Chapel: Background

Chapel Settings

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

    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 –)
  - 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

Outline

- Chapel's Settings and Goals
- Chapel's Themes
  - Global-view abstractions
  - General parallel programming
  - Multiple levels of design
  - Control of locality
  - Mainstream language features

Global-View Abstractions

Definitions

- **Programming model**

  The mental model of a programmer

- **Fragmented model**

  Programmer takes point-of-view of a single processor/thread

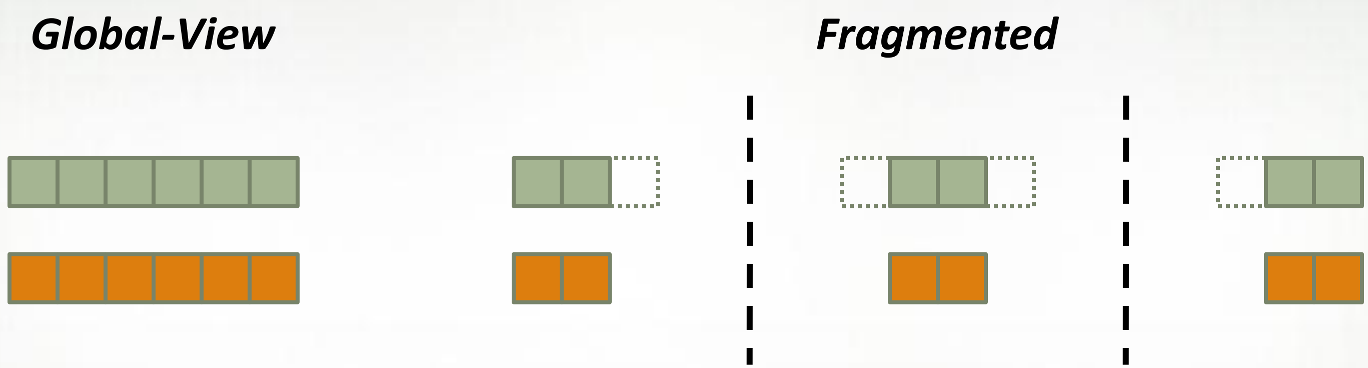
- **SPMD models** (Single Program, Multiple Data)

  Fragmented models with multiple copies of one program

- **Global-view model**

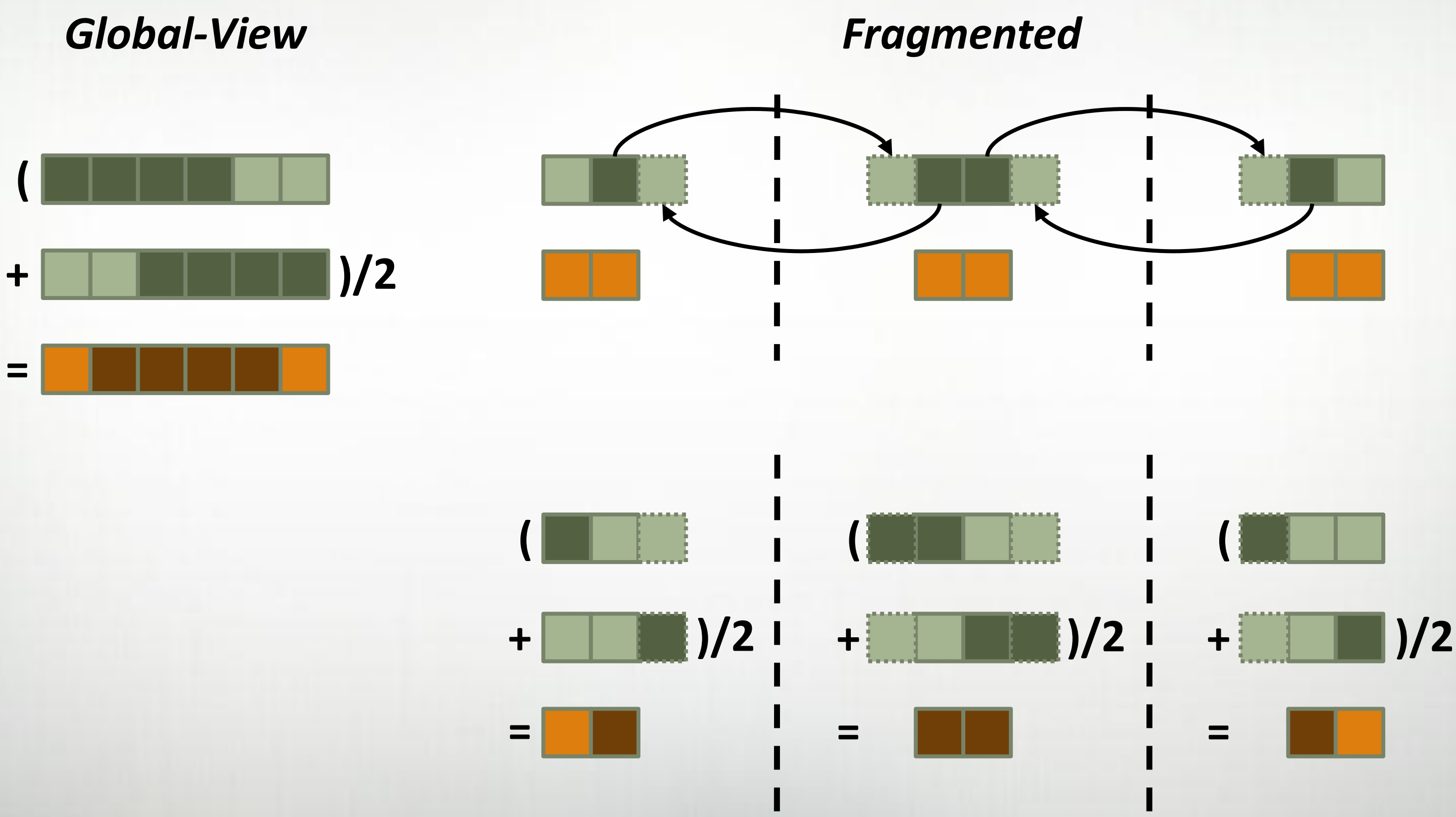
  Programmer writes code to describe computation as a whole

Example: 3-Point Stencil (Data Declarations)



Global-View Abstractions

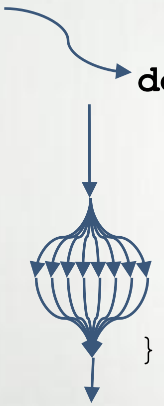
Example: 3-Point Stencil (Computation)



Example: 3-Point Stencil (Code)

Assumes p divides n

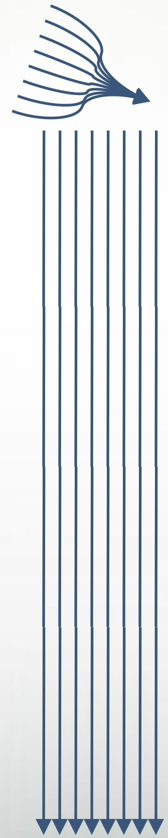
Global-View



```
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;
}
```

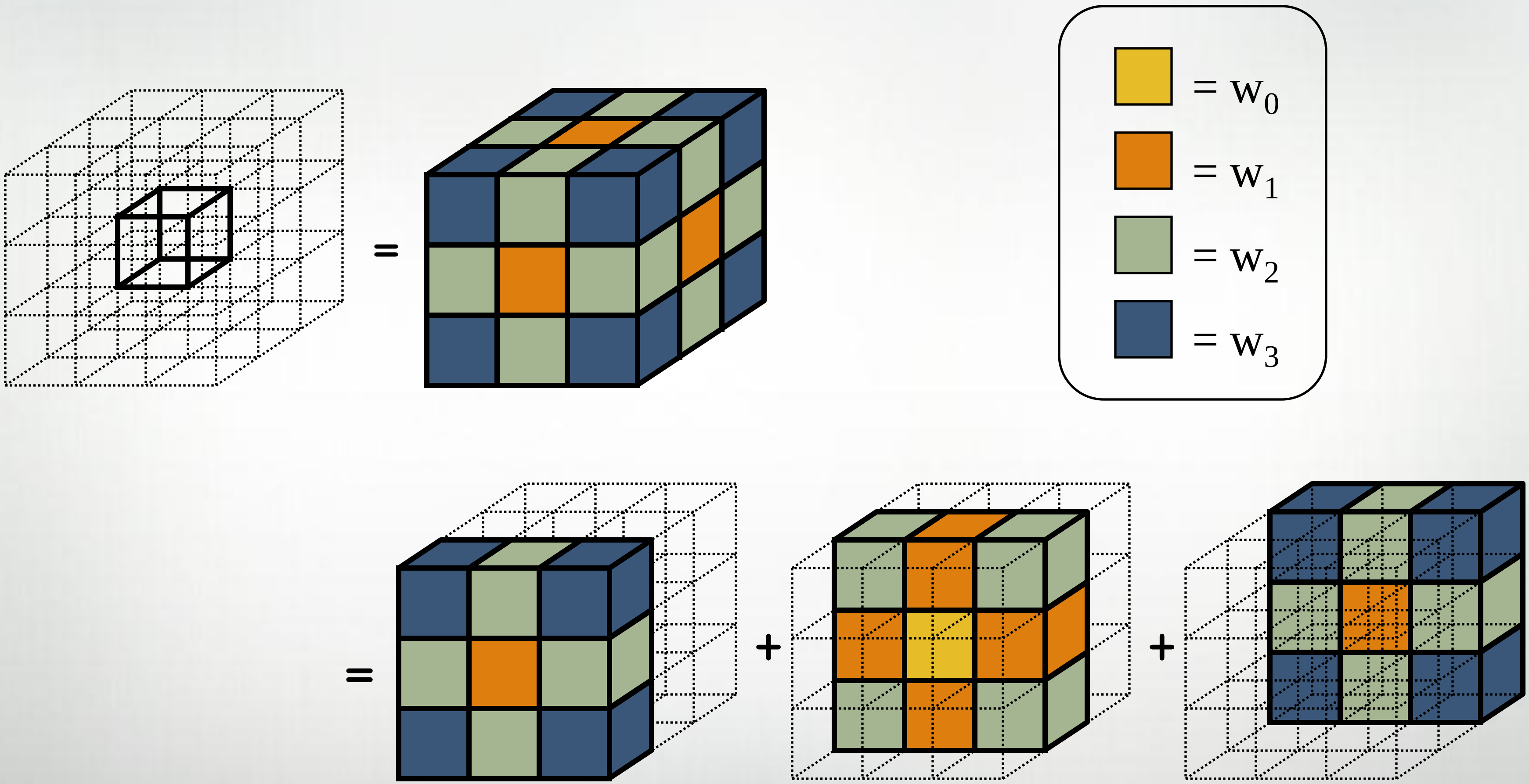
Fragmented



```
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;
}
```

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

    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(1,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(i1,1,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,i2,1) = 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));
}
```

Our previous work in ZPL has shown that such compact codes can result in better performance than the Fortran + MPI.

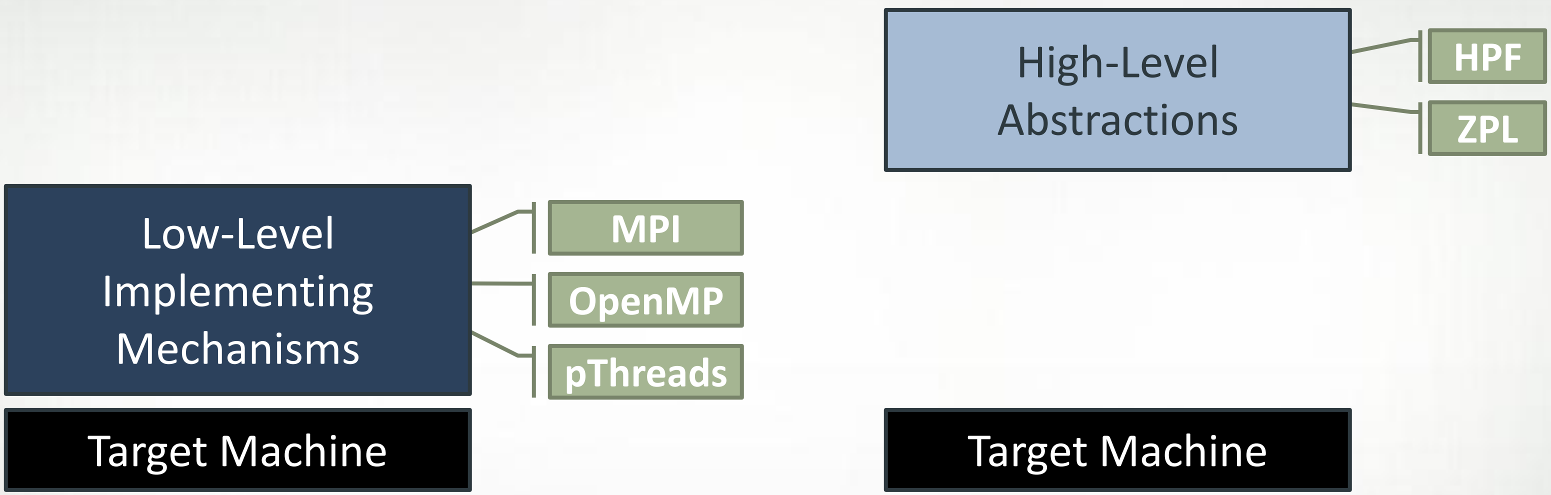
Summary of Current Programming Systems

	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

General Parallel Programming

- Express all parallelism in the software
  - Forms: data, task, nested (arbitrary composition thereof)
  - Levels: module, function, loop, statement
- Target all parallelism in the hardware
  - Systems: multicore desktops, clusters, HPC systems
  - Types: multithreading, vector
  - Levels: across cores, across nodes, across systems

Multiple Levels of Design



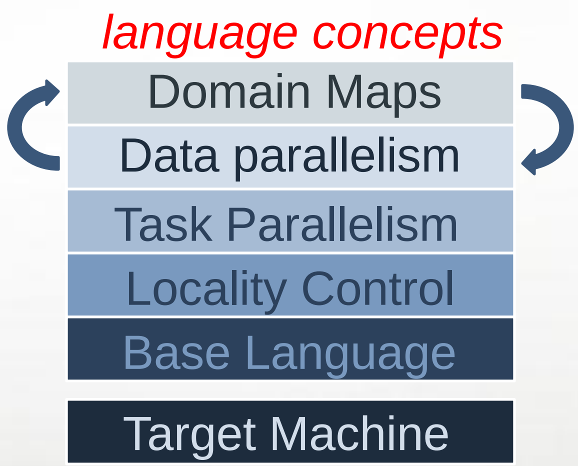
"Why is everything so difficult?"

"Why can't I optimize this?"

Multi-resolution Design

Structure the language in layers, permitting it to be used at multiple levels as required/desired

- support high-level features and automation for convenience
- provide the ability to drop down to lower, more manual levels



Control of Locality

Given

- Scalable systems tend to store memory with processors
- Remote accesses tend to take longer than local accesses

Therefore

- Placement of data relative to computation matters
- Programmers need control over data placement

Note

- As multi-core chips grow, locality matters on desktops
- GPUs/accelerators expose node-level locality

Mainstream Language Features

- Object-oriented programming with value and reference classes
- Generic programming with types and compile-time constants
- Latent typing and a rich set of primitive types
- Modules for libraries and code organization
- Functions with nesting, overloading, and named arguments
- Multi-dimensional and associative arrays with slicing, etc.
- Classes, records, and unions
- Tuples, ranges, and domains
- Standard modules (*e.g.*, Math, Random, Time, BitOps, Norm)

Questions?

- Chapel's Settings and Goals
- Chapel's Design
  - Global-view abstractions
  - General parallel programming
  - Multiple levels of design
  - Control of locality
  - Mainstream language features