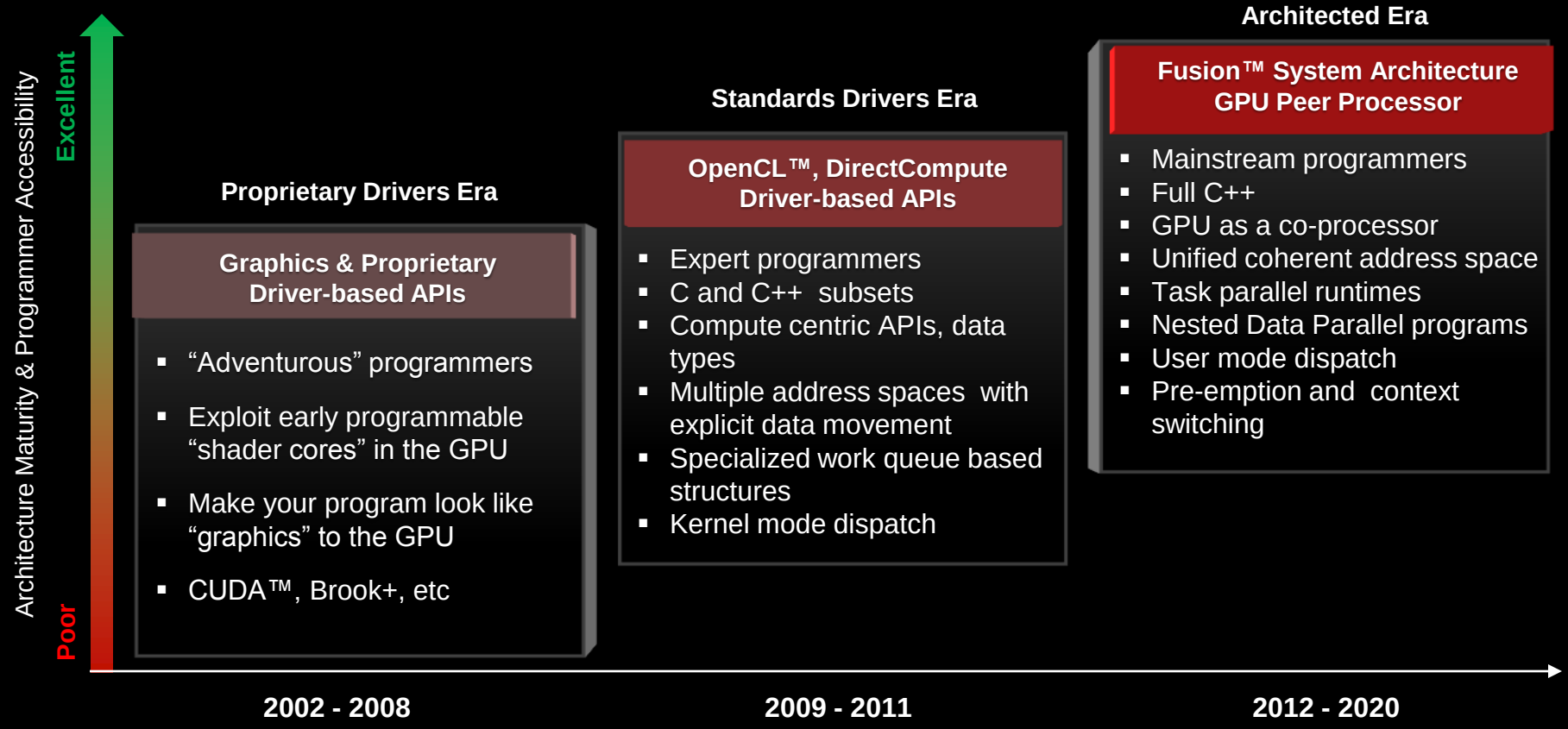
```
void MatrixMult( float* C, const vector<float>& A,  const vector<float>& B,
                 int M, int N, int W )
{
  array_view<const float,2> a(M,W,A), b(W,N,B);
  array_view<writeonly<float>,2> c(M,N,C);

  parallel_for_each( c.grid, [=](index<2> idx) restrict(direct3d) {
    float sum = 0;
    for(int i = 0; i < a.x; i++)
      sum += a(idx.y, i) * b(i, idx.x);
    c[idx] = sum;
  } );
}
```

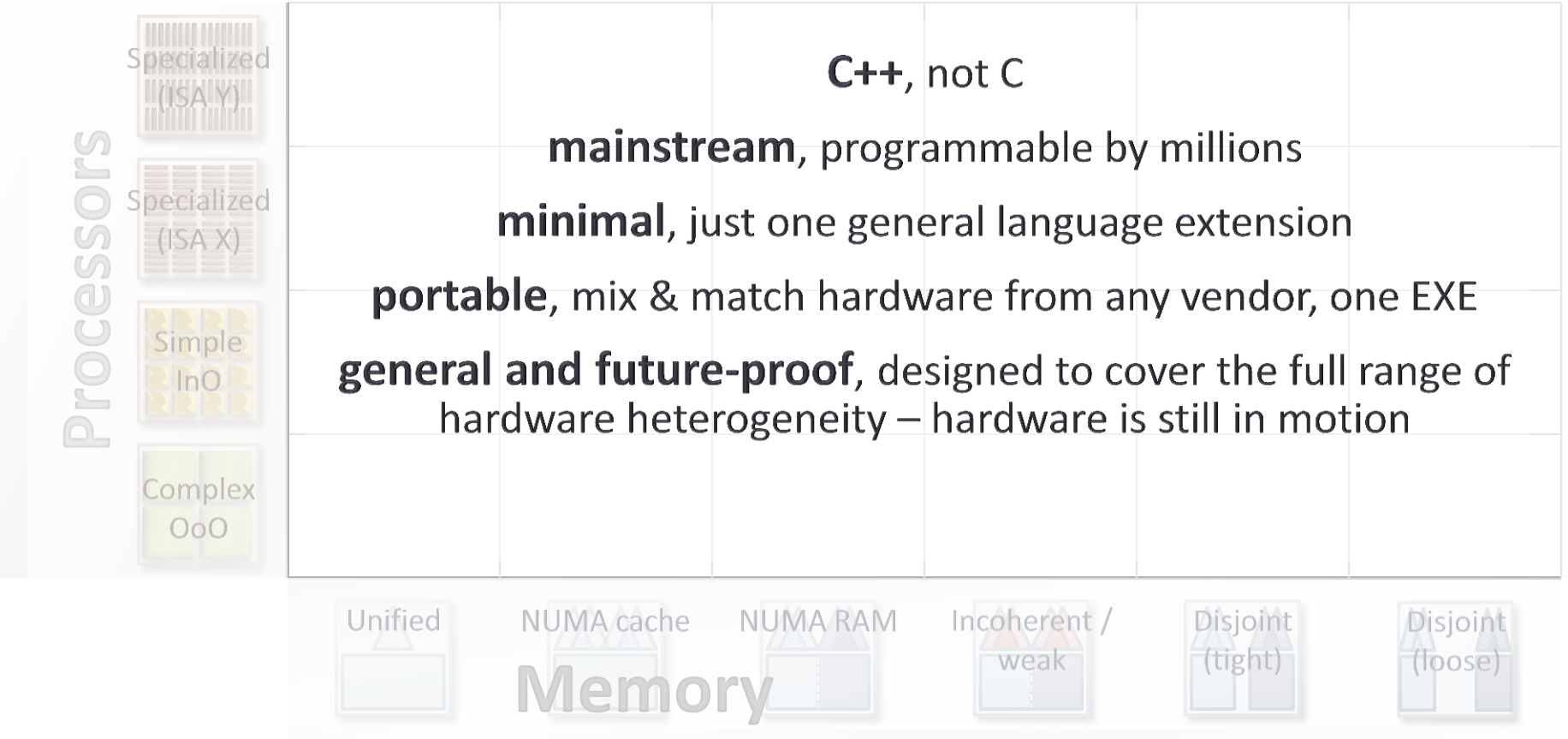
Demo

Daniel Moth
Program Manager
Parallel Computing Platform

EVOLUTION OF HETEROGENEOUS COMPUTING



Why C++ AMP?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Specialized (ISA X)
Simple InO
Complex OoO
C++, not C
mainstream, programmable by millions
minimal, just one general language extension
portable, mix & match hardware from any vendor, one EXE
general and future-proof, designed to cover the full range of hardware heterogeneity – hardware is still in motion
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NUMA cache
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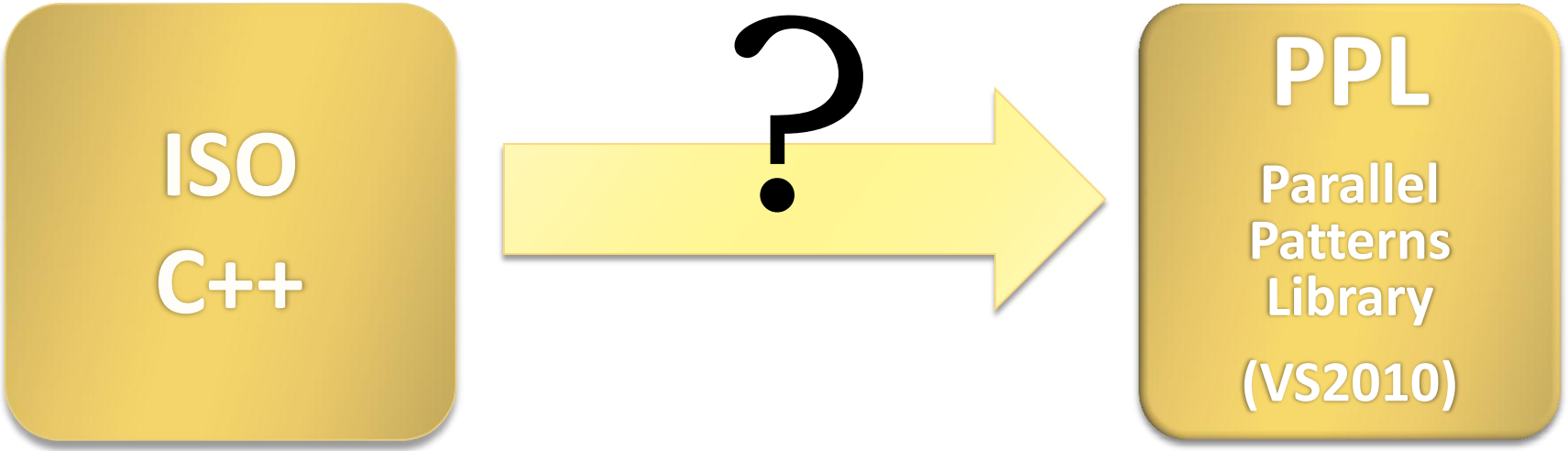
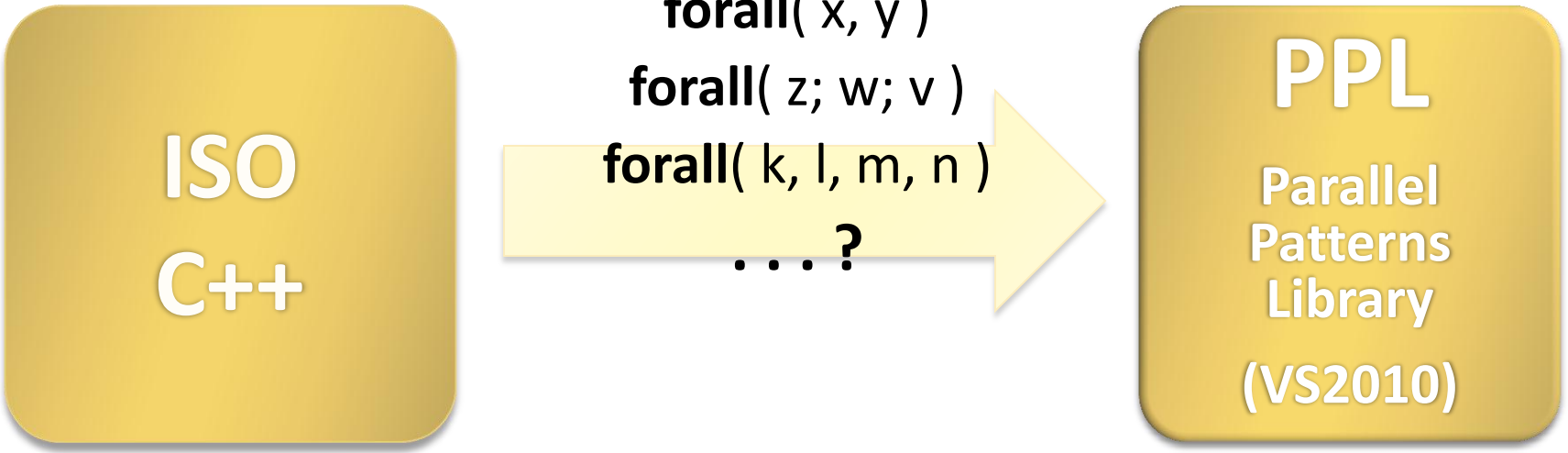
Language Design: Parallelism Phase 1

Single-core to multi-core



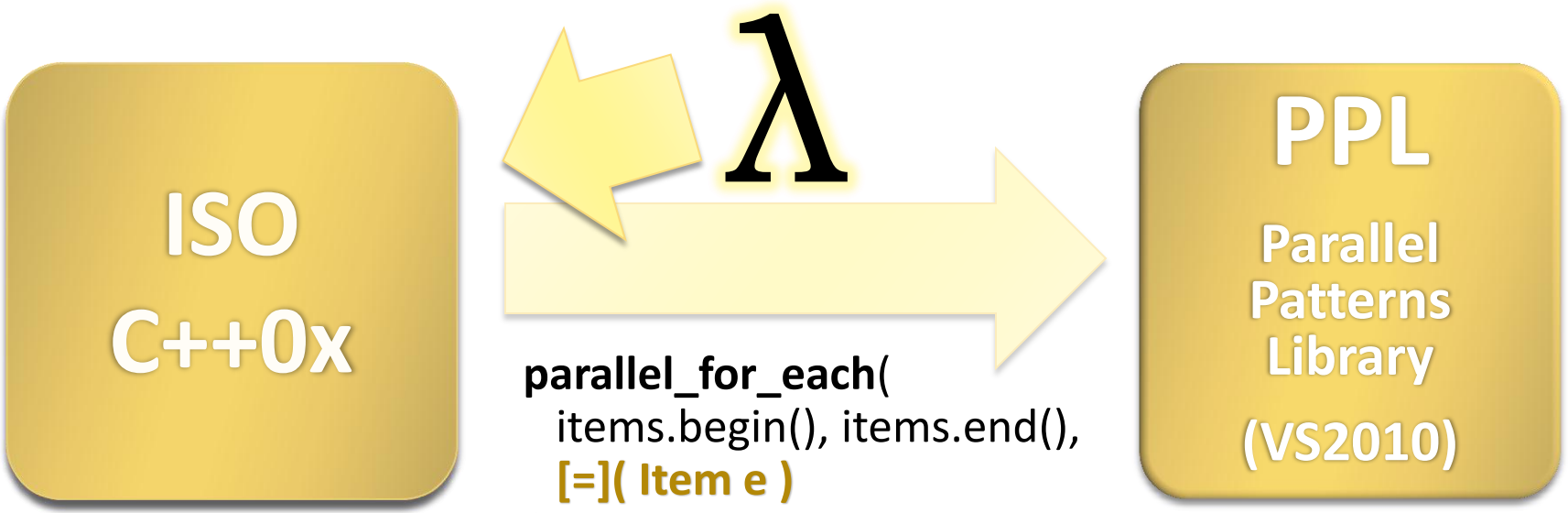
Language Design: Parallelism Phase 1

Single-core to multi-core



Language Design: Parallelism Phase 1

Single-core to multi-core




```
parallel_for_each(
  items.begin(), items.end(),
  [=]( Item e )
{
  … your code here …
} );
```

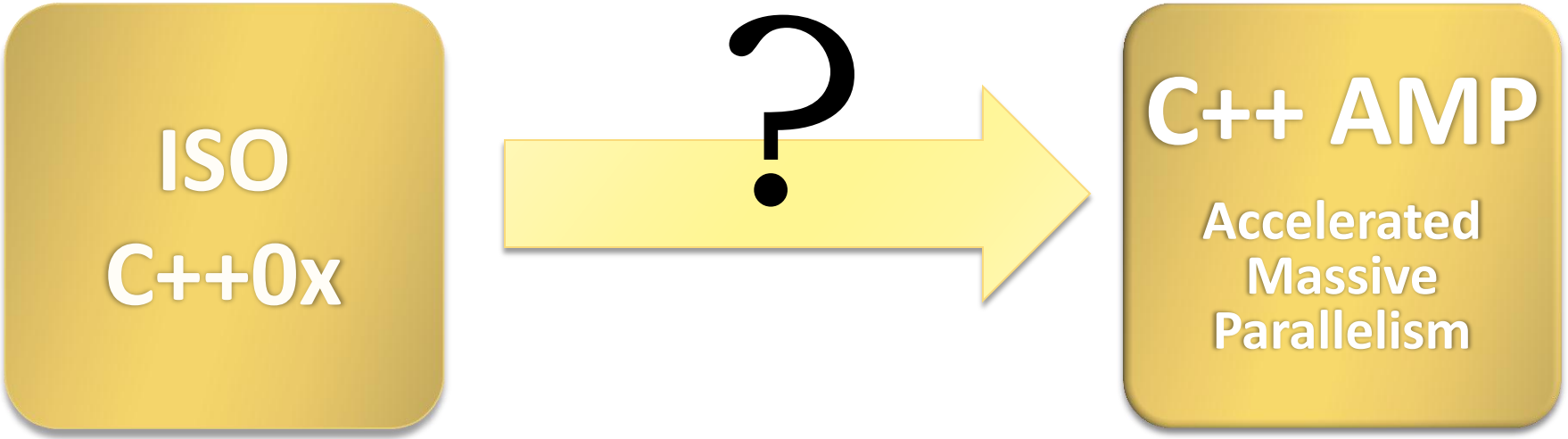
1

language feature for multicore

and STL, functors, callbacks, events, ...

Language Design: Parallelism Phase 2

Multi-core to hetero-core



Language Design: Parallelism Phase 2

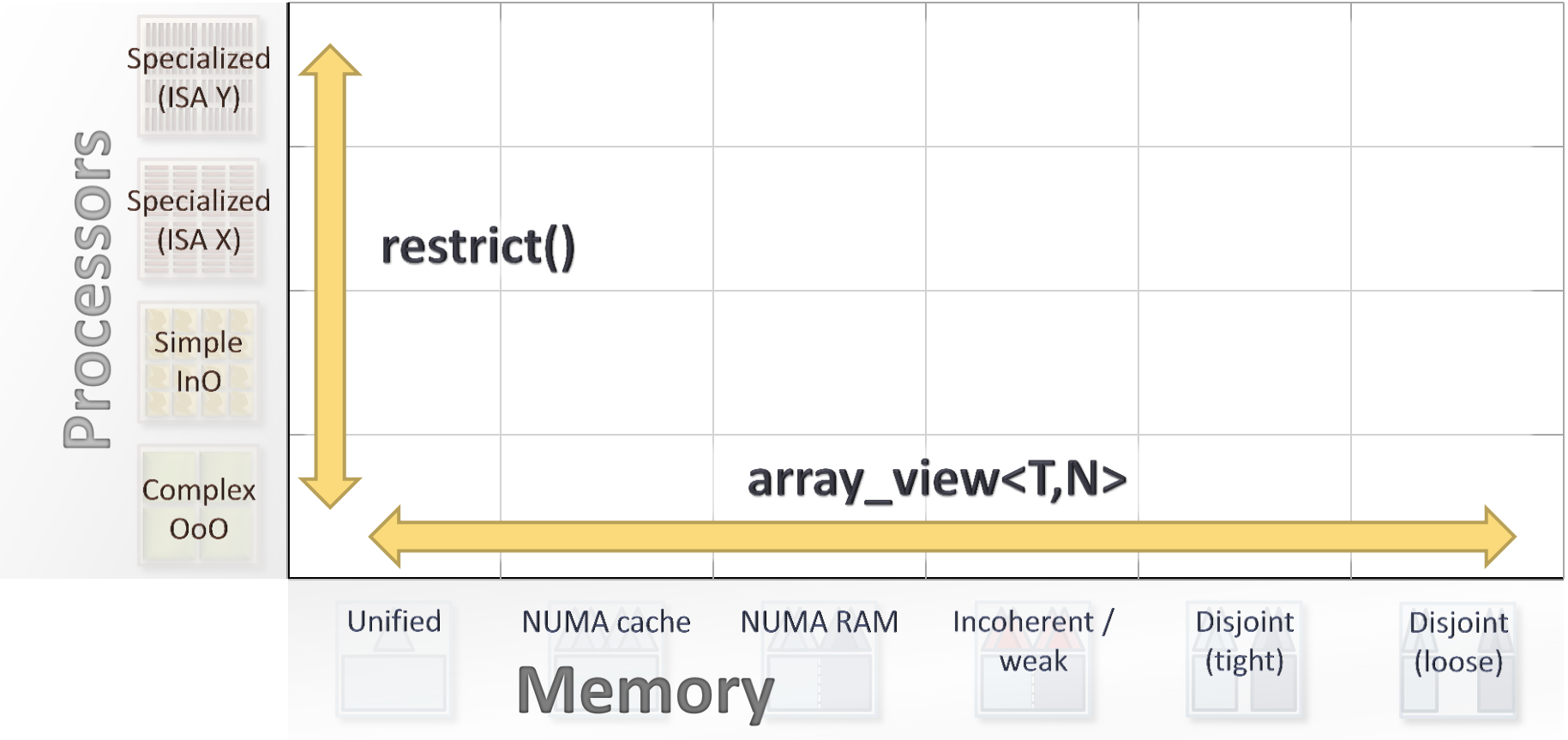
Multi-core to hetero-core


```
parallel_for_each(
   items.grid,
   [=](index<2> i) restrict(direct3d)
{
   … your code here …
} );
```

1

language feature for heterogeneous cores

C++ AMP at a Glance



restrict()

- **Problem:** Some cores don't support the entire C++ language.
- **Solution:** General restriction qualifiers enable expressing language subsets within the language. Direct3d math functions in the box.

Example

```
double sin( double );                          // 1a: general code
double sin( double ) restrict(direct3d);  // 1b: specific code

double cos( double ) restrict(direct3d); // 2: same code for either

parallel_for_each( c.grid, [=](index<2> idx) restrict(direct3d) {
   …
   sin( data.angle );  // ok, chooses overload based on context
   cos( data.angle );  // ok
   …
});
```

restrict()

- Initially supported restriction qualifiers:
  - **restrict(cpu)**: The implicit default.
  - **restrict(direct3d)**: Can execute on any DX11 device via DirectCompute.
    - Restrictions follow limitations of DX11 device model (e.g., no function pointers, virtual calls, goto).
- Potential future directions:
  - **restrict(pure)**: Declare and enforce a function has no side effects. Great to be able to state declaratively for parallelism.
  - General facility for language subsets, not just about compute targets.

array_view

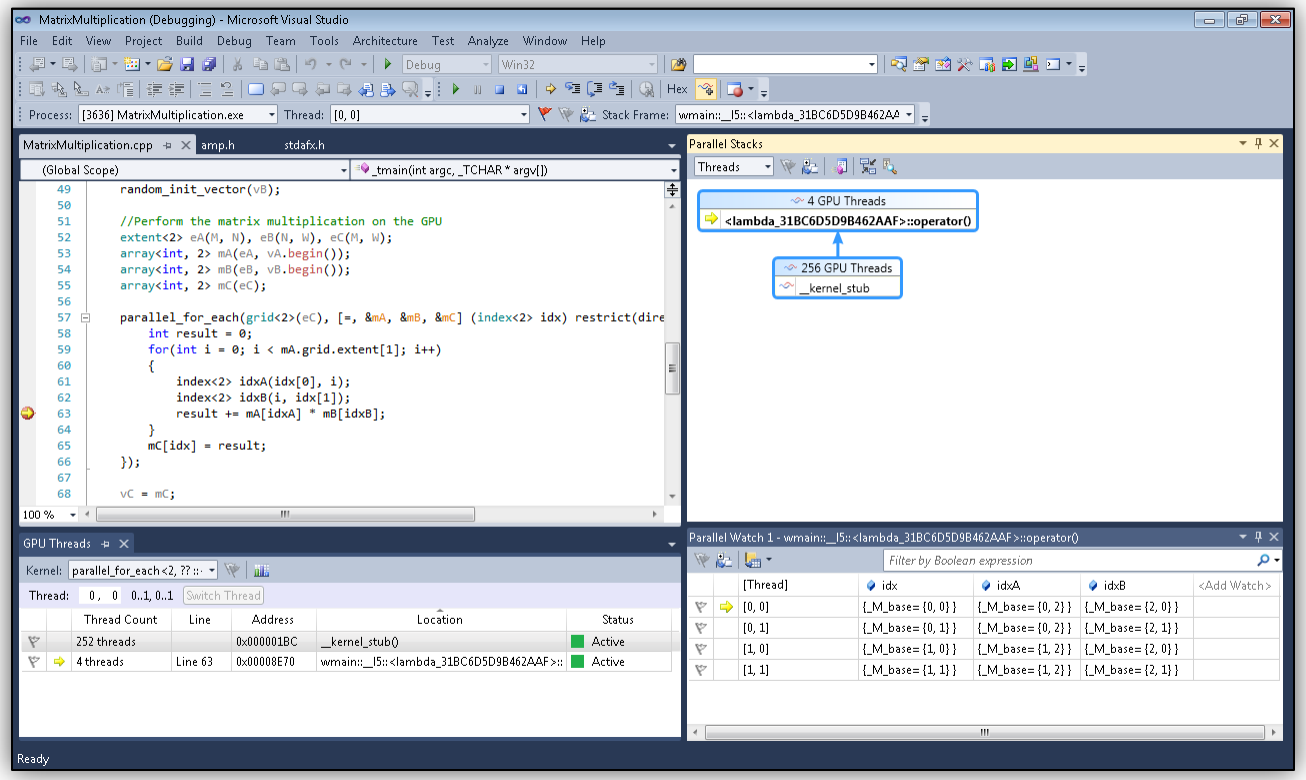
- **Problem:** Memory may be flat, nonuniform, incoherent, *and/or* disjoint.
- **Solution:** Portable view that works like an N-dimensional "iterator range."
  - Future-proof: No explicit .copy()/.sync(). As needed by each actual device.

Example

```
void MatrixMult( float* C, const vector<float>& A,
                 const vector<float>& B, int M, int N, int W )
{
  array_view<const float,2> a(M,W,A), b(W,N,B); // 2D view over C array
  array_view<writeonly<float>,2> c(M,N,C);      // 2D view over C++ std::vector

  parallel_for_each( c.grid, [=](index<2> idx) restrict(direct3d) {
    …
  } );
}
```

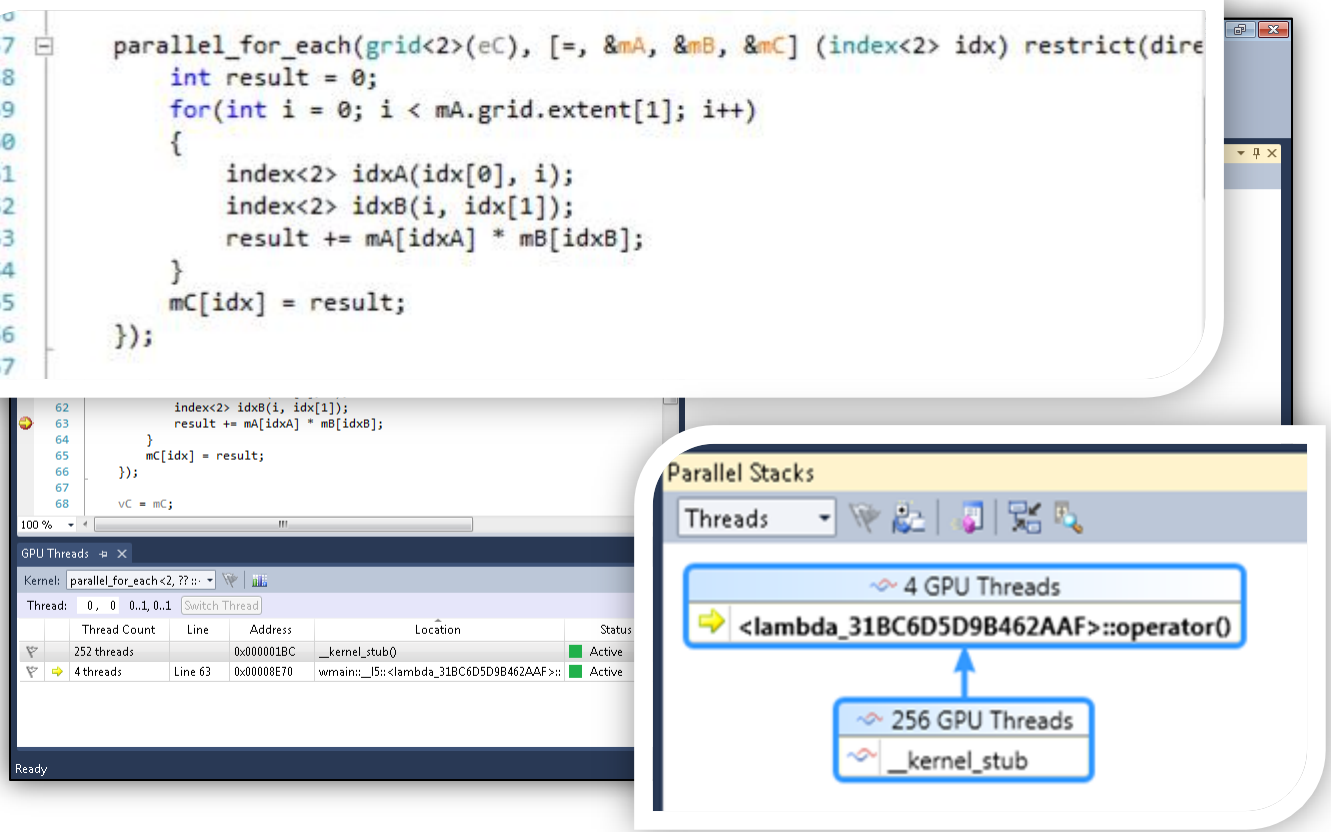
GPU Debugging



Bring CPU debugging experience to the GPU

GPU Debugging

```
57    parallel_for_each(grid<2>(eC), [=, &mA, &mB, &mC] (index<2> idx) restrict(dire
58        int result = 0;
59        for(int i = 0; i < mA.grid.extent[1]; i++)
60        {
61            index<2> idxA(idx[0], i);
62            index<2> idxB(i, idx[1]);
63            result += mA[idxA] * mB[idxB];
64        }
65        mC[idx] = result;
66    });
67
```



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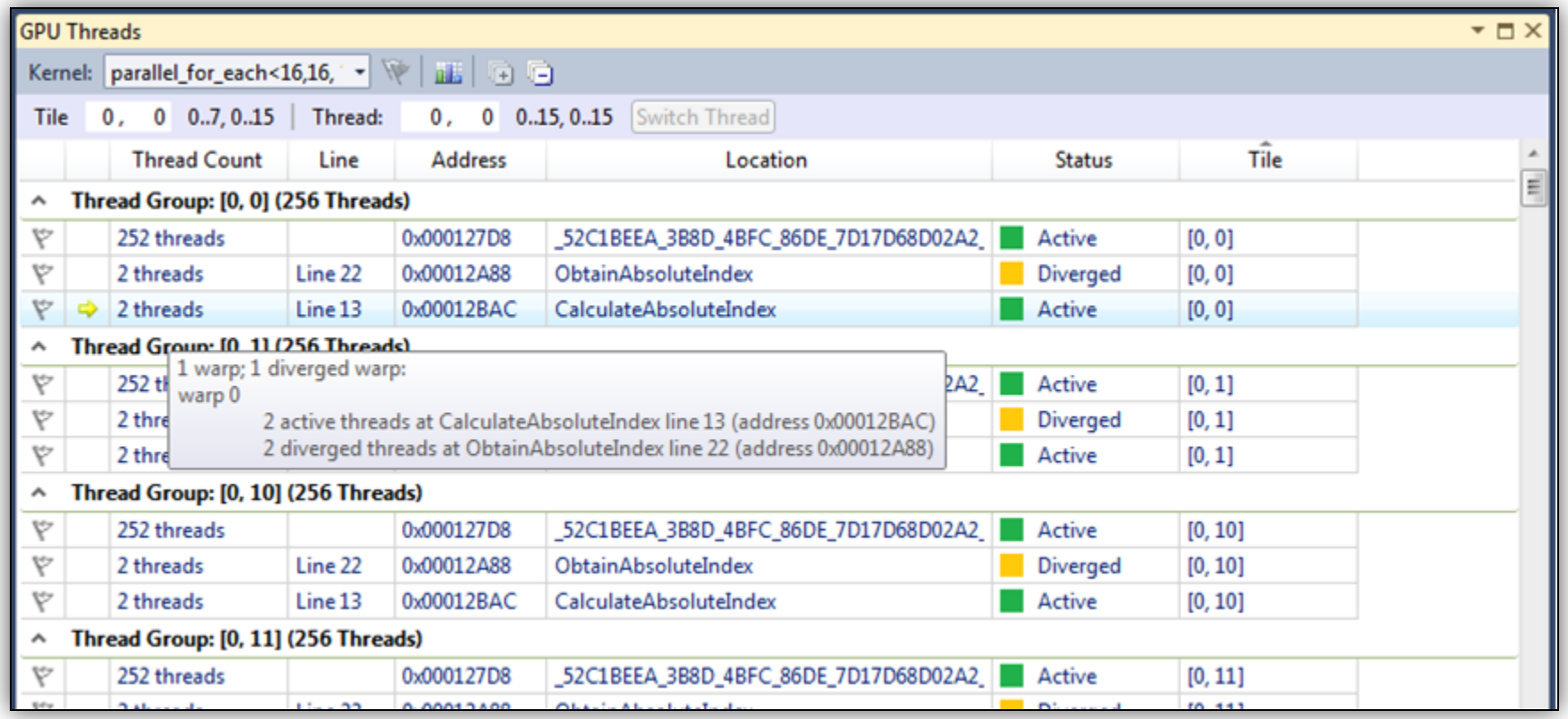
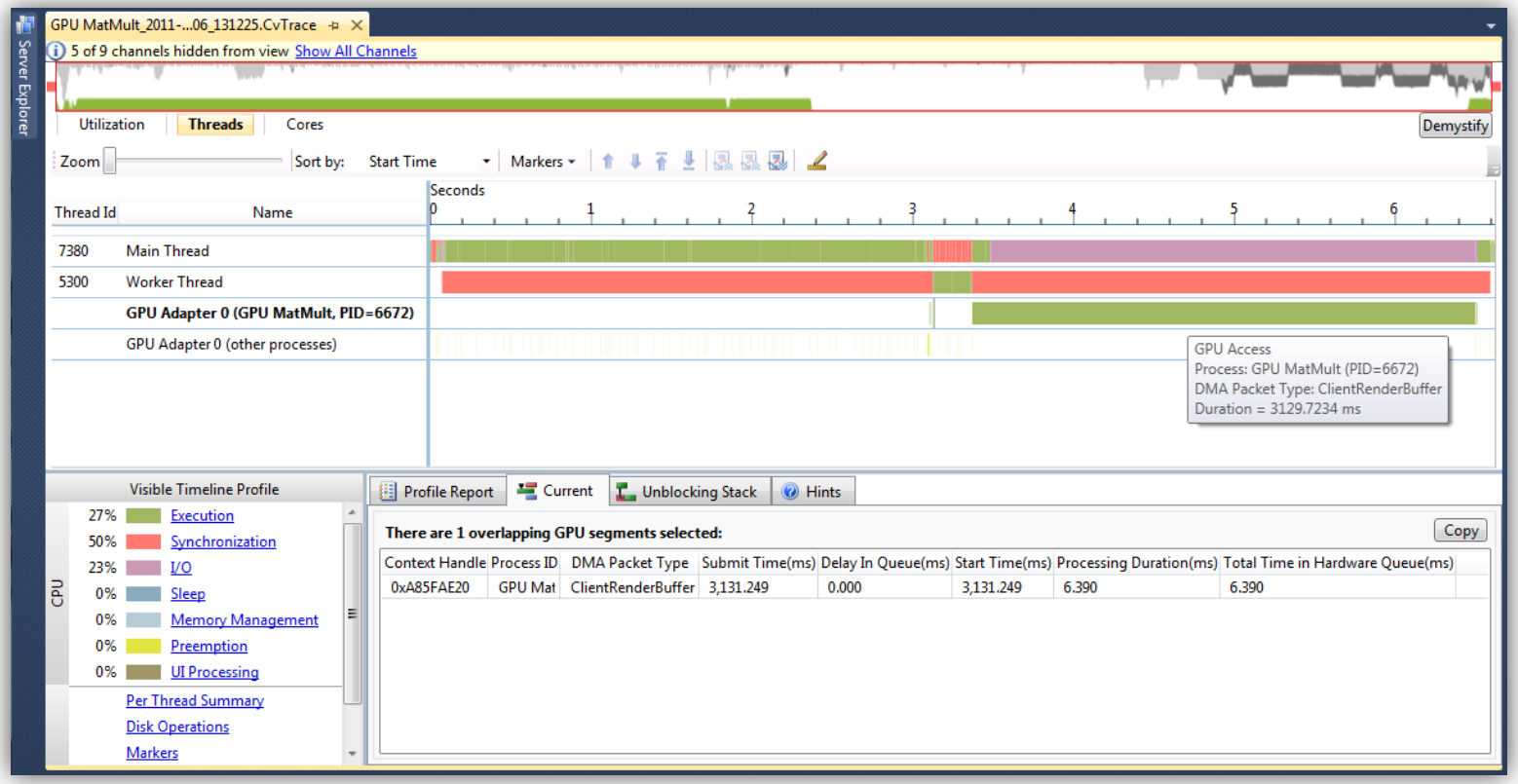
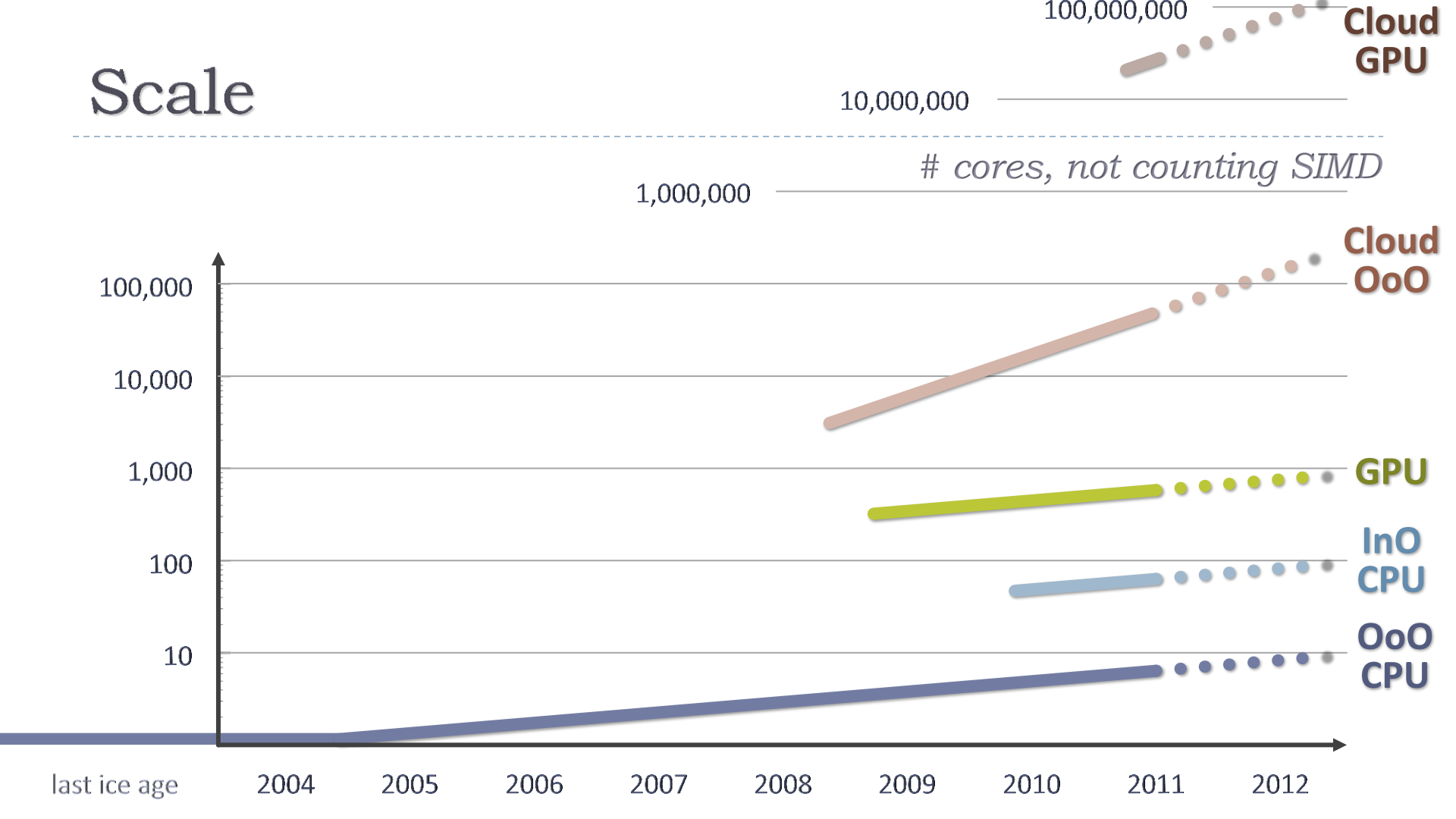


GPU Profiling



Scale


100,000,000
Cloud GPU
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cores, not counting SIMD
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Cloud OoO
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InO CPU
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OoO CPU
last ice age
2004
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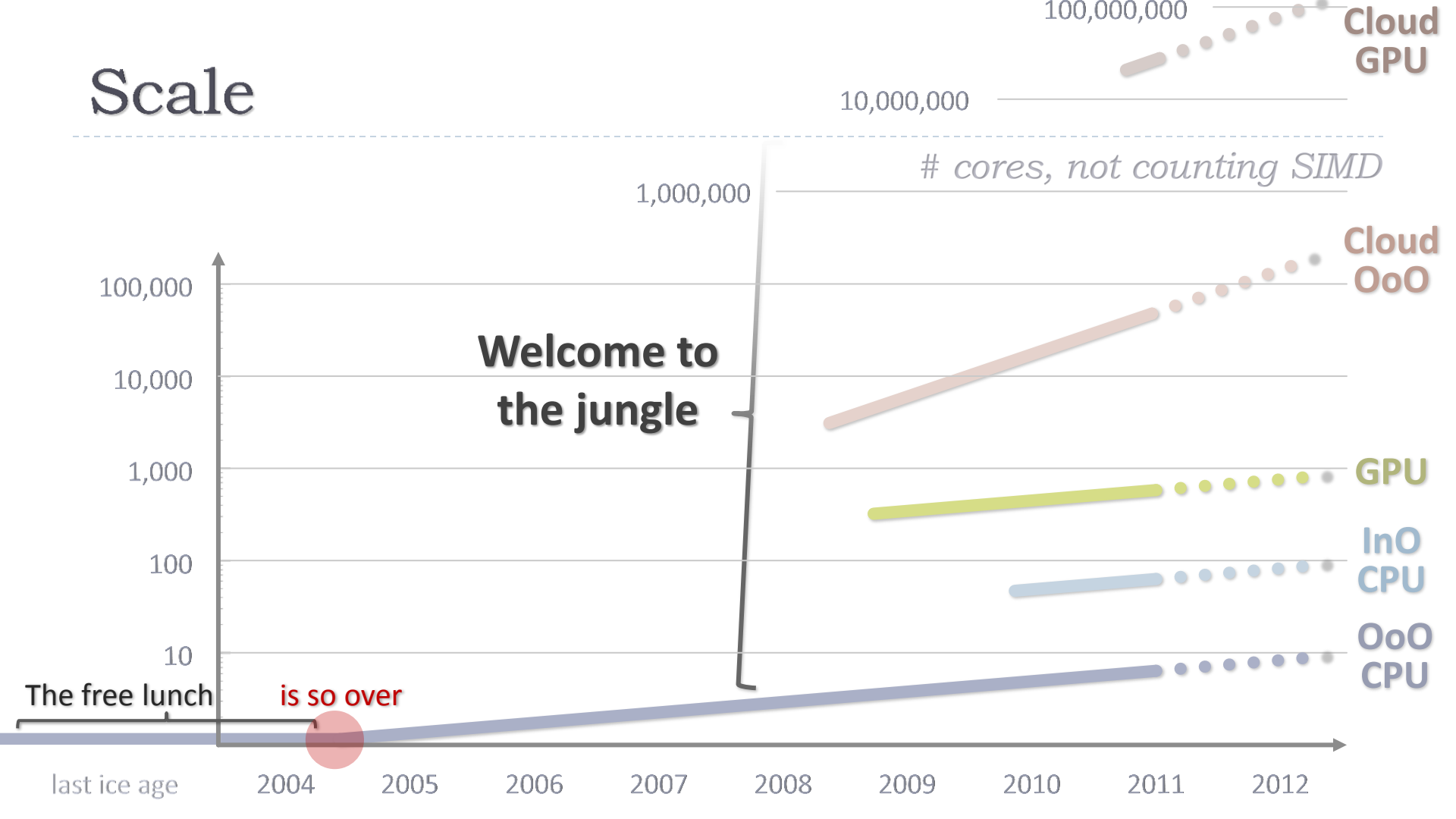
2012

Scale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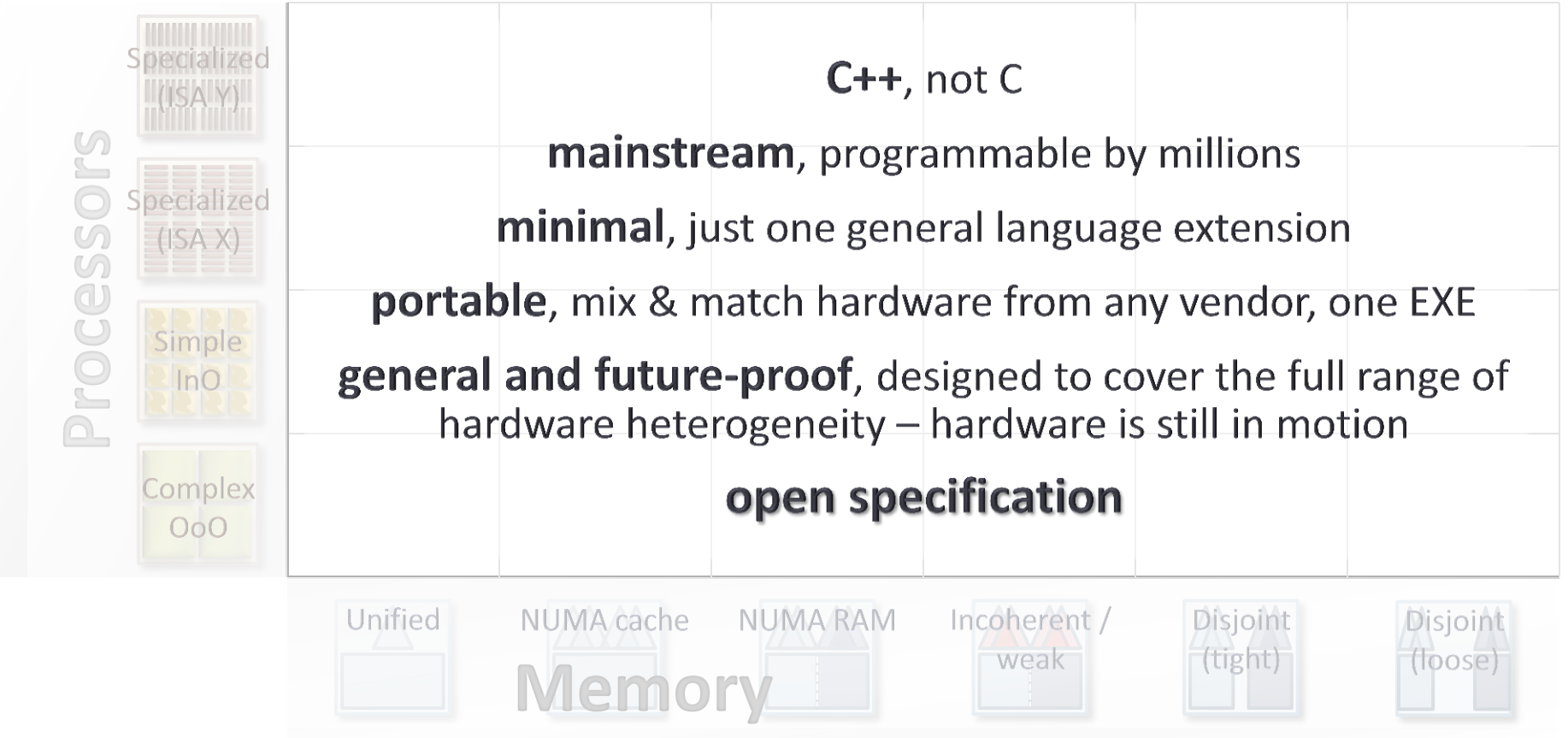
C++ AMP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C++ PPL: 9:45am

C++ AMP: 2:00pm, Room 406

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