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

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

- Runtime GETs and PUTs used to read/write data

```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

```c
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

```c
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

```chapel
// 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

```plaintext
// 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

```plaintext
// 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

```c
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**

  ```c
  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

Over 200 seconds

- **fannkuch**
- **n-body**

<table>
<thead>
<tr>
<th></th>
<th>local</th>
<th>1.10-no-local</th>
<th>1.11-no-local</th>
</tr>
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<td></td>
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<td>fannkuch</td>
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<tr>
<td>n-body</td>
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<td></td>
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</tr>
</tbody>
</table>
Performance results

- HPCC STREAM-EP: Background

```coforall
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:

```scala
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:
    ```javascript
    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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