Data-Centric Locality in Chapel

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Outline

- Background on multi-locale implementation
- 1.10 multi-locale performance issues
- Data-centric approaches to improving performance
- Performance results
- Future work

Background on multi-locale implementation

- 'Wide pointers' represent potentially remote vars

```
typedef struct {
  int localeID: // where this object lives
  myClass addr; // pointer to data
} wide_myClass;
```

- Runtime GETs and PUTs used to read/write data

Compiler-generated C

```
void bar(wide_myClass foo) {
  myClass local_foo;
  local_foo = comm_get(foo.locale, foo.addr);
  // do things with 'local_foo'
}
```

Background on multi-locale implementation

- Runtime will avoid unnecessary communication

```
void* comm_get(int id, void* addr) {
  if (id == here.id) {
    return addr;
  } else {
    // comm layer call
  }
}
```

1.10 multi-locale performance issues

- **Wide pointers are conservatively introduced**
  - Simple implementation
  - Easier to ensure program correctness

- **Local data is often represented with wide pointers**
  - Unnecessary overhead

- **This is particularly bad for arrays**
  - Wide pointer overhead for every array access
  - May prevent back-end C compiler optimizations

1.10 multi-locale performance issues

- **Functions have the most general declaration**

- **If an argument is wide, the function formal will be wide**
  - Insert a temporary if the actual is not wide
  - Particularly bad for member functions

```
void myClass_foo(wide_myClass this) { … }

wide_myClass X;
myClass_foo(X); // 'bar' now has to be wide

myClass Y;
wide_myClass temp;
temp.locale = here.id;
temp.addr = Y;
myClass_foo(temp);
```

1.10 multi-locale performance issues

- **Before 1.11, all fields were conservatively widened**
  - If that field was a class

- **Again, especially bad for arrays**

Chapel code

```
// Simplified internal array representation
class ArrayClass {
  var dom : domain;
  var data : cPtr(int);   // wide pointer
}
```

1.10 multi-locale performance issues

- The ‘local’ block tends to save us in distributed code

```
// Simplified implementation of distributed array access
proc DistArray.access(var idx : int) {
  local {
    if isLocalIdx(idx) then return locData[idx];
  }
  // remote code
}
```

- Assertion that no communication is required
  - Informs the compiler to not insert wide pointers

- Pros: simple implementation, good performance
- Cons: Imprecise, scoping issues

Data-centric improvements

- Problem: too many coarse-grained decisions
- Compiler: “every field must be wide”
- Developer: “everything in this block is local”
- Better: reason about locality on a data-centric basis
- Goal: get rid of the local block

Data-centric improvements – local fields

- **New in 1.11: the "local field" pragma**

- **Allows class designers to assert locality for each field**
  - Only works for class fields within an aggregate type
  - Automatically applied to arrays in an aggregate type

```
// Simplified internal array representation
class ArrayClass {
  var dom : domain;

  pragma "local field"
  var data : cPtr(int);   // compiler can reduce overhead
}
proc ArrayClass.check() {
  return this.locale.id == data.locale.id;
}
```

Data-centric improvements – local fields

- **Applied this pragma to C pointers in DefaultRectangular**
  - DefaultRectangular is…
    …the domain map used to implement local arrays by default
    …also used as the guts of virtually every other domain map (e.g., Block)
  - Its pointers should never point to remote data
  - Represents a significant source of overhead given its widespread use

- **Runtime checks inserted to ensure correctness**
  - Invoked on reads or writes of such fields
  - Generates runtime error if field is assigned remote data
  - Can disable with "--no-local-checks"
    - Or with --no-checks or --fast

Data-centric improvements – functions

- Arrays and domains are implemented as classes

- Compiler tends to widen the "this" argument

```
void myClass_foo(wide_myClass this, …) { … }
```

- Need to insert wide temps if actual isn't wide

Data-centric improvements – functions

- **Possible solution: duplicate member functions**

```
void myClass_foo(wide_myClass this, …) { … }
void myClass_foo(myClass this, …) { … }
```

- **Currently implemented on a dev branch**
  - Complicates implementation
  - Larger generated-C code size
  - Positive performance improvements

Performance results

- **Collected on 64-bit Linux with 2 quad core (8 HT) Intel Xeon processors**
  - 8 cores, 16 threads, 48GB ram
- **Numbers gathered using 1.10 and 1.11 releases**

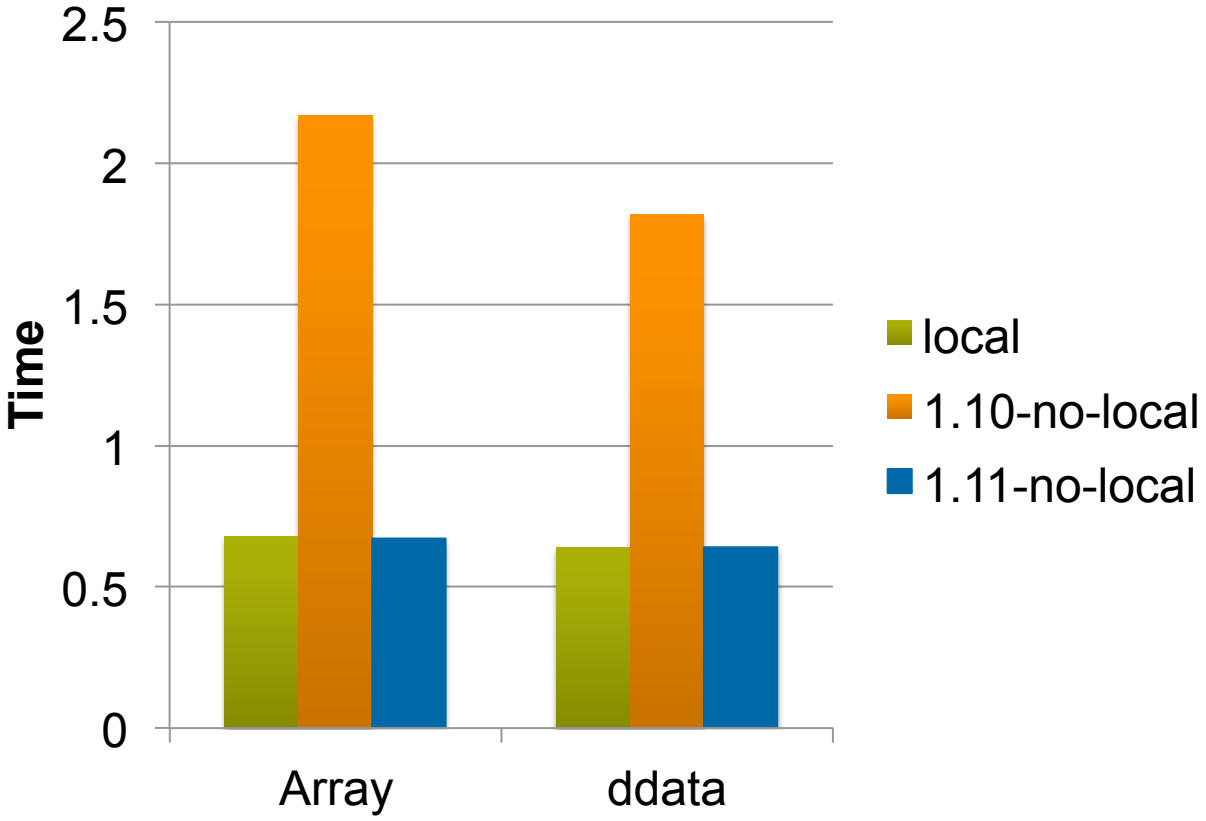
Performance results

- **No multi-locale numbers (yet)**
  - "local" block squashes most distributed overhead

- **These numbers compare local vs no-local**
  - local: compiling without a comm layer, zero wide pointers
  - no-local: inserts wide pointers, even if no comm layer is selected

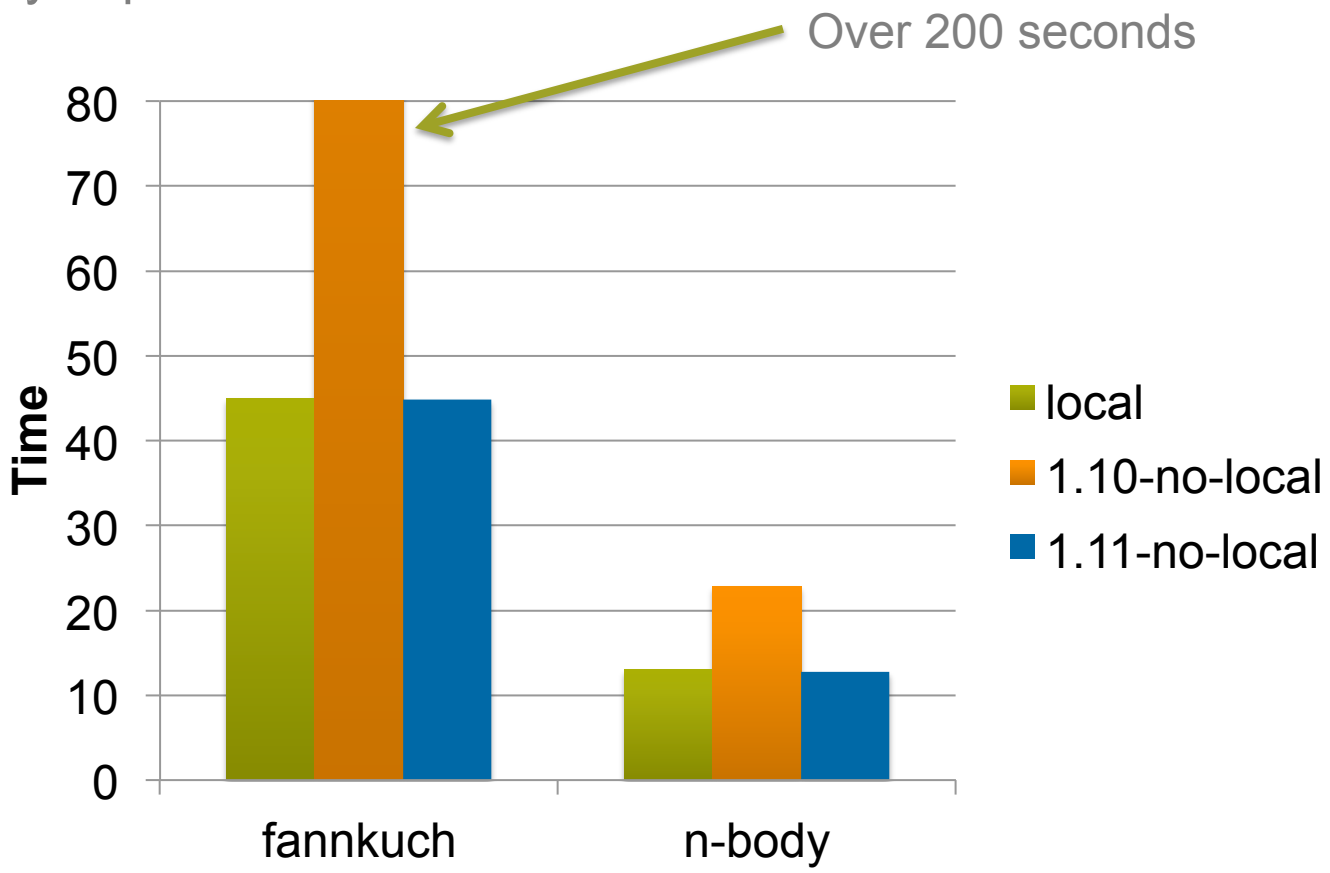
Performance results

- **Serial array iteration**
  - Mostly improved due to local fields



Performance results

- **Computer Language Benchmarks Game**
  - Mostly improved due to local fields



Performance results

- **HPCC STREAM-EP: Background**

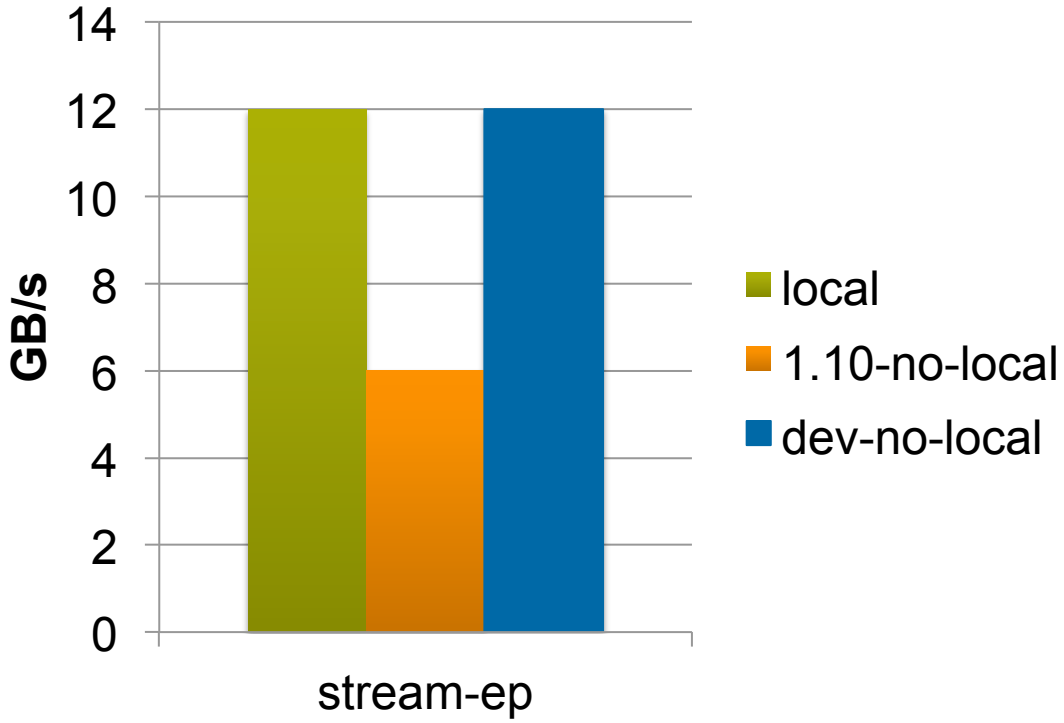
```
coforall loc in Locales do on loc {
  local {  // shouldn't need this, clearly no communication
      var A, B, C : [1..n] real;
      const alpha = 3.0;

      initVectors(B, C);

      for trial in 1..numTrials {
        forall (a, b, c) in zip(A, B, C) do
          a = b + alpha * c;
      }
  }
}
```

Performance results

- **STREAM-EP (without local block)**
  - Bigger is better
  - Mostly improved due to function duplication
  - Gathered with clang 5.1



Future work

- **Use "local field" pragma in more places**

- **Replace pragma with a robust language-level construct**
  - Not just fields
    - Array elements
    - Regularly-scoped variables
  - Still in design phase
    - But here's an idea:

```
var baz : local Foo;

var data : [1..10] local Foo;

// Instead of a pragma…
class Bar {
  var f : local Foo;
}
```

Future work

- **Deprecate the 'local' block**
  - This statement is imprecise
  - Scoping rules limit its applicability
  - We would prefer finer-grained, data-centric locality assertions

- **Support Local Array Views**
  - Often a program wants to only work with local array data
    - typically results in similarly conservative "is this element remote?" checks
  - Doing so today is possible, but a bit clunky
  - Sketch of concept:

```
var myLocArrElts = Arr[local];
…myLocArrElts[i,j]…     // fast local access to A[i,j]; OOB if (i,j) is remote
```

  - Current array-view effort provides a framework for this feature

Future work

- Given "`on foo do` …"

- **Avoid on-statement overhead**
  - If `foo` is local, we can avoid runtime overhead for on-statements
  - Namely, avoid allocating bundled arguments
    - This is important for atomic operations, which have on-statements

- **Optimize `foo` within the on-statement**
  - By definition, the on-statement will execute on `foo`'s locale
  - Thus, we know references to `foo` are local within the on-statement

Summary

- Allowing developers to assert locality is valuable
- The compiler should (and can be) smarter about locality
- These two factors should result in improved performance

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