Task-based Prog. Models and Charm++

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Announcements

• Reminder when sending emails, email: cmsc416-bhatele@cs.umd.edu
Task-based programming models

- Describe program / computation in terms of tasks
- A task can be defined as a code region that can be executed concurrently by multiple processes or threads, and along side other tasks
- Notable examples: Charm++, StarPU, HPX, Legion
- Attempt at classification of task-based programming models: https://link.springer.com/article/10.1007/s11227-018-2238-4
Task-based programming models

- Enable exposing high degree of parallelism
- Number of tasks independent of the number of processors
- Tasks might be short-lived or persistent throughout program execution
- Runtime handles distribution and scheduling of tasks
Charm++: Key principles

- Programmer decomposes data and work into objects (called *char*es)
  - Decoupled from number of processes or cores
- Runtime assigns objects to physical resources (cores and nodes)
- Each object can only access its own data
  - Request data from other objects via remote method invocation: `foo.get_data()`
- Asynchronous message-driven execution
Hello World in Charm++

mainmodule hello {
    array [1D] Hello {
        entry Hello();
        entry void sayHi();
    };
};

Charm++ Tutorial: http://charmplusplus.org/tutorial/ArrayHelloWorld.html
Hello World in Charm++

```charm++
mainmodule hello {
    array [1D] Hello {
        entry Hello();
        entry void sayHi();
    };
}

void Hello ::sayHi() {
    CkPrintf("Hello from chare %d on processor %d.\n", thisIndex, CkMyPe());
}
```

Charm++ Tutorial: [http://charmplusplus.org/tutorial/ArrayHelloWorld.html](http://charmplusplus.org/tutorial/ArrayHelloWorld.html)
Hello World in Charm++

mainmodule hello {
    array [1D] Hello {
        entry Hello();
        entry void sayHi();
    };
};

Main::Main(CkArgMsg* msg) {
    numObjects = 5; // number of objects
    CProxy_Hello helloArray = CProxy_Hello::ckNew(numObjects);
    helloArray.sayHi();
}

void Hello ::sayHi() {
    CkPrintf("Hello from chare %d on processor %d.\n", thisIndex, CkMyPe());
}

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Compiling a charm program

- Charm translator for .ci (Charm++ interface) file
  - Generates charm_hello.decl.h and charm_hello.def.h

  `charmcc hello.ci`

- C++ code:

  `charmcc -c hello.C`
  `charmcc -o hello hello.o`
Chare arrays

- User can create indexed collection of data-driven objects

```cpp
CProxy_Hello helloArray = CProxy_Hello::ckNew(numElements);
```

- Different kinds: 1D, 2D, 3D, ...

- Mapping of array elements (objects) to hardware resources handled by the runtime system (RTS)
Object-based virtualization

- User programs in terms of chares or objects

**User View**

Global Object Space

**System View**

CPU A

CPU B

CPU C
Over-decomposition

• Create lots of “small” objects per physical core
  • Objects grouped into arrays: 1D, 2D, …

• System assigns objects to processors and can migrate objects between physical resources

• Facilitates automatic load balancing
Message-driven execution

- An object is scheduled by the runtime scheduler only when a message for it is received.
- Facilitates adaptive overlap of computation and communication.
Cost of creating more objects?

- Context switch overhead
- Cache performance
- Memory overhead
- Fine-grained messages
Hello world: .ci file

mainmodule hello {

  readonly CProxy_MyMain myMainProxy;
  readonly int numChares;

  mainchare MyMain {
    entry MyMain(CkArgMsg *msg);
    entry void done(void);
  };

  array [1D] Hello {
    entry Hello(void);
    entry void sayHi(int);
  };

};
Hello world: MyMain class

```c++
/*readonly*/ CProxy_MyMain myMainProxy;
/*readonly*/ int numChares;

class MyMain: public CBase_MyMain {
  public:
    MyMain(CkArgMsg* msg) {
      numChares = atoi(msg->argv[1]); // number of elements

      myMainProxy = thisProxy;
      CProxy_Hello helArrProxy = CProxy_Hello::ckNew(numChares);

      helArrProxy[0].sayHi(20);
    }

  void done(void) {
    cout << "All done" << endl;
    CkExit();
  }
};
```
Hello world: Hello class

```cpp
#include "hello.decl.h"
extern /*readonly*/ CProxy_MyMain myMainProxy;

class Hello: public CBase_Hello {
    public:
        Hello(void) { }

        void sayHi(int num) {
            cout << "Char " << thisIndex << " says Hi!" << num << endl;

            if(thisIndex < numChars-1)
                thisProxy[thisIndex+1].sayHi(num+1);
            else
                myMainProxy.done();
        }
};

#include "hello.def.h"
```
Proxy class

- Runtime needs to pack/unpack data and also figure out where the chare is
- Proxy class generated for each chare class
  - Proxy objects know where the real object is
  - Methods invoked on these proxy objects lead to messages being sent to the destination node/core where the real object resides
Broadcast, barrier, and reduction

- Entry method called on a chare proxy without subscript is essentially a broadcast:

  ```
  chareProxy.entryMethod()
  ```

- Barrier: reduction without arguments:

  ```
  contribute();
  ```

- Reduction with arguments:

  ```
  void contribute(int bytes, const void *data, CkReduction::reducerType type);
  ```
Callback for reduction

• Where does the output of the reduction go?

• Use a callback object known as a reduction client

CkCallback* cb = new CkCallback(CkIndex_myType::myReductionFunction(NULL), thisProxy);
contribute(bytes, data, reducerType, cb);

• Use the reduction data in the callback:

    void myType::myReductionFunction(CkReductionMsg *msg) {
        int size = msg->getSize() / sizeof(type);
        type *output = (type *) msg->getData();

        ...
    }

2D Stencil in Charm++

- Data decomposition
- Work decomposition
- Communication?