Distributed CnC for C++

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CnC for Distributed Systems

- Let CnC utilize scalability of memory/cache-incoherency
- Extend Concurrent Collections to generically support distributed memory
  - KNF (Xn), **Sockets**, MPI, ??
  - combination of the above
- Provide a platform for experiments (proof of concept)
  - Opens another non-trivial dimension of scheduling
  - Can we separate the tuning from the domain?
- Proof-point for abstraction from platform
- **Not** meant to be a general solution for distributed computing

- Minimize extra requirements
  - Minimal incremental changes to existing CnC code
  - Auto/default-partitioning/distribution
  - Keep programming methodology of CnC
- Utilize standard techniques
distCnC - Status

- Prototype implementation
- Communication through sockets
- Included in latest what-if release
- Some limitations compared to shared-memory CnC
How to

• #include <cnc/dist_cnc.h>
  – sets #define and declares dist_cnc_init template
• instantiate CnC::dist_cnc_init< ... > object
  – First thing in main, must persist throughout main
  – Template parameters are the contexts used in the program
• Steps do normal gets and puts

• serialization of non-standard data types
  – Simple mechanism (similar to BOOST)
• The information about where to run a step can be provided by a tuner: int tuner::pass_on( ... )
  – return process-id for a given tag

• Start up of remote processes through script (or manually)
What happens in a “tag-put”? 

1. putTag
2. create step-instance
3. tuner pass_on
4. local?
   - yes: schedule
   - no: send step
What happens in a “item-get”? 

- `getItem` 
- available? 
  - yes: `return item`  
  - no: 
    - `request item (bcast)` 
    - `suspend step` 

```
distCnC is an Optimist
```

What happens in a “item-put”?

- **putItem**
- **someone requested it?**
  - yes: **re-queue suspended steps**
  - no: **send item**
    - To interested processes only
    - **continue**
Data Residence
Start up and shut down

- Magic is in `dist_cnc_init<...>`
  - Constructor
    - Initializes factory (in charge of creating objects from type-ids)
    - Assigns type-ids to types (contexts only)
      - types of collections are known as they are members of the context
    - Host launches clients, sets up network and continues execution
    - Clients set up network and go into receiver loop they exit when done
      - Clients never leave the constructor!
  - Destructor
    - Host initiates network shut down
    - Clients do nothing
Termination detection problem

- reset
- wait()
- Loop
- Count messages
- wait()
- Step::execute()
- Step::execute()
- Step::execute()
Communication

Communicator

Collections

Scheduler

Contexts

Dynamically
loaded at runtime

Distributor

Communicator

Collections

Scheduler

Contexts

Distributer
Communicators

- **Sockets**
  - *Loaded at runtime*
  - *Should work across OSes*
- Emulator (incomplete, used to work)
  - Extra thread emulating process
  - Requires special linkage
- MPI (incomplete, prototype implemented)
  - Can be done through loading at runtime
  - With MPICH2, nothing could be required
    - Otherwise mpiexec or similar launches the processes
- KNF Xn, native SDK (incomplete, core functionality implemented)
  - Can be done through loading at runtime
  - KNF peculiarities when building the binaries
- System was laid out to allow combining communicators
Things to keep in mind

• Collections must be members of contexts (constructed in its ctor)
• Contexts must be default constructible and prescribe steps there
• Tags and items must be default constructible
• 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 steps will only locally suppress redundant step execution.
• Tag-ranges cannot be distributed yet, they stay locally

• All this is aligned with CnC’s methodology!
Possible Futures of distCnC

- Performance evaluation
- Alternative communication policies
  - request bundling (lazy)
  - reduce number of broadcasts (user hints, ?)
- Advanced distribution policies
  - Global View
  - Use data about resources (utilization, HW, ...)
  - Declare local availability
- Allow distributing ranges (parallel_for)
- User managed data/items/pointers
- Other communicator layers (MPI, Xn, RUDP)?
- Heterogeneous and/or hierarchical networks (e.g. cluster of GPU attached workstations)
- Adding/removing clients on the fly
- Fault tolerance
  - Checkpointing? Continue? Restart (partially)?
  - Failure on client, failure on host
Execution philosophy

• Program on host
• Clients execute steps only

• N-to-N network
• Steps might trigger steps on other client processes
Operation

• When a context is created, it is cloned on all clients/processes
  – all its collections will be there automatically
  – context creation creates the scheduler, which creates worker threads
• When a step-instance is created, the scheduler might decide that it must be passed on to another process
• Processes schedule steps upon their reception
• Optimistic execution
  – optimizes for local availability of items
  – if an item is unavailable, it is requested with all other processes (broadcast)
  – if a process has (or creates) requested item, it sends it to those processes which requested it
  – data/item traffic quickly dominates communication costs
Example (quickSort)

```cpp
#include "cnc/dist_cnc.h"
...
void serialize( CnC::serializer & ser )
{
    ser & m_isPartitioned & m_size & m_verbose;
    ser & CnC::array_alloc( m_array, m_size );
}
...
CnC::dist_cnc_init< qs_ctxt > dc_init;
...
struct quick_sort_tuner : public CnC::default_tuner< tag_type, qs_ctxt >
{
    int pass_on( const tag_type & parent, qs_ctxt & ) const
    {
        return parent % 4;
    }
};
...
    prescribe( ancestryPathSplitTagSpace,
        quick_sort_split_step(), quick_sort_tuner() );
```
Why Serialization

- Distributed memory systems require serialization for data transfer
- Tags and items must be serializable
- C++ language does not provide serialization (like Java or .NET)
- CnC framework provides serialization capabilities which
  - Make simple things simple
    - Built-in serialization of standard data types and ranges
    - Array-wrappers with and without memory handling
  - Make complex things possible
    - All data types can be serialized
    - Complex structures (e.g. with pointers or virtual methods) require `serialize` method or function
  - Are easy to use and commonly known (like in Boost)
  - Do not provide automatism which might fail
    - auto-serialization only upon request (simple declaration) compiler issues error if serialization is undeclared
Serialization

**Bitwise serializable** (e.g. structs without pointers; default for builtin types)

```cpp
WORKLETS_BITWISE_SERIALIZABLE( MyStruct )
```

**Explicitly serializable** (default)

provide

```cpp
void serialize( CnC::serializer &, YourType & )
```

or

```cpp
void YourType::serialize( CnC::serializer & )
```

one function/method for both serialization and deserialization

very easy syntax, using `operator&` (like in Boost)

```cpp
class MyType {
    int _n;
    float* _arr;
    MySubClass _obj;

public:
    void serialize( CnC::serializer & buf ) {
        buf & _n; // standard data type
        buf & array_alloc( _arr, _n ) // automatic memory allocation
        & _obj; // requires its serializability
    }
};
```
Launching distributed CnC (sockets)

- On Host, set CNC_SOCKET_HOST
  1. number_of_clients
  2. name_of_script
  1. Host prints contact string to manually start clients
     CNC_SOCKET_CLIENT=<contact_string>
  2. Host launches script twice:
     1. -n must return number of clients
     2. Starting clients with given contact string (e.g. through ssh)
     Example scripts for Windows and Linux are provided

Same executable can be used to run on host and clients; even on a single process without clients.
Debugging and Profiling

• Straightforward debugging, no magic mechanisms
  – Use common techniques
    – E.g. totalview with MPI
    – E.g. gdb/idb/Visual Studio with sockets

Hooks for profiling with Intel® Trace Analyzer and Collector
  – Standard use with MPI
  – Built-in hooks in socket runtime and for local-only
  – Convenient macro for manual instrumentation of user code