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LLVM-based Communication Optimizations for Chapel

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TM

A Big Picture

CRAY CHAPEL

BERKELEY UPC UNIFIED PARALLEL C

Habanero-C, ...

LLVM

COMPILER INFRASTRUCTURE

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LLVM-based Chapel compiler

- Use of address space feature of LLVM offers more opportunities for **communication optimization** than C generation

```
// Chapel
x = possibly_remoteData;
```

```
// C-Code generation
chpl_comm_get(&x, …);
```

Backend Compiler's Optimizations
(e.g. gcc –O3)

```
// LLVM IR Generation
%x = load i64 addrspace(100)* %xptr
```

LLVM Optimizations
(e.g. LICM, scalar replacement)

Pictures borrowed from 1) http://chapel.cray.com/logo.html
2) http://llvm.org/Logo.html

An optimization Example : Communication Optimization with the existing LLVM passes

```
(Pseudo-Code: Before LICM)
for i in 1..N {
    // POSSIBLY REMOTE GET
    %x = load i64 addrspace(100)* %xptr
    A(i) = %x;
}
```

Remote data access per each iteration

LICM by LLVM

```
(Pseudo-Code: After LICM)
// POSSIBLY REMOTE GET
%x = load i64 addrspace(100)* %xptr
for i in 1..N {
    A(i) = %x;
}
```

Hoisted out of the loop!

LICM = Loop Invariant Code Motion

An optimization Example : Bulk Transformation (Coalescing)

```
(Pseudo-Code: Before Bulk Transformation)
for i in 1..N {
    // POSSIBLY REMOTE GET
    … = A(i);
}
```

Remote array access per each iteration

Bulk Transformation

```
(Pseudo-Code: After LICM)
var localA: [1..N] int;
localA = A; // Bulk Transfer
for i in 1..N {
    … = localA(i);
}
```

Create Local Buffer & Perform bulk transfer

Converted to Definitely-Local Access!

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An Optimization Example : Locality Inference for avoiding runtime affinity checking

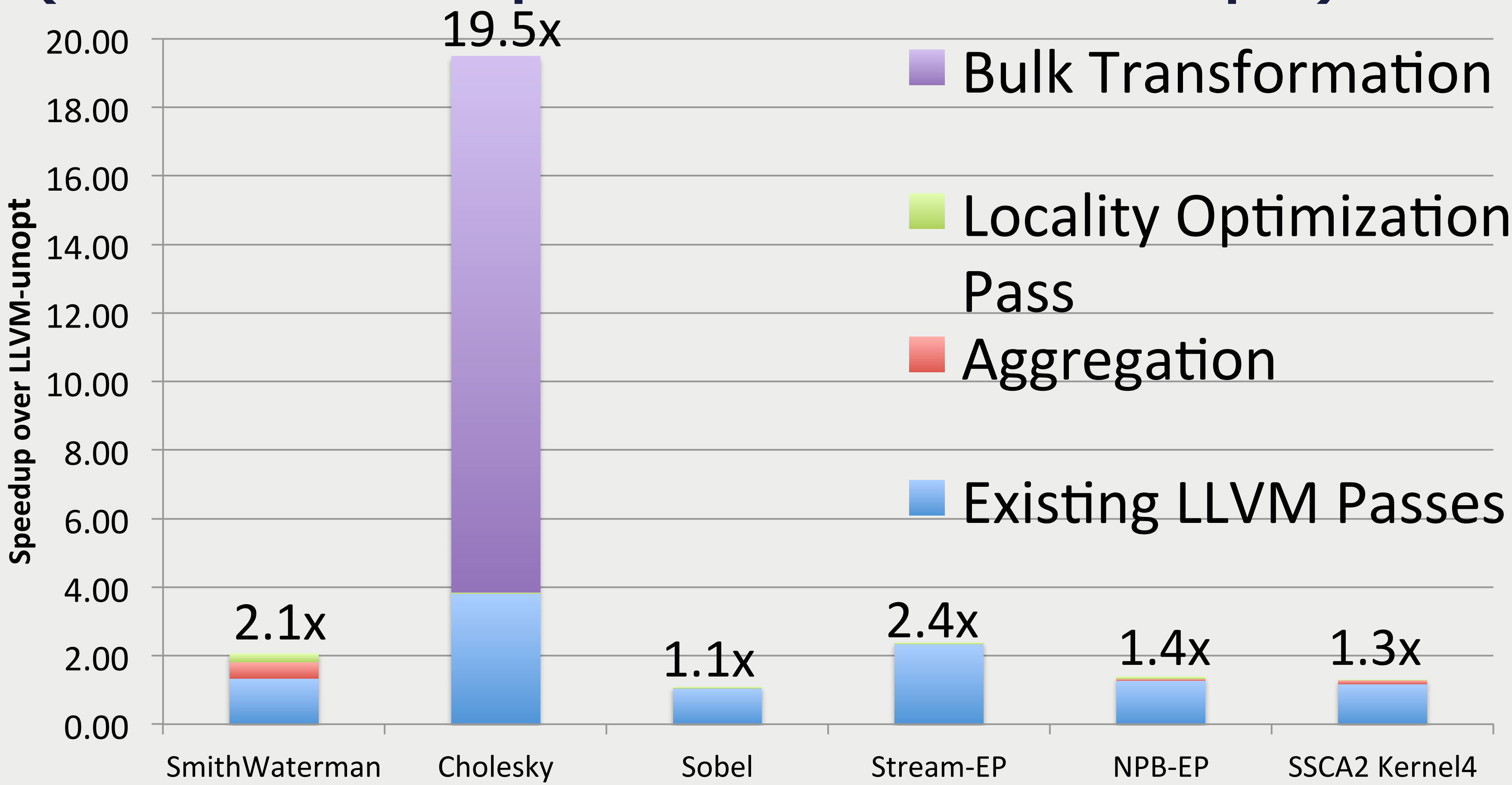
```
proc habanero(ref x, ref y, ref z) {
    var p: int = 0;
    var A:[1..N] int;
    if (x == 0) {
        p = y;
    } else {
        local { p = z; }
    }
    z = A(0) + z;
}
```

A is definitely-local

p and z are definitely local

Definitely-local access!
(avoid runtime affinity checking)

Results on Cray XC-30 (LLVM-unopt vs. LLVM-allopt)



4.6x performance improvement on average
(6 applications, 1, 2, 4, 8, 16, 32, 64 locales)

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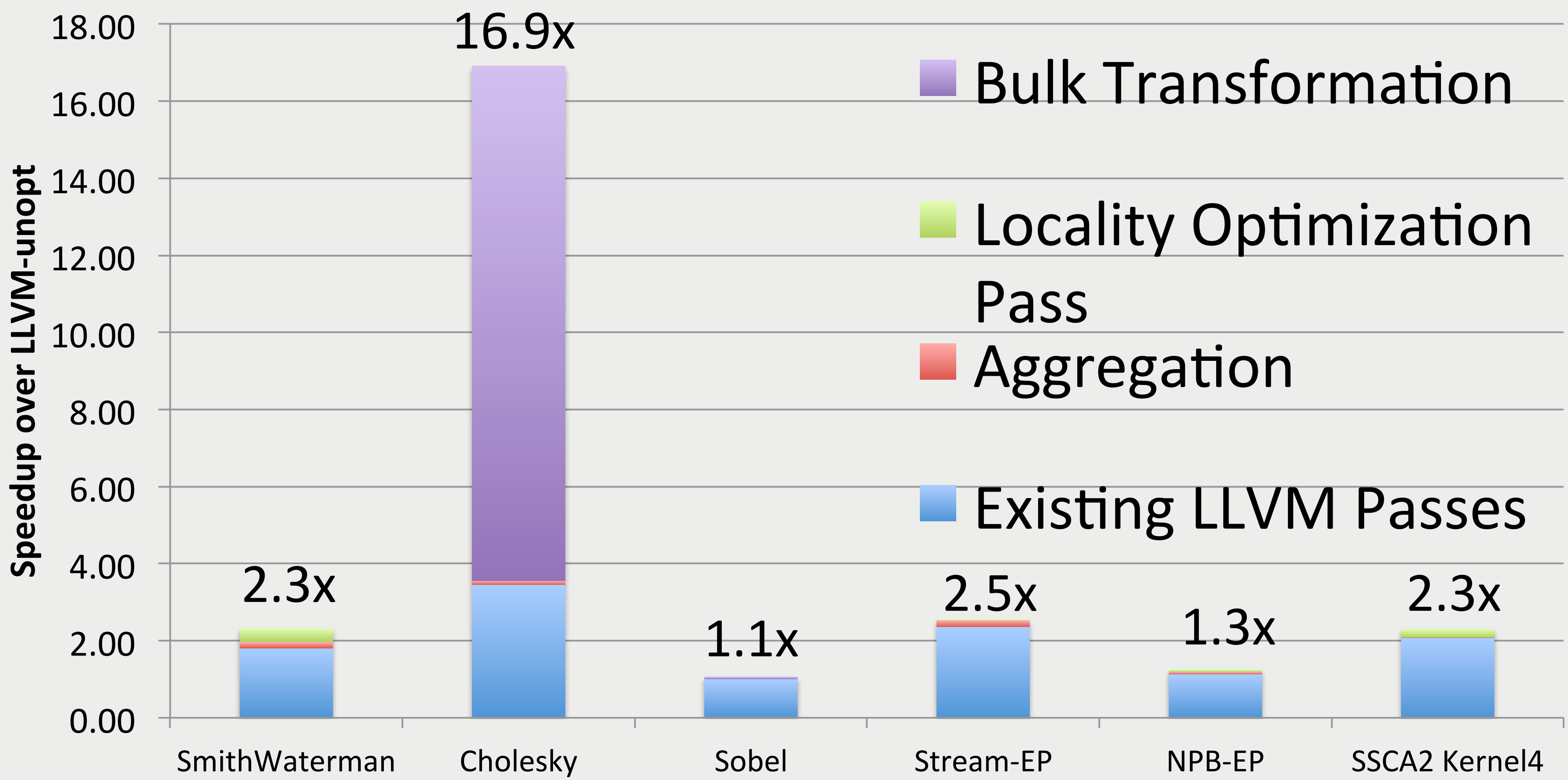
Results on Westmere Cluster (LLVM-unopt vs. LLVM-allopt)



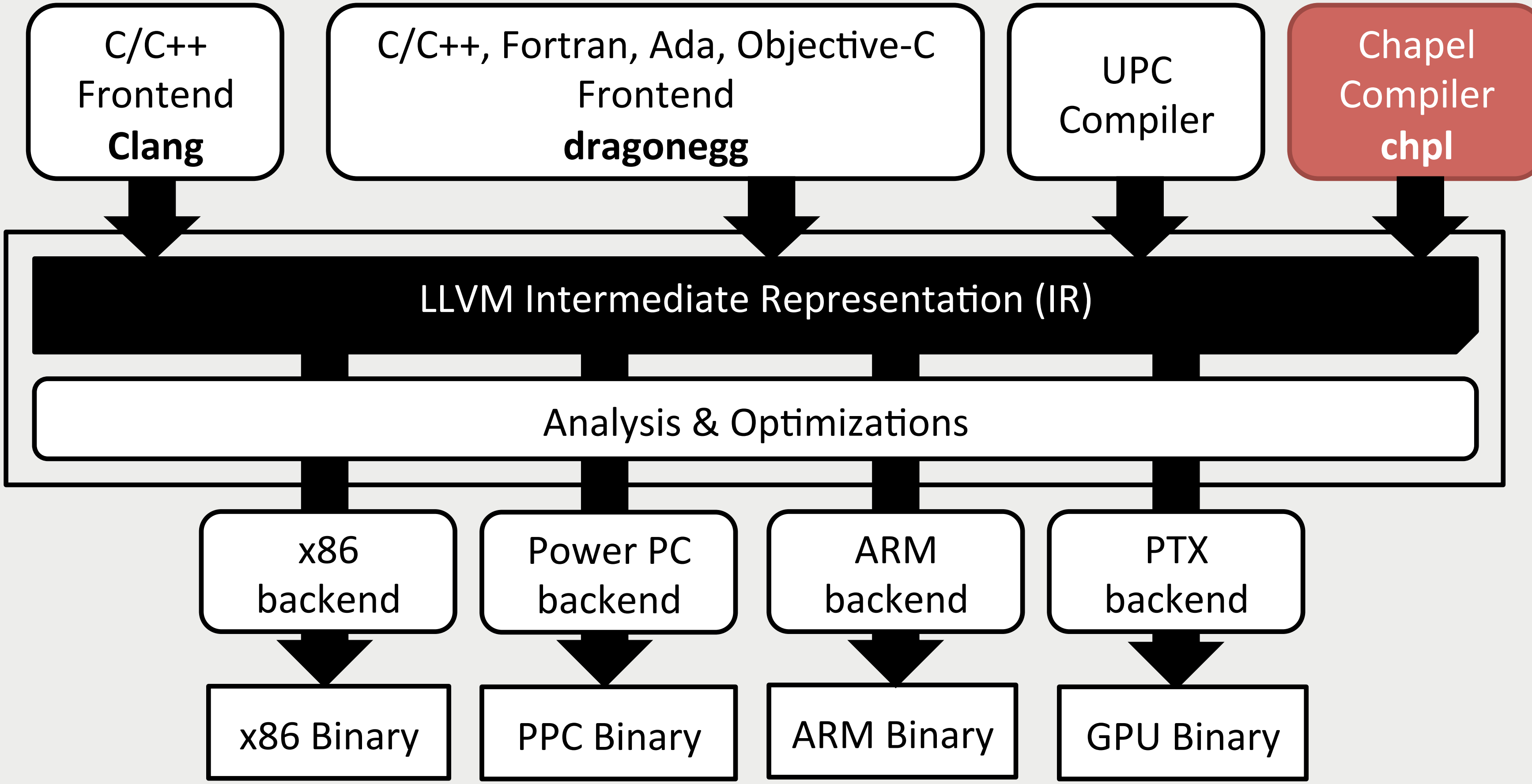
4.4x performance improvement on average
(6 applications, 1, 2, 4, 8, 16, 32 locales)

Conclusions

- LLVM-based Communication optimizations for Chapel
- Preliminary Evaluation with 6 applications
  - Cray-XC30 Supercomputer
    - 4.6x average performance improvement
  - Westmere Cluster
    - 4.4x average performance improvement
- Future Work
  - Extend for other languages

Backup slides

LLVM IR Generation from Chapel



LLVM-based Communication Optimizations for Chapel

- 1) Wide pointer optimization (--llvm-wide-opt)
  - Utilize the existing optimization passes such as loop invariant code motion for the purpose of communication optimization (The Existing LLVM Passes)
  - Combine sequences of loads/stores on adjacent memory locations into a single memcpy (Aggregation Pass)
- *2) Bulk Transformation (Coalescing data accesses)*
  - Create locale-local buffer
  - Insert bulktransfer and replace remote accesses with local buffer access
- *3) Locality optimization (Locality-Inference)*
  - Transform *possibly-remote* access to *definitely-local* access at compile-time to avoid runtime affinity checking

These optimizations are built on top of address space feature of LLVM

Performance Evaluations: Platforms

- Cray-XC30 Supercomputer @ NERSC
  - Per Node information
    - Intel Intel Xeon E5-2695 @2.40GHz x 24 cores
    - 64GB of RAM
  - Interconnect
    - Cray Aries interconnect with Dragonfly topology
- Westmere Cluster @ Rice
  - Per Node information
    - Intel Xeon CPU X5660@2.80GHz x 12 cores
    - 48GB of RAM
  - Interconnect
    - Quad-data rated Infiniband
    - Mellanox FCA support

Performance Evaluations: Details of Compiler & Runtime

- Compiler:
  Chapel version 1.9.0.23154 (Apr. 2014)
  - LLVM 3.3
- Runtime:
  - GASNet-1.22.0
    - Cray-XC30 : aries
    - Westmere Cluster : ibv-conduit
  - qthreads-1.10
    - Cray-XC30 : 2 shepherds, 24 workers/shepherd
    - Westmere Cluster : 2 shepherds, 6 workers/shepherd

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Benchmark	Comm Kind	**Cray XC-30**	
		`LLVM-gopt`	`LLVM-allopt`
Smith-Waterman Note : obtained with 18,560x19,200 input	LOCAL_GET	63.6%	75.5%
	REMOTE_GET	36.4%	36.7%
	LOCAL_PUT	58.0%	58.0%
	REMOTE_PUT	0.0%	0.0%
Cholesky Note : obtained with 2,000x2,000 input	LOCAL_GET	77.6%	87.9%
	REMOTE_GET	84.7%	99.8%
	LOCAL_PUT	10.3%	10.8%
	REMOTE_PUT	0.0%	0.0%
NPB EP	LOCAL_GET	58.6%	58.6%
	REMOTE_GET	39.7%	39.7%
	LOCAL_PUT	29.5%	58.8%
	REMOTE_PUT	0.0%	0.0%
Sobel Note : obtained with CLASS=B	LOCAL_GET	74.6%	95.2%
	REMOTE_GET	0.0%	0.0%
	LOCAL_PUT	35.8%	68.3%
	REMOTE_PUT	0.0%	0.0%
SSCA2	LOCAL_GET	55.6%	56.2%
	REMOTE_GET	60.9%	60.8%
	LOCAL_PUT	5.6%	3.8%
	REMOTE_PUT	0.0%	0.0%
Stream-EP	LOCAL_GET	70.6%	70.6%
	REMOTE_GET	35.7%	35.7%
	LOCAL_PUT	17.3%	17.3%
	REMOTE_PUT	0.0%	0.0%

Table 3. The amount of Chapel Comm APIs calls made by `LLVM-gopt` and `LLVM-allopt` relative to `LLVM-unopt` (Cray-XC30, 16 locales)

Future Work: A compiler that can uniformly optimize PGAS Programs

- Extend LLVM IR to support parallel programs with PGAS and explicit task parallelism
  - Two parallel intermediate representations(PIR) as extensions to LLVM IR (Runtime-Independent, Runtime-Specific)

Parallel Programs (Chapel, X10, CAF, HC, …) → 1.RI-PIR Gen 2.Analysis 3.Transformation → 1.RS-PIR Gen 2.Analysis 3.Transformation → Binary

LLVM Runtime-Independent Optimizations	LLVM Runtime-Specific Optimizations
e.g. Task Parallel Construct	e.g. GASNet API