A Preliminary Performance Comparison of Chapel to MPI and MPI/ OpenMP

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CHIUW 2015, Portland, OR

13 June 2015

Overview

- Background/Motivation
- Methodology
- Coding
- Results
- Conclusions
- Work Left To Do
- Acknowledgements

Background/Motivation

- As the DoD HPC community works towards petascale and exascale computing, we face several challenges as users scale codes to larger core counts
  - Inefficient programming techniques
  - Inefficient memory utilization
  - Increased communication overhead
- We are exploring Chapel, along with other HPCS and PGAS languages, to determine
  - Does this parallel language have the potential capability to perform more efficiently than (or at least as well as) MPI or MPI/OpenMP as core counts increase?
  - Does this parallel language have the potential to be adopted by the HPCMP user community?

Methodology

- Translate a small, practical program into Chapel
  - Iterative Conjugate gradient using diagonal sparse matrix storage format
  - Originally written in Fortran
- Execute at 6 different processor counts…
  - 4 nodes/128 cores
  - 16 nodes/512 cores
  - 32 nodes/1024 cores
  - 64 nodes/2048 cores
  - 128 nodes/4096 cores
  - 256 nodes/8192 cores
- … with 4 different matrix problem sizes
  - 150 x 150
  - 1000 x 1000
  - 10000 x 10000
  - 20000 x 20000
- Compare results with observed performance of existing versions
  - Serial
  - MPI with 1-D decomposition
  - MPI/OpenMP with 1-D decomposition

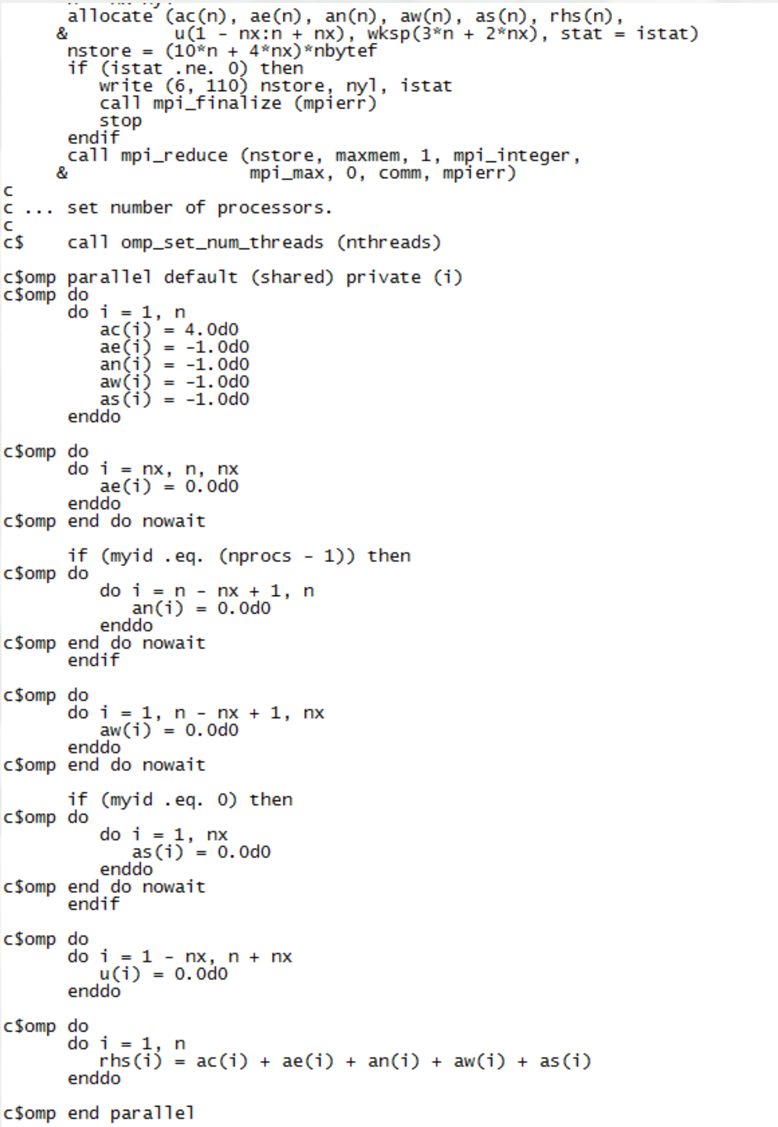
Methodology

- All runs were performed on GARNET at ERDC DSRC in Vicksburg, MS
  - Cray XE6
  - 2 16-core 2.5 GHz AMD Interlagos chips per node (32 procs/node)
    - 2 GB memory per core (64 GB per node)
  - Gemini interconnect
  - Cray Compiler Environment
  - Chapel version 1.10.0

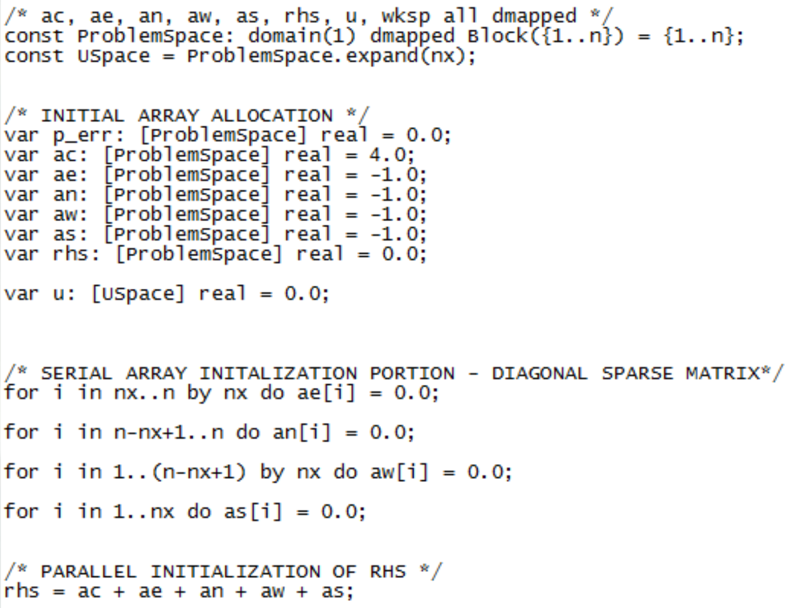
Coding

- MPI-style domain decomposition replaced with a single `dmapped` distributed array for each array of coefficients
  - ► All distributed arrays declared over the same domain

Coding



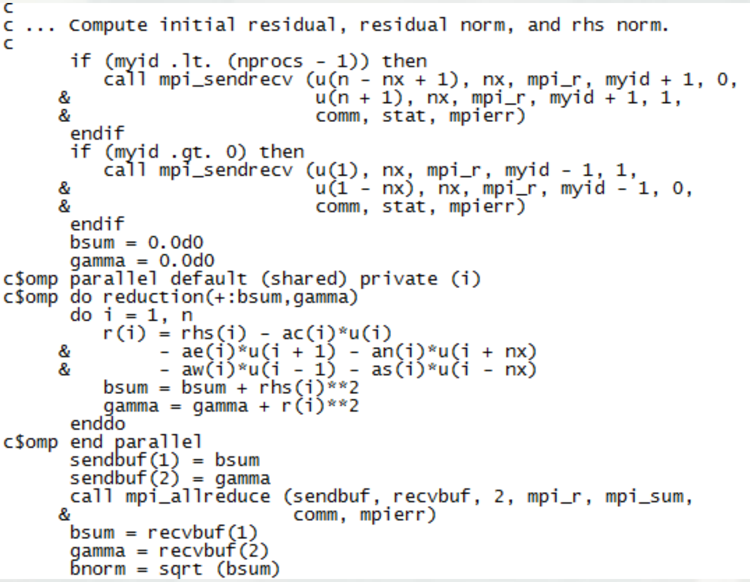
```
      allocate (ac(n), ae(n), an(n), aw(n), as(n), rhs(n),
     &          u(1 - nx:n + nx), wksp(3*n + 2*nx), stat = istat)
      nstore = (10*n + 4*nx)*nbytef
      if (istat .ne. 0) then
         write (6, 110) nstore, nyl, istat
         call mpi_finalize (mpierr)
         stop
      endif
      call mpi_reduce (nstore, maxmem, 1, mpi_integer,
     &                 mpi_max, 0, comm, mpierr)
c
c ... set number of processors.
c
c$    call omp_set_num_threads (nthreads)

c$omp parallel default (shared) private (i)
c$omp do
      do i = 1, n
         ac(i) = 4.0d0
         ae(i) = -1.0d0
         an(i) = -1.0d0
         aw(i) = -1.0d0
         as(i) = -1.0d0
      enddo

c$omp do
      do i = nx, n, nx
         ae(i) = 0.0d0
      enddo
c$omp end do nowait

      if (myid .eq. (nprocs - 1)) then
c$omp do
         do i = n - nx + 1, n
            an(i) = 0.0d0
         enddo
c$omp end do nowait
      endif

c$omp do
      do i = 1, n - nx + 1, nx
         aw(i) = 0.0d0
      enddo
c$omp end do nowait

      if (myid .eq. 0) then
c$omp do
         do i = 1, nx
            as(i) = 0.0d0
         enddo
c$omp end do nowait
      endif

c$omp do
      do i = 1 - nx, n + nx
         u(i) = 0.0d0
      enddo

c$omp do
      do i = 1, n
         rhs(i) = ac(i) + ae(i) + an(i) + aw(i) + as(i)
      enddo

c$omp end parallel
```



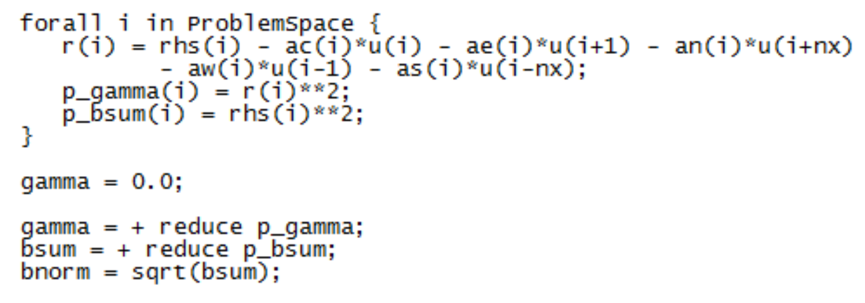
```
/* ac, ae, an, aw, as, rhs, u, wksp all dmapped */
const ProblemSpace: domain(1) dmapped Block({1..n}) = {1..n};
const USpace = ProblemSpace.expand(nx);


/* INITIAL ARRAY ALLOCATION */
var p_err: [ProblemSpace] real = 0.0;
var ac: [ProblemSpace] real = 4.0;
var ae: [ProblemSpace] real = -1.0;
var an: [ProblemSpace] real = -1.0;
var aw: [ProblemSpace] real = -1.0;
var as: [ProblemSpace] real = -1.0;
var rhs: [ProblemSpace] real = 0.0;

var u: [USpace] real = 0.0;



/* SERIAL ARRAY INITALIZATION PORTION - DIAGONAL SPARSE MATRIX*/
for i in nx..n by nx do ae[i] = 0.0;

for i in n-nx+1..n do an[i] = 0.0;

for i in 1..(n-nx+1) by nx do aw[i] = 0.0;

for i in 1..nx do as[i] = 0.0;


/* PARALLEL INITIALIZATION OF RHS */
rhs = ac + ae + an + aw + as;
```

Coding

- Concurrency handled via `forall` loops



```
c
c ... Compute initial residual, residual norm, and rhs norm.
c
      if (myid .lt. (nprocs - 1)) then
         call mpi_sendrecv (u(n - nx + 1), nx, mpi_r, myid + 1, 0,
     &                      u(n + 1), nx, mpi_r, myid + 1, 1,
     &                      comm, stat, mpierr)
      endif
      if (myid .gt. 0) then
         call mpi_sendrecv (u(1), nx, mpi_r, myid - 1, 1,
     &                      u(1 - nx), nx, mpi_r, myid - 1, 0,
     &                      comm, stat, mpierr)
      endif
      bsum = 0.0d0
      gamma = 0.0d0
c$omp parallel default (shared) private (i)
c$omp do reduction(+:bsum,gamma)
      do i = 1, n
         r(i) = rhs(i) - ac(i)*u(i)
     &        - ae(i)*u(i + 1) - an(i)*u(i + nx)
     &        - aw(i)*u(i - 1) - as(i)*u(i - nx)
         bsum = bsum + rhs(i)**2
         gamma = gamma + r(i)**2
      enddo
c$omp end parallel
      sendbuf(1) = bsum
      sendbuf(2) = gamma
      call mpi_allreduce (sendbuf, recvbuf, 2, mpi_r, mpi_sum,
     &                    comm, mpierr)
      bsum = recvbuf(1)
      gamma = recvbuf(2)
      bnorm = sqrt (bsum)
```

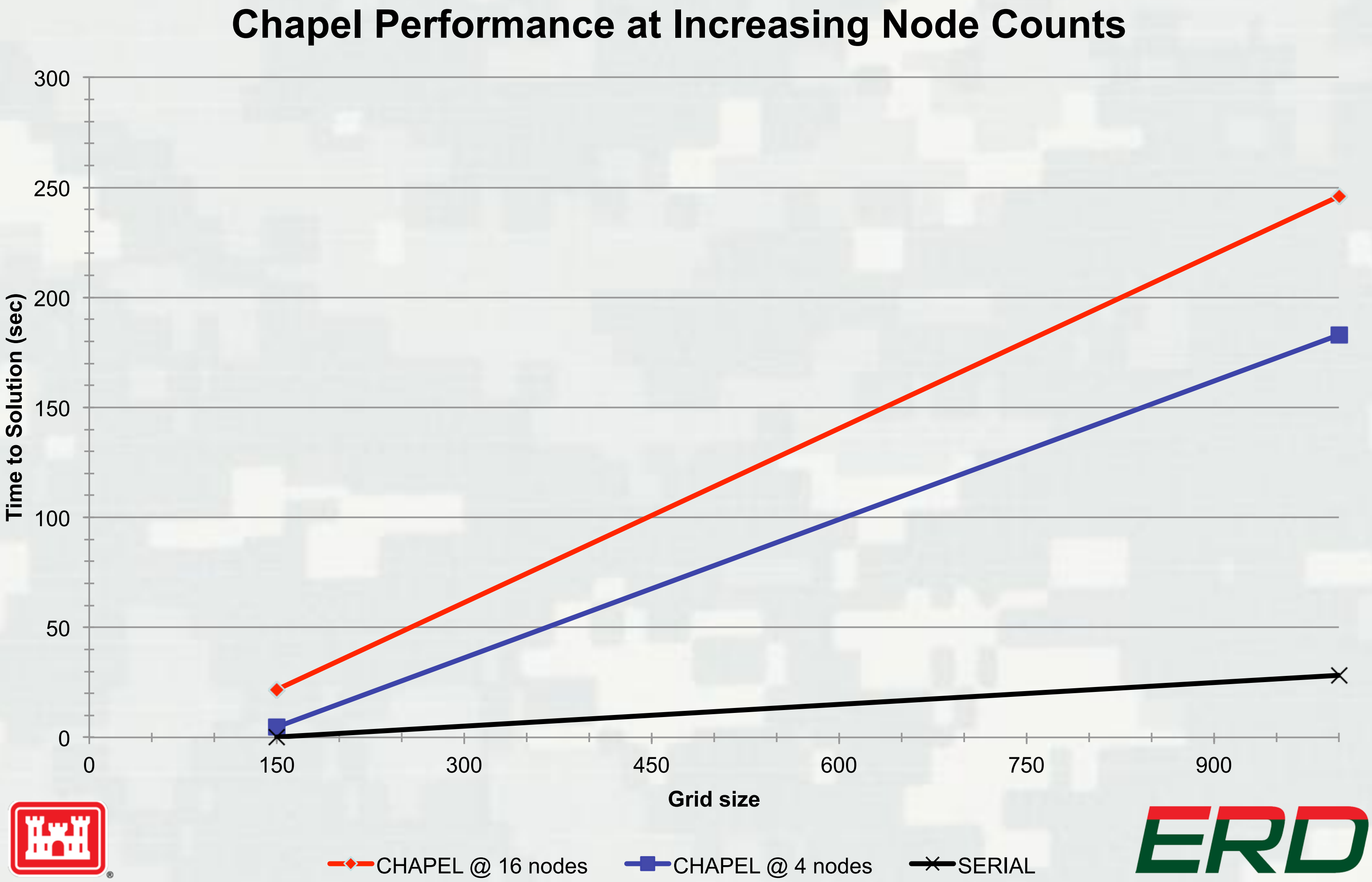


```
forall i in ProblemSpace {
   r(i) = rhs(i) - ac(i)*u(i) - ae(i)*u(i+1) - an(i)*u(i+nx)
          - aw(i)*u(i-1) - as(i)*u(i-nx);
   p_gamma(i) = r(i)**2;
   p_bsum(i) = rhs(i)**2;
}

gamma = 0.0;

gamma = + reduce p_gamma;
bsum = + reduce p_bsum;
bnorm = sqrt(bsum);
```

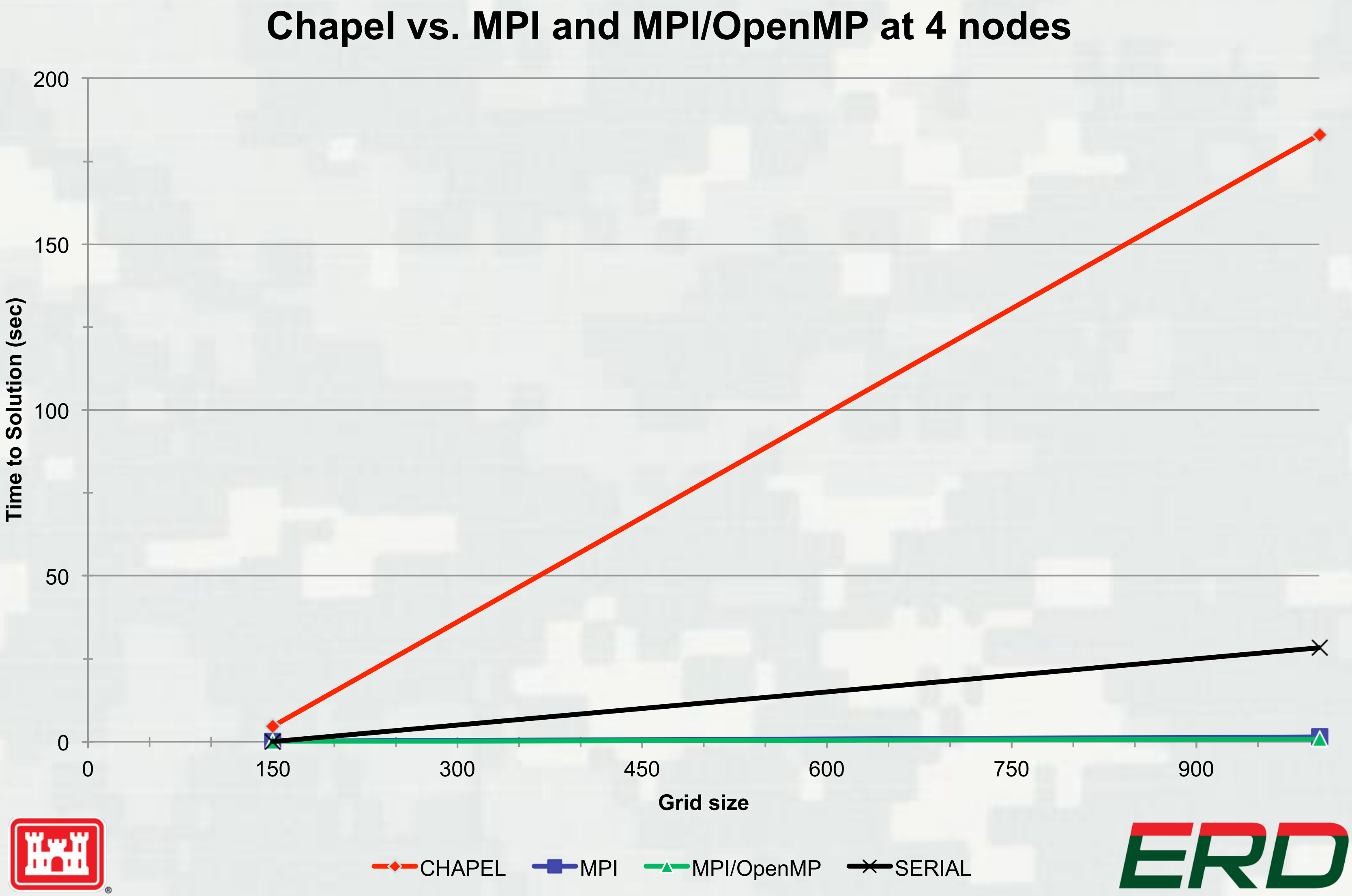
Results

- Size of each implementation
  - Serial: 394 LOC
  - MPI: 492 LOC
  - MPI/OpenMP: 525 LOC
  - Chapel: 256 LOC

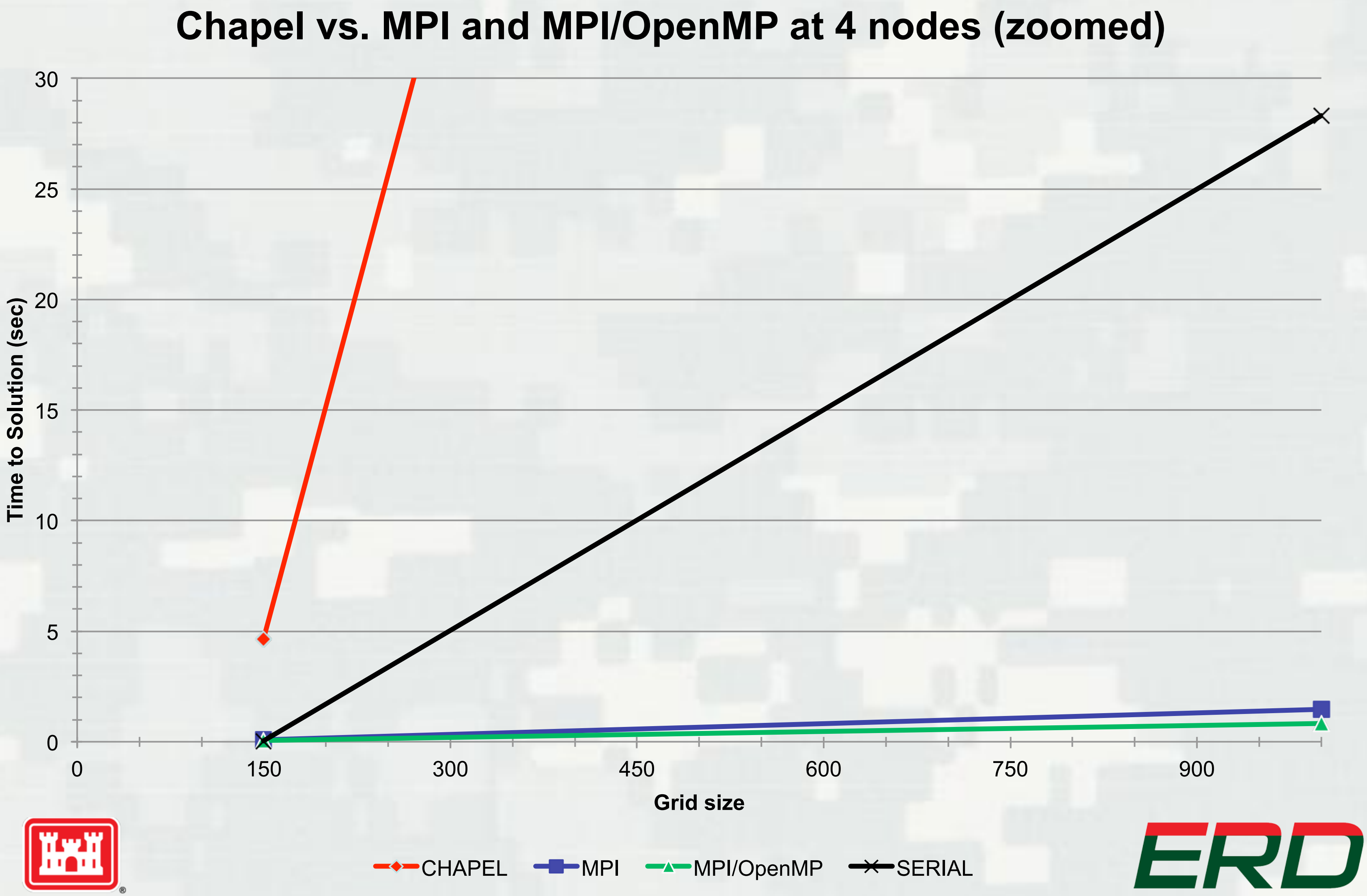
Results


Chapel Performance at Increasing Node Counts
300
250
200
150
100
50
0
Time to Solution (sec)
0
150
300
450
600
750
900
Grid size
CHAPEL @ 16 nodes
CHAPEL @ 4 nodes
SERIAL

Results


Chapel vs. MPI and MPI/OpenMP at 4 nodes
200
150
100
50
0
Time to Solution (sec)
0
150
300
450
600
750
900
Grid size
CHAPEL
MPI
MPI/OpenMP
SERIAL

Results



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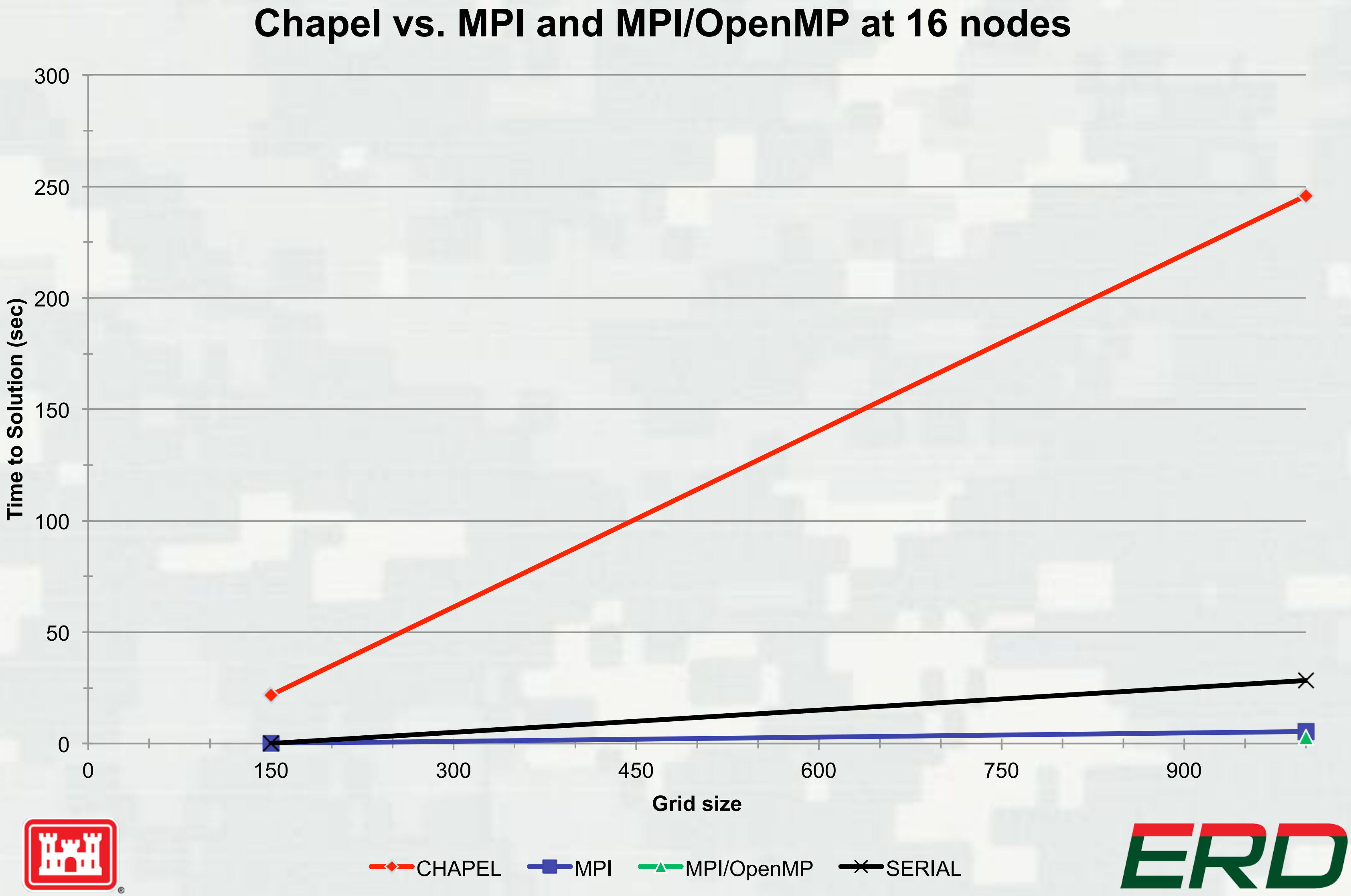
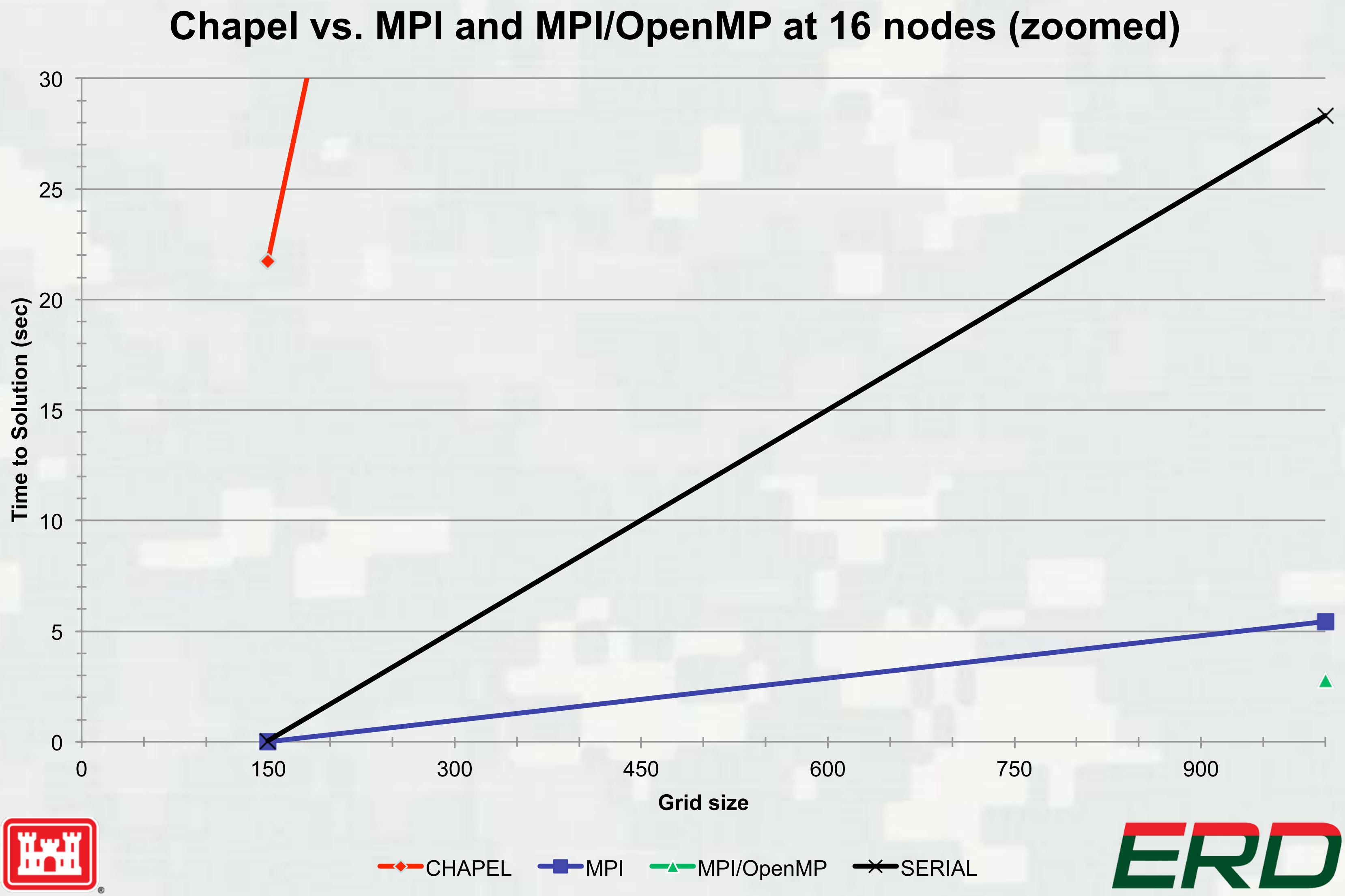
Results


Chapel vs. MPI and MPI/OpenMP at 16 nodes
300
250
200
150
100
50
0
Time to Solution (sec)
0
150
300
450
600
750
900
Grid size
CHAPEL
MPI
MPI/OpenMP
SERIAL

Results


Chapel vs. MPI and MPI/OpenMP at 16 nodes (zoomed)
Time to Solution (sec)
30
25
20
15
10
5
0
0
150
300
450
600
750
900
Grid size
CHAPEL
MPI
MPI/OpenMP
SERIAL

Results

- What's going on?
  - Chapel does not scale well (for this code)!
    - Increasing the number of nodes increases the runtime, regardless of problem size
    - Increasing the problem size increases the runtime at an exponential rate

NX	NY	RUNTIME (sec)
150	150	4.64201
1000	1000	183.006
10000	10000	43200+**

**Timed out after 12 hours

Results

- What's going on?
  - Contacted Ben Harshbarger and Brad Chamberlain (Cray) in order to determine the issue
  - Updating compiler versions (in this case, from 1.9.0 to 1.10.0) and adding compiler optimization flags positively impacted performance
  - We determined that the main factor impacting performance was the use of Chapel's implementation of reductions (can be used in manner equivalent to `mpi_allreduce`)
    - Example: `err = + reduce p_err;`
  - There are 6 instances of `reduce` in this code. Two of them occur within the main iteration loop
    - The number of times this iteration loop executes increases as the problem size increases
      - 150x150: 314 iterations
      - 1000x1000: 1934 iterations
      - 10000x10000: 18133 iterations
      - 20000x20000: 35690 iterations
    - As problem size increases, runtime becomes dominated by these reductions

Conclusions, currently

- Chapel is not ready for our use in a production environment
  - Developers are working to modify/add features to make language more useful to average user, but they're not there yet.
  - Documentation/tutorials can be an unorganized mixture of useful and outdated
    - Direct guidance from Chapel developers was extremely helpful, but not every user would have access to this
  - Even with code-tuning assistance, Chapel does not impress when compared to MPI and MPI/OpenMP
    - Does not seem to scale well with large problem sizes or large core counts
    - While Chapel itself is easy to read/use, will our code developers want to spend the effort learning/implementing a new programming language only to get similar or worse results than with MPI?

Conclusions, currently

- However…
  - As a language, Chapel is clean, concise and easy to understand (even after parallelization is implemented)
    - This could attract portions of our user base starting new coding projects
  - Once the performance improves, others looking to get gains from existing Fortran/C/C++ with MPI could follow

Work Left to Do

- Rerun tests with Chapel v.1.11.0
- When able, make changes necessary to Chapel code in order to increase performance

Acknowledgements

- DoD High Performance Computing Modernization Program (HPCMP)
  - This work was performed using computer time from the DoD HPCMP at the ERDC DoD Supercomputing Resource Center (DSRC).
- Ben Harshbarger and Brad Chamberlain (Cray) for Chapel support