Intel Threading Building Blocks

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What is TBB?

- C++ library for multi-threading.
  - Internally uses pthreads (Linux).
  - Abstracts from threading details.
  - Based on tasks.
  - Offers concurrent data-structures.
  - C++
  - Dual licensed GPL/commercial.

Benefits

- Specify tasks instead of thread.
  - Thread programming: map work to threads, do the load balancing etc…
  - Task programming lets the library schedule threads for you.
  - Abstraction on raw threads, more portable.
- Threading for performance.
  - Higher level simple solutions for computationally intensive work.
- Compatible with other threading packages.
  - Mix with OpenMP or pthreads.

Benefits

- TBB emphasizes scalable data-parallel programming.
  - Data-parallel programming scales well with large problems – partition data set.
  - Special constructs to do the partioning.
- Generic programming.
  - Write best possible algorithms with as few constraints as possible.

Important Concepts

- Recursive splitting.
  - Break problems recursively down to some minimal size.
  - Works better than static division, works well with task stealing.
- Task stealing.
  - A way to manage load balancing.
- Generic algorithms
  - algorithm templates.

Overview

- Algorithms
  - parallel_for
  - parallel_reduce
  - parallel_scan
  - parallel_while
  - pipeline
  - parallel_sort
- Concurrent containers
  - concurrent_queue
  - concurrent_vector
  - concurrent_hash_map

Basic Algorithms

- Loop parallelization
  - parallel_for
  - parallel_reduce
  - parallel_scan
  - → building blocks.

Start & End

- Need to start task scheduler.
- Declaring: `task_scheduler_init init;`
  in main does the job.

- Can be tweaked but the default is usually good enough.
  - Number of threads automatic.

parallel_for

Original code:

```
void SerialApplyFoo(float a[], size_t n)
{
  for(size_t i = 0; i < n; ++i) Foo(a[i]);
}
```

parallel_for

Algorithm class:

```
#include "tbb/blocked_range.h"
class ApplyFoo
{
    float *const my_a;
public:
    void operator ()(const block_range<size_t>& r) const
    {
        float *a = my_a;
        for(size_t i = r.begin(); i != r.end(); ++i) Foo(a[i]);
    }
    ApplyFoo(float a[]) : my_a(a) {}
};
```

parallel_for

Algorithm call:

```
#include "tbb/parallel_for.h"

void ParallelApplyFoo(float a[], size_t n)
{
    parallel_for(blocked_range<size_t>(0,n,GrainSize),
                 ApplyFoo(a));
}
```

Recursive Splitting

- General form of the constructor: blocked_range<T>(begin,end,grainsize)
  - [Setting the grain to 10000 is a good rule of thumb. The grain should take 10000-100000 instructions at least.]
- This range is used to do recursive splitting automatically.
  - If *currentSize* > grainsize then split.
  - It’s not the minimal size of the data-sets.
  - <u>Minimum threshold for parallelization</u>.
  - Concept → minimum block size.

Automatic Grain Size

- New version of TBB support automatic grain sizes.
  - The algorithms (parallel_for...) need a partitioner.
  - There's a default auto_partitioner().
  - It's using heuristics.

Aha - Recursive Algorithms

- How to implement recursive algorithms using parallel_for?
  - Define your own range splitting class.
  - Call parallel_for.
  - TBB will split recursively as needed.

parallel_reduce

Original code:

```
float SerialSumFoo(float a[], size_t n)
{
    float sum = 0;
    for(size_t i = 0; i != n; ++i) sum += Foo(a[i]);
    return sum;
}
```

parallel_reduce

Algorithm class:

```
class SumFoo
{
    float* my_a;
public:
    float sum;
    void operator()(const blocked_range<size_t>& r)
    {
        float *a = my_a;
        for(size_t i = r.begin(); i != r.end(); ++i) sum += Foo(a[i]);
    }
    SumFoo(SumFoo& x, split) : my_a(x.my_a), sum(0) {}
    void join(const SumFoo& y) { sum += y.sum; }
    SumFoo(float a[]) : my_a(a), sum(0) {}
};
```

Reduce

- Associative operator.
- Recursive algorithm to compute it.
  - Schwartz' algorithm.
- TBB:
  - splitting constructor
  - non-const method to compute on blocks
  - join to combine results

parallel_reduce

Call:

```
float ParallelSumFoo(const float a[], size_t n)
{
    SumFoo sf(a);
    parallel_reduce(blocked_range<size_t>(0,n,GrainSize),
                                  sf);
    return sf.sum;
}
```

parallel_scan

Methods needed:

```
class Body {
    T reduced_result; … x & y data
public:
    Body(x & y)…
    T get_reduced_result() const { return reduced_result; }
    void operator()(range, tag) {
        T temp = reduced_result;
        for(i : range) {
            temp <op>= x[i];
            if (tag::is_final_scan()) y[i] = temp;
        }
        reduced_result = temp;
    }
    Body(Body&b, split) – split constructor
    void reverse_join(Body& a) {
        reduced_result = a.reduced_result <op> reduced_result;
    }
    void assign(Body& b) { reduced_result = b.reduced_result; } };
```

parallel_scan

- One class to define the operations for both passes of the algorithm (recall 2 passes).
  - Differentiation with is_final_scan().
  - prescan computes the reduction, doesn’t touch y.
  - final scan updates y.
  - reverse_join: *this* is the right argument.

Advanced Algorithms

- Different kinds of parallelizations:
  - parallel_while
    - suitable for streams of data
  - pipeline
  - parallel_sort

parallel_while

Original code:

```
void SerialApplyFooToList(Item *root)
{
   for(Item* ptr = root; ptr != NULL; ptr = ptr->next)
      Foo(ptr->data);
}
```

parallel_while

```
class ItemStream
{
    Item *my_ptr;
public:
    bool pop_if_present(Item*& item) {
        if (my_ptr) {
            item = my_ptr;
            my_ptr = my_ptr->next;
            return true;
        } else {
            return false;
        }
    }
    ItemStream(Item* root) : my_ptr(root) {}
};
```

parallel_while

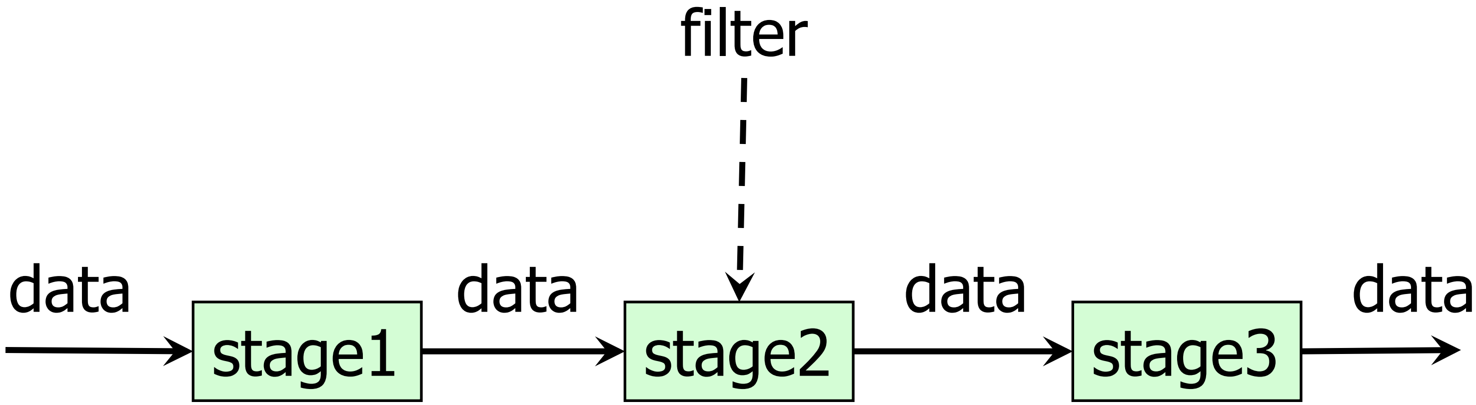
- The class acts as an item generator and writes items where specified.
- The pop_if_present does not need to be thread safe because it is never called concurrently.
  - This makes it non-scalable – could be a bottleneck.
  - It makes more sense when parallel_while can acquire more work: call to parallel_while::add (item).

parallel_while

(functor)

```
class ApplyFoo {
public:
    void operator()(Item* item) const {
        Foo(item->data);
    }
    typedef Item* argument_type;
};

void ParallelApplyFooToList(Item* root) {
    parallel_while<ApplyFoo> w;
    ItemStream stream;
    ApplyFoo body;
    w.run(stream,body);
}
```

Pipelining



TBB: One stream of data – linear pipeline.

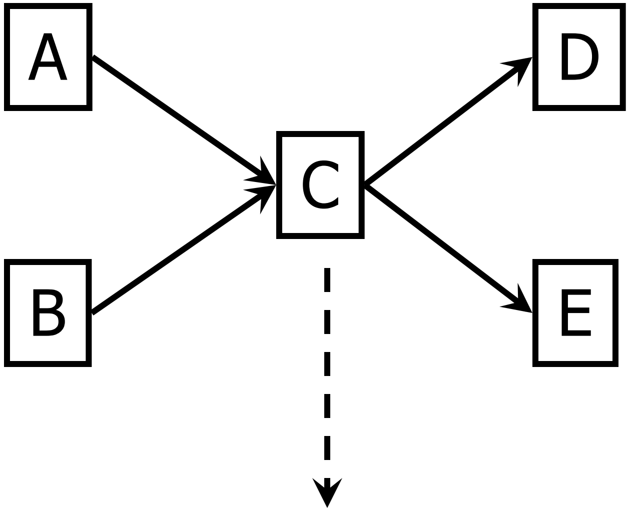
Filter Interface

```
namespace tbb {
    class filter {
    protected:
        filter(bool is_serial);
    public:
        bool is_serial() const;
        virtual void* operator()(void* item) = 0;
        virtual ~filter();
    };
}
```

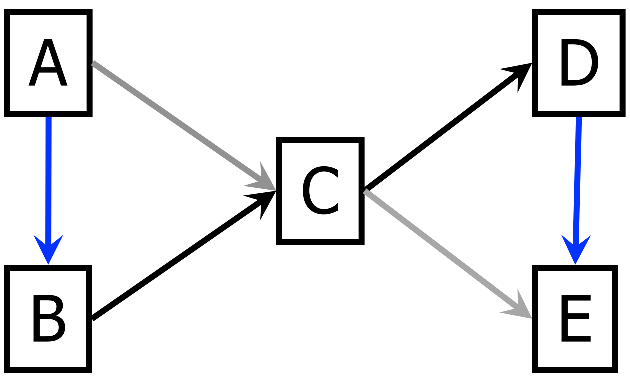
Building Pipelines

```
tbb::pipeline pipeline;

MyInputFilter input(args);
pipeline.add_filter(input);

MyTransformFilter transform(args);
pipeline.add_filter(transform);

MyOutputFilter output(args);
pipeline.add_filter(output);

pipeline.run(buffer_args);

pipeline.clear();
```

Non-Linear Pipelines



Topologically sorted pipeline



parallel_sort

- parallel_sort(i,j,comp).
- Types i and j are compared using comp (functor).
- Types i and j must be accessible randomly (are std::RandomAccessIterator).
- Uses quicksort internally, average time O (n*log* n).

Concurrent Queue

- concurrent_queue<T>
  - no allocator argument, uses scalable allocators.
  - pop_if_present, pop (blocks).
  - size() (signed) = #push - #started pop
    if <0 then there are pending pops.
  - empty()
  - no front() or back() – could be unsafe.
- Inherently bottlenecks, threading explicit, passive structure.

Concurrent Vector

- concurrent_vector<T>
  - similar to stl
- Iterators supported.

Concurrent Hash Table

- concurrent_hash_map<Key,T,HashCompare>
- HashCompare is a trait.
  - static size_t hash(const Key& x)
    static bool equal(const Key& x, const Key& y)
- Read/write access by accessor classes
  - const_accessor
    accessor
  - ~ smart pointers.
  - Accessors lock elements.

concurrent_hash_map

- Interesting methods:
  - bool insert(const accessor& result, const Key& key);
  - bool erase(const Key& key);
  - bool find(const accessor& result, const Key& key) const;
- Iterators supported too.

Memory Allocation

- You know of false sharing.
- Scalable allocator allocates in multiple of cache line sizes and pads memory.

Locks

- Support for locks.
  - scoped_lock object, keeps exception safety.
  - Can use constructor argument to avoid lock-unlock, like synchronized in Java.

```
typedef spin_mutex MyMutex;
MyMutex myMutex;
…
{
  MyMutex::scoped_lock mylock(myMutex);
  …
}
or
MyMutex::scoped_lock lock;
lock.acquire(myMutex);
…
lock.release();
```

Different types of locks available, good to use a typedef to change if needed.

mutex, spin_mutex, queuing_mutex…

Atomic Operations

- atomic<T>
  - some simple scalar atomic operations supported,
  - compare and swap