Intel® Concurrent Collections In Action

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Action Overview

- Overview
  - CnC textual syntax
  - API
- Install, CnC kit, environment etc.
- Hands on Fibonacci in CnC
  - Simple
  - Tuning
  - Distributed CnC
  - Ranges

Main features

- Domain expert oriented
  - Focus on application semantics
  - Parallelization expertise not required
- High scalability
  - No over-constraints of computations (no arbitrary serialization)
  - Only constraints are fine level data dependencies and control dependencies
- Deterministic and race-free
  - No overwriting of data
  - Computation units are functional (no side effects)
- General enough for all styles of parallelism
  - Task, data, pipeline, etc
- Portable
  - Interchangeable runtimes

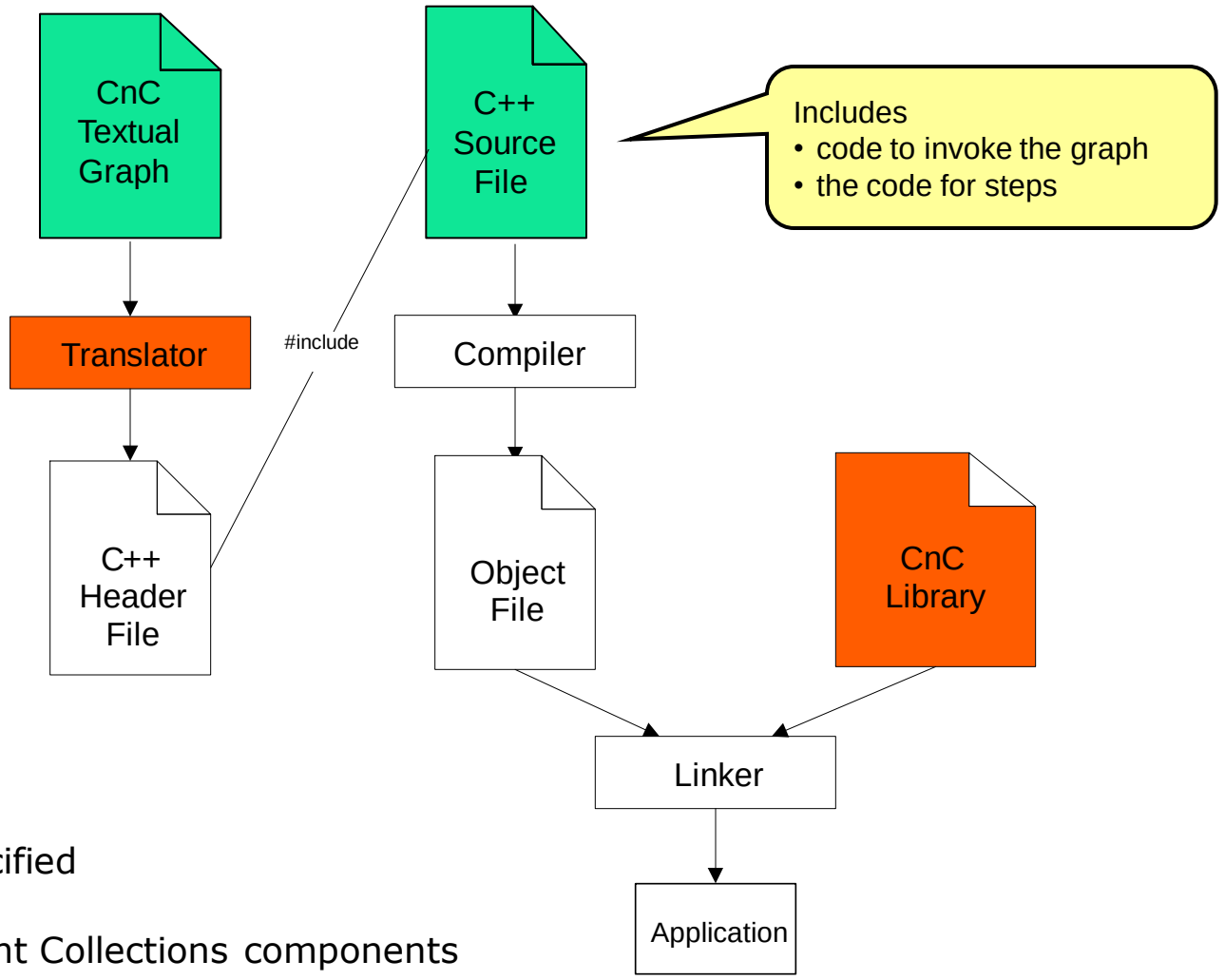
Intel® Concurrent Collections for C++

- Runtime Library
  - For Windows/Linux IA-32 and Intel-64
- Translator
  - A tool to make it easier to use the CnC runtime
  - Command line program
  - Translate `.cnc` file into C++ header file and coding hints file
- Visual Studio 2005 & 2008 IDE integrations
  - Add-ins that set up the CnC paths and register `.cnc` files to be processed by the translator
- Documentation
- Samples

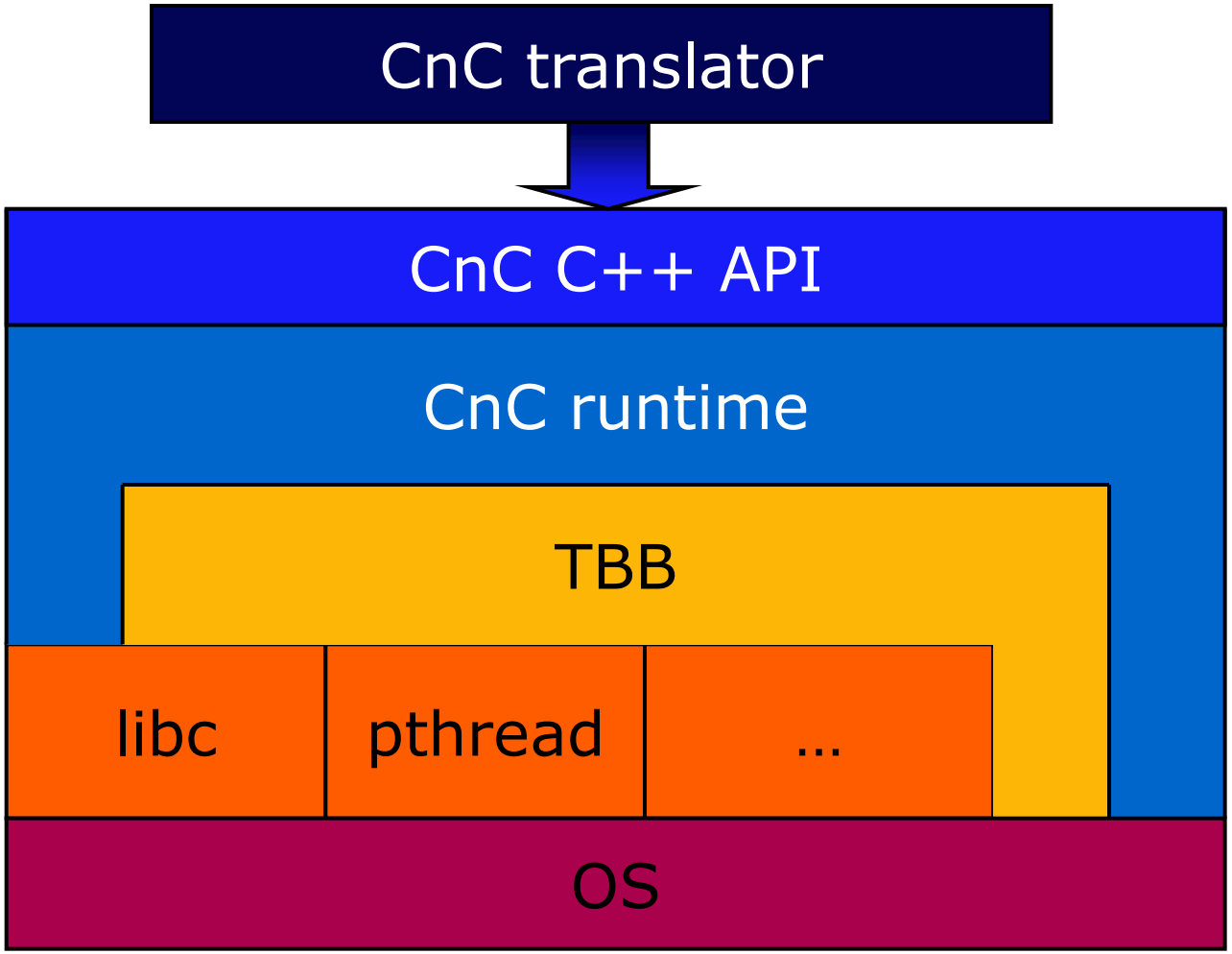
Translator and C++ API

- CnC language and translator can only create skeleton, which uses the API
- C++ coding required in any case
- The API puts CnC concepts into C++
  - Generality through collection being templates
  - Type safety
  - Debug and tuning interface
- Additional features include (new in v0.5)
  - Tuning options
  - Range support for tags
  - Running on distributed systems

Build Model

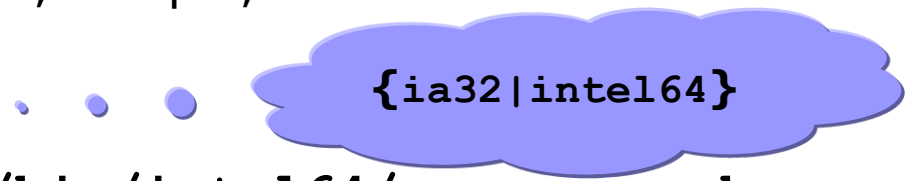


Intel® Concurrent Collections



Linux Installation

- Enter a temporary directory
- **`scp lxbsp1505:/pool/Intel/cnc_0.5_kit.tgz .`**
- Unpack "**`/pool/Intel/cnc_0.5_kit.tgz`**"
- **`cd`** to "**`cnc_0.5_kit`**" and execute install.sh
- Accept license agreement
- Install path could be "…**`/Intel/cnc/0.5`**"
- Ingredients
  - include, doc, sample, misc
  - bin/$arch
  - lib/$arch
- Edit **`<path>/bin/intel64/cncvars.csh`**
  - enter installation path (CNC_INSTALL_DIR)



How to write a CnC application

- Design
  - What are the steps and how are they tagged?
  - When are the tags produced?
  - What are the items, how are they indexed, when are they produced?
- Write textual graph specification in a .cnc file
  - CnC translator generates a header file and a coding-hints file
- Write C++ code of the application matching the graph
  - Include the generated header file
  - Each step is a user function with required interface
  - Steps consume and produce item/tag instances with **`get`** and **`put`**
  - Steps call **`gets`** before any **`puts`** and any memory allocation
  - The environment produces initial tag/item instances and invokes the graph

CnC Translator: Syntax

- Step: name enclosed in parenthesis:
  `(my_step)`
- Item-collection: name enclosed in square brackets:
  `[my_items]`
  - Declaration: leading item type, trailing tag-type:
    `[itemType my_items <itemTagType>]`
- Tag-collection: name enclosed in angle brackets:
  `<my_tags>`
  - Declaration: leading type:
    `<tagType my_tags>`

CnC is a C++ template library.
Tags and items can be of any C++ type.

Major classes provided by CnC C++ API

Tag collection: `CnC::tag_collection< tag_type, range_type >`

`put, put_range, iterate`

Item collection: `CnC::item_collection< tag_type, item_type >`

`put, get, iterate`

Graph/context: `CnC::context< DerivedContext >`

`prescribe`

Context brings everything together

Creating your own context "yourContext"

- Derive from CnC::context< yourContext >
- Declare collections as members
- Initialize collections in context constructor with context as argument
- Prescribe your steps in context constructor

Environment

- Setup TBB:
  `source`
  `/afs/cern.ch/sw/IntelSoftware/linux/x86_64/Compiler/11.1/059/bin/iccvars.csh intel64`
- Recommended to **`source`** **`<cnc-v0.5>/bin/intel64/cncvars.csh`** (requires using **`csh`** or **`tcsh`**)

- Manually, you can do the following
  - Translator and binaries use shared libs
    - **$LD_LIBRARY_PATH** should contain **`<cnc-v0.5>/lib/intel64`**
  - CnC/Intel convention in Makefiles use
    - **$CNC_INSTALL_DIR**
    - **$CNC_ARCH_PLATFORM**
  - Might want to extend **$PATH** to use cnc translator on command line

Tutorial

- Copy tutorial material
  "`scp lxbsp1505:/pool/Intel/cnc_hands_on.tgz`"
- Unpack

- Each exercise comes in a separate directory
- Accompanied by slide-show
- All come with a starting point
  - Initial code (CnC file and/or C++ code)
  - Makefile (link to parent dir's Makefile)
- Exercises start with solution of their predecessors
  - Symbolic link in each directory to solution in successor

Implementing Fibonacci

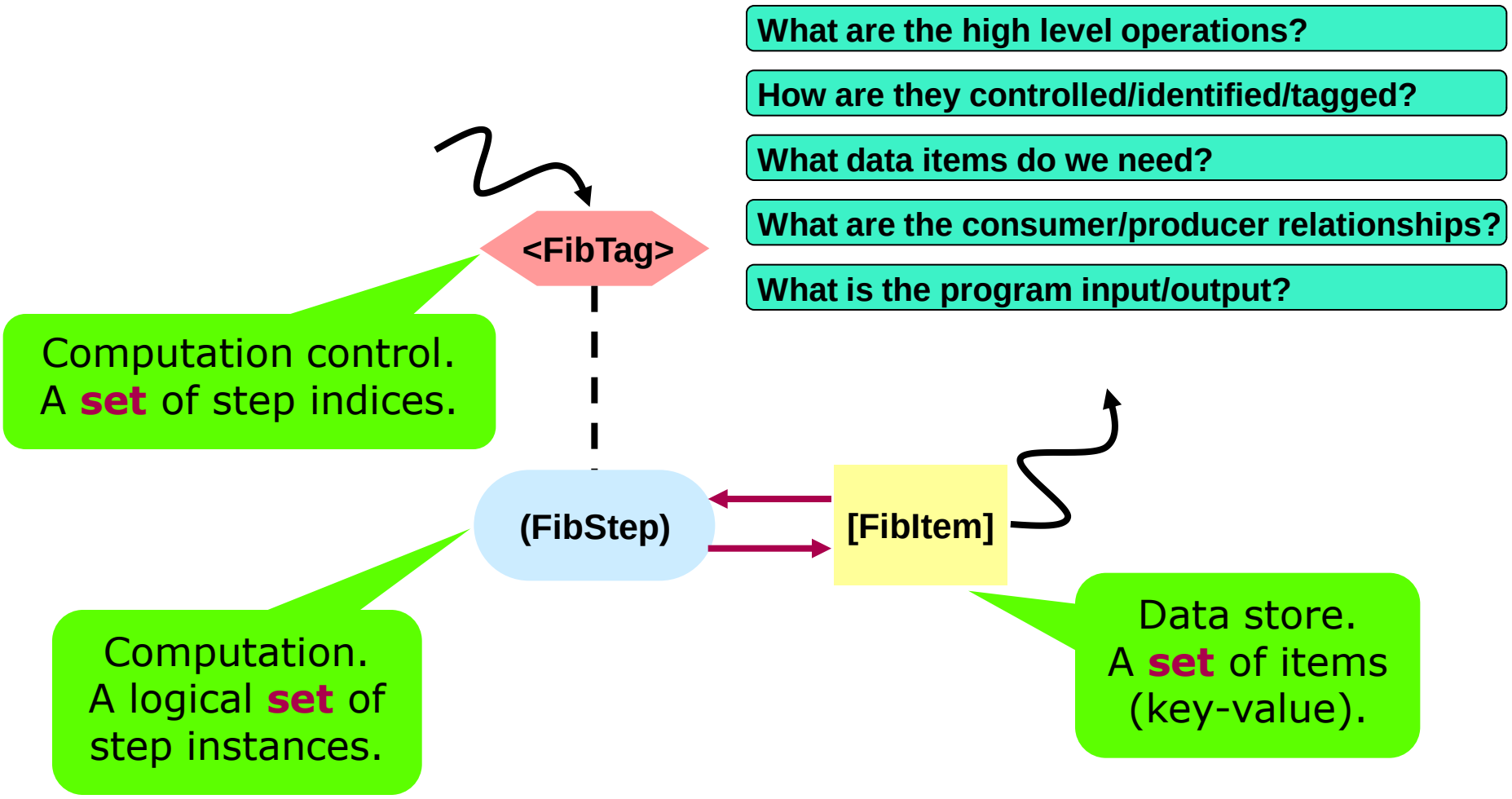
- Start with a CnC-spec
- Use translator to generate
  - header-file and
  - coding hints
- Copy coding hints and edit
- Compile and link executable
- Run!

Fibonacci Numbers

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

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

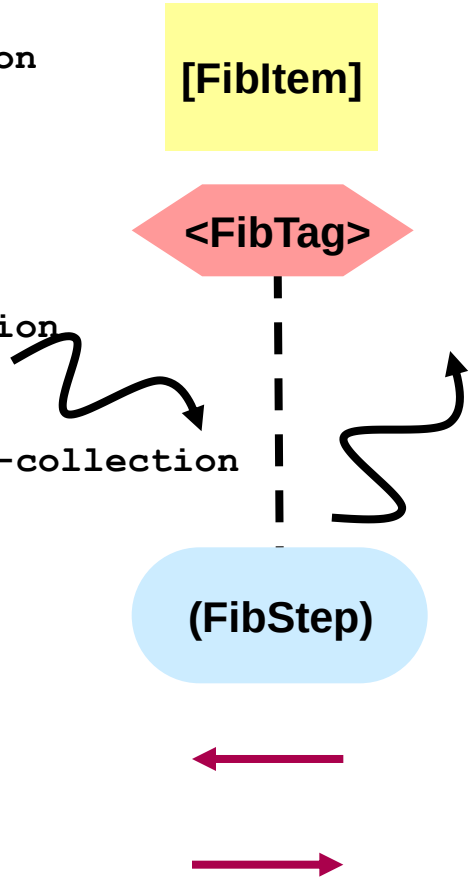
Fibonacci – Graphical CnC



Hands on Fibonacci

Enter directory "`fib`". Edit/create "`fib.cnc`"*

```
// CnC spec to compute fibonacci numbers fib( n ) = fib( n-1 ) + fib( n-2 )

// here we store the fibonacci numbers in an item-collection
[fib_type m_fibs <fib_type>];

// we need a tag-collection to control evaluation
<fib_type m_tags>;

// the environment prescribes tags and so triggers evaluation
env -> <m_tags>;

// the environment reads/consumes the result from the item-collection
env <- [m_fibs];

// prescribe/control step "fib_step"
<m_tags> :: (fib_step);

// the step reads/consumes fibonacci numbers from m_fibs
[m_fibs] -> (fib_step);

// the step also writes numbers
(fib_step) -> [m_fibs];
```



Translate!

```
[fib]> cnc fib.cnc
Or
[fib]> make fib.h
```

Creates fib.h and fib_codinghints.txt

Generated Header (fib.h)

```
// … declarations etc.

struct fib_context : public CnC::context< fib_context >
{
    // Item collections
    CnC::item_collection< fib_type, fib_type > m_fibs;

    // Tag collections
    CnC::tag_collection< fib_type > m_tags;

    // The context class constructor
    fib_context()
        : CnC::context< fib_context >(),
          // Initialize each item collection
          m_fibs( this ),
          // Initialize each tag collection
          m_tags( this, false )
    {
        // Prescriptive relations
        prescribe( m_tags, fib_step() );
    }
};
```

- Step-declarations
- Context definition
  - Collections
- Context constructor
  - Step-prescription

Coding Hints - main

Copy "`fib_codinghints.txt`" to "`fib.cpp`". Edit/create "`fib.cpp`"*

```
typedef unsigned long long fib_type; // define our type
#include <iostream>                  // needed for output
#include "fib.h"

int main( int argc, char * argv[] )
{
    // Create an instance of the context class which defines the graph
    fib_context c;

    fib_type n = atol( argv[1] );   // read from command line, not safe...

    // For each tag value from the environment (ENV), put the tag into
    // the proper tag collection
    for( fib_type m_tags_Tag = 0; m_tags_Tag <= n; ++m_tags_Tag ) // need to iterate
       c.m_tags.put( m_tags_Tag );

    // Wait for all steps to finish
    c.wait();

    // For each output to the environment (ENV), get the item using the
    // proper tag
    fib_type m_fibs_ENV;
    c.m_fibs.get( n, m_fibs_ENV );
    std::cout << "fib(" << n << ") = " << m_fibs_ENV << std::endl; // print

    return 0;
}
```

Step execution might start before `wait()`.

Software

Writing steps

When prescribing a step, the step must be a class with an execute method:

```
class my_step
{
    int execute( const tagType & tag,
                 yourContext & context ) const;
};
```

`execute` must be `const` with no side-effects
The step can have a global/constant status
The step must be copy-constructible

Coding Hints – step code

```
int fib_step::execute( const fib_type & t,
                       fib_context & c ) const
{
    switch( t ) {
        case 0 : c.m_fibs.put( t, 0 ); break;
        case 1 : c.m_fibs.put( t, 1 ); break;
        default :
            // get previous 2 results
            fib_type f_1; c.m_fibs.get( t - 1, f_1 );
            fib_type f_2; c.m_fibs.get( t - 2, f_2 );
            // put our result
            c.m_fibs.put( t, f_1 + f_2 );
    }
    return CnC::CNC_Success;
}
```

Delete the provided hints in the step-body and add the appropriate code to compute fib.

Compile and link!

At compile time, you need

- `-I$CNC_INSTALL_DIR/include`
- `-I$TBB_INSTALL_DIR/include`

At link time, you need

- `-L$CNC_INSTALL_DIR/lib/$CNC_ARCH_PLATFORM`
- `-lcnc`
- `-L$TBB22_INSTALL_DIR/lib/$TBB_ARCH_PLATFORM`
- `-ltbb -ltbbmalloc`

```
[fib]> make fib
```

Creates binary “fib”.

Run!

At run time, your **LD_LIBRARY_PATH** must include
$CNC_INSTALL_DIR/lib/$CNC_ARCH_PLATFORM

```
[fib]> ./fib 10
```

```
[fib]> env LD_LIBRARY_PATH=${LD_LIBRARY_PATH}:<path>\
       ./fib 10
```

```
[fib]> ./fib 10
fib(10) = 55
```

What we've learned

- CnC is focused on semantics
- Translator generates data structures, interfaces and coding hints and so eases getting started
- How to translate, compile, link and run a CnC program
- No thinking about parallelism

Execution trace

- CnC can print an execution trace to stdout
- Selectively per collection
- Coding hints:

```
// Debug trace can be enabled for a collection with the call:
// CnC::debug::trace( c.m_tags, "m_tags" );
```

In "`fib.cpp:main`": Uncomment trace statement (2nd line)
Build and run

```
[fib]> ./fib 3
Put tag <m_tags: 0>
Put tag <m_tags: 1>
Put tag <m_tags: 2>
Put tag <m_tags: 3>
fib(3) = 2
```

A more interesting execution trace

- Let's trace all collections:

```
CnC::debug::trace( c.m_tags, "m_tags" );
CnC::debug::trace( c.m_fibs, "m_fibs" );
CnC::debug::trace( fib_step(), "fib_step" );
```

In "`fib.cpp:main`":
Insert the two additional trace statements above
Build and run

```
./fib 2
Put tag <m_tags: 0>
Put tag <m_tags: 1>
Put tag <m_tags: 2>
Start step ( fib_step: 2;  )
Start step ( fib_step: 0;  )
Get item [m_fibs: 1]  ( not ready )
Put item [m_fibs: 0] -> 0
Start step ( fib_step: 1;  )
Put item [m_fibs: 1] -> 1
End step ( fib_step: 0 )
End step ( fib_step: 1 )
Requeue step ( fib_step: 2 )  ( input item not ready )
Start step ( fib_step: 2;  )
Get item [m_fibs: 1] -> 1
Get item [m_fibs: 0] -> 0
Put item [m_fibs: 2] -> 1
End step ( fib_step: 2 )
Get item [m_fibs: 2] -> 1
fib(2) = 1
```

- If an item is unavailable, the requesting step is rolled back
- A step will be re-scheduled once the item becomes available

Scheduler Statistics

- CnC can print scheduler statistics when the context is destructed:

```
CnC::debug::collect_scheduler_statistics( c );
```

In "`fib.cpp:main`": Comment out/delete trace statements
Add the above statement
Build and run

```
[fib]> ./fib 10
fib(10) = 55
Steps created( 11 )
Steps scheduled( 20 ) inflight( 0, 0 )
Steps requeued( 9 ) resumed( 9 )
```

What we've learned

- CnC debugging API helps with understanding the runtime behavior

Don’t like the put-loop

- It would be more elegant to invoke step recursion within the step and let the env put only one tag

`Put`ting tags before `get`s can express call/return (or concurrent co-routine).

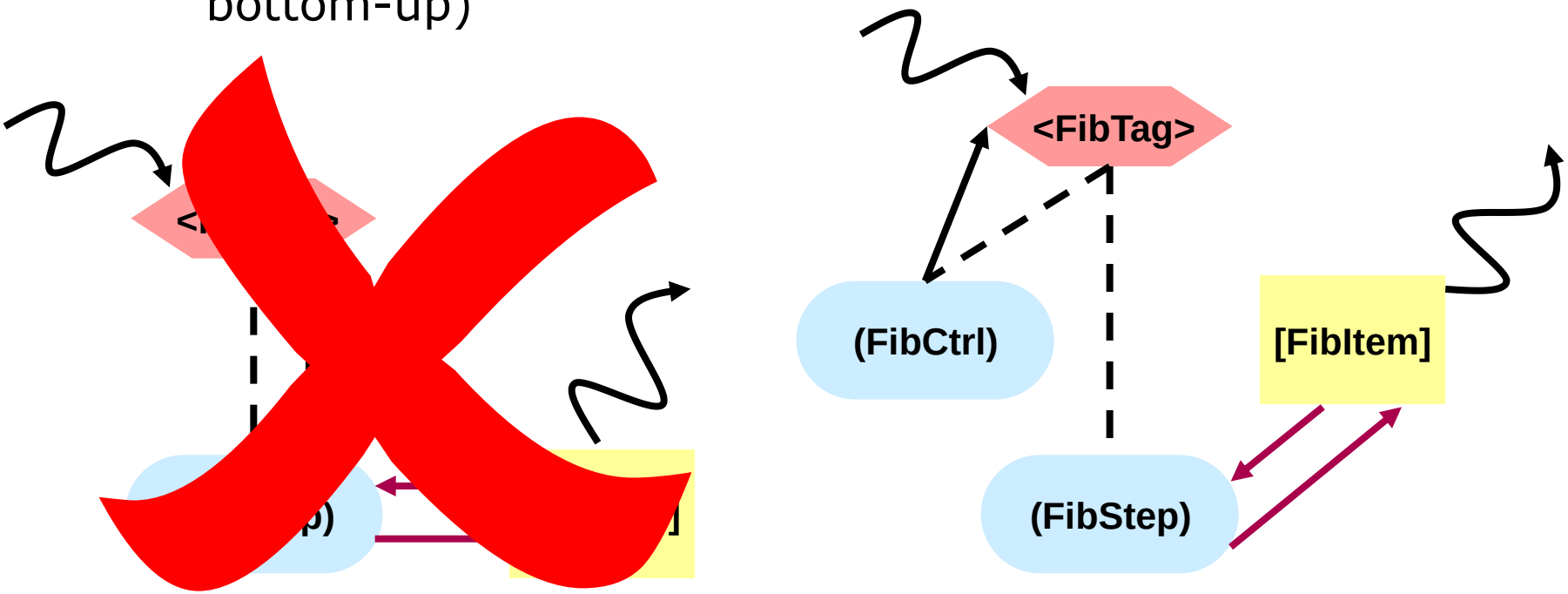
This is not supported by the CnC model.

`Put`ting items before `get`s is not supported by our replay implementation (exception!).

Steps must not put items or tags before getting any items.

Avoiding cycles

- Let's split the step into
  - One step for execution control (controller/controlee, top-down)
  - Another step for actual computation (producer/consumer, bottom-up)



Hands on CnC-spec!

Enter directory "`fib_rec`"
In "`fib.cnc`":
Add the extra step, its prescription dependencies

```
...

// prescribe/control step "fib_ctrl"
<m_tags> :: (fib_ctrl);

// the control step also put tags
(fib_ctrl) -> <m_tags>;
```

Translate
`[fib_rec]> cnc fib.cnc`
Or
`[fib_rec]> make fib.h`

Hands on C++ code!

In "`fib_rec/fib.cpp:main`": Replace for-loop with

```
c.m_tags.put( n );
```

Add new step (can copy signature from coding-hints).

```
int fib_ctrl::execute(const fib_type & t, fib_context & c ) const
{
    if( t > 0 ) c.m_tags.put( t - 1 );
    if( t > 1 ) c.m_tags.put( t - 2 );

    return CnC::CNC_Success;
}
```

Build

```
[fib_rec]> make fib
```

Run!

What we've learned

- Get all items before putting tags or items
- CnC runtime can do the hard part for you

Writing steps safely

Always get all items before putting tags or items

Defer allocation and computation to after last get

- If an item is unavailable, an exception will be thrown.
- The runtime catches the exception and re-starts the step once the item becomes available.
- The above rules protect you from
  - Memory leaks
  - Dead-locks
  - Inefficient code

Tuning

- Intel® Concurrent Collections for C++ comes with tuning knobs
- Programmer gives hints to the runtime
  - Identical tags might be put more than once
    - ⇨ Runtime can perform or avoid redundant step execution. Tradeoff between recording-cost and reduced computation.
  - Pre-declare data dependencies
    - ⇨ Runtime can choose to delay step execution until all items are available
  - Number of gets to items
    - ⇨ Garbage collection: if an item's get-count has reached 0, the runtime can remove it (and free memory)

Multiply Prescribed Tags

- Most tags in our recursive Fibonacci example are prescribed **multiple times** (due to multi-way recursion)
- By default CnC runtime creates a step-instances for each tag

```
[fib]> ./fib 10
fib(10) = 55
Steps created( 11 )
Steps scheduled( 20 ) inflight( 0, 0 )
Steps requeued( 9 ) resumed( 9 )
```

```
[fib_rec]> ./fib 10
fib(10) = 55
Steps created( 464 )
Steps scheduled( 483 ) inflight( 0, 0 )
Steps requeued( 19 ) resumed( 19 )
```

- Runtime can be instructed to preserve tags and so execute a step only once for each tag-value

Preserving Tags

Enter directory "`fib_preserve`"
Int "`fib.cnc`":
Add the `preserve` attribute to the tag-collection.

```
...
// we need a tag-collection to control evaluation
<fib_type m_tags> preserve=true;
...
```

Build
`[fib]> make fib`
Run!

```
[fib_rec]> ./fib 10
fib(10) = 55
Steps created( 464 )
Steps scheduled( 483 ) inflight( 0, 0 )
Steps requeued( 19 ) resumed( 19 )
```

```
[fib_preserve]> ./fib 10
fib(10) = 55
Steps created( 22 )
Steps scheduled( 31 ) inflight( 0, 0 )
Steps requeued( 9 ) resumed( 9 )
```

The Tuner

- Class/object attached to step prescriptions
- Provided by programmer
- Controls tuning knobs through giving hints
  - Pre-declare dependencies to consumed items
  - Declare a step as non thread-safe
  - Provide partitioning strategy for using ranges
  - Provide distribution strategy for distributed CnC
  - others
- Default implementation

Providing a tuner

Enter directory "`fib_tuner`"
In "`fib.cnc`":
Add a (new) step-declaration with `tuner` attribute.

```
...
(fib_step) tuner=fib_tuner;
...
```

Providing a tuner

In "`fib_tuner/fib.cpp`": before #including "`fib.h`"
declare `fib_context`
add `fib_tuner`
Might copy it from "`fib_tuner/fib_codinghints.txt`"
Build and Run!

```
typedef unsigned long long fib_type; // define our type
#include <iostream>                  // for printing to stdout
#include <cnc/cnc.h>

struct fib_context;

struct fib_tuner : public CnC::default_tuner< fib_type, fib_context >
{ // empty class for now, using defaults
};

#include "fib.h"
...
```

Tuner is empty
✓No change in runtime behavior yet

Filling up the tuner

Provide "depends" method and declare consumed items. Build and Run!

```
...
struct fib_tuner : public CnC::default_tuner< fib_type, fib_context >
{
    template< typename T >
    void depends( const fib_type & tag, fib_context & c, T &dC ) const;
};

#include "fib.h"

template< typename T >
void depends( const fib_type & tag, fib_context & c, T & dC ) const
{
    if( tag > 1 ) {
        dC.depends( c.m_fibs, tag - 1 ); // step will consume this
        dC.depends( c.m_fibs, tag - 2 ); // step will consume this
    }
}
...
```

```
[fib_tuner]> ./fib 10
fib(10) = 55
Steps created( 22 )
Steps scheduled( 22 ) inflight( 0, 0 )
Steps requeued( 18 ) resumed( 18 )
```

Runtime Options

- CnC runtime has two switches used through environment variables
  - CNC_NUM_THREADS sets the number of threads
  - CNC_SCHEDULER sets the scheduling policy
    - TBB_TASK (default): TBB's task-stealing
    - TBB_QUEUE: custom task queue
      - CNC_STEAL=1 with local queues and task-stealing
      - CNC_STEAL=0 one global task queue
    - TBB_WHILE: TBB's task-stealing through a while-loop
    - TBB_FOR: TBB's task-stealing through a for-loop and a double buffer
    - TBB_QUEUE_ONLY_STEALING: custom task stealing with local queues only

Run with CNC_SCHEDULER set to TBB_QUEUE

What we've learned

- CnC runtime is tunable
- Translator greatly helps with getting started
- Later in the development cycle it might add overhead

Garbage Collection

- Dead items can be removed and memory freed
- Current CnC cannot detect when an item becomes dead

⇨Programmer can provide the number of expected gets when an item is put

Providing get-counts is not always possible.

It breaks if steps are fully executed more than once.

Providing get-counts

Enter directory "`fib_gc`"
in "`fib.cpp`":
- **Enable tracing of items (`m_fibs`)**
- **Add expected get-count when `put`ting items.**

Build and Run!

```
int fib_step::execute(const fib_type & t, fib_context & c ) const
{
    switch( t ) {
        case 0 : c.m_fibs.put( t, 0, 1 ); break;
        case 1 : c.m_fibs.put( t, 1, 2 ); break;
        default :
            // get previous 2 results
            fib_type f_1; c.m_fibs.get( t - 1, f_1 );
            fib_type f_2; c.m_fibs.get( t - 2, f_2 );
            // put our result
            c.m_fibs.put( t, f_1 + f_2, 2 );
    }
    return CnC::CNC_Success;
}
```

```
[fib_gc]> ./fib 10
Put item [m_fibs: 1] -> 1 getcount=2
Put item [m_fibs: 0] -> 0 getcount=1
Get item [m_fibs: 1] -> 1
Get item [m_fibs: 0] -> 0
Put item [m_fibs: 2] -> 1 getcount=2
item [m_fibs: <1>] m_getCount decremented to 1
item [m_fibs: <0>] m_getCount decremented to 0
Get item [m_fibs: 2] -> 1
Get item [m_fibs: 1] -> 1
Put item [m_fibs: 3] -> 2 getcount=2
item [m_fibs: <2>] m_getCount decremented to 1
item [m_fibs: <1>] m_getCount decremented to 0
Get item [m_fibs: 3] -> 2
Get item [m_fibs: 2] -> 1
Put item [m_fibs: 4] -> 3 getcount=2
item [m_fibs: <3>] m_getCount decremented to 1
Get item [m_fibs: 4] -> 3
item [m_fibs: <2>] m_getCount decremented to 0
Get item [m_fibs: 3] -> 2
Put item [m_fibs: 5] -> 5 getcount=2
item [m_fibs: <4>] m_getCount decremented to 1
Get item [m_fibs: 5] -> 5
item [m_fibs: <3>] m_getCount decremented to 0
```

What we've learned

- Garbage collection requires understanding of the dynamic graph execution

Distributed CnC

- Current release V0.5 on whatif.intel comes with support for distributed memory
- Runtime can offload step execution to other machines
- If standard data types are used, only minor changes are needed to existing CnC code
- Serialization for non-standard data types is simple. Only one method/function for marshalling and un-marshalling needed.
- Work distribution can be controlled through tuner

Distributing Fibonacci

Enter directory "`fib_dist`"
In "`fib.cpp`":
`#include <cnc/dist_cnc.h>`
in `main`: add context-initializer
Build (`[]> make fib DIST=1`) and Run!

```
...
#ifdef _DIST_
#include <cnc/dist_cnc.h>
#else
#include <cnc/cnc.h>
#endif
...
int main( int argc, char * argv[] )
{
#ifdef _DIST_
    CnC::dist_cnc_init< fib_context > _dinit;
#endif
...
```

Manually Going Distributed

```
[fib_dist]> ./fib 10
start clients manually with contact string: 0:1025_111@127.0.1.1
```

In a separate shell

- **Log into another machine (if possible)**
- **Enter directory "`fib_dist`"**
- **Run `./fib` with environment-var**
  CNC_SOCKET_CLIENT set to contact string

```
[fib_dist]> env CNC_SOCKET_CLIENT=0:1025_111@127.0.1.1 ./fib
```

```
fib(10) = 55
Steps created( 12 )
Steps scheduled( 11 ) inflight( 0, 0 )
Steps requeued( 18 ) resumed( 18 )
```

Going Distributed with a script

- If environment variable CNC_SOCKET_HOST is set to a number, the host expects as many clients
- Otherwise it is interpreted as a name of a dual-mode script which
  - either returns number of clients
  - or launches them
- CnC kit comes with a sample script "**`misc/start.sh`**"
  - Launches clients on **`localhost`**, but using **`ssh`**
  - Copy and edit the script to start clients on remote hosts (just replace "**`localhost`**" with the respective names) and/or to adapt the number of clients

Going Distributed with a script

Run `./fib` with environment-var
CNC_SOCKET_HOST set to the launch-script

```
[]> env CNC_SOCKET_HOST=$CNC_INSTALL_DIR/misc/distributed/socket/start.sh \
? `pwd`/fib 10
--> established socket connection 3, 2 still missing ...
--> established socket connection 2, 1 still missing ...
--> established all socket connections to the host.
--> establishing client connections to client 1 ... done
--> establishing client connections to client 2 ... done
fib(10) = 55
Steps created( 11 )
Steps scheduled( 9 ) inflight( 0, 0 )
Steps requeued( 13 ) resumed( 13 )
```

Things to keep in mind

- Collections must be members of contexts (constructed in its ctor)
- Context must be default constructible and prescribe steps there
- Pointers are dangerous
  - Tags must not be of pointer type
  - Items of pointer type need special treatment; better avoid them
- Global variables are evil and must not be used (within the execution scope of steps)
- In contrast to local-only execution, preservation of tags will only locally suppress redundant step execution.

- **All this is aligned with CnC's methodology!**

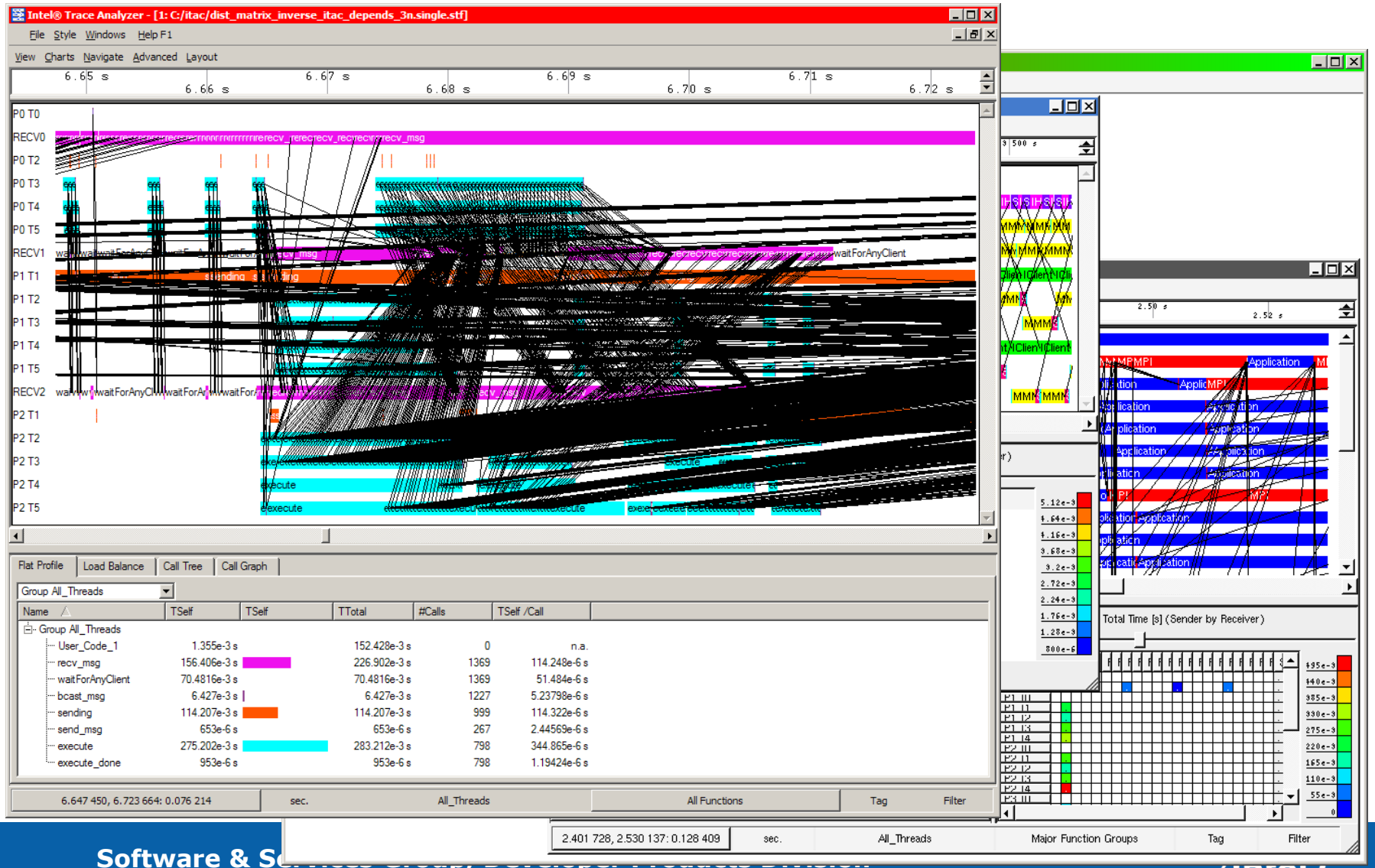
Serialization Example

```
struct my_struct
{
        bool     m_isPartitioned;
        bool     m_verbose;
        int      m_size;
        double * m_array;

        void serialize( CnC::serializer & ser )
        {
                ser & m_isPartitioned & m_size & m_verbose;
                ser & CnC::array_alloc( m_array, m_size );
        }
};
```

Alternatively a (global) serialize function can be used. Simple structs/classes are serialized trivially through

```
CNC_BITWISE_SERIALIZABLE( type );
```

Debugging and Profiling



What we've learned

- With some discipline, almost any valid CnC program can easily be ported to run across a network – with little effort.

Tag Ranges

- Step execution comes with scheduling overhead
- When putting single tags, the runtime can't (easily) agglomerate step-instances
- The CnC C++ API provides means to put entire ranges of tags (in the spirit of TBB ranges)
- The runtime can then partition/split the range and schedule several steps at once
- For small steps, ranges can lead to significant performance gains

Tag-Ranges do not play well with the translator (yet).

Range Features

- Tags can have any type
- Works with **`TBB::blocked_range<…>`**
- Custom ranges possible, narrow interface required
  - Split-constructor
  - Iterator
- Comes with
  - fixed-size parititioner
  - Adaptive-size partitioner (depends on # threads)
  - Partitioning of self-dividing tags/ranges
- Allows custom partitioners (also with a narrow interface)

Primes

- Basic implementation puts many individual tags in a loop
- This could be replaced by a range
- tbb::blocked_range does not support strides, so we will use CnC's internal range
- Using ranges is expected to decrease
  - Number of scheduled steps
  - runtime

Enter directory "`primes_ranges`"
Let's start with running basic version for comparison.
Build (`make primes`) and Run (`./primes 646678`)!

Hands on Ranges

Enter directory "`primes_ranges`"
In "`primes.cpp`": declare range type with tag-collection
replace loop with putting a range
Build (`make primes`) and Run (`./primes 646678`)!

```
...
struct my_context : public CnC::context< my_context >
{
  CnC::tag_collection< int, CnC::Internal::strided_range< int > > m_tags;
  CnC::item_collection< int,int > m_primes;
...
```

```
...
  tbb::tick_count t0 = tbb::tick_count::now();

  if( n > 2 )
    c.m_tags.put_range( CnC::Internal::strided_range< int >( 3, n+1, 2 ) );

    c.wait();
...
```

Comparison

```
[primes_basic]> ./primes 646678
Determining primes from 1-646678
Found 52571 primes in 4.4708 seconds
Steps created( 323338 )
Steps scheduled( 323338 ) inflight( 0, 0 )
Steps requeued( 0 ) resumed( 0 )
```

```
[primes_range]> ./primes 646678
Determining primes from 1-646678
Found 52571 primes in 5.3769 seconds
Steps created( 43 )
Steps scheduled( 42 ) inflight( 0, 0 )
Steps requeued( 0 ) resumed( 0 )
```

Load Balancing issue!
We'd need a more sophisticated partitioner.

Left to the interested as an exercise…

Intel® Concurrent Collections

http://software.intel.com/en-us/articles/intel-concurrent-collections-for-cc/

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The End.

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