# An Empirical Performance Study of Chapel Programming Language

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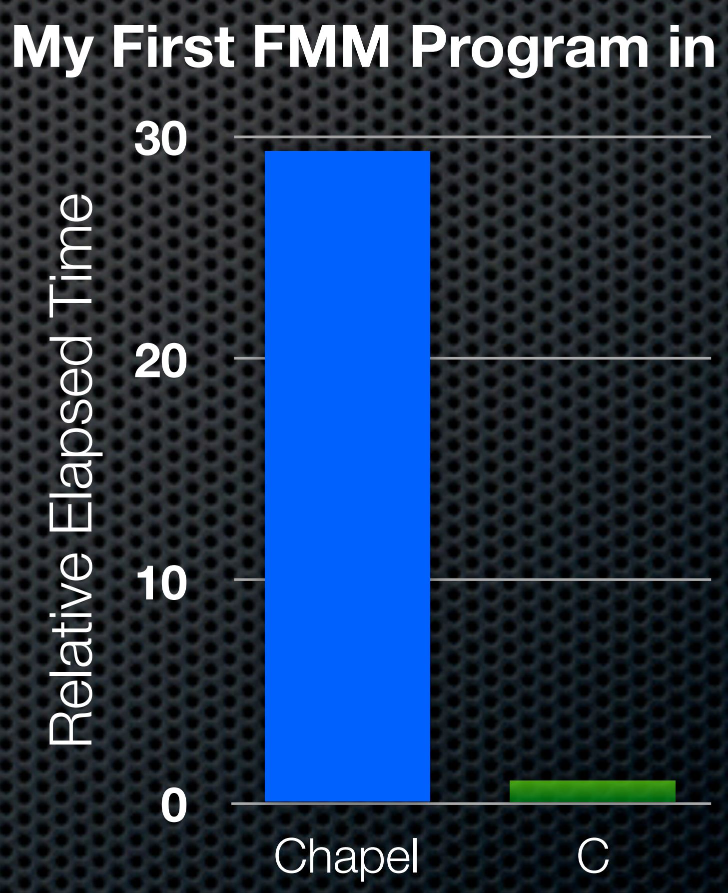
# Background

- Modern parallel machines
  - Massive parallelism: 100K~ cores
  - Heterogenous architecture: CPUs + GPGPUs
- Modern parallel programming languages
  - Programmability, portability, robustness, performance
    - Chapel, X10, and Fortress, etc.

# Motivation

- Programmability has been well illustrated
  - Abstract of parallelism
- Performance is yet unknown
  - Performance implications
  - Performance tuning
  - Language improvements




The performance should not surprise newbies...

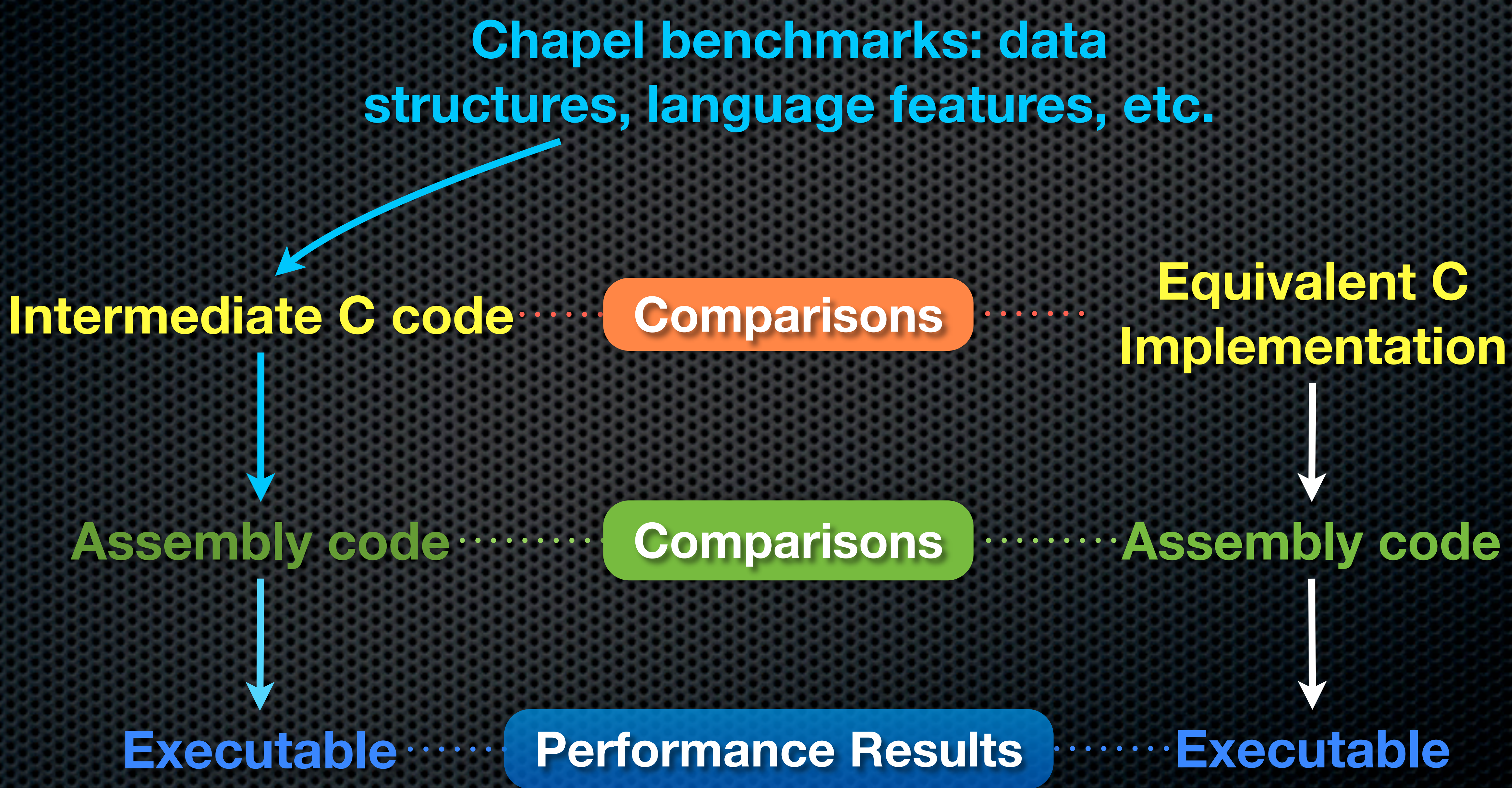
# Agenda

- Short overview of Chapel
- Approach
- Evaluation
  - Microbenchmark results
  - Suggestions for writing efficient Chapel programs
  - N-body FMM results
- Conclusions

# The Chapel Language

- Developed by Cray Inc, initiated by HPCS in 2003
- Designed to improve programmability
  - Global view model vs. fragmented model
  - Abstract of parallelism (task, data parallelism, etc.)
  - Object-oriented, generic programming
- For more details: http://chapel.cray.com

# Evaluation Approach

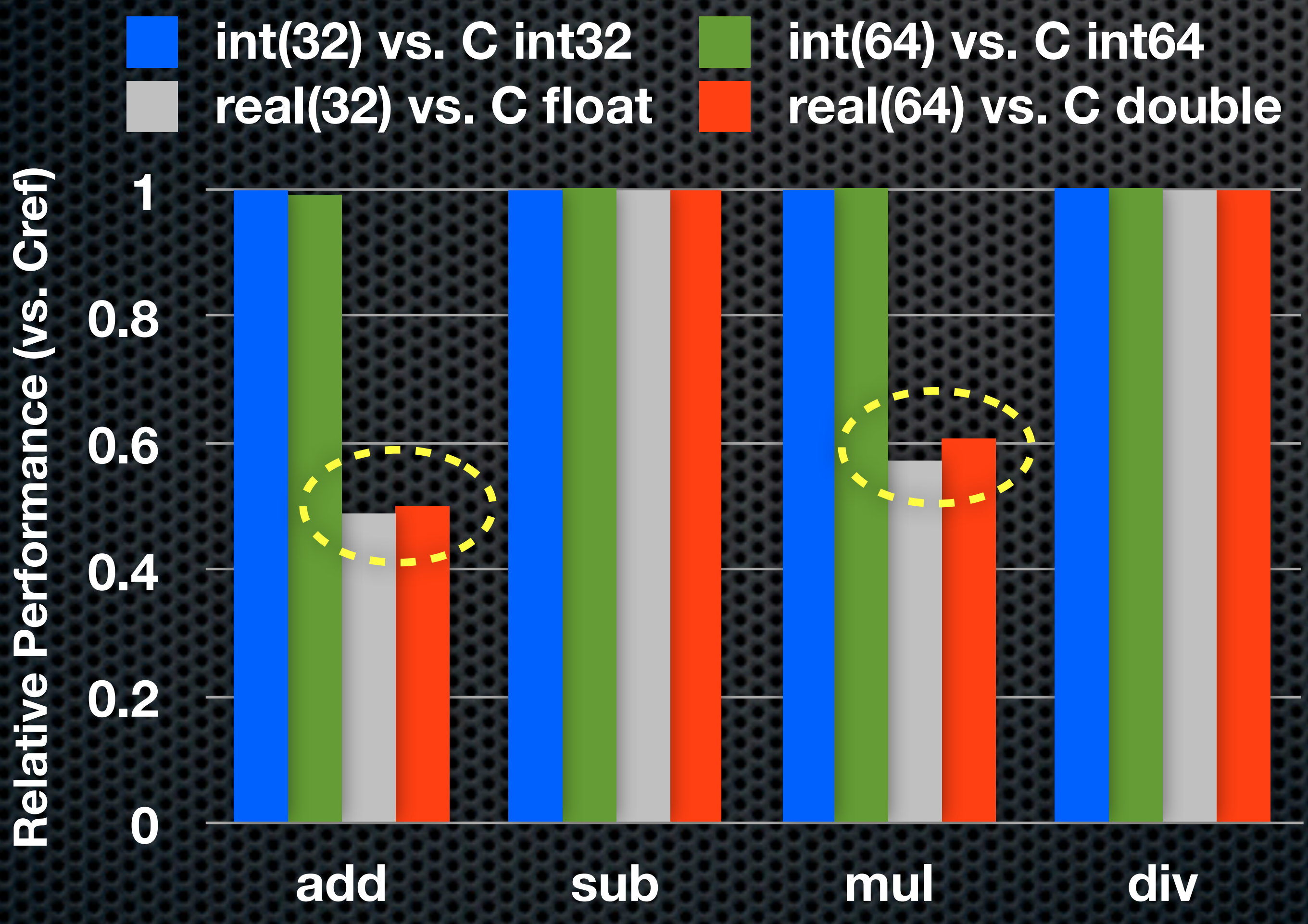


# Environment

- Xeon 2.33GHz 8 core CPU, 32GB MEM
- Linux 2.6.26, GCC 4.6.2, Chapel 1.4.0
- Compile options
  - ```
    $ chpl -o prog --fast prog.chpl // Chapel
    $ gcc -o prog -O3 -lm prog.c     // C
    ```
  - Use "`--savec`" to keep intermediate C code
  - "`$CHPL_COMM=none`" for single locale, malloc series used
- Synthesized benchmarks from N-Body simulations
    ```

# Primitive Types (1/3)

```
var res: int(32);
for i in 1..N do res = res + i;
```



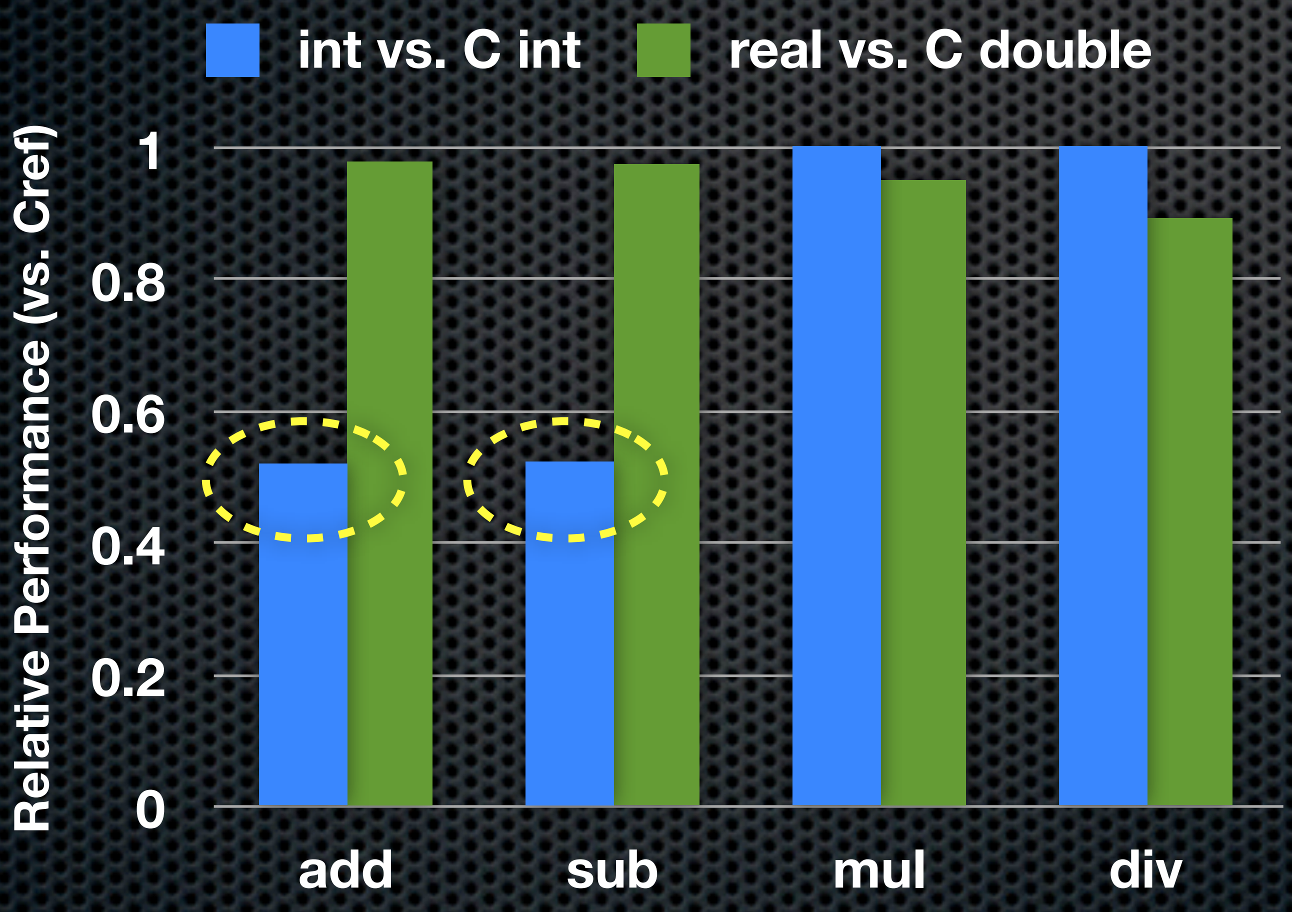

```
while (...) {
  T1 = ((_real32)(i);
  T2 = (resReal32 + T1);
  resReal32 = T2;
  i = ...;
}
```

```
.L1046:
  cvtsi2ss %eax, %xmm0
  addl     $1, %eax
  cmpl     %eax, %r12d
  addss    %xmm2, %xmm0
  movaps   %xmm0, %xmm2
  jge .L1046
```

The redundant instruction can be removed by combining T2 assignments

# Primitive Types (2/3)

```
var arr: [1..N] int;   // int and real
for d in arr.domain do
  res = res + arr(d);  // read only
```

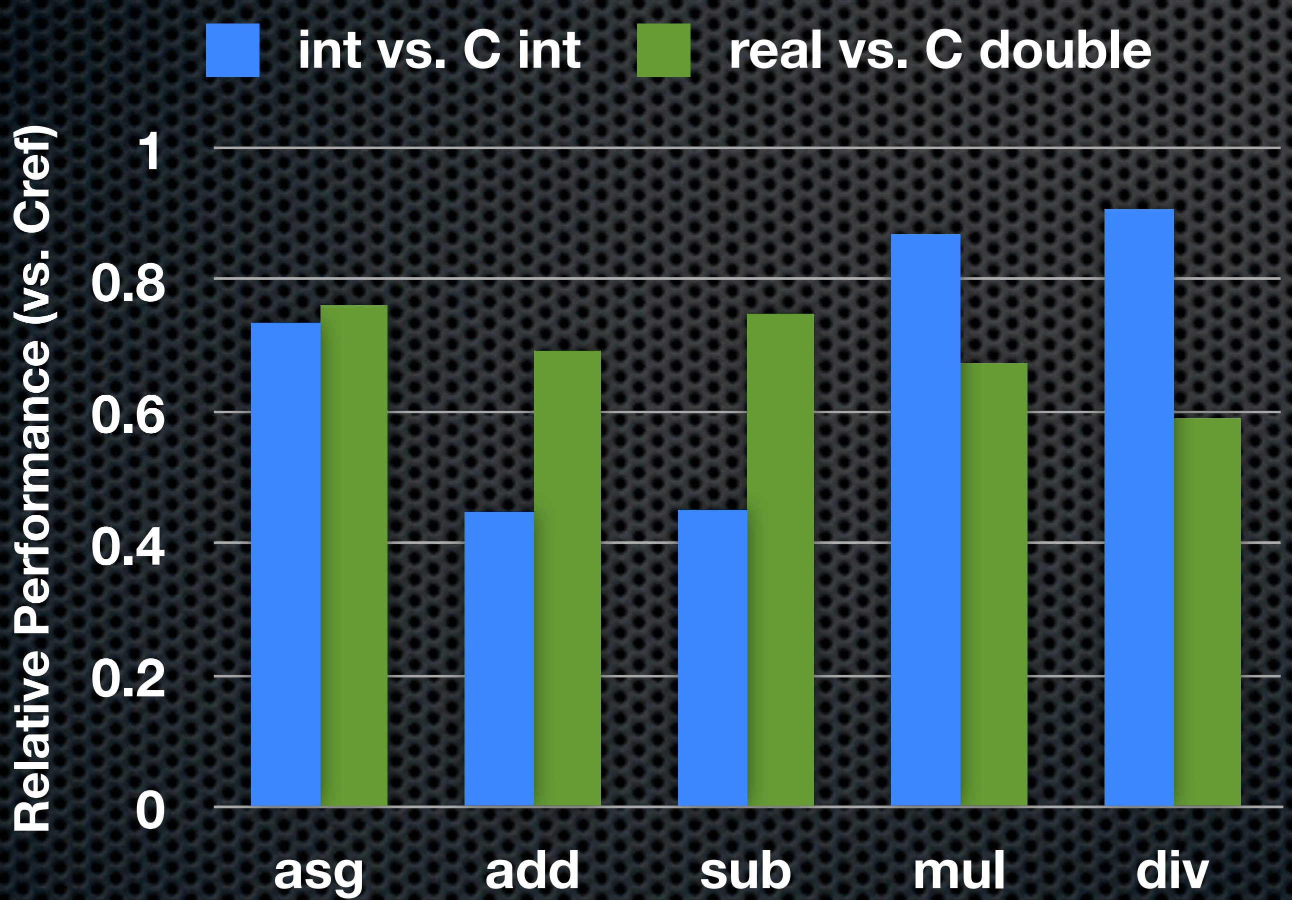



```
while (T80) {
  _ret42 = arrInt;
  _ret43 = (_ret42->origin);
  _ret_10 = (&(_ret42->blk));
  _ret_x110 = (*_ret_10)[0];
  T82 = (i5 * _ret_x110);
  T83 = (_ret43 + T82);
  _ret44 = (_ret42->factoredOffs);
  T84 = (T83 - _ret44);
  T85 = (_ret42->data);
  T86 = (&((T85)->_data[T84]));
  _ret45 = *(T86);
  T87 = (resInt / _ret45);
  resInt = T87;
  T88 = (i5 + 1);
  i5 = T88;
  T89 = (T88 != end5);
  T80 = T89;
}
```

```
$ gcc ... -ftree-vectorize -ftree-vectorizer-verbose=5
```

# Primitive Types (3/3)

```
var arr: [1..N] int;   // int and real
for d in arr.domain do
  arr(d) = arr(d) + d; // read + write
```




```
# Assembly of Chapel C mappings
.L1046:
  cvtsi2sd  %edx, %xmm1
  addl      $1, %edx
  movsd     (%rax), %xmm0
  divsd     %xmm1, %xmm0
  movsd     %xmm0, (%rax)
  addq      %rcx, %rax
  cmpl      %edx, %r12d
  jne .L1046

# Assembly of hand-written C
.L32:
  leal      (%rsi,%rax), %ecx
  movsd     (%rdx,%rax,8), %xmm0
  cvtsi2sd  %ecx, %xmm1
  divsd     %xmm1, %xmm0
  movsd     %xmm0, (%rdx,%rax,8)
  addq      $1, %rax
  cmpq      %rdi, %rax
  jne .L32
```

LEA instruction is executed
by a separate addressing unit



Monday, May 21, 12

# Structured Types (1/3)

## Tuple

```
var Tuple:
  (real, real, real);

var 2D_Tuple:
  (Tuple, Tuple, Tuple);
```

## C Mapping of Tuple

```
double Tuple[3];

double Tuple[3][3];
```

## Record

```
record Record {
  var x, y, z: real
}

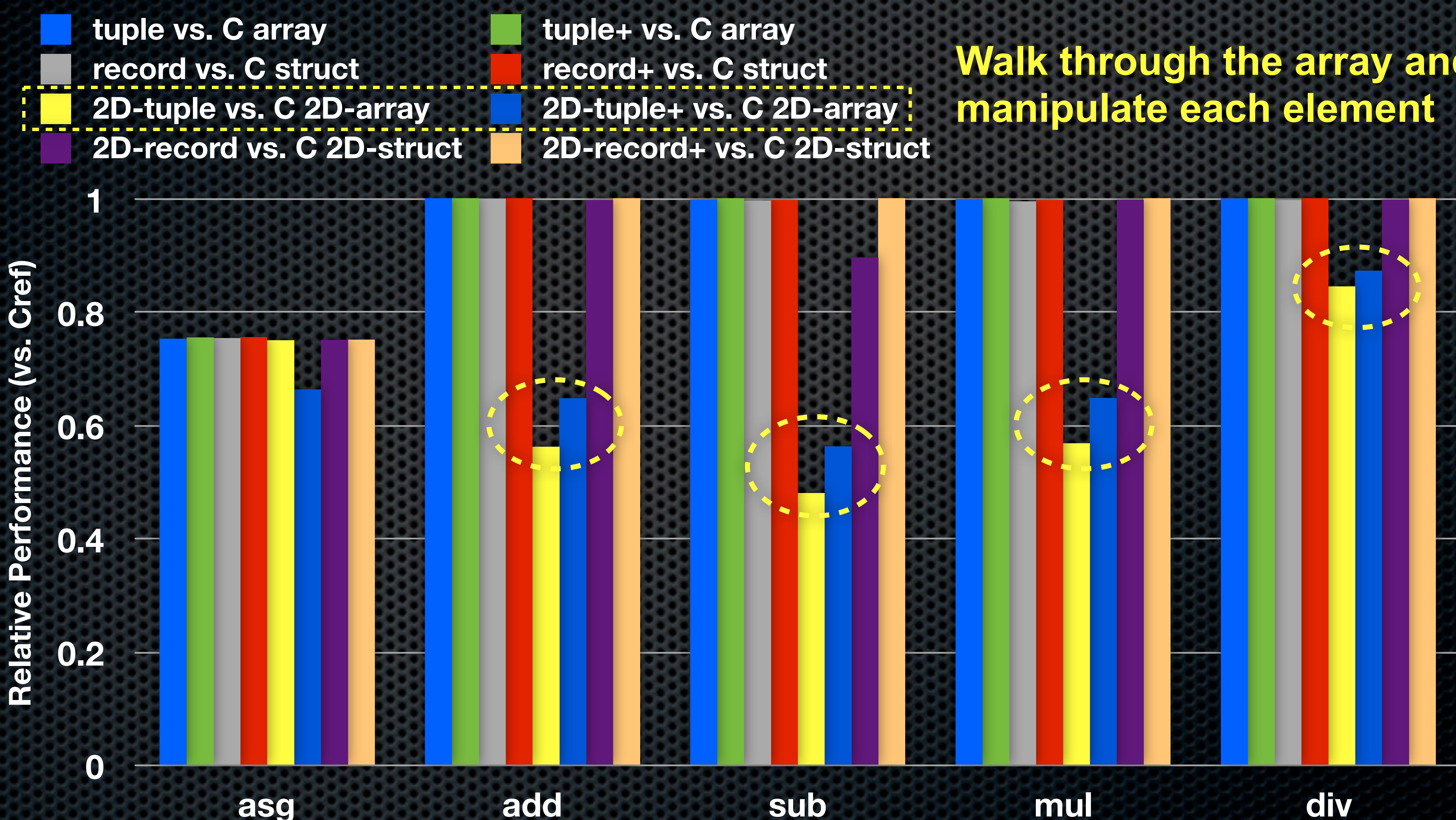
record 2D_Record {
  var x, y, z: Record;
}
```

## C Mapping of Record

```
struct Record {
  double x, y, z;
}

struct 2D_Record {
  struct Record x, y, z;
}
```

# Structured Types (2/2)




Walk through the array and manipulate each element

# Structured Types (3/3)

- Redundant address substitution in 2D-Tuple
  - Asm: 197 vs. 33 of $C_{ref}$
  - Complex for GCC to optimize
    - Data references
    - Redundant operations
  - May be related to construction of heterogenous tuple

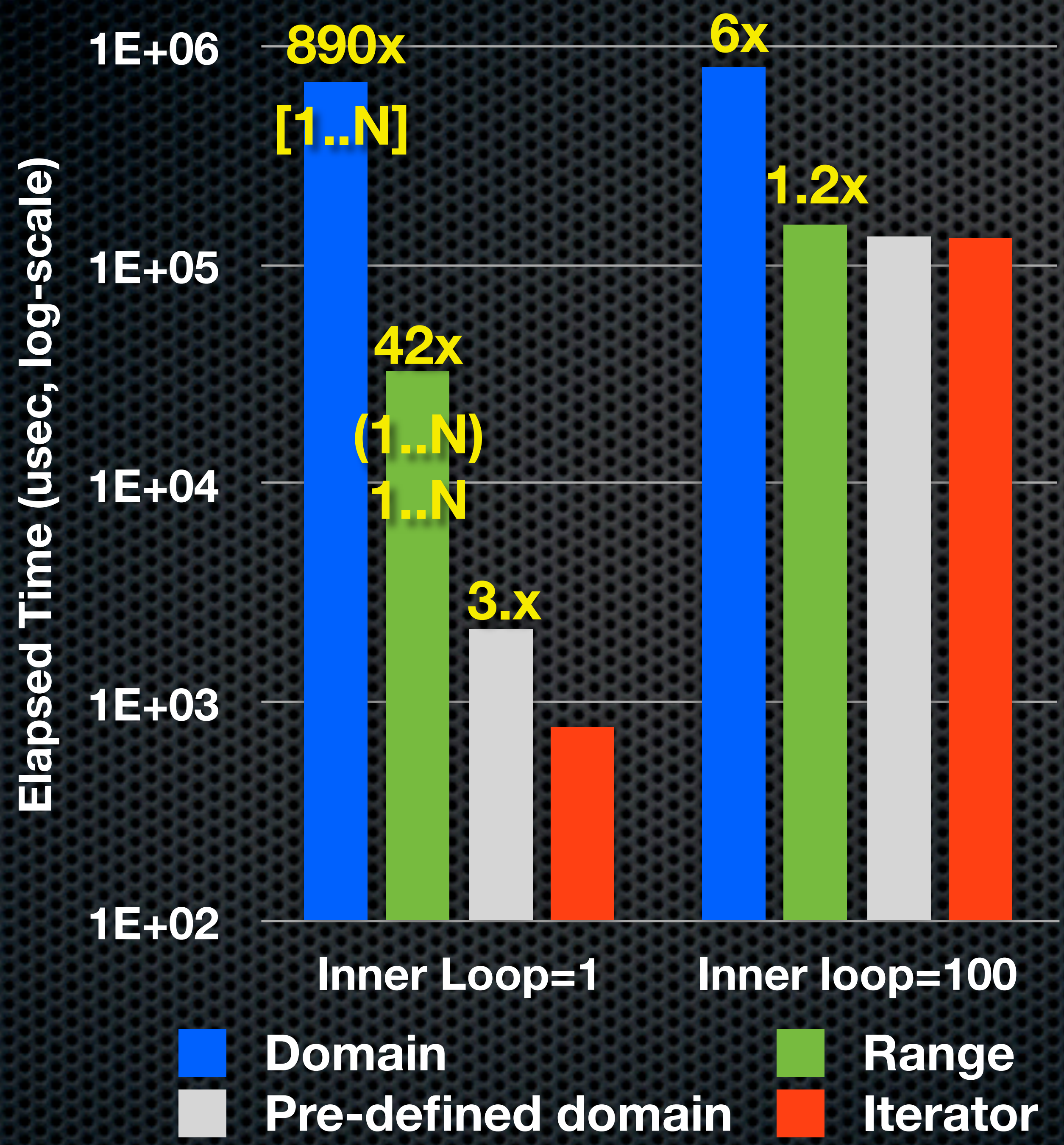
```
while (...) {
    _tmp_37 = (&(_ret57[0]));
    _tmp_x139 = (*_tmp_37)[0];
    _tmp_x239 = (*_tmp_37)[1];
    _tmp_x339 = (*_tmp_37)[2];
    ...
    chpl__tupleRestHelper(...)
    ...
    T297[0] = _tmp_x139;
    T297[1] = _tmp_x239;
    T297[0] = _tmp_x339;
    ...
}
```

# Iterators for Loops (1/2)

```
iter myIter(min: int, max: int, step: int = 1) {
    while min <= max {
        yield min;
        min += step;
     }
}

// Nested loops
var dom = [1..N]; // or 1..N
for i in 1..M do
    for j in [1..N] do ...; // domain
    for j in 1..N do ...;   // range
    for j in dom do ...;    // pre-defined domain
    for j in myIter(1, N) do ...; // iterator
```

# Iterators for Loops (2/2)




```
// Domain
chpl__buildDomainExpr(...);
while (loop_variable) { ... }
chpl__autoDestroy(...);

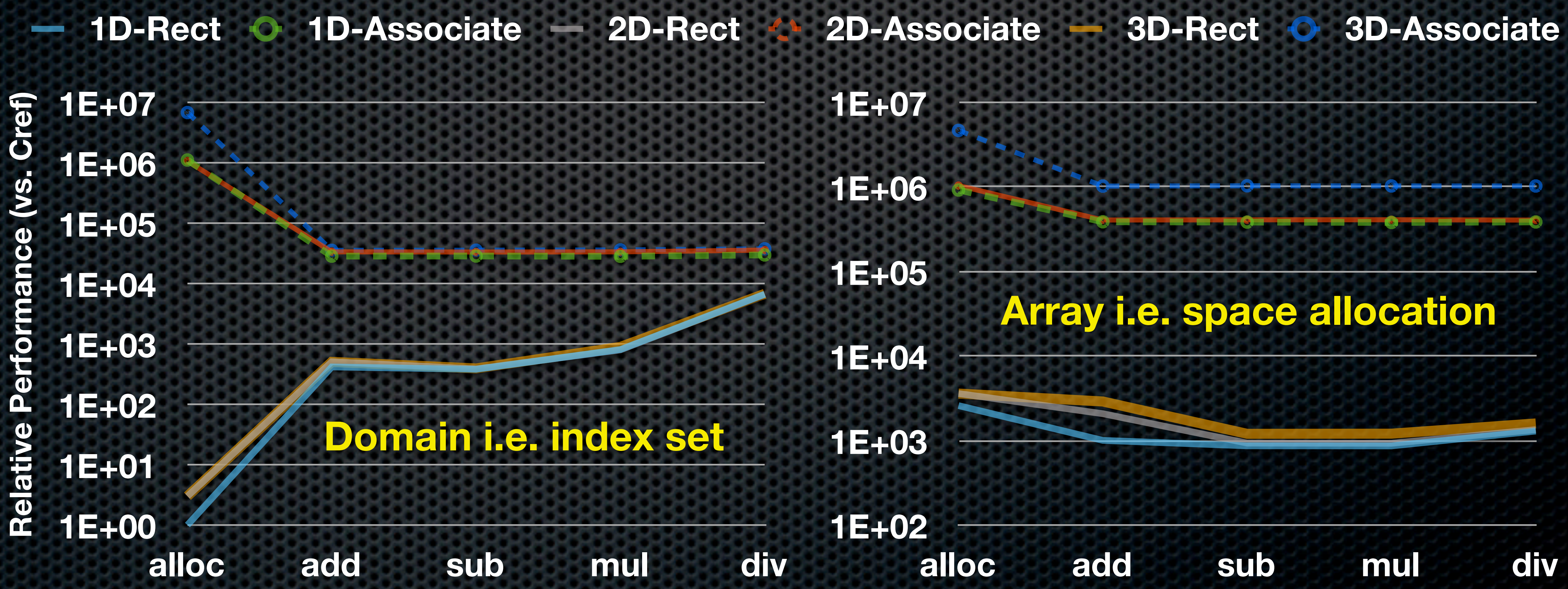
// Range
_build_range(...);
while (loop_variable) { ... }

// Pre-defined domain
_ret10 = dom;
...
_ret12 = (T45._low);
_ret13 = (T45._high);
...
while (loop_variable) { ... }

// User defined iterator
while (loop_variable) { ... }
```

# Domain and Array

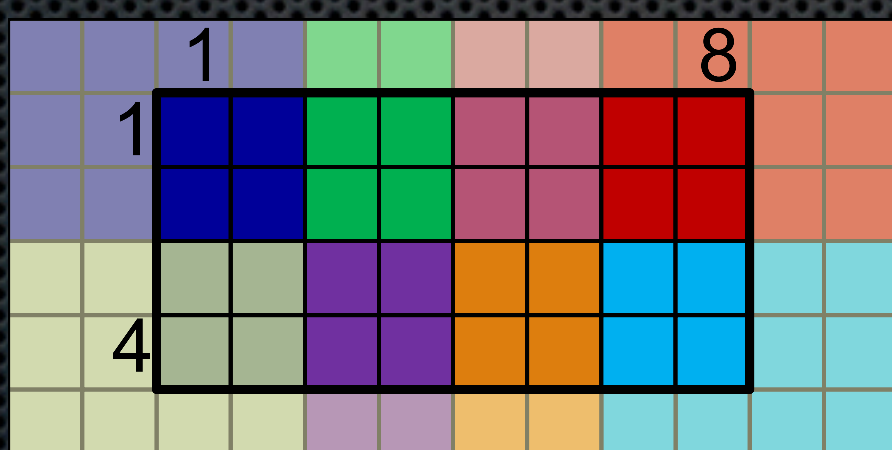
```
var rctDom3D: domain(3) = [1..N, 1..N, 1..N];// rectangular
domain
var rctArr3D: [rctDom3D] real;
var irrDom3D: domain(3*int);                      // irregular domain
var irrArr3D: [irrDom3D] real;
```



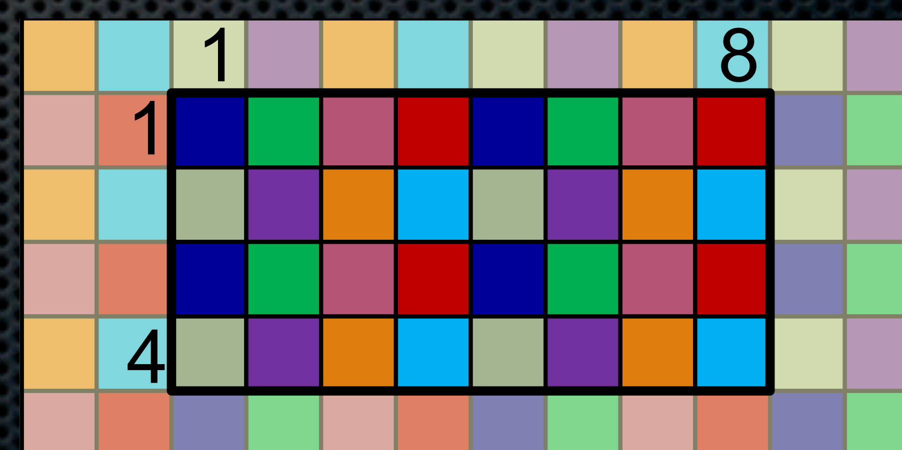
# Domain Maps (1/2)

```
var space = [1..N, 1..N];
var blockSpace = space dmapped Block(space);
var arrBlock: [blockSpace] real;
var cyclicSpace = space dmapped Cyclic(space);
var arrCyclic: [cyclicSpace] real;
var blkCycSpace = space dmapped BlockCyclic(space);
var arrBlkCyc: [blkCycSpace] real;
var replicatedSpace = space dmapped ReplicatedDist();
var arrRep: [replicatedSpace] real;

for d in arr.domain do on Locales(here.id) do
  /* arithmetic on arr(d) */
```

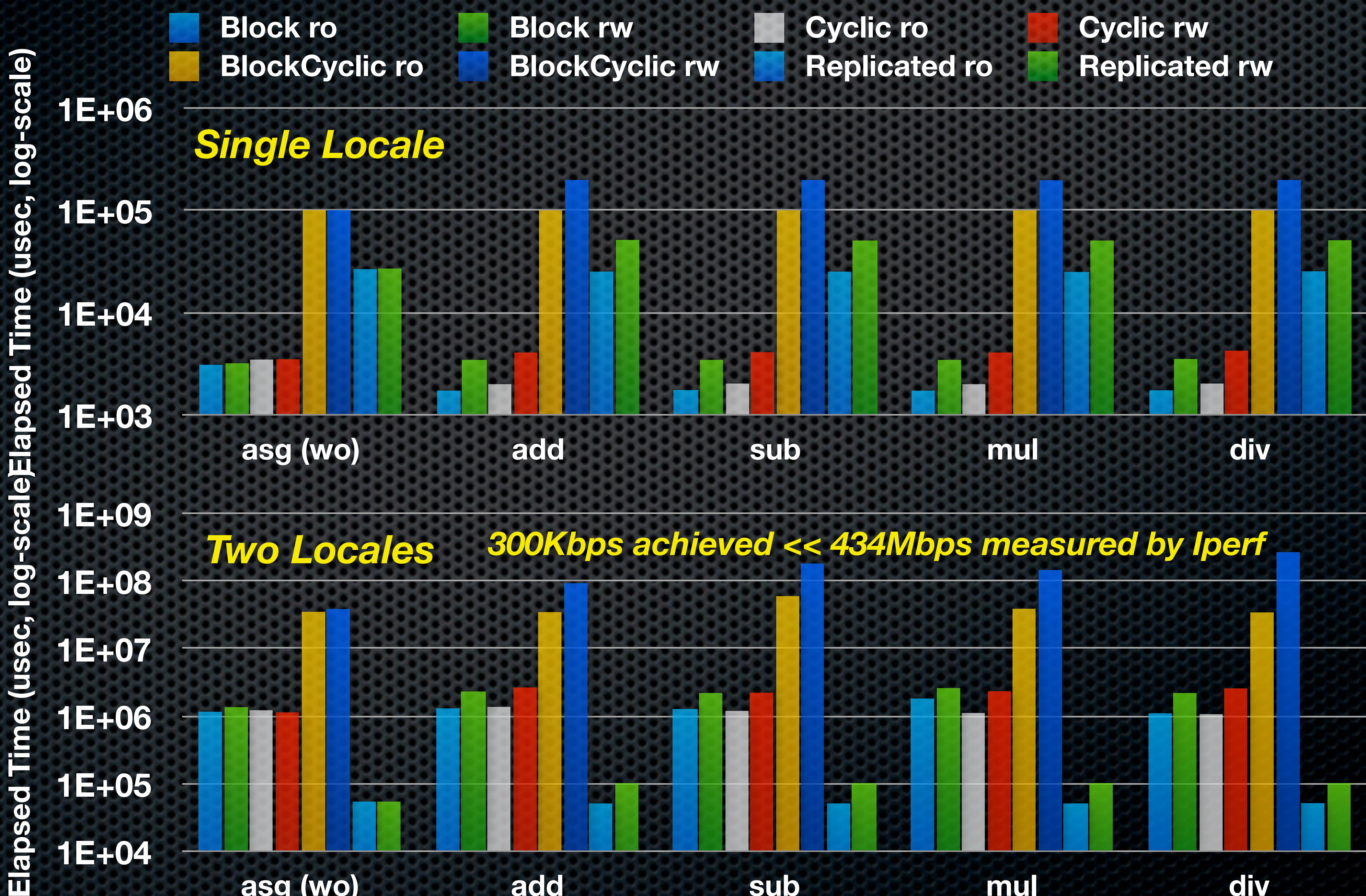




**Block Distribution**




**Cyclic Distribution**

# Domain Maps (2/2)

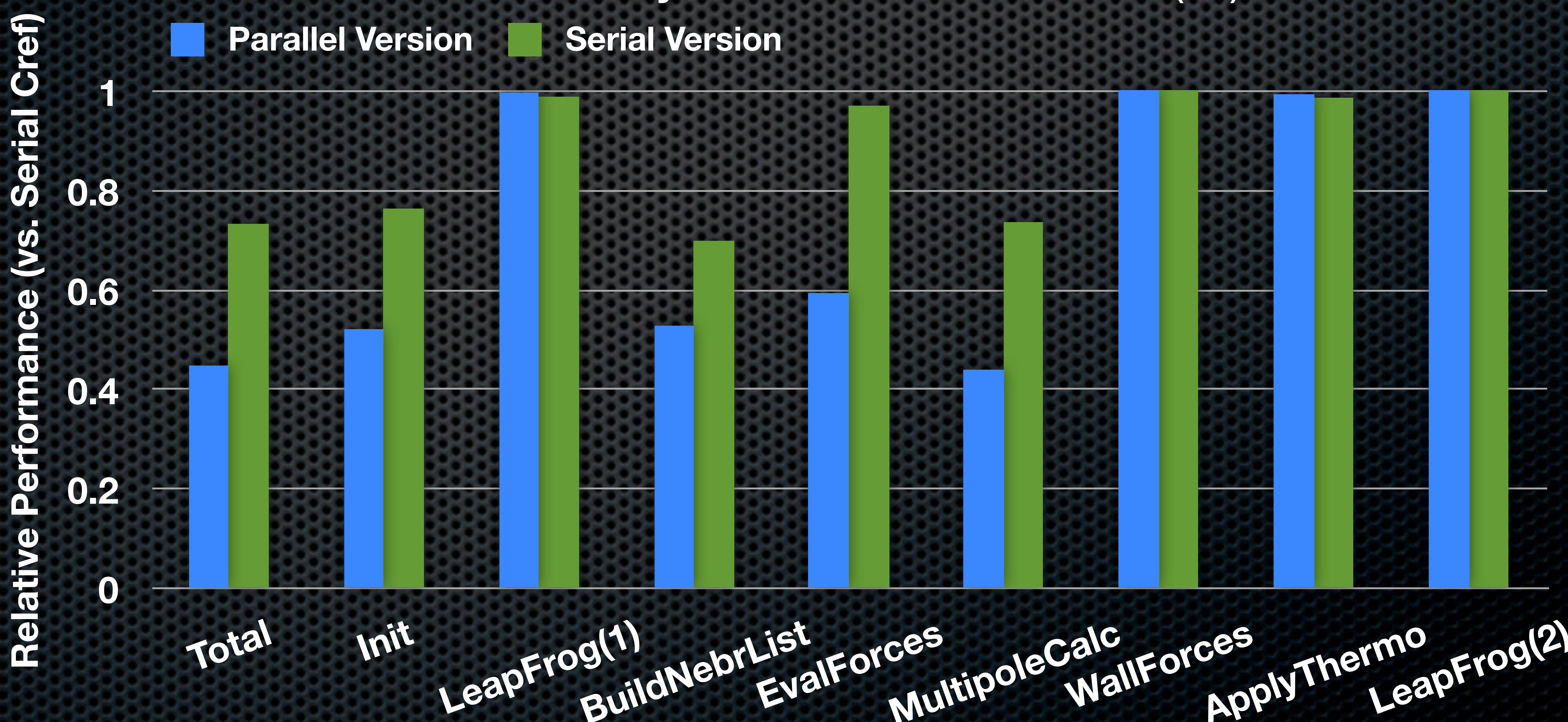


# Speedup FMM Application

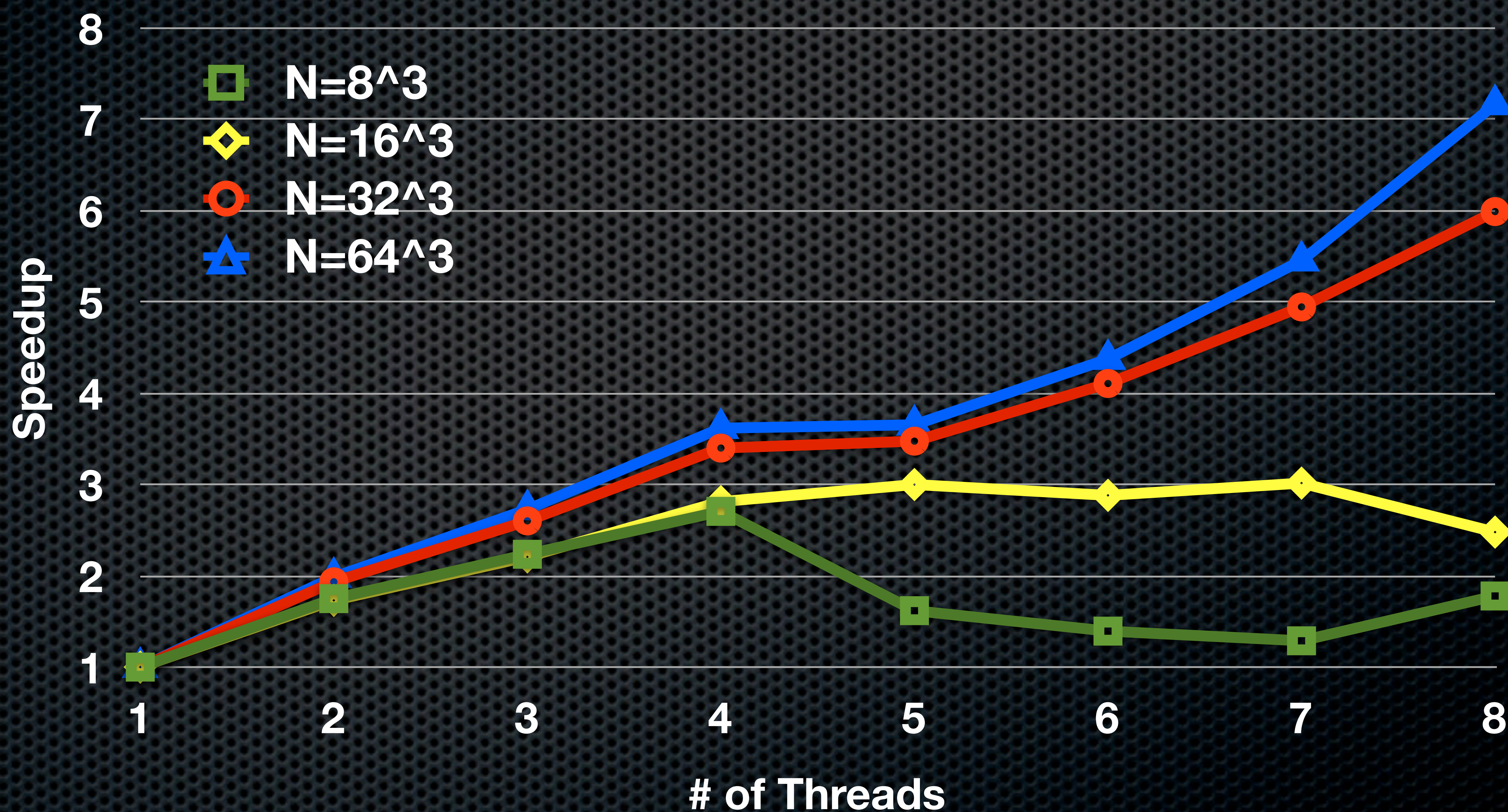
- Manipulate a large array of structured elements
  - Use record instead of tuple
  - Optimize small inner loop
- Auxiliary data structure
  - Use rectangular domain instead of associative domain
- Reduce locks to improve scalability
  (increase computation in some cases)

# Molecular Dynamics (1/2)

- Fast Multipole Method
  - Calculate the *N*-body interactions in O(*N*) time



# Molecular Dynamics (2/2)



# Related Work

- Evaluations of the Chapel language
  - Programmability [Chamberlain et al. '06,'07,'08,'11]
  - Performance potential [Barrett et al. '08]
  - HPCC benchmark [Chamberlain et al. '11]
    - 95% for EP STREAM & 50% for Random Access
  - Task parallel feature [Weiland et al. '09]
  - On GPGPU [Ren et al. '11]

# Conclusions

- Chapel can achieve comparable performance to C
  - 70%~ on single locale (w/ current v1.4.0)
  - User should be aware of performance implications
    - Choose proper data structure
    - Write program in proper structure
  - Current performance penalties are FIXABLE
    - By improving the Chapel compiler

# Questions?