On the Evolution of Communication in Parallel Systems

Marc Snir

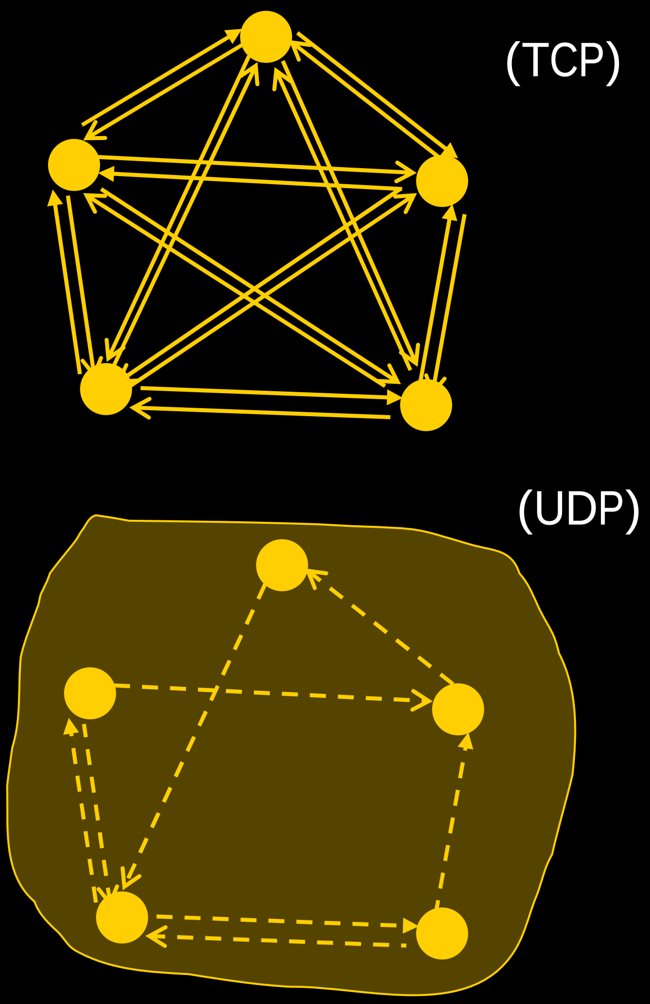
September 05

Focus of talk

- How do parallel programs express communication?
- Does this provide the communication hardware performance to the application?
- Does this fit application communication patterns?

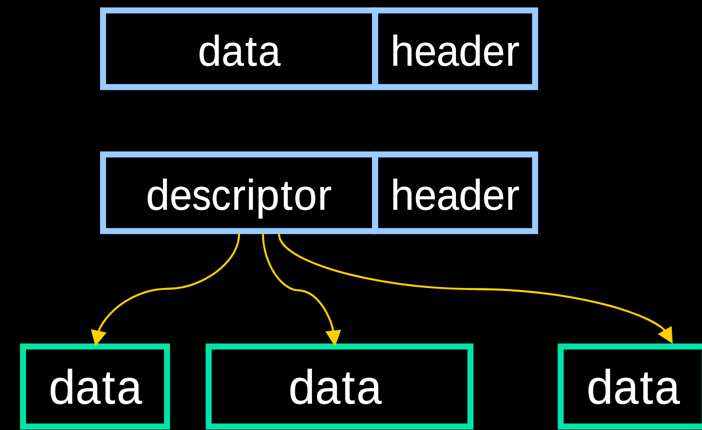
60 second tutorial on communication protocols

- Reliable vs. unreliable
  - need reliable
- User space vs. kernel space
  - parallel computing communication works better with user space
- Connection-oriented vs. connectionless
  - connection oriented does not scale well
  - connectionless needs congestion control
    - Less of a problem for parallel computing (?)

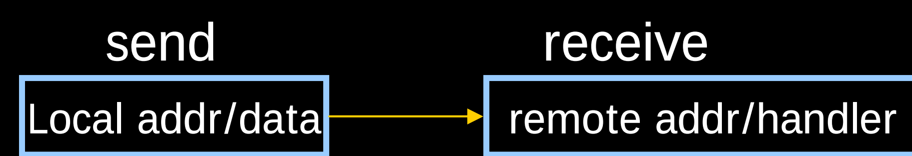


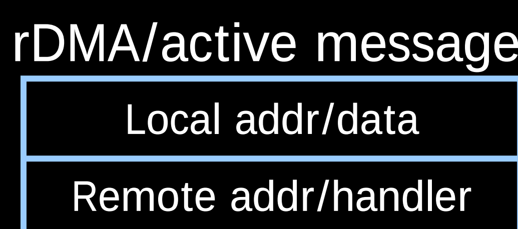
60 seconds advanced tutorial on communication protocols

- Immediate data vs. Buffer descriptor
  - scatter/gather – how general?



- Two-sided vs. one-sided
  - send-recv: need matching engine
  - one sided: need smart comm coprocessor

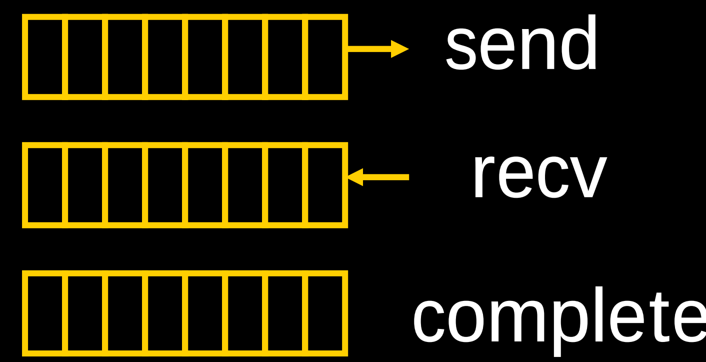




Get (read)
Put (write)
Read-Modify-Write

Example: Infiniband

- Everything but the kitchen sink:
  - Reliable or unreliable
  - User space (or kernel)
  - Connectionless or connection-oriented
  - 2-sided or 1-sided
  - Immediate data or buffer descriptor
- 2507 pages standard
  - but no standard sw binding…
- Caveat: products do support only part of the standard
  - Usually not the parts needed for HPC…



- Send commands (1 or 2 sided) queued in send queue
- Recv commands (for 2 sided comm) queued in recv queue
- Sends matched to receives in FIFO order
- Entry posted in complete queue once command is consumed

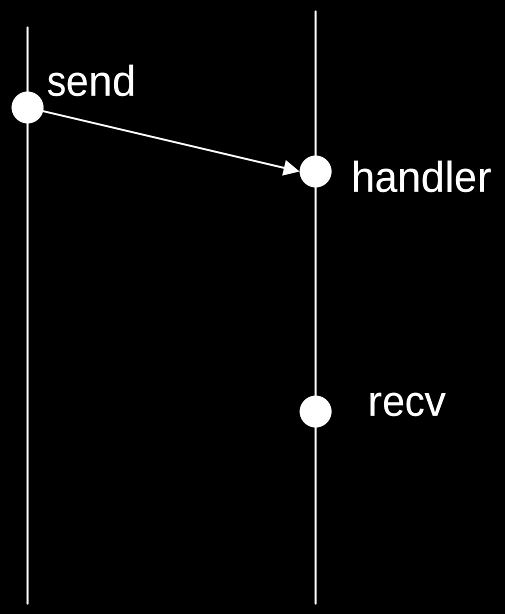
MPI (1)

- Does MPI provide to parallel application the performance potential of Infiniband (or Quadrics, or Myricom, or...)?
- Does MPI express well common communication patterns?

MPI Performance

Why does MPI need > 1,000 instructions to transfer a byte from one processor to another?

"Best case"



Short message protocol: eager protocol

- Not one reason: death by one thousands cuts;
  - the cost of generality

Where does the time go (send)

- MPI_SEND(buf, count, datatype, dest, tag, comm)
  - Check and interpret six parameters
  - Check for MPI_PROC_NULL
  - Check if data buffer is contiguous
  - Check for self-loop
  - Pick communication protocol according to message length
  - Allocate communication object
  - Initialize communication object
  - Invoke lower layer to push message (pass comm object)
  - Wait for lower layer completion
  - Free communication object

Where does the time go (handler)

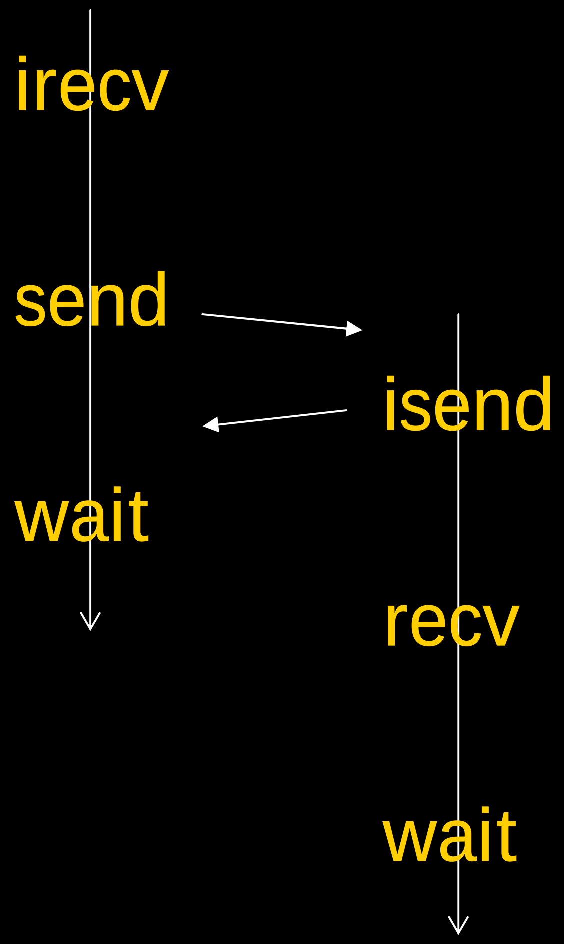
- Polling handler
  - invoke lower layer (pull message)
  - wait for lower layer completion
  - Unpack header
  - If "eager send" then
    - Search queue of premature receives (linear search, 3 comparisons per item)
    - If not found then
      - allocate premature send object
      - initialize premature send object
      - enqueue in premature send queue

Where does the time go (recv)

- MPI_RECV(buf, count, datatype, dest, tag, comm, status)
  - Check and interpret seven parameters
  - Check for MPI_PROC_NULL
  - Check if data buffer is contiguous
  - Search queue of premature sends (linear search, 3 comparisons per item)
  - In found then
    - Dequeue object
    - Copy data to receive buffer
    - Set status object
    - Free object
    - Return

More complexities

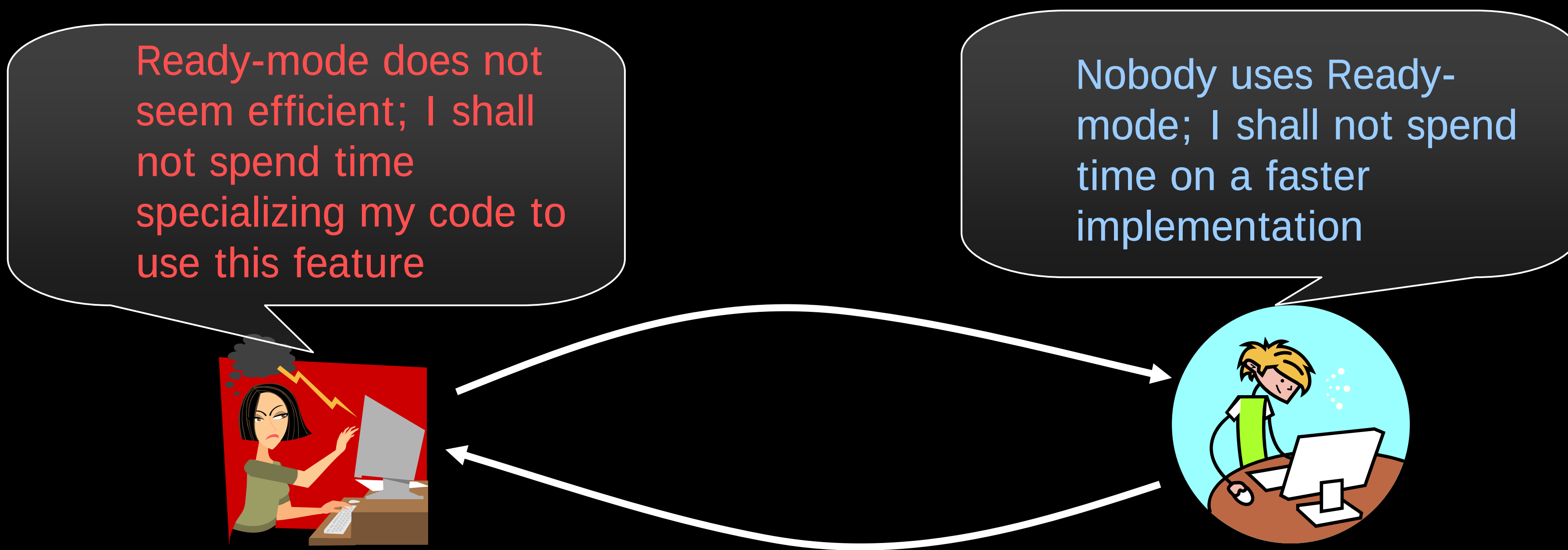
- Locks, to ensure thread safety
- Side calls to polling handler to ensure progress
  - tradeoff on polling frequency
  - potential problem of endless recursion (in MPICH)
- MPI_CANCEL
- …



MPI1 approach to performance

- Provide special case calls with lower overhead
  - Example: ready-mode send
    - can use eager send protocol for long messages (avoids one round-trip and two handler invocations)
  - Redefined as standard-mode send in MPICH

The classical vicious circle



MPI1 approach to performance (2)

- Example: persistent communication request
  - MPI_SEND_INIT, MPI_RECV_INIT, MPI_START
  - Saves the need to check and decode long parameter list
  - Can be (almost) used to create a channel and eliminate almost all MPI overhead (e.g., with Infiniband)

  - Need to ensure that other receives cannot match the persistent send
  - Need ready-mode, rather than standard mode

The classical screw-up

If we must speed-up MPI1…

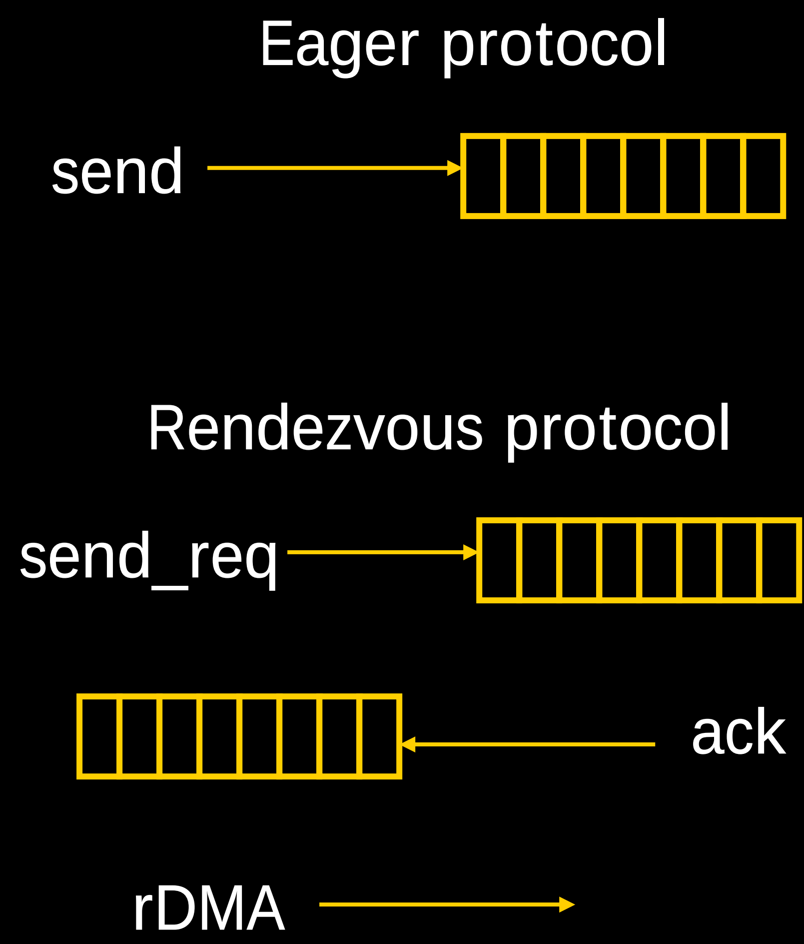
- Shift some/all of MPI library code to communication co-processor
  - move queues management, matching and handling of unexpected sends to co-processor
    - Myrinet, Quadrics, Blue Gene\L (*)
    - offload main processor
    - saves context switches
    - use more specialized hw (network processor) and sw
- but NIC's are often behind main processor in raw speed

If we must speed-up MPI1 (2)

- Specialize and tune MPI code via preprocessor/compiler (or library designer if communication layer is encapsulated in library)
  - break the vicious circle...
- Need:
  - Local analysis (to inline, avoid parameter checking, preallocate objects...)
  - Global analysis (e.g., to replace standard mode with ready mode)
  - Recommended restricted programming style that avoids the “curse of generality”?
    - no premature sends, no dontcares...
  - Lower level, exposed communication layer

What should be this lower layer?

- Need two things:
  - Simple reliable datagram service
    - connectionless messaging
    - short messages received in strict arrival order
  - RDMA – remote put



- Strategy used for MPI on T3E (EPCC), Infiniband (Ohio), etc.
- Can achieve x4 reduction in sw overhead (IBM 96)
- Usually need to “fake” datagram service.
- Need to virtualize, for effective support of migration and load balancing

Should one directly use rDMA?

- Communication:
  - matches src id, src addr, dest id, dest addr
- Send-recv:
  - source provides dest id, src addr; destination provides src id, dest addr; each side decides when transfer can occur on its side
- Put:
  - source provides all parameters and decides when transfer can occur on both sides
- Put can be used, rather than send-recv whenever
  - association of src address to dest address is persistent
  - synchronization is global and separated from communication
  - This is a very frequent scenario!

MPI2 One-sided

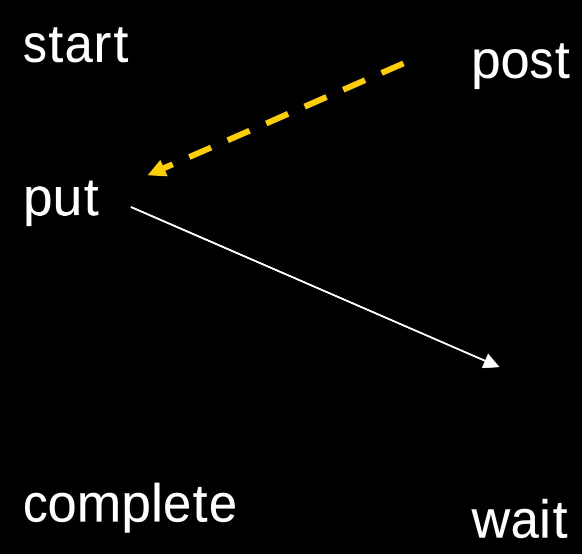
- Aimed at exploiting rDMA within MPI
  - PUT, GET, ACCUMULATE (similar to shmem)
  - Consistent with MPI syntax and semantics
- Often seems much slower than SHMEM on systems that have hardware supported rDMA [Luecke, Spanoyannis, Kraeva 2004]
  - up to x300 difference!

Issues with MPI2 one-sided

- Some difference due to more general interface
  - MPI_PUT(origin_addr, origin_count, origin_datatype, target_rank, target_disp, target_count, target_datatype, win)
  - shmem_X_put(target, source, len, pe)
  - could be avoided by preprocessing?
- Some (most?) difference due to lax implementation and obscurity of standard

Apparent inefficiency of MPI2 one-sided

- MPI2 requires that data not be put in remote memory before "post" executes
  - additional handshake (global barrier or rendezvous)
- Shmem moves this responsibility to the user
- MPI2 provides an option to bypass check (MPI_MODE_NOCHECK)
  - not used in paper comparing MPI2 to shmem!
  - either not implemented or not understood



Real MPI2 one-sided issues

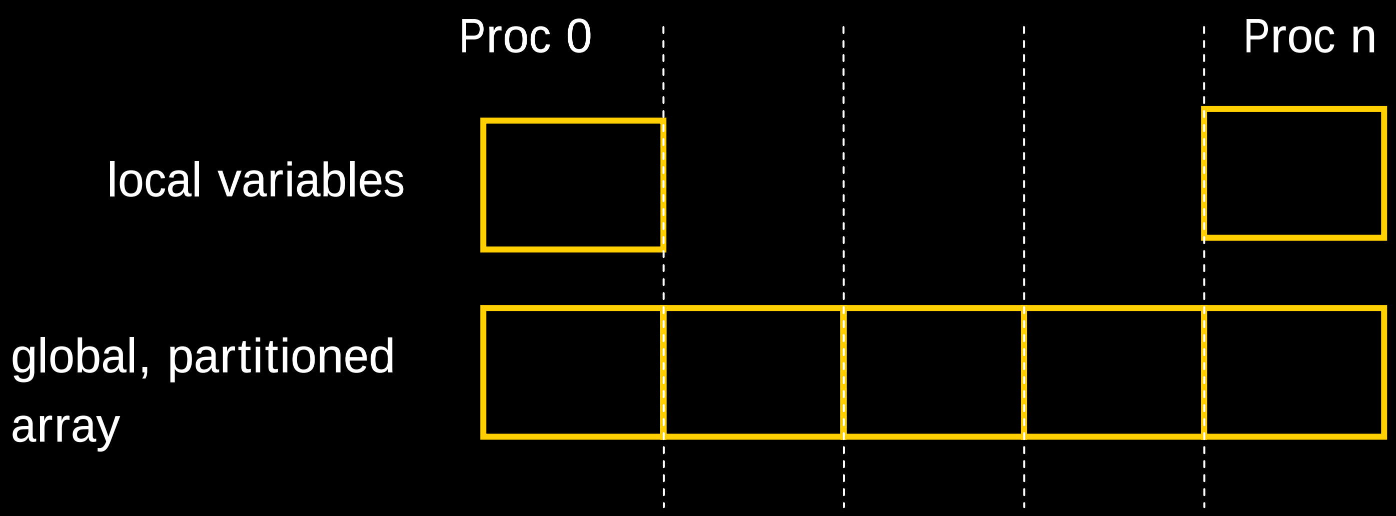
- Too complicated (hard to understand)
- No real fence call (MPI2 fence is a barrier)
- No yet implemented well
- Tried to accommodate too many requirements!
- Time to reconsider?
  - change default to MPI_MODE_NOCHECK – shift handshake to user code
  - provide true fence
  - restrict and simplify

Should communication be encapsulated in a library?

- ✓ A compiler can do many of the optimizations we mentioned
- ✗ Parallel languages have a bad reputation
  - Shared memory languages (e.g. OpenMP) perform badly on clusters
    - do not provide user control of communication
  - Distributed memory languages (e.g. HPF) never matured
    - HPF1 was to restrictive, HPF2 never happened
- Latest attempt: Partitioned Global Address Space (PGAS)
  - UPC, CAF, Titanium

PGAS Languages

- Fixed number of processes, each with one thread of control
- Global partitioned arrays that can be accessed by all processes
  - Global arrays are syntactically distinct
    - compiler generates communication code for each access
- Limited number of global synchronization calls



Co-Array Fortran

- Global array ≡ one extra dimension
  - integer a[*] - one copy of a on each process
  - real b(10)[*] - one copy of b(10) on each process
  - real c(10)[3,*] – one copy of c(10) on each process; processes indexed as 2D array
- SPMD
  - code executed by each process independently
  - communication by accesses to global arrays
  - split barrier synchronization

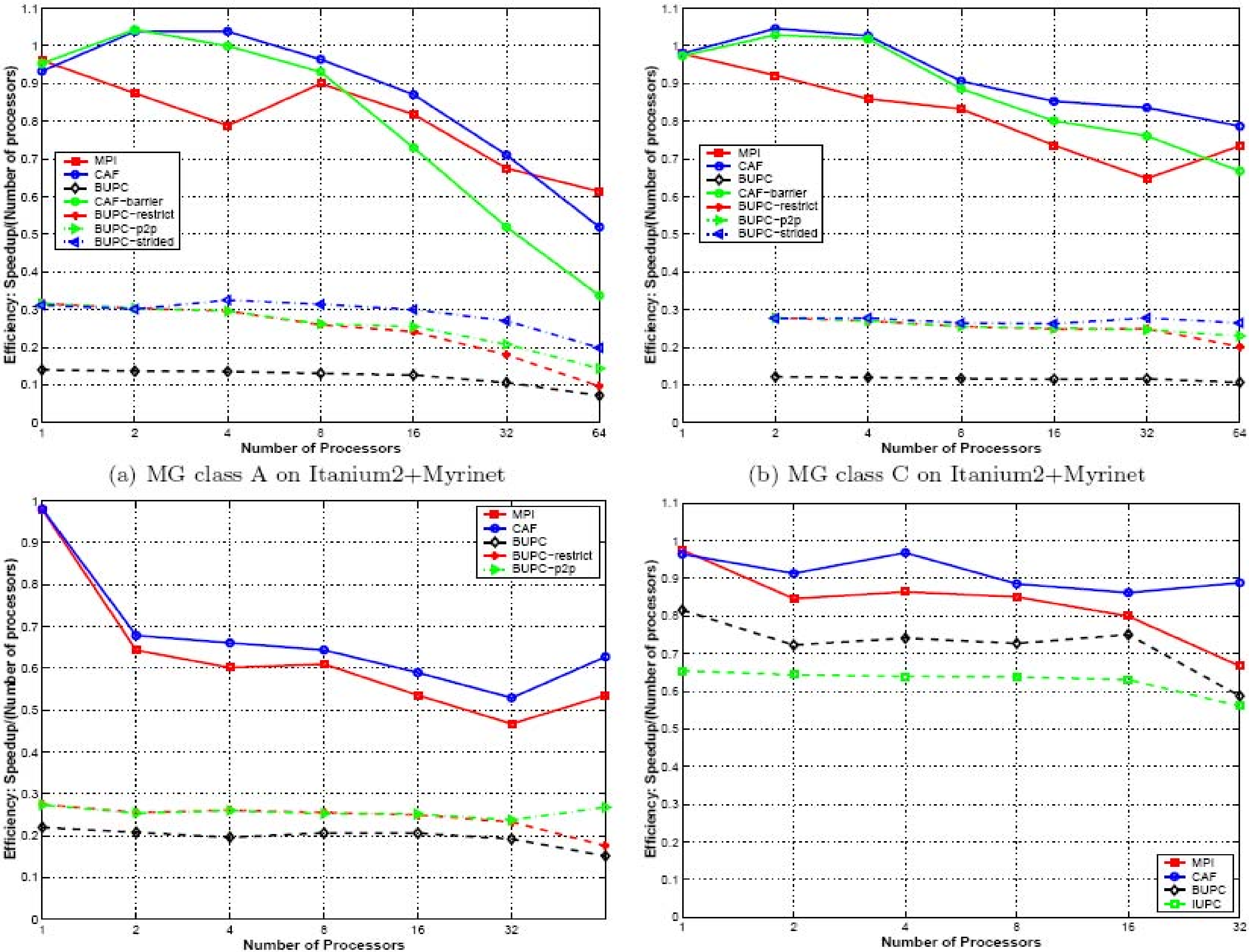
notify_team(team)   sync_team(team)

Unified Parallel C

- (Static) global array is declared with qualifier shared
  - shared int q[100] – array of size 100 distributed round-robin
  - shared [*] int q[100] – block distribution
  - shared [3] int q[100] – block-cyclic distribution
  - shared int* q – local pointer to shared
- SPMD model
  - code executed by each process independently
  - communication by accesses to global arrays
    - global barrier or global split barrier
    - upc_barrier, upc_notify, upc_wait
  - simple upc_forall: each iteration is executed on process specified by affinity expression

Not too far from message-passing

- MPI Fortran (resp. C) code with encapsulated communication layer can be recoded into CAF (resp. UPC) by recoding communication layer only
- Such code can achieve similar or better performance than MPI on NAS kernels [Coarfa, Dotsenko, Mellor-Crummey, Cantonnet, El-Ghazawi, Mohanti, Yao, Chavarria-Miranda, PPoPP June 05]



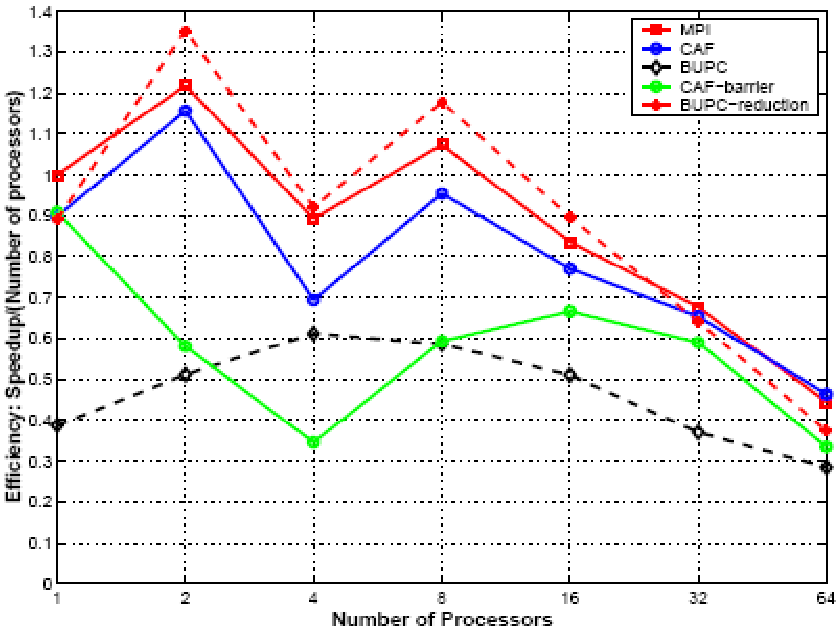
(a) MG class A on Itanium2+Myrinet

(b) MG class C on Itanium2+Myrinet

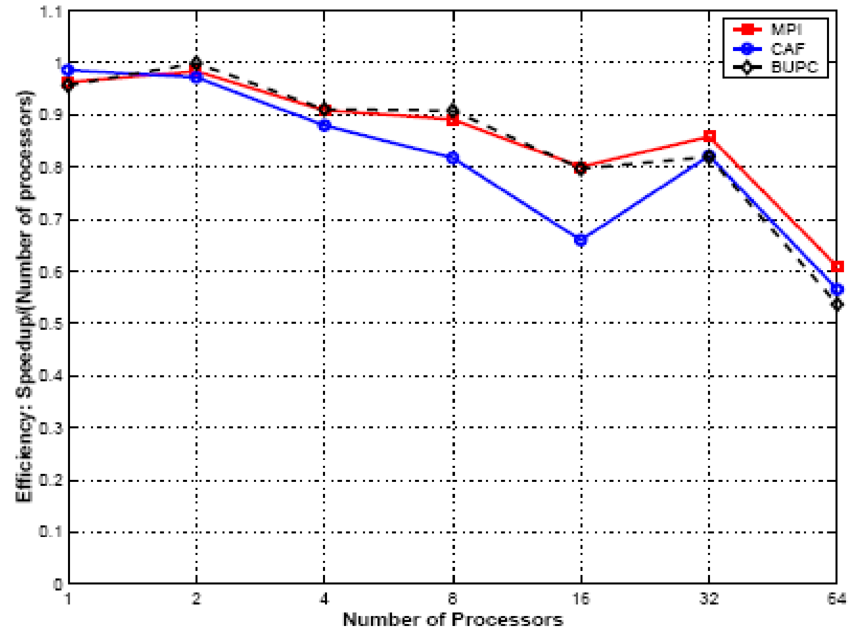
(c) MG class B on Altix 3000

(d) MG class B on Origin 2000

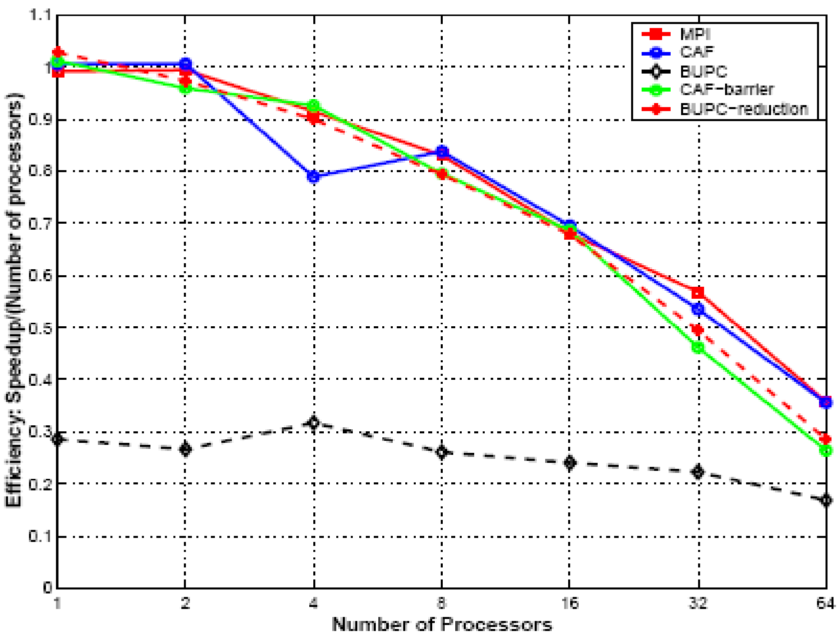
PPoPP05



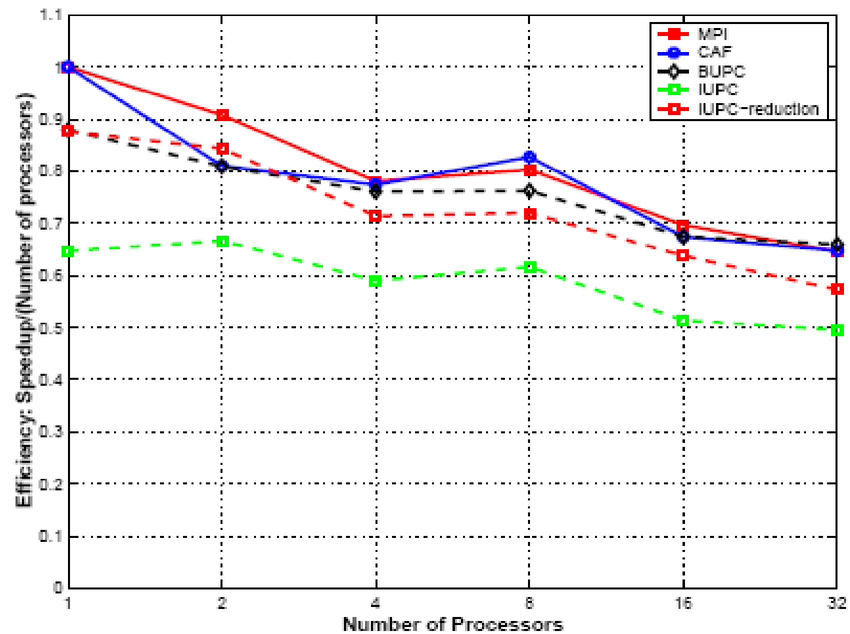
(a) CG class C on Itanium2+Myrinet



(b) CG class B on Alpha+Quadrics

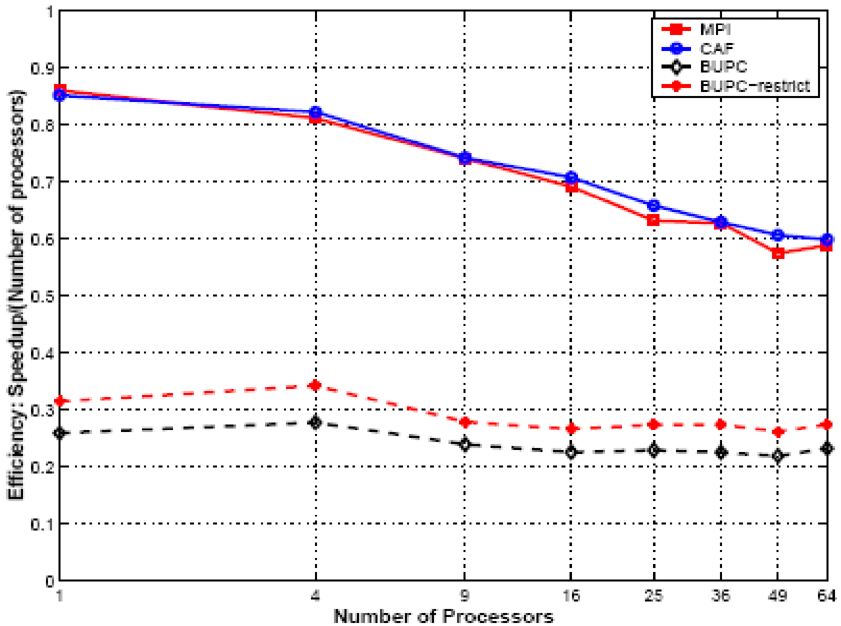


(c) CG class C on Altix 3000

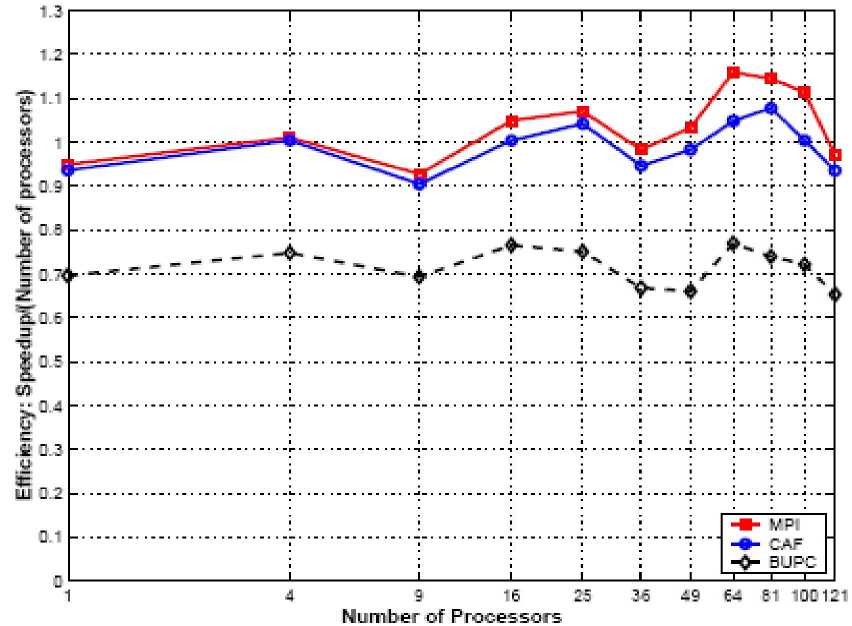


(d) CG class B on Origin 2000

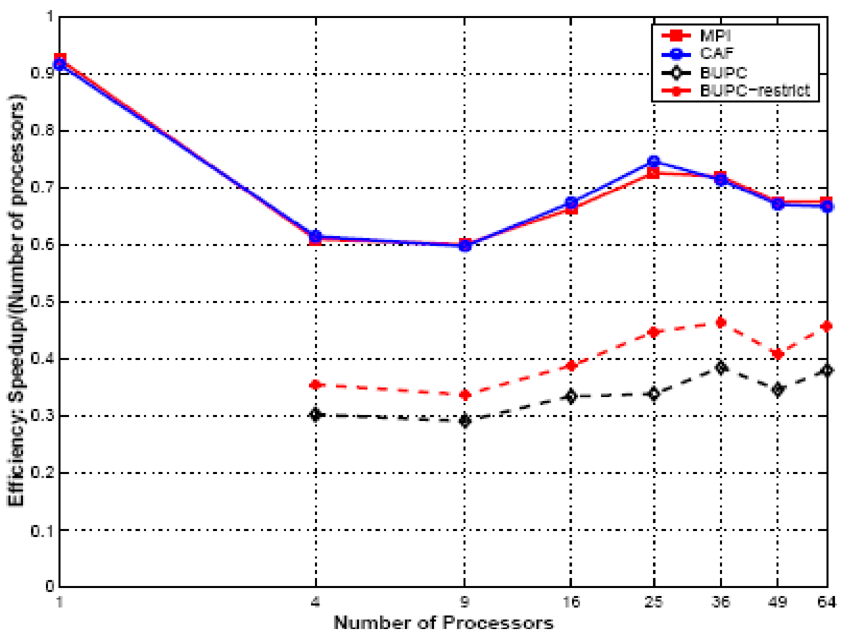
PPoPP05



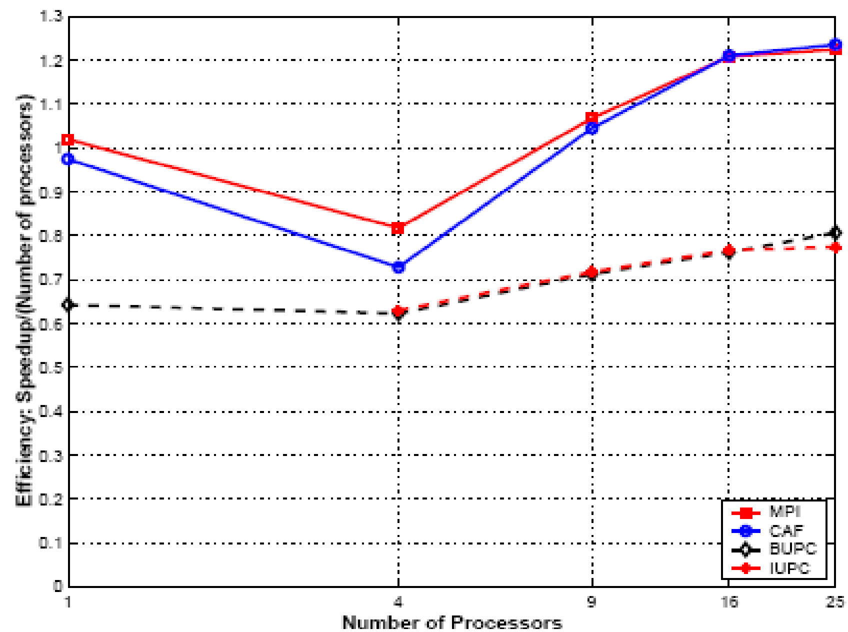
(b) SP class C on Itanium2+Myrinet



(a) SP class C on Alpha+Quadrics

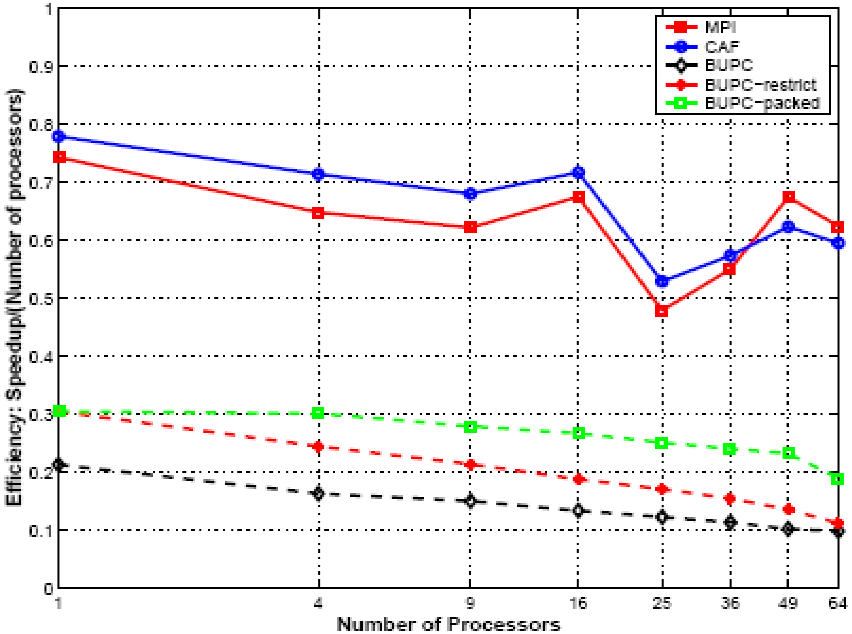


(c) SP class C on Altix 3000

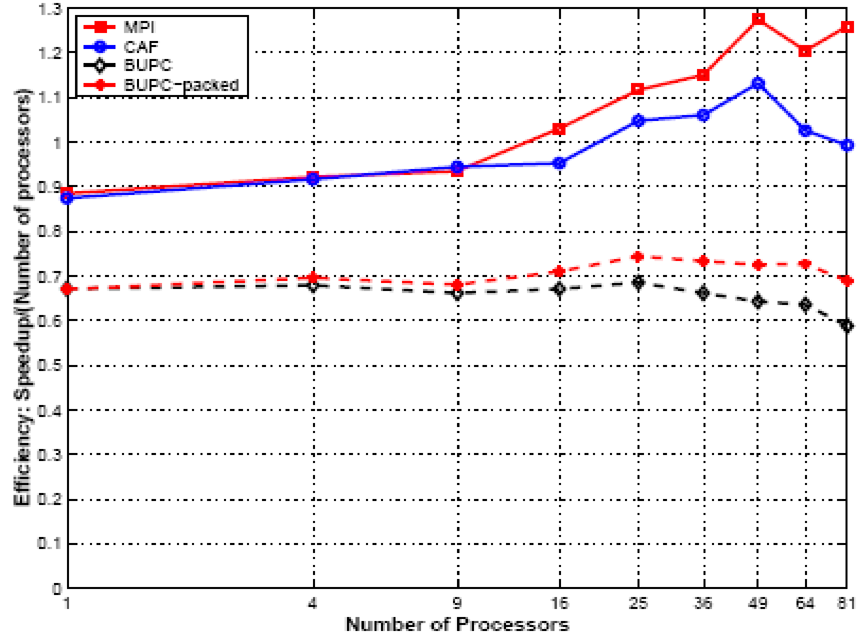


(d) SP class B on Origin 2000

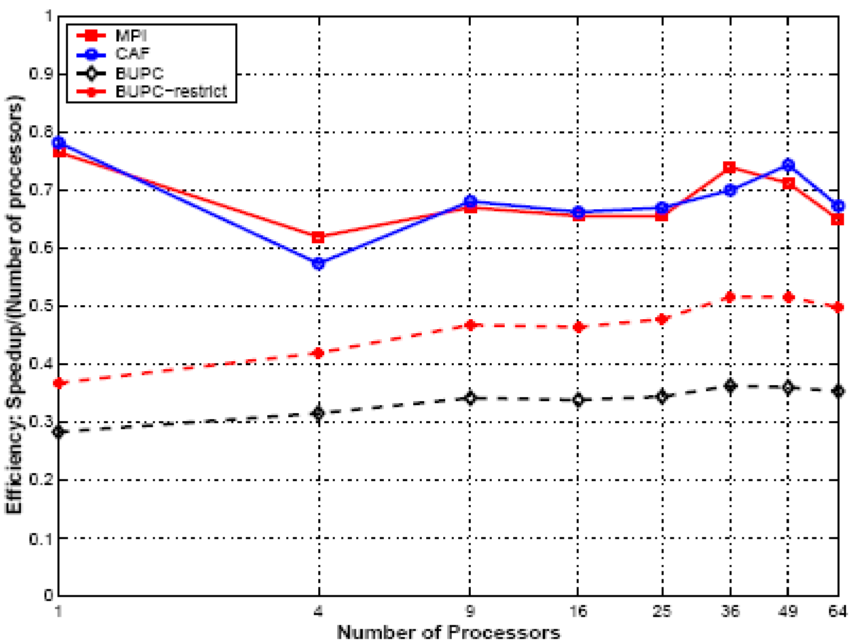
PPoPP05



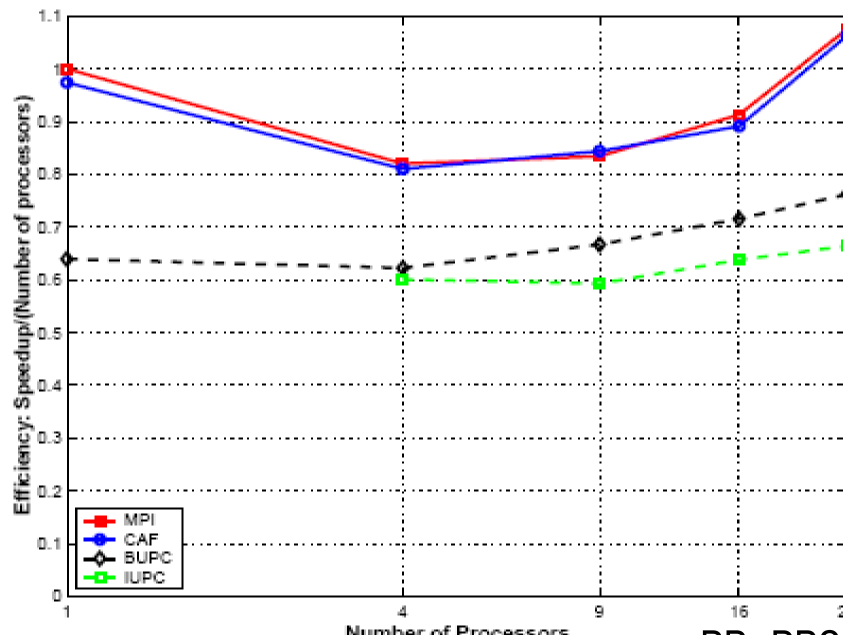
(a) BT class C on Itanium2+Myrinet



(b) BT class B on Alpha+Quadrics



(c) BT class B on Altix 3000



(d) BT class A on Origin 2000

PPoPP05

Will MPI be replaced by PGAS languages?

- There is still work to be done
  - Simple to fix issues:
    - F90 array notation allows for bulk transfer, but UPC misses such notation
    - global synchronization too restrictive
    - compiler optimizations of communication not very sophisticated
      - communication coalescing, split-phase communication,...
  - More significant issues:
    - Not obvious what happens with more dynamic, irregular codes
    - Both CAF and UPC need better encapsulation
      - support for “communicators” (they only have “MPI_COMM_WORLD”)
      - support for OO

Meantime DARPA is forging ahead…

- High Productivity Computing Systems program: Cray, IBM, Sun
- Chapel, X10, Fortress
  - Chapel: distributions (HPF) + control parallelism and atomic transactions (multithreading) + OO + generic programming
  - X10: Java + cluster memory model + remote asynchronous invocations + clocks + atomic blocks
  - Fortress: focus on abstraction & type inference
- Several more years of research are needed
- No concrete plans for convergence yet
- No portability/compatibility solutions
- Economic model is not obvious

Summary

- We can extract better performance from MPI
- We can fix MPI2, esp. one-sided, to improve usability
- PGAS languages are not yet ready for prime-time, but could get there in a few years
  - will improve performance, but will not significantly change programming model
- The HPCS languages could be a significant game changer
  - but will not happen for a while

?