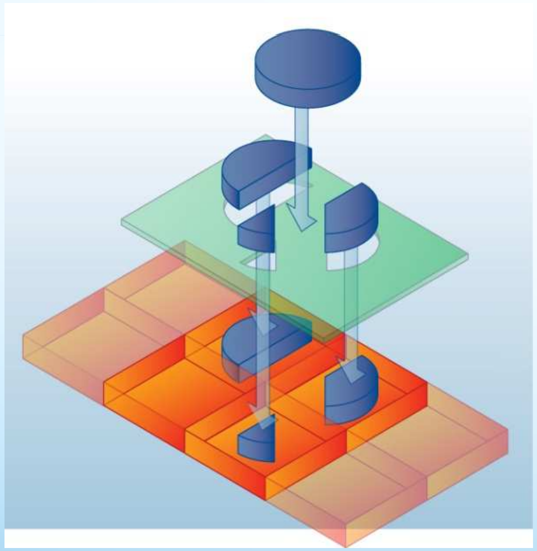

Parallel Programming Models

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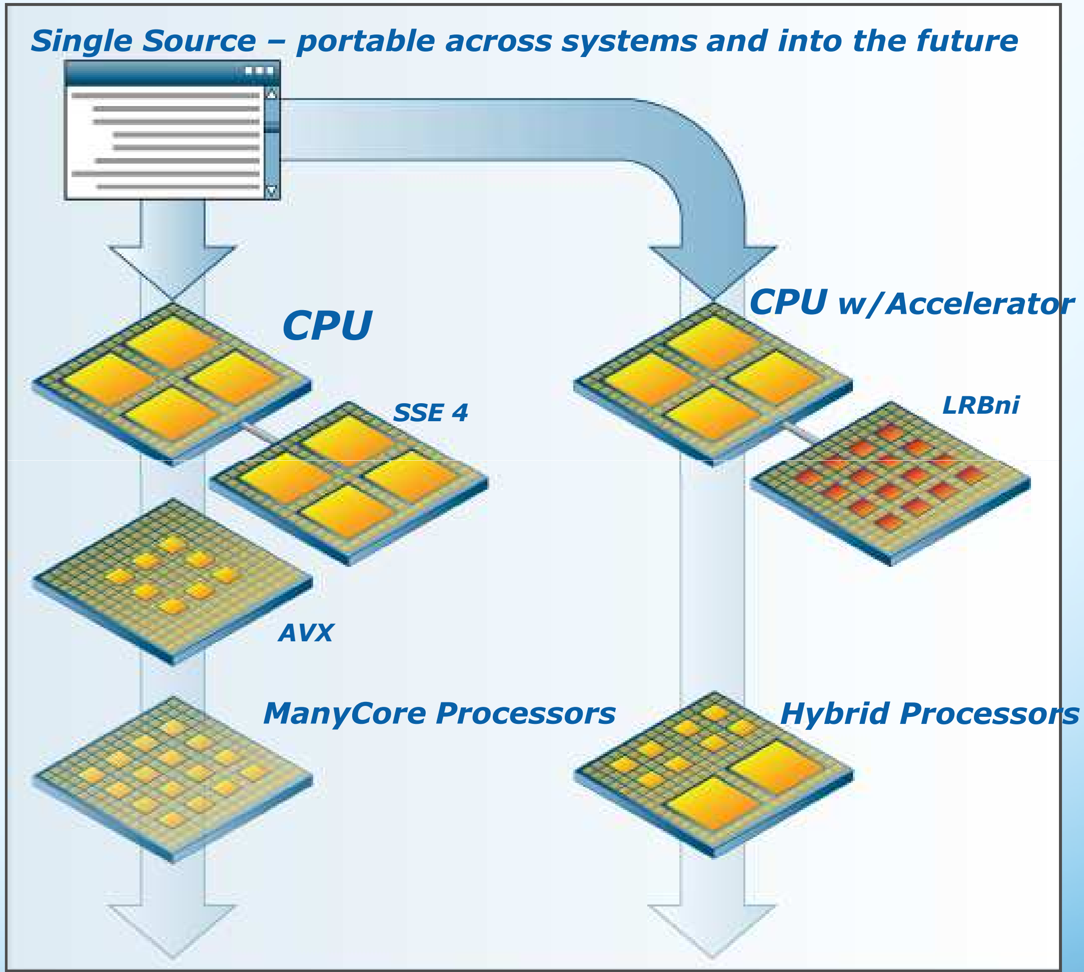
Our Vision: Making models survive future architectures



Today's Parallelism

- There are lots of programming options from Intel:
  - Old recommendations (e.g. OpenMP)
  - Newer recommendations (e.g. TBB, Ct)
  - New acquisitions (i.e. Cilk, RapidMind)
  - Competitive offerings (e.g. OpenCL, CUDA)

- An initiative (or a few initiatives) to clarify the programming options for our customers

TBB
Ct
Cilk
RapidMind
OpenMP
MPI
OpenCL
Xntask
CnC

POSIX* pthreads*: Example

```
#include <stdio.h>
#include <pthread.h>
const int num_threads = 4 ;

void* thread_func(void* arg) {
  do_work();
  return NULL;
}
main() {
  pthread_t threads[num_threads];
  for( int i = 0; i < num_threads; i++)
       pthread_create(&threads[i], NULL, thread_func, NULL);

  for(int j = 0; j < num_threads; j++)
         pthread_join (threads[j], NULL);
}
```

OpenMP* Threads: Implicit

Create Threads	Split loop iterations among threads	Make local variables for each thread

```
#pragma omp parallel for private(pixelX,pixelY)

for (pixelX = 0; pixelX < imageWidth; pixelX++)
{
   for (pixelY = 0; pixelY < imageHeight; pixelY++)
   {
      newImage[pixelX,pixelY] =
                  ProcessPixel(pixelX, pixelY, image);
   }
}
```

General MPI Program Structure

MPI include file

.
.
.

Initialize MPI environment

.
.
.

Do work and make message passing calls

.
.
.

Terminate MPI Environment

C/C++

```
#include "mpi.h"
int main(argc,argv){
rc = MPI_Init(&argc,&argv);
  if (rc != MPI_SUCCESS) {
    printf ("Error starting MPI program. \n");
    MPI_Abort(MPI_COMM_WORLD, rc);
    }
MPI_Comm_size(MPI_COMM_WORLD,&numtasks);
MPI_Comm_rank(MPI_COMM_WORLD,&rank);
printf ("Number of tasks= %d My
rank= %d\n",ntasks,rank);
 /*******  do some work *******/
MPI_Finalize();
}
```

What about the other approaches ?

What about Cilk++ ?

- Cilk++ offers a compiler keyword alternative to TBB
- Every Cilk program preserves the ***serial semantic***
- Cilk provides ***performance guarantees*** since it is based on theoretically efficient scheduler
- There are three additional keywords: ***cilk***, ***spawn*** and ***sync***
- Cilk uses parallel stacks (cactus stacks) in contrast to linear stacks (TBB)
- Beta starts in ~ Q2 2010

Cilk - The main principle

- The programmer should be responsible for ***exposing*** the parallelism:
  - identifying elements that can safely be executed in parallel
- It should then be left to the run-time environment, particularly the scheduler, to decide ***during execution*** how to actually divide the work between processors.
  - It is because these responsibilities are separated that a Cilk program can run without rewriting on any number of processors, including one.

Fibonacci – recall the functionality

$$F_n = \begin{cases} 0 & \text{if } n = 0; \\ 1 & \text{if } n = 1; \\ F_{n-1} + F_{n-2} & \text{if } n > 1. \end{cases}$$

F_0	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	F_{18}
0	1	1	2	3	5	8	13	21	34	55	89	144	233	377	610	987	1597	2584

*n*th Fibonacci number – C

```
int fib (int n) {
if (n<2) return (n);
  else {
    int x,y;
    x = fib(n-1);
    y = fib(n-2);
    return (x+y);
  }
}
```

Fibonacci – Cilk code

```
cilk int fib (int n) {
  if (n<2) return (n);
  else {
    int x,y;
    x = spawn fib(n-1);
    y = spawn fib(n-2);
    sync;
    return (x+y);
  }
}
```

Basic Cilk Keywords

```
cilk int fib (int n) {
  if (n<2) return (n);
  else {
    int x,y;
    x = spawn fib(n-1);
    y = spawn fib(n-2);
    sync;
    return (x+y);
  }
}
```

Identifies a function as a *Cilk procedure*, capable of being spawned in parallel.

The named *child* Cilk procedure can execute in parallel with the *parent* caller.

Control cannot pass this point until all spawned children have returned. The **sync** done implicitly on every **return**.

Why Do We Need One More?

- ***So many cores, so hard to harvest parallelism***
  - Parallel programming is too hard for the masses of developers → need to emphasize ease of use
  - Data races are too easy to create, way too hard to debug → preclude races through safety
  - Target-specific specialization is required to get performance, but makes code very difficult to maintain and port → raise to a natural level of abstraction and enable forward scaling across architectures and ISAs
  - Uniform model for harvesting SIMD and thread-level parallelism in either scalar kernels or array syntax → compiler + runtime
  - ValArray too limited → universal set of operators across (even irregular) data structures

What about Threading Building Blocks ?

- It's a C++ library and integrates nicely with the STL
- TBB provides advanced C++ abstraction concepts
- Particularly suited when parallelism is hidden in generic C++ structures like containers & iterators
- You specify task patterns instead of threads
- A task scheduler does the mapping to the threads
- Targets threading for performance (not usability)

Intel® Threading Building Blocks

Generic Parallel Algorithms
- parallel_for
- parallel_reduce
- parallel_do (new)
- pipeline
- parallel_sort
- parallel_scan

Concurrent Containers
- concurrent_hash_map
- concurrent_queue
- concurrent_vector

Task scheduler

Synchronization Primitives
- atomic operations
- scoped locks

Miscellaneous
- tick_count
- tbb_thread

Memory Allocation
- tbb_allocator (new), cache_aligned_allocator, scalable_allocator

… and OpenCL

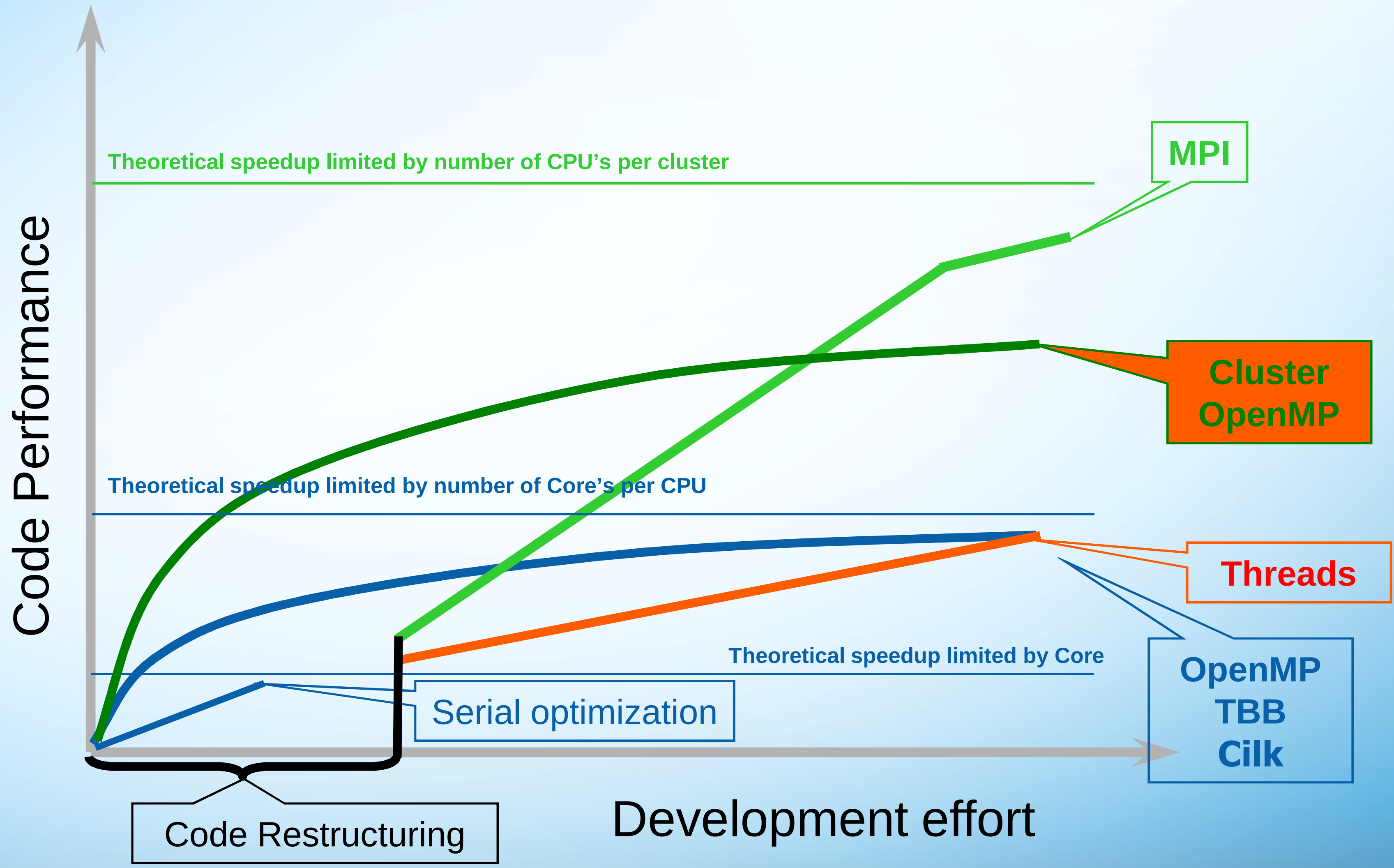
OpenCl is a portable intermediate low-level language layer for a wide variety of different Hardware (FPA, GPU, Cell, CPU, …)

- Intel is part of the OpenCL consortium
- Intel provided input for the specification
- Plans to have some OpenCL support out next year
- OpenCl is already available on Snow Leopard

My take on OpenCl

- Data parallel meets Task parallel on a very low abstraction level
- A good target language for API developers like Ct/RapidMind
- Programmers should use higher levels of abstraction such as Ct/RapidMind, TBB, Cilk++ or OpenMP if at all possible

Performance versus effort



BUT - Today's On-going Realities

- Programming parallel apps is ***~100x** less* productive than sequential
  - Non-deterministic programming errors (race conditions, …)
  - Performance tuning is extremely complicated
- Strong interest by ISVs for a parallel programming model which is:
  - **Abstract**: Avoid dealing with OS and HW details
  - **Simple**: Deterministic, eliminate threading problems
  - **Fast & Scalable**: Achievable through simpler programming API
  - **Portable**: Desire the flexibility to target various HW platforms (CPU, LRB, GPU, Cell and a Mix)

Where does Ct fit?

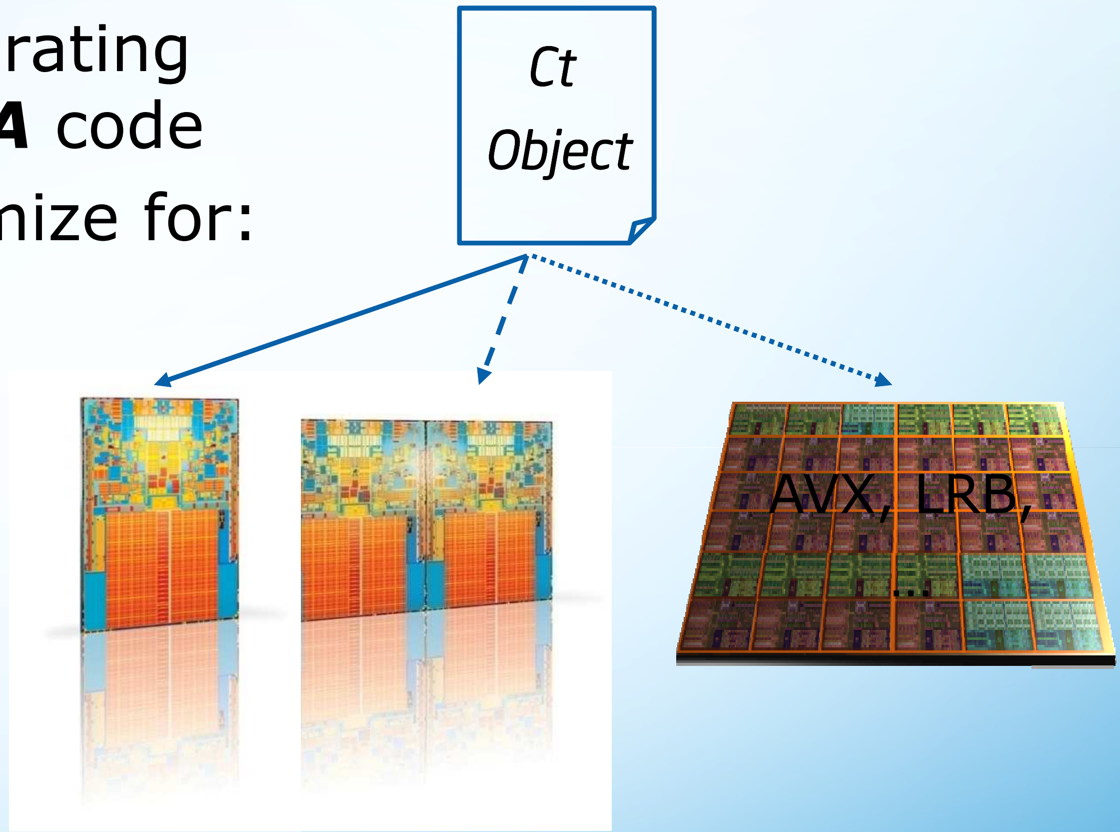
“Ct Technology: a new perspective on data-parallel programming”

What’s new and different?

- Why do we need one more programming model?
- Where does Ct fit within Intel other tools?
- Where does Ct fit within the rest of the industry?

Forward Scaling with Ct

- Compile *once*, generating optimized, native ***IA*** code
- Dynamically reoptimize for:
  - More cores
  - More cache
  - More bandwidth
  - More instruction set enhancements



Ct forward scales software with Moore's law for Throughput and Visual Computing

Design Constraints

Target language: C++

- C++ will continue to be the dominant languages for high performance for the next 5+ years

…and we *mean* **standard** C++!

- Custom syntactic extensions face huge barriers to adoption
- It is possible to design a desirable semantics through an API-like interface with some Macro magic

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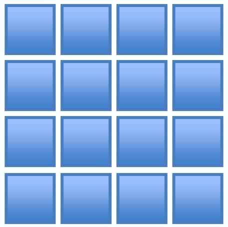
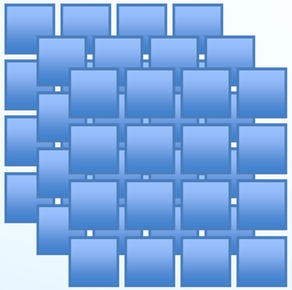
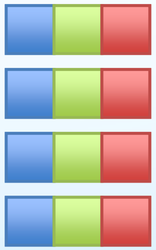
Ct’s Parallel Collections

Regular Vecs

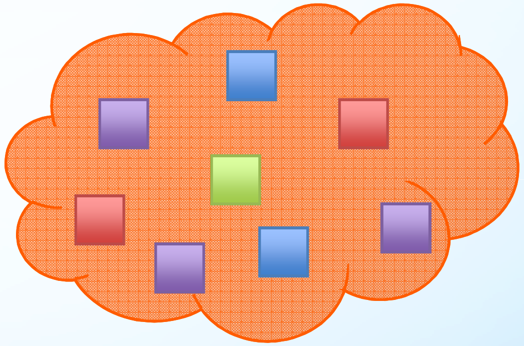

Vec

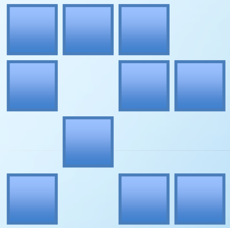

Vec2D


Vec3D


Vec<Tuple<…>>

Irregular Vecs


VecIndexed


VecNested

& growing…

Priorities: VecSparse, Vec2DSparse, VecND

Ct Semantics

The basic type in Ct is a *polymorphic collection* called a Vec

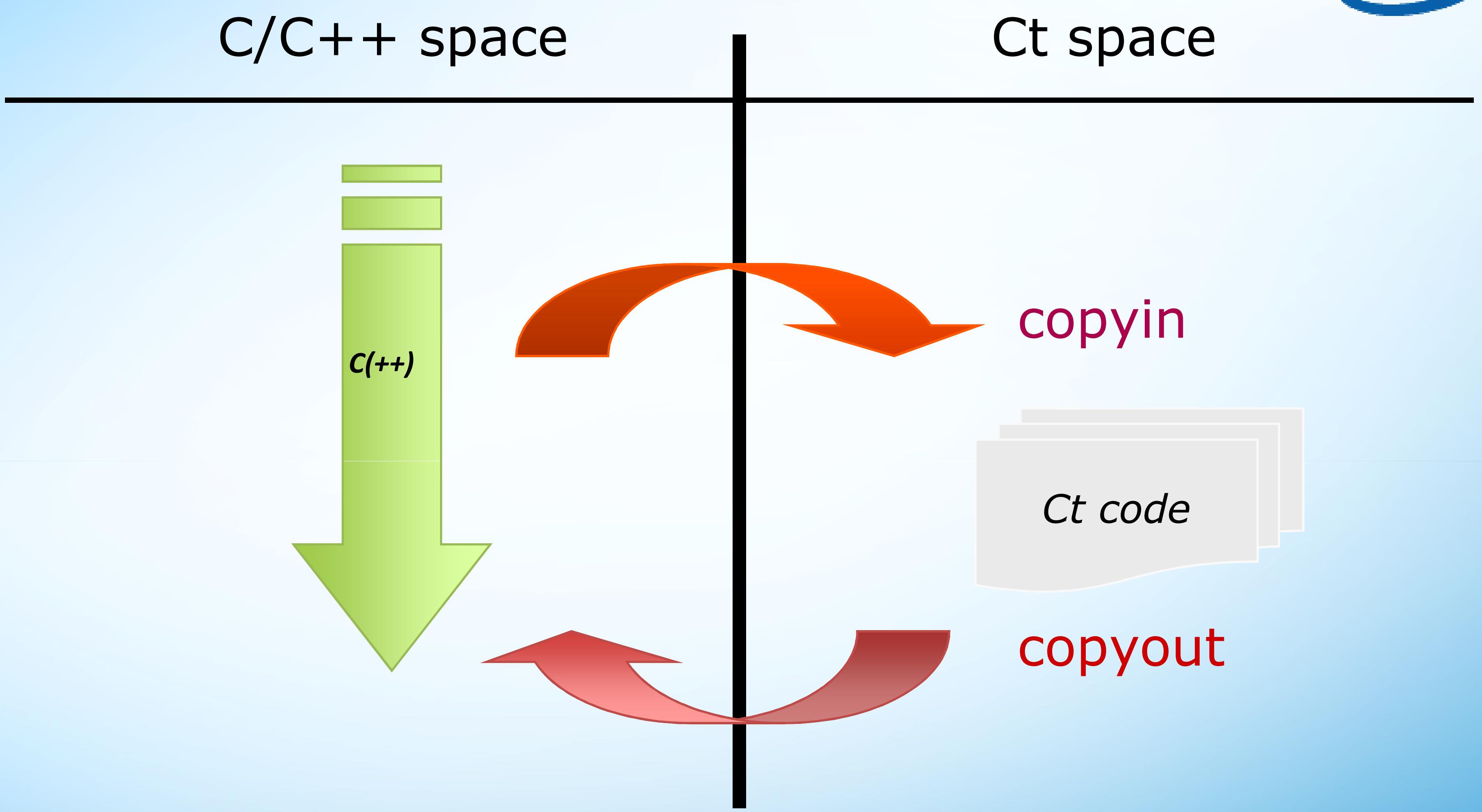
- Vecs are managed by the Ct runtime
- Vecs are single-assignment vectors
- Vecs are flat, multidimensional, sparse, or nested
- Vec values are exclusively created & manipulated through Ct API

Declared Vecs are simply references to immutable values

```
Vec<F64>DoubleVec;   // DoubleVec can refer to any vector of doubles
…
DoubleVec = Src1 + Src2;
DoubleVec = Src3 * Src4;
```

Assigning a value to **DoubleVec** doesn't modify the value representing the result of the add, it simply refers to a *new* value.

Segregated C/C++ and Ct Spaces



Ct is garbage collected; *practically, a small number of Vecs are uncollected by compiler (ref counting)*

Apply Functions: Black Scholes for Options Pricing

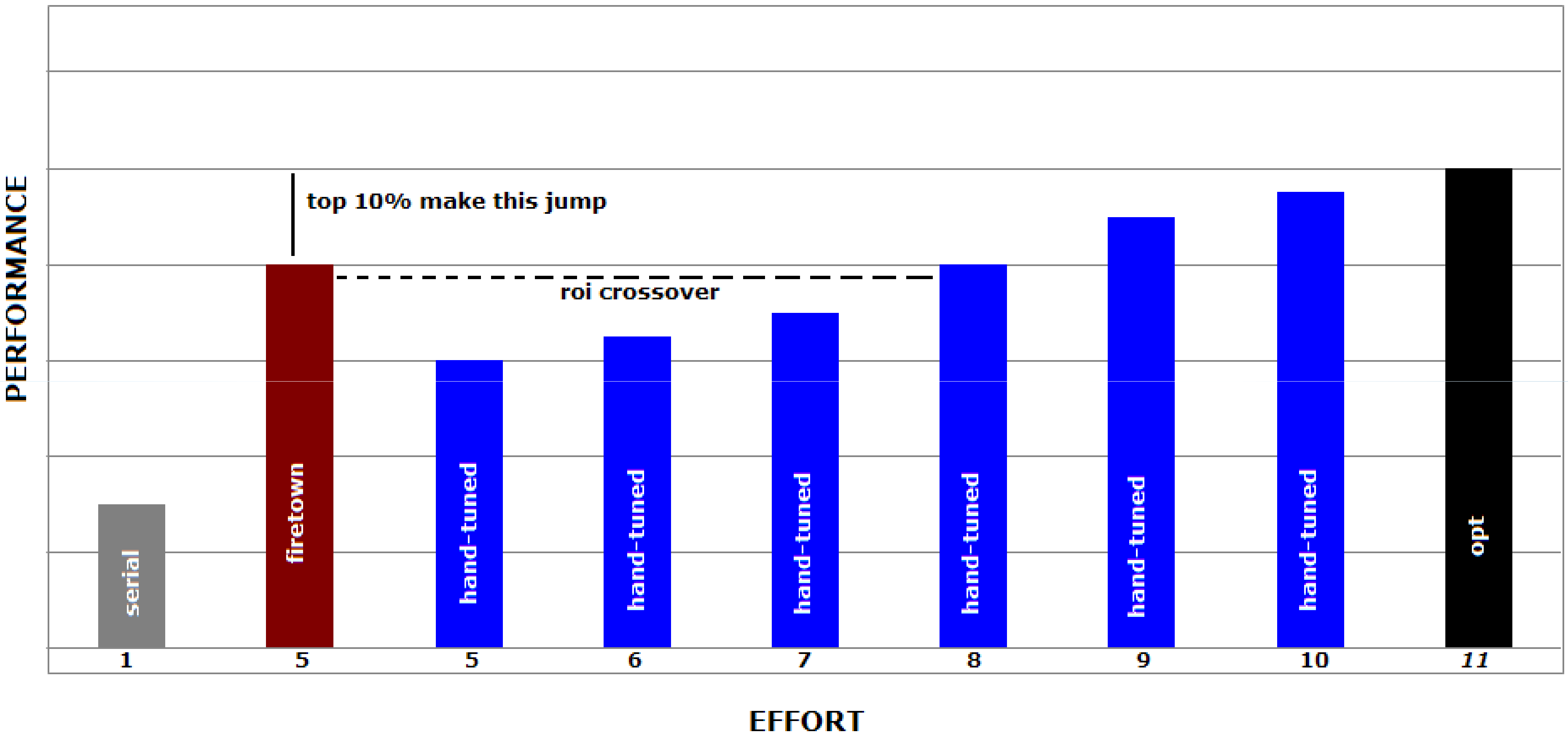
```
float s[N], x[N], r[N], v[N], t[N];
float result[N];

_ct{
  Vec<F32> S(s, N), X(x, N), R(r, N), V(v, N), T(t, N);

  Vec<F32> d1 = S / ln(X);
  d1 += (R + V * V * 0.5f) * T;
  d1 /= sqrt(T);
  Vec<F32> d2 = d1 – sqrt(T);

  Vec<F32> tmp = X * exp(R * T) *
     ( 1.0f - CND(d2)) + (-S) * (1.0f - CND(d1));

  copyOut(tmp, result, N * Sizeof(float));
}_endCt
```

```
Vec<F32> BlackScholes(Vec<F32> S, Vec<F32> X,
            Vec<F32> R, Vec<F32> V, Vec<F32> T)
{

  Vec<F32> d1 = S / ln(X);
  d1 += (R + V * V * 0.5f) * T;
  d1 /= sqrt(T);
  Vec<F32> d2 = d1 – sqrt(T);

  Vec<F32> tmp = X * exp(R * T) *
     ( 1.0f - CND(d2)) + (-S) * (1.0f - CND(d1));

  return tmp;
}
```

```
float s[N], x[N], r[N], v[N], t[N];
float result[N];

_ct
  Vec<F32> S(s, N), X(x, N), R(r, N), V(v, N), T(t, N);

  tmp = call(BlackScholes)(S, X, R, V, T);

  tmo.copyOut(result, N * Sizeof(float));
}_endCt
```

Red color shows the differences between “normal” and function Ct code

ROI Crossover Graph



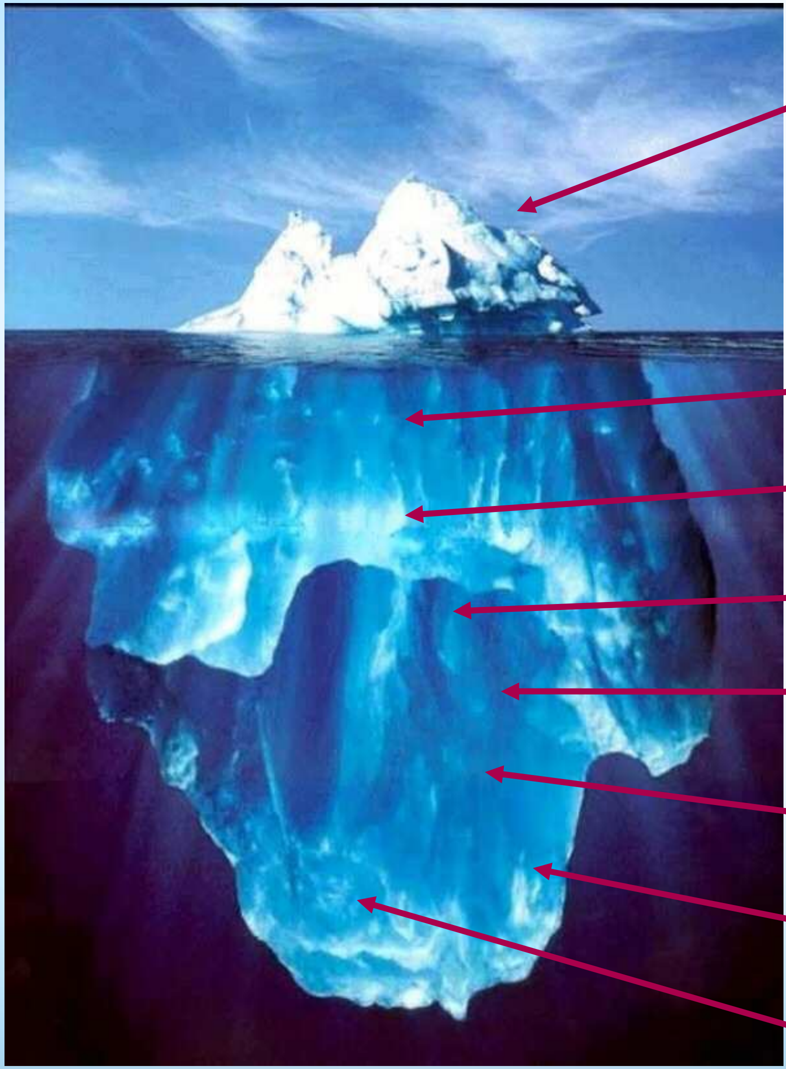
Key Features and Benefits - Productivity

- **Integrates with existing IDEs, tools, and compilers**: no new compiler needed
- **Incremental:** allows selective and targeted modification of existing code bases
- **Generalized data parallel model:** widely applicable to many types of computations
- **Safe by default:** deterministic semantics avoid race conditions and deadlock by construction
- **Easy to learn:** serially consistent semantics and simple interface leverage existing skills

Key Features and Benefits - Portability

- **High-level**: avoids dependencies on particular hardware mechanisms or architectures
- **ISA extension independent**: common binary can exploit different ISA extensions transparently
- **Hardware independent:** Allows choice of deployment hardware today: including scaling to many cores
- **Scaling:** Allows migration and forward-scaling: will support AVX, Larrabee and beyond

Language Vehicle for General Purpose Parallel Programming



Ct Api
- Nested Data Parallelism
- *Deterministic Task Parallelism*

Deterministic parallel programming

Fine grained concurrency and synch

Dynamic (JIT) compilation

High-performance memory management

Forward-scaling binaries for SSEx, LRBNI

Parallel application library development

Performance tools for Future Architectures

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

When do we recommend what?

- TBB can be considered the lead or default option for hands-on parallel programmers
  - General solution - addresses the most use cases, supports system access
  - Widely available - open source and compiler independent
- Compiler extensions (e.g. Cilk) target minimal syntax changes
  - Provides the easiest way to introduce parallelism into an app
  - **OpenMP** involves less invasive code changes for very regular, singly-nested loops
    - When a compiler is preferred vs. a library
    - Unique in supporting FORTRAN

Summary

- Ct enables you to write simple parallel algorithms in standard C++
- Ct can get you performance on Intel Architecture *today*
- Ct apps scale to future architectures: Larrabee, SandyBridge (+AVX),and beyond
- Ct will intermix with other parallel programming models and tools

Ct extends the many choices that Intel provides for Parallel Computing

Any questions ?