Los Alamos
NATIONAL LABORATORY
EST. 1943

The ARES High-level Intermediate Representation

Nick Moss, Kei Davis, Pat McCormick

11/14/16

About ARES

- HLIR is part of the ARES project (Abstract Representations for the Extreme-Scale Stack)
- Inter-operable tools and approaches for programming next-generation architectures
- LANL (Pat McCormick) + ORNL (Jeffrey Vetter)
- Funded by: Advanced Scientific Computing Research, Office of Science, of the United States Department of Energy

HLIR Motivation

- LLVM remains a purely sequential representation while parallel programming is becoming increasingly ubiquitous with the end of Moore's law.

- Parallel functionality is often achieved through libraries, but use of libraries alone lead to missed optimization opportunities and programmability challenges.

HLIR Motivation

- Essential information about high level structures of the program is lost such as loops and typically has to be reconstructed from IR.

- Approaches such as Clang’s OpenMP perform analysis/transformations in the front-end. It would be preferable to write such parallel transformations once in the backend for targeting by multiple frontends.

HLIR Motivation

- Adding parallel extensions directly to LLVM is a challenging problem; adds complexity and would be very disruptive to core features of LLVM, e.g. control flow graph analysis and other types of analysis

- IR alone is perhaps too low-level; sequential may not be the best form; we posit the need for an AST-like representation

HLIR

- To address these concerns and needs we created HLIR (High Level Intermediate Representation)… to allow multiple frontends to target parallel functionality
- HLIR is an extension of LLVM, taking advantage of LLVM’s broad capabilities and infrastructure – HLIR can be viewed as a superset of LLVM.
- HLIR = representation + code generation / runtime interface

Parallel Constructs

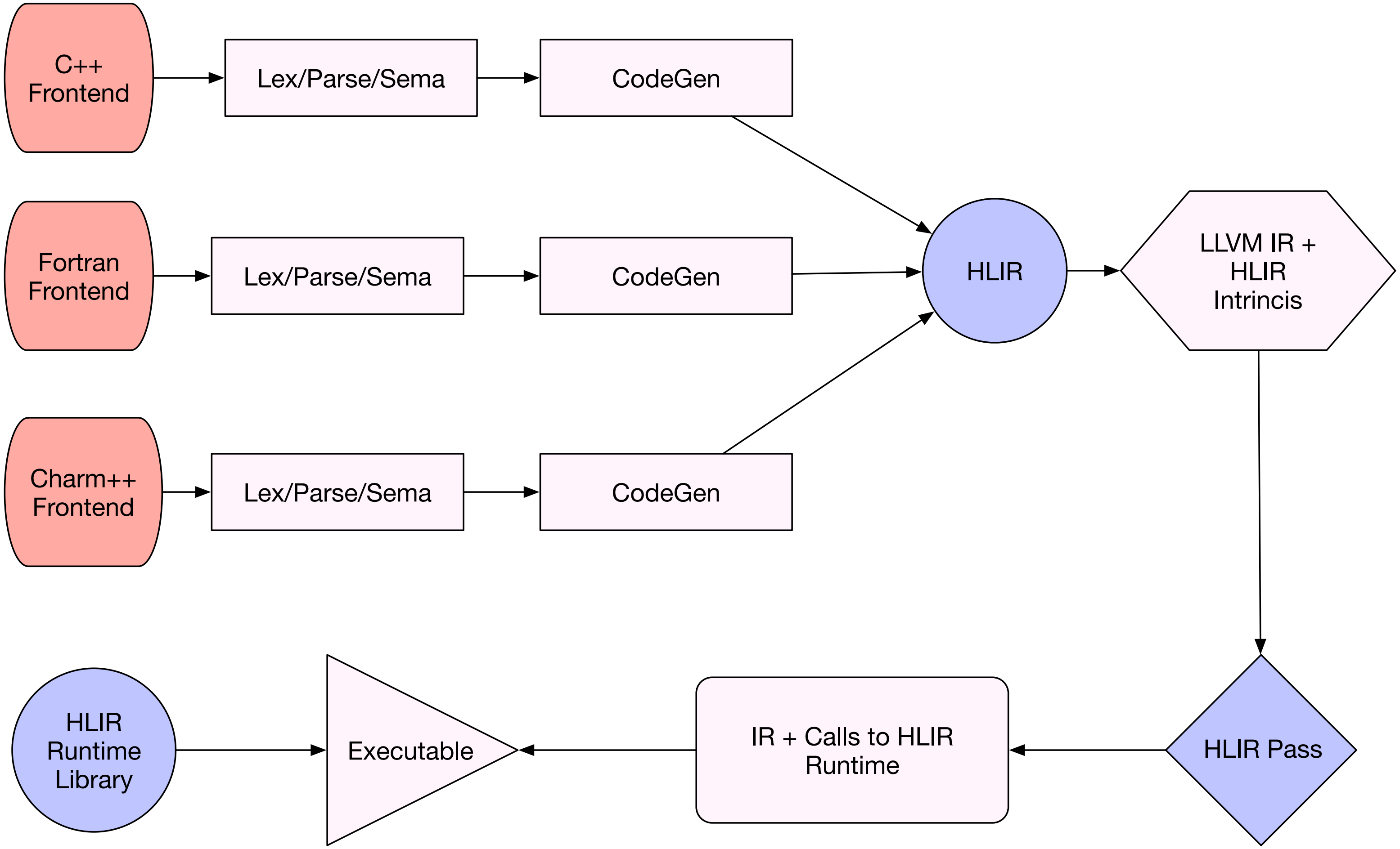
Our current implementation supports:

- tasks
- parallel for
- parallel reduce
- communication and synchronization building blocks

HLIR Features

- Extensibility
- Ease of use
- Human readable and in-memory representations
- Targetable by diverse types of frontends: C++, Fortran, … any language that uses LLVM for code generation
- Nested/hierarchical to represent AST-like structures such as parallel for loops
- Mutability and successive transformation

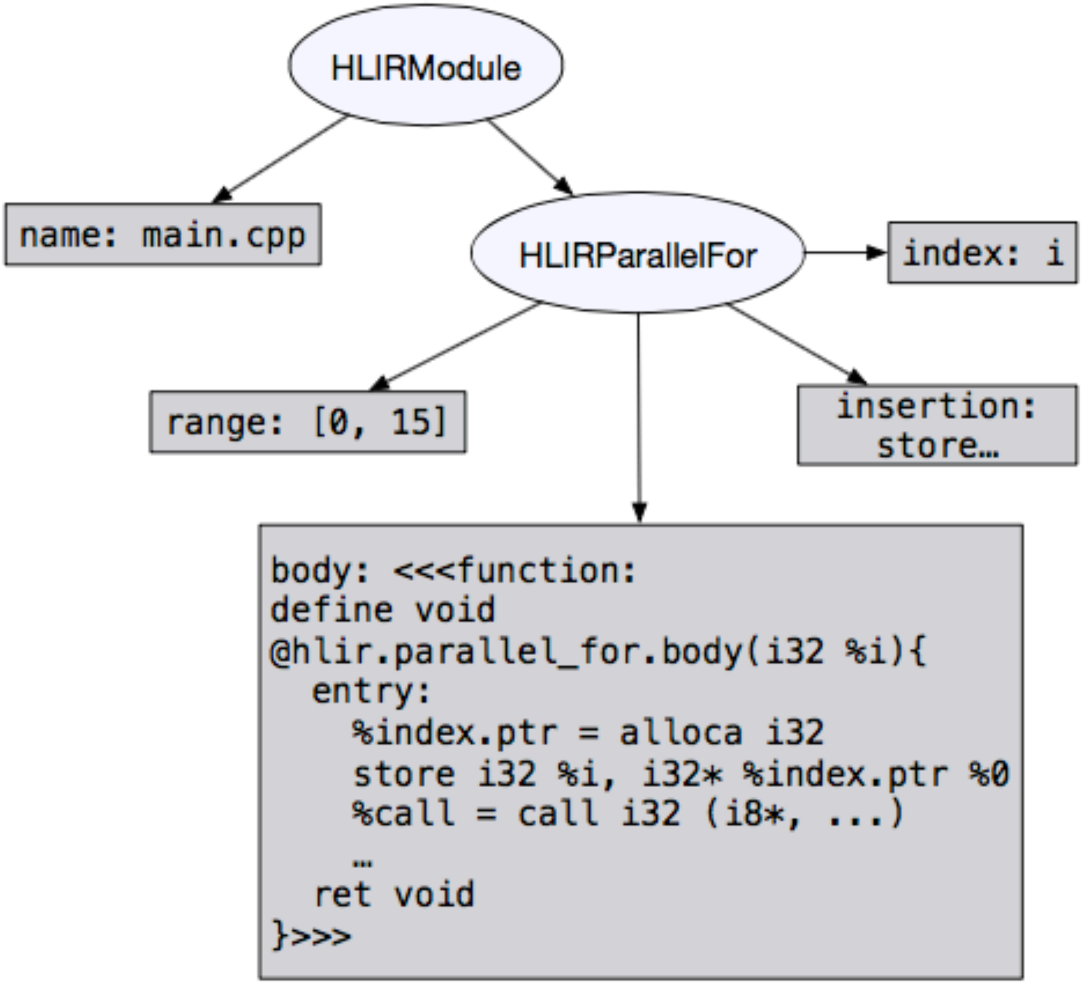
HLIR Flow


C++
Frontend
Lex/Parse/Sema
CodeGen
Fortran
Frontend
Lex/Parse/Sema
CodeGen
Charm++
Frontend
Lex/Parse/Sema
CodeGen
HLIR
LLVM IR +
HLIR
Intrincis
HLIR Pass
IR + Calls to HLIR
Runtime
Executable
HLIR
Runtime
Library

HLIR Module

- HLIR module – one-to-one correspondence with IR module
- HLIR module provides methods for creating parallel constructs, e.g. parallel for, contains top-level metadata
- For example, in the case of parallel for/reduce, HLIR sets up an outlined function and provides entry points for the body to be defined or induction or reduce variables retrieved

Sample HLIR Representation



UNCLASSIFIED

HLIR nodes

- Leaf nodes: symbol, string, floating, integer, IR Value, IR Type, arbitrary sequence of IR wrapped in function, etc.
- Dynamic/flexible, recursive nodes – heterogenuos types – vector, symbol map
- Constructs: Parallel For/Reduce, Task, etc. Constructs have key-mapped values, e.g: body, induction var, return type, etc.

Data Dependencies & Capturing

- One of the important benefits/abstractions that HLIR provides is capturing of data dependencies and bundling them up into a struct so that can be queued along with a function ptr to outlined function to our thread pool.

- A front-end performing code generation can conveniently neglect that values appearing within, e.g. a task body were defined externally.

Runtime

- Simple prototype runtime – defines an ABI interface which is potentially swappable with a different runtime
- Uses Argonne Argobots user-level threads => yield(), solves recursion problem, thread waits while occupying

- Thread pool, depth, synch
- Synchronization – barrier, “virtual” semaphores
- Communication building blocks – channels, message handlers

Tasks Implementation

- Body specified by frontend => outline, data capturing
- Transform calls to task-marked functions into HLIR intrinsic for task launch
- The return value becomes a future, HLIR pass looks for uses of this value and turns them into runtime calls to yield/await this future.

Parallel For/Reduce Implementation

- Body specified by frontend => outline, data capturing, same machinery as task

- Nested parallel for/reduce loops add complexity, data dependencies are unwrapped, and re-queued at each level

- Parallel Reduce – divide and conquer – entire algorithm code generated

Clang-based Frontend

- We implemented a proof of concept frontend by extending Clang to target HLIR. Adds first-class support for tasks and parallel for/reduce

- Only required <= approximately 100 lines of code added to Clang for each construct

Clang-based Frontend - Tasks

```
task int fib(int i){
  if(i <= 1){
    return i;
  }
  return fib(i- 1) + fib(i- 2);
}
```

Clang-based Frontend – Parallel For

```
float A[SIZE];
for(auto i : Forall(0 , SIZE)){
  A[i] = i;
}
```

Clang-based Frontend – Parallel Reduce

```
float sum = 0.0;
for(auto i : ReduceAll(0 , SIZE, sum)){
  sum += 1.0;
}
```

Related Work

- Open64
- Diderot
- GCC Gimple
- OpenARC
- OpenCL SPIR
- Scout, Kokkos Clang (LANL)

Future Work

- Additional parallel constructs, e.g. data layout and memory placement, data parallel, etc.
- Distributed functionality, integrate with communication infrastructure, tasks: data dependence
- Optimize execution/runtime, depth, priority, chunking parallel for, etc.
- Next phase: targeting/extending HLIR with OpenMP/OpenACC/pragma-based semantics

Conclusion

- Multiple frontends can target HLIR to benefit from a centrally optimized lowering and runtime system

- Target at a high-level while attaining benefits of low-level code generation and optimization

- Flexible and hierarchical, extensibility

Questions?

- Thanks for your time!

- ARES HLIR can be found at:
  https://github.com/losalamos/ares

- Questions?