Chapel: Background

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Chapel Settings

- **HPCS**: **H**igh **P**roductivity **C**omputing **S**ystems (DARPA)
  - Goal: Raise HEC user productivity by 10x by 2010

    Productivity = Performance + Programmability + Portability + Robustness
- Phase II: Cray, IBM, Sun (July 2003 – June 2006)
  - Evaluated entire system architecture
  - Three new languages (Chapel, X10, Fortess)
- Phase III: Cray, IBM (July 2006 – 2010)
  - Implement phase II systems
  - Work continues on all three languages

Chapel Productivity Goals

- Improve programmability over current languages
  - Writing parallel codes
  - Reading, changing, porting, tuning, maintaining, ...
- Support performance at least as good as MPI
  - Competitive with MPI on generic clusters
  - Better than MPI on more capable architectures
- Improve portability over current languages
  - As ubiquitous as MPI
  - More portable than OpenMP, UPC, CAF, ...
- Improve robustness via improved semantics
  - Eliminate common error cases
  - Provide better abstractions to help avoid other errors

Chapel Design Concepts

- Support general parallel programming
  - Data, task, and nested parallelism
  - Express all levels of software parallelism
  - Target all levels of hardware parallelism
- *Support global-view abstractions*
- *Support multiple levels of design*
- Allow for control of locality
- Bring mainstream features to parallel languages

Outline

- Concepts, Settings and Goals
- Chapel's Programming Model
  - Fragmented vs. **Global-View**
  - Low-Level vs. High-Level vs. **Multiple Levels**

Fragmented vs. Global-View: Definitions

- Programming model

  The mental model of a programmer

- Fragmented models

  Programmers take point-of-view of a single processor/thread

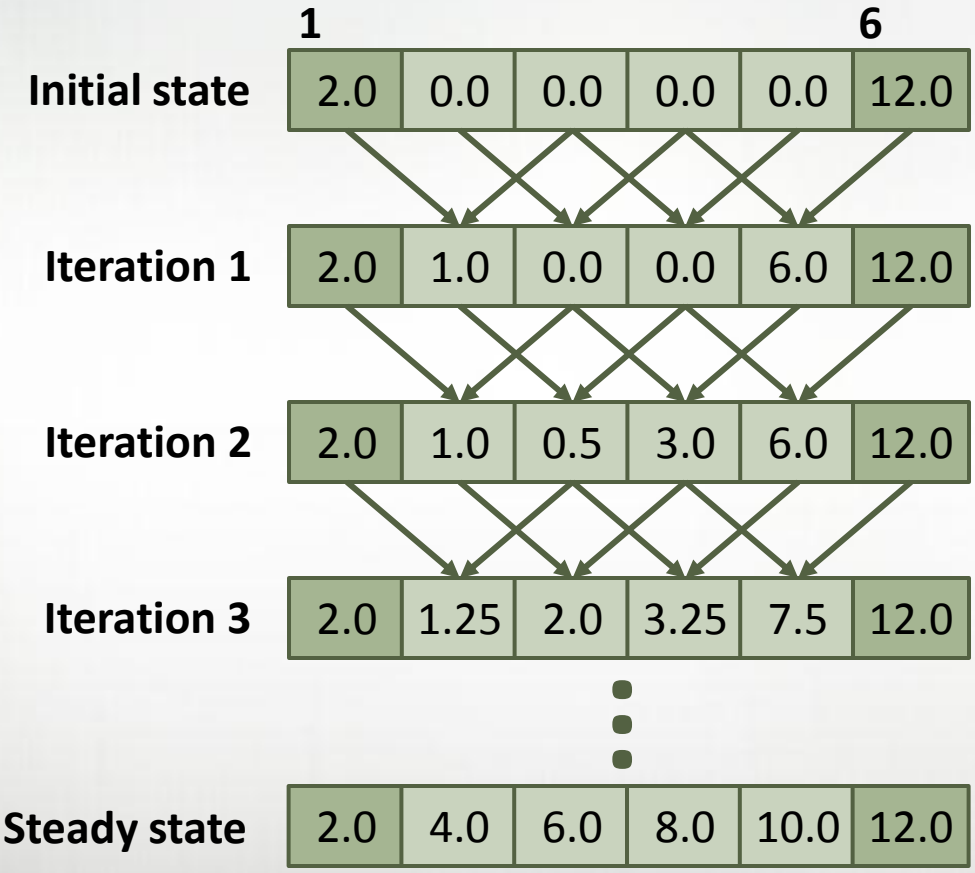
- SPMD models (Single Program, Multiple Data)

  Fragmented models with multiple copies of one program

- Global-view models

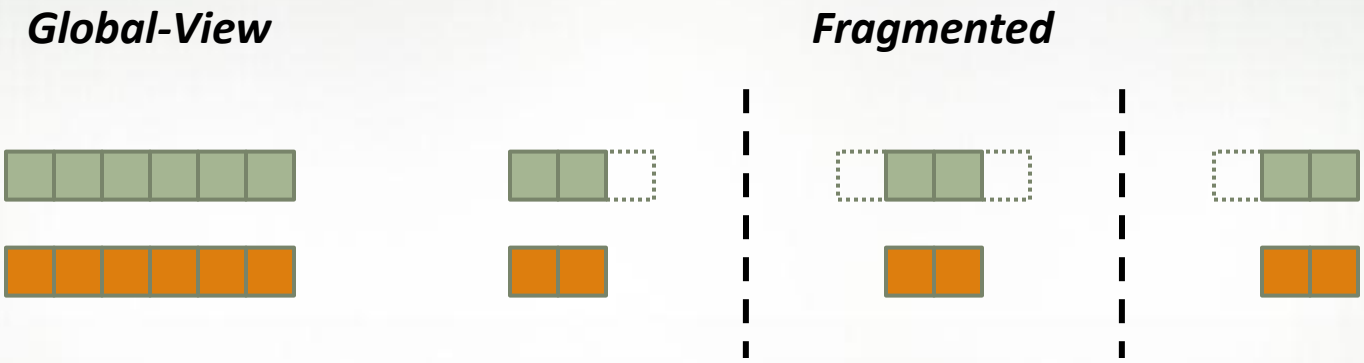
  Programmers write code to describe computation as a whole

3-Point Stencil Example (n=6)



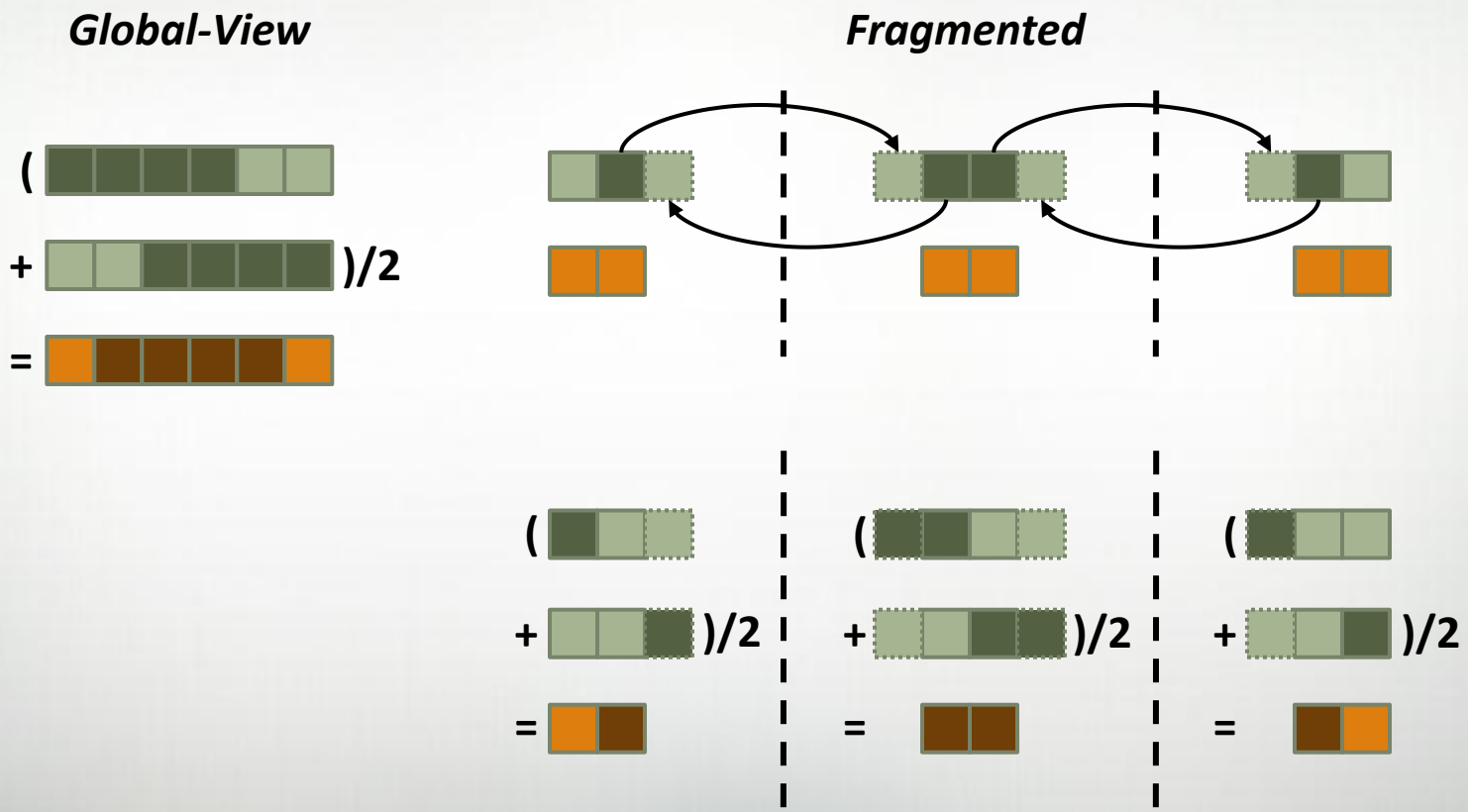
3-Point Stencil Example: Data

Global-View vs. Fragmented Data Declarations



3-Point Stencil Example: Computation

Global-View vs. Fragmented Computation



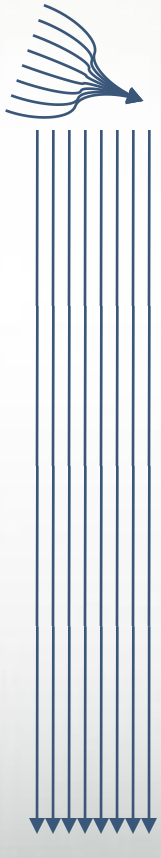
3-Point Stencil Example: Code

Global-View vs. Fragmented Code

Global-View

```
def main() {
  var n = 1000;
  var A, B: [1..n] real;

  forall i in 2..n-1 do
    B(i) = (A(i-1)+A(i+1))/2;
}
```



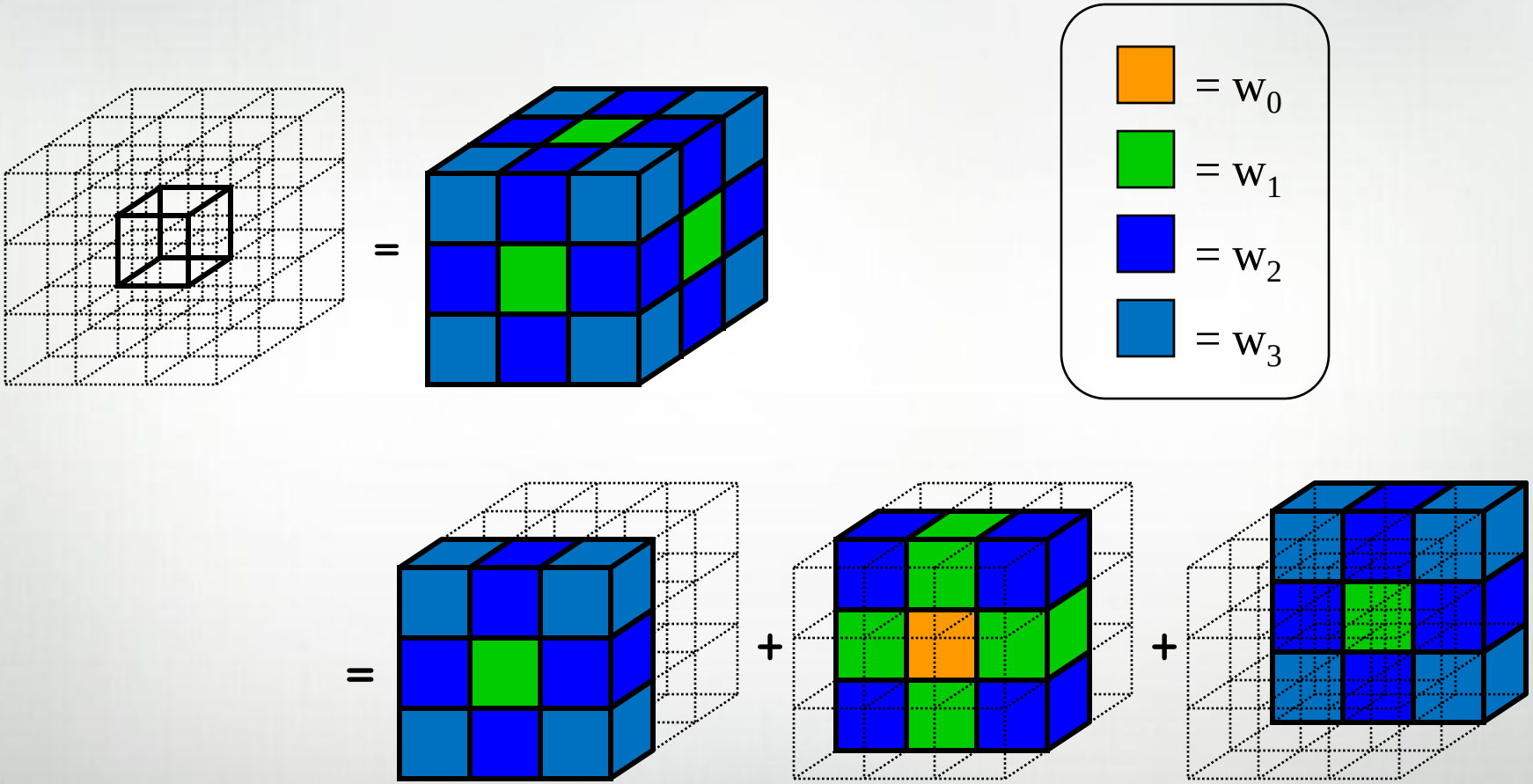
Fragmented

```
def main() {
  var n = 1000;
  var me = commRank(), p = commSize(),
    myN = n/p, myLo = 1, myHi = myN;
  var A, B: [0..myN+1] real;

  if me < p {
    send(me+1, A(myN));
    recv(me+1, A(myN+1));
  } else myHi = myN-1;
  if me > 1 {
    send(me-1, A(1));
    recv(me-1, A(0));
  } else myLo = 2;
  for i in myLo..myHi do
    B(i) = (A(i-1)+A(i+1))/2;
}
```

Assumes p divides n

NAS MG Stencil



NAS MG Stencil in Fortran + MPI

```
use caf_intrinsics

 implicit none

 include 'cafnpb.h'
 include 'globals.h'

 integer n1, n2, n3, kk
 double precision u(n1,n2,n3)
 integer axis

 if( .not. dead(kk) )then
    do  axis = 1, 3
       if( nprocs .ne. 1) then
          call sync_all()
          call give3( axis, +1, u, n1,
     n2, n3, kk )
          call give3( axis, -1, u, n1,
     n2, n3, kk )
          call sync_all()
          call take3( axis, -1, u, n1,
     n2, n3 )
          call take3( axis, +1, u, n1,
     n2, n3 )
       else
          call comm1p( axis, u, n1, n2,
     n3, kk )
       endif
    enddo
 else
    do  axis = 1, 3
       call sync_all()
       call sync_all()
    enddo
    call zero3(u,n1,n2,n3)
 endif
 return
 end

 subroutine give3( axis, dir, u, n1, n2,
     n3, k )
 use caf_intrinsics


 implicit none

 include 'cafnpb.h'
 include 'globals.h'  subroutine
     comm3(u,n1,n2,n3,kk)

 integer axis, dir, n1, n2, n3, k, ierr
 double precision u( n1, n2, n3 )

 integer i3, i2, i1, buff_len,buff_id

 buff_id = 2 + dir
 buff_len = 0

 if( axis .eq.  1 )then
    if( dir .eq. -1 )then

       do  i3=2,n3-1
          do  i2=2,n2-1
             buff_len = buff_len + 1
             buff(buff_len,buff_id ) =
     u( 2,  i2,i3)
          enddo
       enddo


    buff(1:buff_len,buff_id+1)[nbr(axis
     ,dir,k)] =
>      buff(1:buff_len,buff_id)

    else if( dir .eq. +1 ) then

       do  i3=2,n3-1
          do  i2=2,n2-1
             buff_len = buff_len + 1
             buff(buff_len, buff_id ) =
     u( n1-1, i2,i3)
          enddo
       enddo


    buff(1:buff_len,buff_id+1)[nbr(axis
     ,dir,k)] =
>      buff(1:buff_len,buff_id)

    endif
 endif

 if( axis .eq.  2 )then
    if( dir .eq. -1 )then

       do  i3=2,n3-1
          do  i1=1,n1
             buff_len = buff_len + 1
             buff(buff_len, buff_id ) =
     u( i1,  2,i3)
          enddo
       enddo


    buff(1:buff_len,buff_id+1)[nbr(axis
     ,dir,k)] =
>      buff(1:buff_len,buff_id)
 else if( dir .eq. +1 ) then

       do  i3=2,n3-1
          do  i1=1,n1
             buff_len = buff_len + 1
             buff(buff_len,  buff_id )=
     u( i1,n2-1,i3)
          enddo
       enddo


    buff(1:buff_len,buff_id+1)[nbr(axis
     ,dir,k)] =
>      buff(1:buff_len,buff_id)

    endif
 endif

 if( axis .eq.  3 )then
    if( dir .eq. -1 )then

       do  i2=1,n2
          do  i1=1,n1
             buff_len = buff_len + 1
             buff(buff_len, buff_id ) =
     u( i1,i2,2)
          enddo
       enddo


    buff(1:buff_len,buff_id+1)[nbr(axis
     ,dir,k)] =
>      buff(1:buff_len,buff_id)

    else if( dir .eq. +1 ) then

       do  i2=1,n2
          do  i1=1,n1
             buff_len = buff_len + 1
             buff(buff_len, buff_id ) =
     u( i1,i2,n3-1)
          enddo
       enddo


    buff(1:buff_len,buff_id+1)[nbr(axis
     ,dir,k)] =
>      buff(1:buff_len,buff_id)

    endif
 endif

 return
 end


 subroutine take3( axis, dir, u, n1, n2,
     n3 )
 use caf_intrinsics


 implicit none

 include 'cafnpb.h'
 include 'globals.h'

 integer axis, dir, n1, n2, n3
 double precision u( n1, n2, n3 )

 integer buff_id, indx

 integer i3, i2, i1

 buff_id = 3 + dir
 indx = 0

 if( axis .eq.  1 )then
    if( dir .eq. -1 )then

       do  i3=2,n3-1
          do  i2=2,n2-1
             indx = indx + 1
             u(n1,i2,i3) = buff(indx,
     buff_id )
          enddo
       enddo

    else if( dir .eq. +1 ) then

       do  i3=2,n3-1
          do  i2=2,n2-1
             indx = indx + 1
             u(1,i2,i3) = buff(indx,
     buff_id )
          enddo
       enddo

    endif
 endif

 if( axis .eq.  2 )then
    if( dir .eq. -1 )then

       do  i3=2,n3-1
          do  i1=1,n1
             indx = indx + 1
             u(i1,n2,i3) = buff(indx,
     buff_id )
          enddo
       enddo

    else if( dir .eq. +1 ) then

       do  i3=2,n3-1
          do  i1=1,n1
             indx = indx + 1
             u(i1,1,i3) = buff(indx,
     buff_id )
          enddo
       enddo

    endif
 endif

 if( axis .eq.  3 )then
    if( dir .eq. -1 )then

       do  i2=1,n2
          do  i1=1,n1
             indx = indx + 1
             u(i1,i2,n3) = buff(indx,
     buff_id )
          enddo
       enddo

    else if( dir .eq. +1 ) then

       do  i2=1,n2
          do  i1=1,n1
             indx = indx + 1
             u(i1,i2,1) = buff(indx,
     buff_id )
          enddo
       enddo

    endif
 endif

 return
 end


 subroutine comm1p( axis, u, n1, n2, n3,
     kk )
 use caf_intrinsics


 implicit none

 include 'cafnpb.h'
 include 'globals.h'

 integer axis, dir, n1, n2, n3
 double precision u( n1, n2, n3 )

 integer i3, i2, i1, buff_len,buff_id
 integer i, kk, indx

 dir = -1

 buff_id = 3 + dir
 buff_len = nm2

 do  i=1,nm2
    buff(i,buff_id) = 0.0D0
 enddo


 dir = +1

 buff_id = 3 + dir
 buff_len = nm2

 do  i=1,nm2
    buff(i,buff_id) = 0.0D0
 enddo


 dir = +1

 buff_id = 2 + dir
 buff_len = 0

 if( axis .eq.  1 )then
    do  i3=2,n3-1
       do  i2=2,n2-1
          buff_len = buff_len + 1
          buff(buff_len, buff_id ) = u(
      n1-1, i2,i3)
       enddo
    enddo
 endif

 if( axis .eq.  2 )then
    do  i3=2,n3-1
       do  i1=1,n1
          buff_len = buff_len + 1
          buff(buff_len,  buff_id )= u(
      i1,n2-1,i3)
       enddo
    enddo
 endif

 if( axis .eq.  3 )then
    do  i2=1,n2
       do  i1=1,n1
          buff_len = buff_len + 1
          buff(buff_len, buff_id ) = u(
      i1,i2,n3-1)
       enddo
    enddo
 endif

 dir = -1

 buff_id = 2 + dir
 buff_len = 0

 if( axis .eq.  1 )then
    do  i3=2,n3-1
       do  i2=2,n2-1
          buff_len = buff_len + 1
          buff(buff_len,buff_id ) = u(
     2,  i2,i3)
       enddo
    enddo
 endif

 if( axis .eq.  2 )then
    do  i3=2,n3-1
       do  i1=1,n1
          buff_len = buff_len + 1
          buff(buff_len, buff_id ) = u(
      i1,  2,i3)
       enddo
    enddo
 endif

 if( axis .eq.  3 )then
    do  i2=1,n2
       do  i1=1,n1
          buff_len = buff_len + 1
          buff(buff_len, buff_id ) = u(
      i1,i2,2)
       enddo
    enddo
 endif

 do  i=1,nm2
    buff(i,4) = buff(i,3)
    buff(i,2) = buff(i,1)
 enddo

 dir = -1

 buff_id = 3 + dir
 indx = 0

 if( axis .eq.  1 )then
    do  i3=2,n3-1
       do  i2=2,n2-1
          indx = indx + 1
          u(n1,i2,i3) = buff(indx,
     buff_id )
       enddo
    enddo
 endif

 if( axis .eq.  2 )then
    do  i3=2,n3-1
       do  i1=1,n1
          indx = indx + 1
          u(i1,n2,i3) = buff(indx,
     buff_id )
       enddo
    enddo
 endif

 if( axis .eq.  3 )then
    do  i2=1,n2
       do  i1=1,n1
          indx = indx + 1
          u(i1,i2,n3) = buff(indx,
     buff_id )
       enddo
    enddo
 endif

 return
 end

 subroutine
     rprj3(r,m1k,m2k,m3k,s,m1j,m2j,m3j,k
     )
 implicit none
 include 'cafnpb.h'
 include 'globals.h'

 integer m1k, m2k, m3k, m1j, m2j, m3j,k

 double precision r(m1k,m2k,m3k),
     s(m1j,m2j,m3j)
 integer j3, j2, j1, i3, i2, i1, d1, d2,
     d3, j
 double precision x1(m), y1(m), x2,y2

 if(m1k.eq.3)then
   d1 = 2
 else
   d1 = 1
 endif

 if(m2k.eq.3)then
   d2 = 2
 else
   d2 = 1
 endif

 if(m3k.eq.3)then
   d3 = 2
 else
   d3 = 1
 endif

 do  j3=2,m3j-1
   i3 = 2*j3-d3
   do  j2=2,m2j-1
     i2 = 2*j2-d2
     do j1=2,m1j
       i1 = 2*j1-d1
       x1(i1-1) = r(i1-1,i2-1,i3  ) +
     r(i1-1,i2+1,i3  )
>                + r(i1-1,i2,  i3-1) +
     r(i1-1,i2,  i3+1)
       y1(i1-1) = r(i1-1,i2-1,i3-1) +
     r(i1-1,i2-1,i3+1)
>                + r(i1-1,i2+1,i3-1) +
     r(i1-1,i2+1,i3+1)
     enddo
     do  j1=2,m1j-1
       i1 = 2*j1-d1
       y2 = r(i1,  i2-1,i3-1) + r(i1,
     i2-1,i3+1)
>           + r(i1,  i2+1,i3-1) + r(i1,
     i2+1,i3+1)
       x2 = r(i1,  i2-1,i3  ) + r(i1,
     i2+1,i3  )
>           + r(i1,  i2,  i3-1) + r(i1,
     i2,  i3+1)
       s(j1,j2,j3) =
>            0.5D0 * r(i1,i2,i3)
>          + 0.25D0 * (r(i1-1,i2,i3) +
     r(i1+1,i2,i3) + x2)
>          + 0.125D0 * ( x1(i1-1) +
     x1(i1+1) + y2)
>          + 0.0625D0 * ( y1(i1-1) +
     y1(i1+1) )
       enddo
     enddo
   enddo
   j = k-1
   call comm3(s,m1j,m2j,m3j,j)
   return
   end
```

NAS MG Stencil in Chapel

```
def rprj3(S, R) {
  const Stencil = [-1..1, -1..1, -1..1],
        W: [0..3] real = (0.5, 0.25, 0.125, 0.0625),
        W3D = [(i,j,k) in Stencil] W((i!=0)+(j!=0)+(k!=0));

  forall inds in S.domain do
    S(inds) =
      + reduce [offset in Stencil] (W3D(offset) *
                                    R(inds + offset*R.stride));
}
```

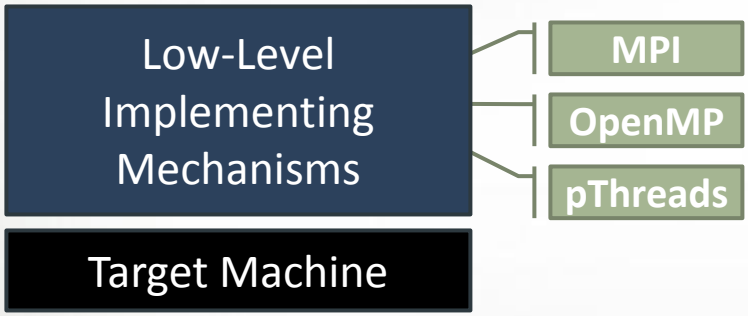
Previous work shows performance is still possible:

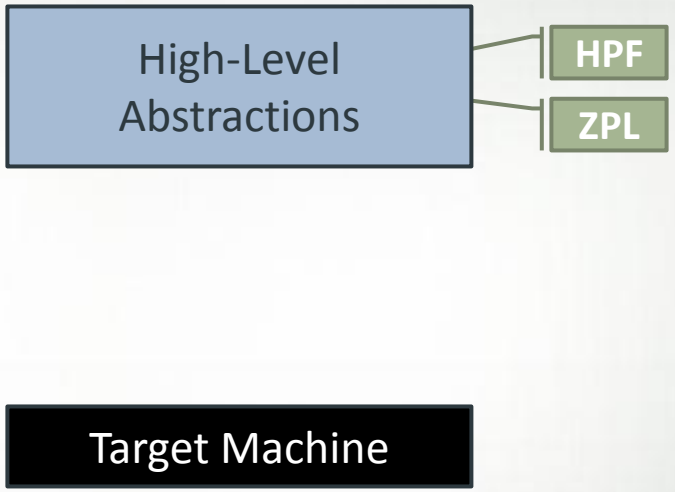
B. L. Chamberlain, S. J. Deitz, and L. Snyder. ***A comparative study of the NAS MG benchmark across parallel languages and architectures*****. In Proceedings of the ACM Conference on Supercomputing, 2000.**

Summary of Current Programming Systems

	System	Data Model	Compute Model
Communication Libraries	MPI/MPI-2	Fragmented	Fragmented
	SHMEM	Fragmented	Fragmented
	ARMCI	Fragmented	Fragmented
	GASNet	Fragmented	Fragmented
Shared Memory	OpenMP, pThreads	Global-View (trivially)	Global-View (trivially)
PGAS Languages	Co-Array Fortran	Fragmented	Fragmented
	UPC	Global-View	Fragmented
	Titanium	Fragmented	Fragmented
HPCS Languages	Chapel	Global-View	Global-View
	X10 (IBM)	Global-View	Global-View
	Fortress (Sun)	Global-View	Global-View

Low-Level vs. High-Level Programming

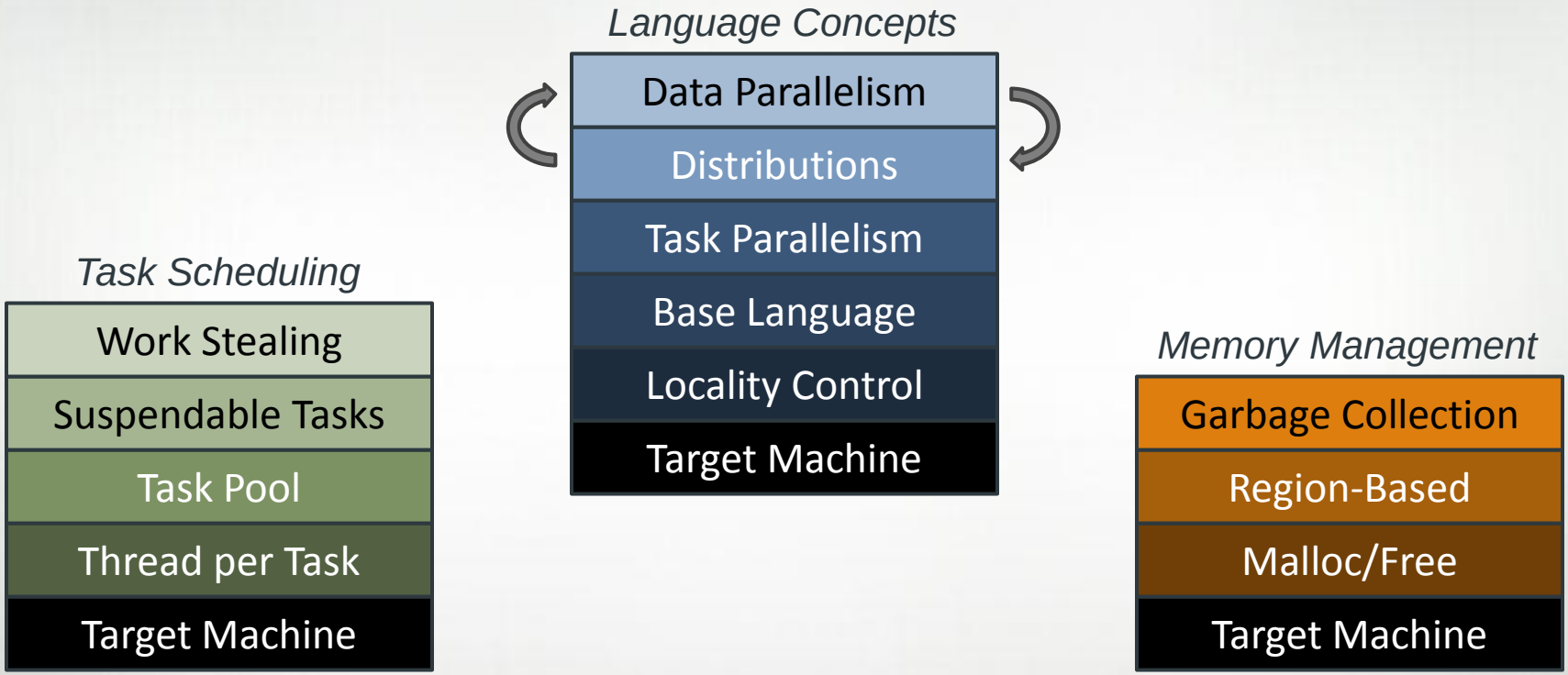




"Why is everything so difficult?"

"Why can't I optimize this?"

Multiple Levels of Design



Questions?

- Concepts, Settings and Goals
- Chapel's Programming Model
  - Fragmented vs. **Global-View**
  - Low-Level vs. High-Level vs. **Multiple Levels**