CHARM++ :
A Portable Concurrent Object Oriented System Based on C++

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Parallel Computing

1. Computationally demanding applications exist :
   - grand challenge problems
   - commercial applications
2. Parallel computing can make these problems tractable
3. Large scale commercial parallel computers are available – CM-5, Paragon, nCUBE/2, Cray T3D, KSR-1, SP-1.

A Hurdle

1. Programming parallel machines is difficult
2. Scheduling, load balancing, synchronization, communication latency
3. Portability
4. A new dimension to the complexity of programs

Object Orientation

A way of organizing and thinking about programming

1. Abstraction and encapsulation
2. Modularity and clean interfaces
3. Inheritance hierarchies
4. Software Reuse and libraries
5. Polymorphism

Can Object Orientation help

Parallel Programming ?

1. Fundamental concepts overlap :
   Processes and Objects
   - State and persistence
   - Interaction by messages
2. Abstraction controls complexity
3. Modularity helps reuse for different data distributions

Combine the benefits of two powerful technologies

The CHARM Parallel Programming

philosophy

1. Portablity

2. Latency tolerance
   - Simple message passing wastes resources
   - Message driven execution overlaps computation and communication

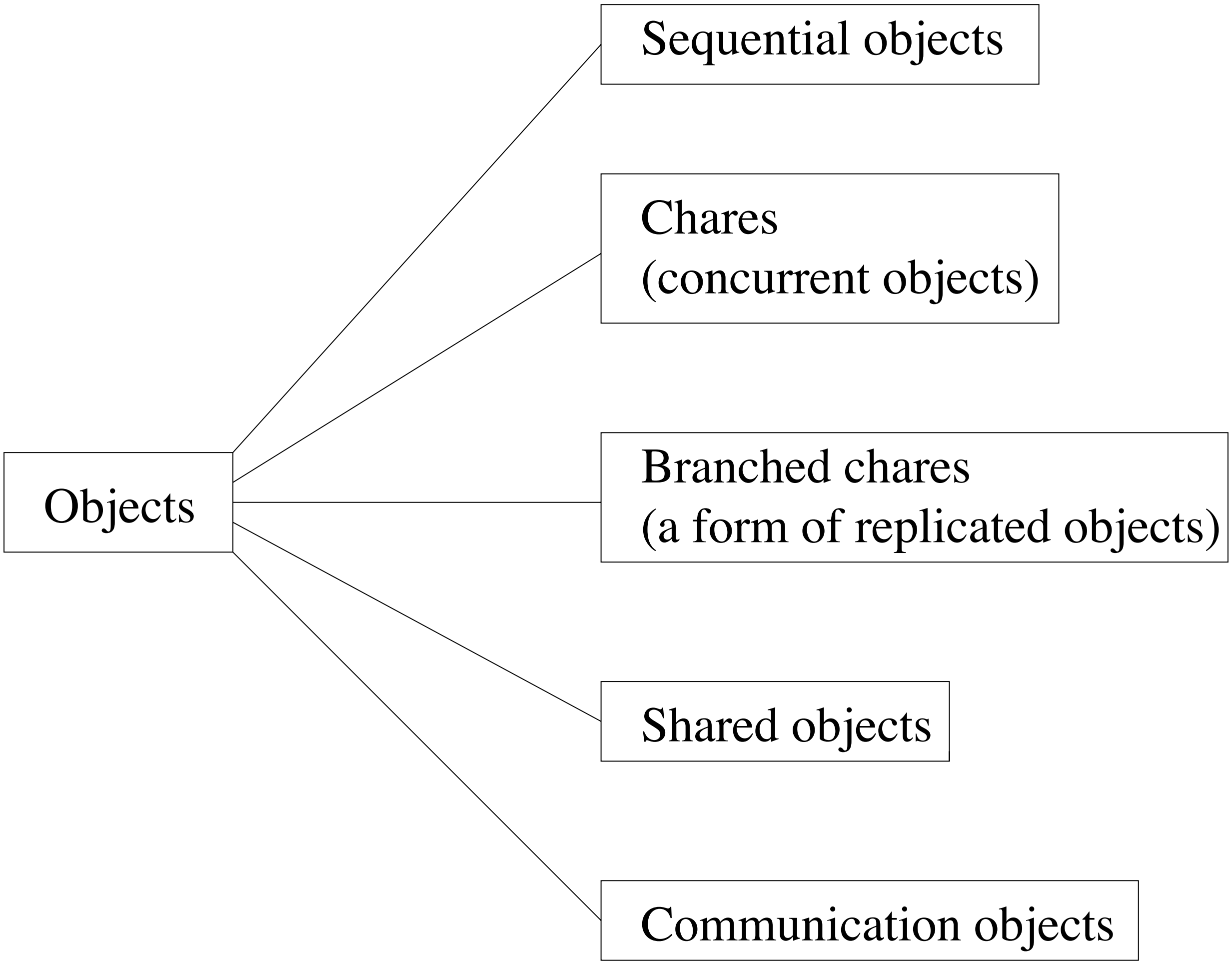
3. Support dynamic creation of work :
   dynamic load balancing

4. Provide specific abstractions for sharing information

5. Support irregular as well as regular, data-parallel computations

CHARM : A C based parallel programming language

CHARM++ : A high level view



Objects

Sequential objects

Chares
(concurrent objects)

Branched chares
(a form of replicated objects)

Shared objects

Communication objects

Sequential objects are different from parallel objects

1. Programmers need to know how much an action costs (simple local call v/s expensive remote call)
2. Asynchronous, split-phase remote calls : different from function calls
3. Better algorithm design : parallel objects coordinate sequential objects
4. Reuse code for existing sequential classes
5. Better performance by explicit grainsize control

CHARM++ Language

Communication Objects

```
message MessageName {

          .... data members ....

} ;
```

CHARM++ Language

Concurrent Objects : chares

```
chare class ChareName {

    .... data and function members ....

entry:
        void EntryPoint1(MessageType1 *Pointer)
        {
                .... C++ code block ....
        }

        void EntryPoint2(MessageType2 *Pointer)
        {
                .... C++ code block ....
        }
} ;
```

CHARM++ Language

Replicated Objects

```
branched_chare class ChareName {


    .... data and function members ....


entry:
        void EntryPointName(MessageType *Pointer)
        {
                .... C++ code block ....
        }
} ;
```

1. One branch on every processor
2. Public members can be accessed on the local processor by LocalBranch`(ChareHandle)->Function()`

CHARM++ Language : System calls

1. Creating objects :
    - new_chare(`ChareName, EntryPoint, Message`)
    - new_branched_chare(`ChareName, EP, Message`)
    - new_message(`MessageType`) ;
2. Sending messages :
    - to chares : `ChareHandle=>EntryPoint(Message)`
    - to branched chares :
      `ChareHandle[PE]=>EntryPoint(Message)`
      `ChareHandle[ALL]=>EntryPoint(Message)`
3. Other calls for termination, I/O, timing.

Shared Objects : Data Sharing

1. Messages are too low level and generic
2. Communication overheads can be optimized if the pattern of data sharing is known
3. Need abstract template types for sharing information in specific modes

Shared Objects : Abstract Types

1. *Read Only* : initialize at beginning, read efficiently
2. *Write Once* : initialize anytime, read efficiently
3. *Accumulator* : efficient update, read once (e.g. global sum)
4. *Monotonic* : many reads and updates, need monotonicity
5. *Distributed Tables* :
   each entry has a key and data field
   asynchronous Insert, Delete and Find operations

Modularity

1. Separate compilation, libraries
2. Function pointers cannot be passed across address spaces
    - function reference indices
3. Modules must exchange data in a fully distributed manner
4. Modules must not assume data distribution
    - branched chares, distributed tables

Load balancing

1. Necessary to support irregular, dynamic creation of work

2. User selectable at compile time from many strategies
   - Random
   - Adaptive Contracting Within Neighborhood
   - Central Manager
   - Token based

Other Features

1. Many user selectable scheduling strategies
2. Prioritized Execution
    - Integer priority
    - Bit vector (unbounded) priority
3. Conditional Message Packing
    - Complex data structures having pointers must be packed before sending them across processors
    - System does packing *only* if message crosses address space

An Example : Primes

```
extern int seqPrimes(int low, int high);
const int LENGTH = 10000;
message MsgAccCount { int data; };
message RangeMsg {
  int Low, High;
};
class AccCount :  public Accumulator {
  MsgAccCount *msg;
public:
  AccCount(MsgAccCount *initmsg)
  { msg = (MsgAccCount *)new_message(MsgAccCount)
    msg->data = initmsg->data;
  }
  void Accumulate (int x)
  { msg->data += x;
  }
  void Combine (MsgAccCount *y)
  { msg->data += y->data;
  }
};
AccCount *total;
```

Primes Example page 2

```
chare class main {
entry:
  main()
  { int Limit;
    CPrintf("Enter upper limit of range :  ");
    CScanf("%d", &Limit);
    AccInitMsg *acc_msg = new_message(AccInitMsg);
    acc_msg->data = 0;
    total = new AccCount(acc_msg);
    RangeMsg *msg = new_message(RangeMsg);
    msg->Low = 1; msg->High = Limit;
    new_chare(PrimesChare, Goal, msg);
  }
  Quiescence()
  { main handle *myid = MyChareHandle();
    total->CollectAccValue(PrintResult, myid);
  }
  PrintResult(MsgAccCount * result)
  { CPrintf("The total is:%d.",result->data);
    CharmExit(); }
};
```

Primes Example page 3

```
chare class PrimesChare {
entry:
  Goal(RangeMsg * msg1)
  { int L = msg1->Low;
    int H = msg1->High;
    if ((H-L+1) > LENGTH)
    { int Mid = L + (H-L+1)/2;
      RangeMsg *msg2 = new_message( RangeMsg);
      msg2->Low = Mid; msg2->High = H;
      msg1->High = Mid-1;
      new_chare(PrimesChare, Goal, msg1);
      new_chare(PrimesChare, Goal, msg2);
    }
    else {
      int count = seqPrimes(L,H);
      delete_message(msg1);
      total->Accumulate(count);
    }
    ChareExit();
  }
};
```

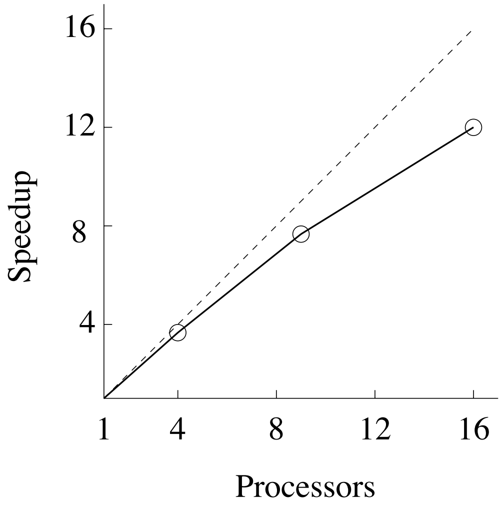
Implementation

1. Translator + Charm runtime system
2. Charm runtime ported to CM5, Paragon, nCUBE/2, networks of workstations, iPSC/860, Sequent, Multimax, uniprocessor
    - Others in future
    - See references for details
3. Translator produces C++ code and runtime interface code
4. Remote function call requires encoding function names into ids which can be sent across processors
5. Complicated by separate compilation requirement
6. Solved using mapping generated at run time

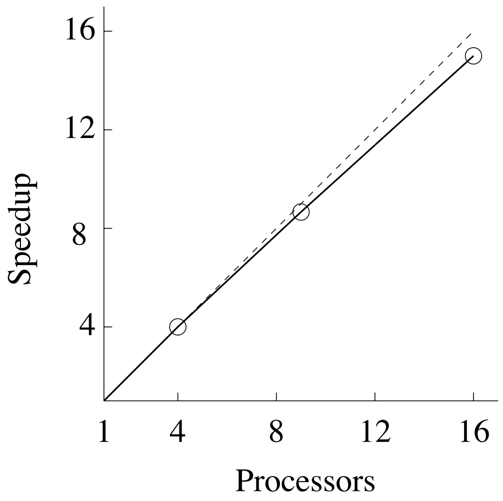
Current Status

1. First version completed in February
2. Second version now complete
    - full C++ parser
    - error recovery
    - some syntax changes
3. Currently running on CM5, nCUBE/2, networks of workstations

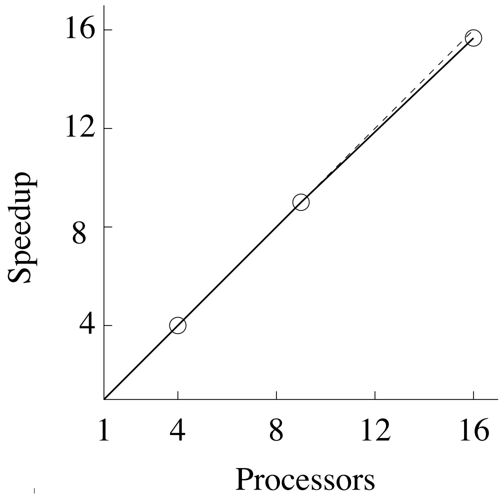
Performance : Sequent Symmetry



Jacobi

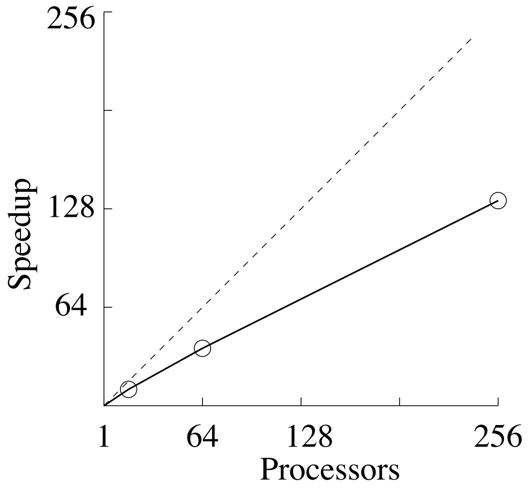


TSP



Primes

Performance : nCUBE/2



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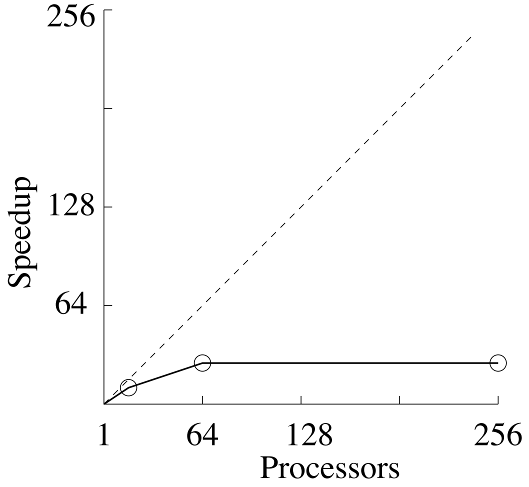

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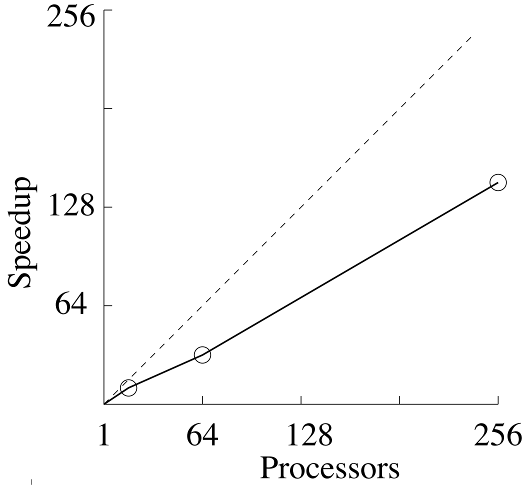

Primes

Projections slide

Related work

- Actors (Agha)
- CST (Dally)
- Concurrent Aggregates, Concert (Chien)
- ABCL (Yonezawa)
- pC++ (Gannon)
- CC++ (Chandy and Kesselman)
- Mentat (Grimshaw)
- ESP-C++ (from MCC)
- Amber (Chase et al)
- Many others

Distinguishing features of Charm++

1. Message driven execution
2. Information sharing abstractions
3. Dynamic load balancing
4. Support for irregular AND data-parallel applications
5. Clean separation : sequential and parallel objects
6. Runs on many commercial parallel machines
7. Does not require threads package

Future work

1. Further optimize runtime system
2. Integrate Charm and Charm++ programs
3. Combine with Dagger (a visual language for specifying dependences between messages and computations)
4. Libraries
5. Applications