Asynchronous Parallel Methods
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Overview

• What’s the problem?
• What is an asynchronous method?
• Reducing synchronisation in existing models
The Problem

• Synchronisations often essential for program correctness
  - waiting for an MPI receive to complete before reading from buffer
  - barriers at the end of an OpenMP parallel loop
  - ...

• But they cost time
  - and slow down the calculation

• Cost is usually not the synchronisation operation itself
  - it is waiting for other tasks to catch up with each other
  - all calculations have some load imbalance from random fluctuations
  - a real problem as we increase the number of cores

• Try to reduce synchronisation
  - and let things happen in their “natural” order
Reference

• See:
  - “The Case of the Missing Supercomputer Performance: Achieving Optimal Performance on the 8,192 Processors of ASCI Q”
  - Fabrizio Petrini, Darren J. Kerbyson, Scott Pakin
  - http://dx.doi.org/10.1145/1048935.1050204
  - “[W]hen you have eliminated the impossible, whatever remains, however improbable, must be the truth.”
  - Sherlock Holmes, *Sign of Four*, Sir Arthur Conan Doyle
An example

• “Although SAGE [the application] spends half of its time in allreduce (at 4,096 processors), making allreduce seven times faster leads to a negligible performance improvement.”

• Collectives an extreme example
  - point-to-point is also an issue
Collectives

• Reduce frequency of calculation by a factor $X$
  - e.g. trade more calculation for fewer synchronisations

  loop over iterations:
  update arrays;
  compute local delta;
  compute global delta using allreduce;
  stop if less than tolerance value;
end loop

• Possible because array updates independent of global values
  - may not be true for, e.g., Conjugate Gradient; can use different algorithms, e.g. Chebyshev iteration
  - again, more iterations but less synchronisation
Barriers

• (Almost) never required for MPI program correctness

• Why?
  - because collectives do the appropriate synchronisation
  - because MPI_Recv is synchronous
Normal halo swapping

swap data into 4 halos: \(i=0, \ i=M+1, \ j=0, \ j=M+1\)

loop \(i=1:M; \ j=1:N;\)

\[
\text{new}(i,j) = 0.25*( \ \text{old}(i-1,j) + \text{old}(i+1,j) \\
+ \text{old}(i,j-1) + \text{old}(i,j+1) \\
- \text{edge}(i,j) )
\]
Point-to-point

• Do not impose unnecessary ordering of messages

- loop now just counts the correct number of messages

loop over sources:
  receive value from particular source;
end loop

loop over sources:
  receive value from any source;
end loop

• Alternative
  - first issue a separate non-blocking receive for each source
  - then issue a single Waitall
Halo swapping

- Do not impose unnecessary ordering of messages

loop over directions:
  send up; recv down;
  send down; recv up;
end loop

loop over directions:
  isend up; irecv down;
  isend down; irecv up;
end loop
wait on all requests;

- Extensions
  - can now overlap communications with core calculation
  - only need to wait for receives before non-core calculation
  - wait for sends to complete before starting next core calculation
Overlapping

start non-blocking sends/recvs
loop i=2:M-1; j=2:N-1;
    new(i,j) = 0.25*( old(i-1,j) + old(i+1,j) 
    + old(i,j-1) + old(i,j+1) 
    - edge(i,j) )
wait for completion of non-blocking sends/recvs
complete calculation at the four edges
Halos of Depth $D$ every $D$ iterations

- Smaller number of larger messages; increased computation

$$\text{loop } d=D:1:-1$$
$$\text{loop } i=2-d:M+d-1; j=2-d:N+d-1;$$
$$\text{new}(i,j) = 0.25*( \text{old}(i-1,j) + \text{old}(i+1,j)$$
$$+ \text{old}(i,j-1) + \text{old}(i,j+1)$$
$$- \text{edge}(i,j) )$$
Swap depth $D$ every $D$ iterations

- Need diagonal communications
Implementation

• Do 8 non-blocking sends and 8 non-blocking receives
  - as opposed to only 4 for depth=1
  - ... or 26 vs 6 for three dimensions
  - when we wanted to send fewer messages!

• Can “carry” halos rather than explicit diagonal comms
  - ordered swaps: left/right after up/down ... 
  - – ... but introduces more synchronisation

• Quite hard to implement in practice
  - $D=1$ is (thankfully) special case for 5-point stencil with no diagonals
Persistent communications

• Standard method: run this code every iteration
  
  ```c
  MPI_Irecv(..., procup, ..., &reqs[0]);
  MPI_Irecv(..., procdn, ..., &reqs[1]);
  MPI_Isend(..., procdn, ..., &reqs[2]);
  MPI_Isend(..., procup, ..., &reqs[3]);
  MPI_Waitall(4, reqs, statuses);
  ```

• Persistent comms: setup once
  
  ```c
  MPI_Recv_init(..., procup, ..., &reqs[0]);
  MPI_Recv_init(..., procdn, ..., &reqs[1]);
  MPI_Send_init(..., procdn, ..., &reqs[2]);
  MPI_Send_init(..., procup, ..., &reqs[3]);
  ```

• Every iteration:
  
  ```c
  MPI_Startall(4, reqs);
  MPI_Waitall(4, reqs, statuses);
  ```

• Message ordering not guaranteed to be preserved