Cross-platform Software Optimization with Intel’s Ct Technology
Agenda

• What is Intel’s Ct Technology?
• How does Intel’s Ct Technology work?
• How to port C++ code to Intel’s Ct Technology?
What is Intel’s Ct Technology?
Throughput and Visual Computing Applications

- TIPS: Terabytes
- GIPS: Gigabytes
- MIPS: Megabytes
- KIPS: Kilobytes

**Performance**

- IPS = Instruction per second

**Dataset Size**

- Single Core
- Multi-core
- Tera-scale

**Applications**

- Entertainment
- Learning & Travel
- Personal Media Creation and Management
- Health

- "RMS" Applications: Recognition, Mining, Synthesis

3D & Video

- Text

= Instruction per second
Many-core architecture offers unprecedented opportunities for differentiation:

- **Model-based applications**: New functionalities enriching the user’s experience
- **Improved quality**: Higher resolution/accuracy in results
- **Increased usability**: Raw power to fuel more sophisticated usage models
Software Opportunities and Risks

Opportunities:
- **SW Performance**
- **ISV Differentiation**

Reduced Productivity:
- **Data races**: New class of bugs that increase exponentially with degree of parallelism
- **Performance tuning**: Programmers can expect to spend most time here
- **Forward scaling**: Anticipating future HW enhancements
- **Modularity**: Difficult to compose parallel programs
- **Proprietary Tools**: Reduces choice and challenges build infrastructure

Risk:
- Programmer "Headaches" (Reduced Productivity)
Visual computing software technologies make it easier:

- **Industry Standard APIs:** DirectX*, OpenGL*
- **Native Tools:** SSE/AVX/Co-processor Native Compilers, OpenMP*, Intel® Threading Building Blocks, etc.
- **New Tools,** including:
  - *Ct* - *Forward-scaling, easy-to-use, and deterministic*
Software Opportunities and Risks

Opportunities:
- SW Performance
- ISV Differentiation

Risk:
- Programmer "Headaches" (Reduced Productivity)

Productivity is greatly increased with the right choice of tools
Intel’s Ct Technology

• **Productive Data Parallel Programming**
  – Presented as high-level abstraction, natural notation
  – Delivers application performance with ease of programming

• **Ct forward-scales software written today**
  – Ct is designed to be dynamically retargetable to SSE, AVX, co-processor, and beyond

• **Extends standard C++ using templates**
  – No changes to standard C++ compilers

• **Ct abstracts away architectural details**
  – Vector ISA width / Core count / Memory model / Cache sizes

• **Ct is deterministic**
  – No data races
Forward Scaling with Ct

**Productivity**
- Integrates with existing tools
- Applicable to many problem domains
- Safe by default: maintainable

**Performance**
- Efficient and scalable
- Harnesses both vectors and threads
- Eliminates modularity overhead of C++

**Portability**
- High-level abstraction
- Hardware independent
- Forward scaling
What Does the Product Based on Intel Ct Technology Look Like?

- Core API
  - Flexible, forward scaling data parallelism in C++

- Application Libraries
  - Linear Algebra, FFT, Random Number Generation
    - Powered by Intel® Math Kernel Library (Intel® MKL)

- Samples
  - Medical Imaging, Financial Analytics, Seismic Processing, and more

- Initial release on Windows, followed by Linux*
  - IA-32 and Intel® 64
  - Works with Intel® C/C++ Compiler, Microsoft* Visual C++*, and GCC*
  - Works with Intel® VTune™ Analyzer
How does Intel’s Ct Technology work?
Ct’s Parallel Collections

- Ct operates on data collections called containers
  - Based on C++ templates
- Ct’s containers represent a variety of regular and irregular data collections
  - dense<T>, dense<T,2>, dense<T,3>, nested<T>, indexed <T>
Expressing Computation in Ct

The Ct JIT Automates This Transformation

Vector Processing

Scalar Processing

Native/Intrinsic Coding

```
dense<f32> A, B, C, D;
A += B/C * D;
```

```
f32 kernel(f32 a, b, c, d) {
    return a + (b/c)*d;
}
... dense <f32> A, B, C, D;
A = map(kernel)(A, B, C, D);
```

```
native(ndense<f32> a, b, c, d) {
    __asm__ {
      ...
    }
    ...
    ndense<f32> A, B, C, D;
    A = nmap(native)(A, B, C, D);
```

Or Programmers Can Choose Desired Level of Abstraction
The Ct Runtime

- Intel Ct Technology offers a standards compliant C++ library...
...
backed by a runtime

- Runtime generates and manages threads and vector code, via
  - Machine independent optimization
  - Offload management
  - Machine specific code generation and optimizations
  - Scalable threading runtime (based on Intel® Threading Building Blocks)
Dynamic Ct: Supporting All Intel Platforms

Once compiled, run on all Intel platforms
int ar_a[1024], ar_b[1024]
dense<i32> A(ar_a, ...);
dense<i32> B(ar_b,...);
call( work ) ( A, B );
int ar_a[1024], ar_b[1024]
dense<i32> A(ar_a, ...);
dense<i32> B(ar_b, ...);
call( work ) ( A, B );
Ct Dynamic Engine Execution

```c
int ar_a[1024], ar_b[1024];
dense<i32> A(ar_a, ...);
dense<i32> B(ar_b, ...);
call( work ) ( A, B );
```

```c
void work(dense<i32> a, dense<i32> & b )
{
    b = a + 1;
}
```
int ar_a[1024], ar_b[1024]
dense<i32> A(ar_a, ...);
dense<i32> B(ar_b, ...);
call(work) (A, B);

void work(dense<i32> a, dense<i32>& b)
{
    b = a + 1;
}
int ar_a[1024], ar_b[1024]
dense<i32> A(ar_a, ...);
dense<i32> B(ar_b,...);
call( work ) ( A, B );

void work(dense<i32>a,
    dense<i32>& b )
{
    b = a + 1;
}
int ar_a[1024], ar_b[1024]
dense<i32> A(ar_a, ...);
dense<i32> B(ar_b,...);
call( work ) ( A, B );

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dense<i32> B(ar_b,...);
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dense<i32> B(ar_b, ...);
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Ct Dynamic Engine Execution

```c
int ar_a[1024], ar_b[1024]
dense<i32> A(ar_a, ...);
dense<i32> B(ar_b,...);
call work ( A, B );
```

```c
void work(dense<i32> a, dense<i32> & b )
{
    b = a + 1;
}
```
Ct Dynamic Engine Implications

• Second stage of compilation at runtime
  
  Allows run-time specialization

• Ct kernel: exists as C function, but
  
  - Executes only once => for dynamic compilation
  - Symbolic “capture” of computation
  - Takes a snapshot of current bindings and state

• Ct call: execution is a remote function call
  
  - Data flow dependencies inferred
  - Automatic (and always safe) synchronization
  - Enables remote execution and data storage
Why Does this Matter?

Widely used libraries often give up performance for well designed generic interfaces and modularity

- Virtual function calls, function pointers, and control flow dependent on parameters not known until runtime can limit performance
- Modularity inherently spreads computation across methods
- In extreme cases, the application is effectively an interpreter for a computation specified at runtime

→ Dynamic compilation can “compile out” the overhead of such “late binding”

→ This advantage is MULTIPLICATIVE with parallelism
How to port C++ code to Intel’s Ct Technology?
Ct Programming Common Steps

- Identify the computation logic to be written in Ct
- Figure out the signature of the kernel
- Prepare C data buffer for input/output
- Set up C=>Ct kernel bridge by rcall
- Implement kernel
Step 1: Figure Out Kernel Signature

```c
#include "ct.h"
using namespace Ct;
...
...
int ar_a[1024];
int ar_b[1024];
...
dense<i32> A( ar_a, 1024 );
dense<i32> B( ar_b, 1024 );
call( work ) ( A, B );
...
void work(dense<i32>a, dense<i32> &b){
    b = a + 1;
}
```
Step 2: Prepare Data

```c
int ar_a[1024];
int ar_b[1024];
...
for( i=0; i<1024; i++ ) {
    ar_b[i] = ar_a[i] + 1;
}
```

```c
#include "ct.h"
using namespace Ct;
...
...
int ar_a[1024];
int ar_b[1024];
...
dense<i32> A( ar_a, 1024 );
dense<i32> B( ar_b, 1024 );
call( work ) ( A, B );
...
void work(dense<i32> a,dense<i32>&b ){
    b = a + 1;
}
```
Step 3: Set Up Bridge

```cpp
#include "ct.h"
using namespace Ct;
...
...
int ar_a[1024];
int ar_b[1024];
...
dense<i32> A( ar_a, 1024 );
dense<i32> B( ar_b, 1024 );
call( work ) ( A, B );
...
void work(dense<i32> a, dense<i32>&b ){
    b = a + 1;
}
```
Step 4: Implement Kernel

```
#include "ct.h"
using namespace Ct;
...
...
int ar_a[1024];
int ar_b[1024];
...
...
for( i=0; i<1024; i++) {
    ar_b[i] = ar_a[i] + 1;
}
void work(dense<i32>a, dense<i32>&b ){
    b = a + 1;
}
```
Example: Black-Scholes for Options Pricing

**Black-Scholes Using C Loops**

```c
float s[N], x[N], r[N], v[N], t[N];
float result[N];
for(int i = 0; i < N; i++) {
    float d1 = s[i] / ln(x[i]);
    d1 += (r[i] + v[i] * v[i] * 0.5f) * t[i];
    d1 /= sqrt(t[i]);
    float d2 = d1 - sqrt(t[i]);
    result[i] = x[i] * exp(r[i] * t[i]) * 
(1.0f - CND(d2)) + (-s[i]) * (1.0f - CND(d1));
}
```

**Black-Scholes Using Ct**

```c
#include <ct.h>
using namespace OpenCt;
float s[N], x[N], r[N], v[N], t[N];
float result[N];
dense<f32> S(s, N), X(x, N), R(r, N), V(v, N), T(t, N);
dense<f32> d1 = S / ln(X);
d1 += (R + V * V * 0.5f) * T;
d1 /= sqrt(T);
dense<f32> d2 = d1 - sqrt(T);
dense<f32> tmp = X * exp(R * T) * 
(1.0f - CND(d2)) + (-S) * (1.0f - CND(d1));
tmp.copyOut(result, sizeof(result));
```

1. `#include <ct.h>` and using namespace
2. Vector operations subsumes loop
3. The Ct code is almost the same as the original loop body
4. `copyOut` at the end (if you’re done!)

*Vector-style computation is a natural approach here.*
Ct Debugging

- Link with the Emulation Library and debug with a C++ debugger
- Ct provides an Add-in to help watch Ct variables in Visual Studio*
- Dump the Intermediate Representation at various levels
- Use environments to control the Intermediate Representation level output level:
  - CT_DUMPJIT=y
  - HLO_TRACE_LEVEL =n
  - HLO_DISABLE_OPT=dump_cpp=f

CT Add-in in Visual Studio*
Summary

• Ct enables you to write simple parallel algorithms in standard C++
• Ct can get you performance on Intel Architecture today
• Ct Technology today will be forward-scalable to new many core and compute co-processors
• Ct will intermix with other parallel programming models and tools

*Ct extends the many choices that Intel provides for Parallel Computing*
Call to Action

Sign up for the opportunity to participate in Ct technology beta!

http://www.intel.com/software/data_parallel/
Additional sources of information on this topic:

- Visit our demo and talk to us at Booth #1116: Medical imaging on deformable registration


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