Parallel and Distributed Extensions to the LLVM Compiler

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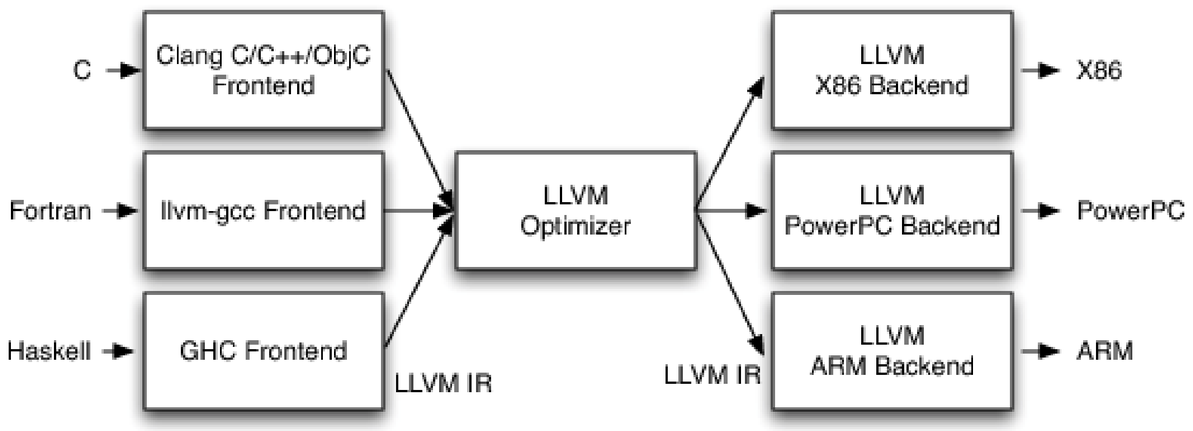
SuperUROP

The LLVM Compiler - Overview

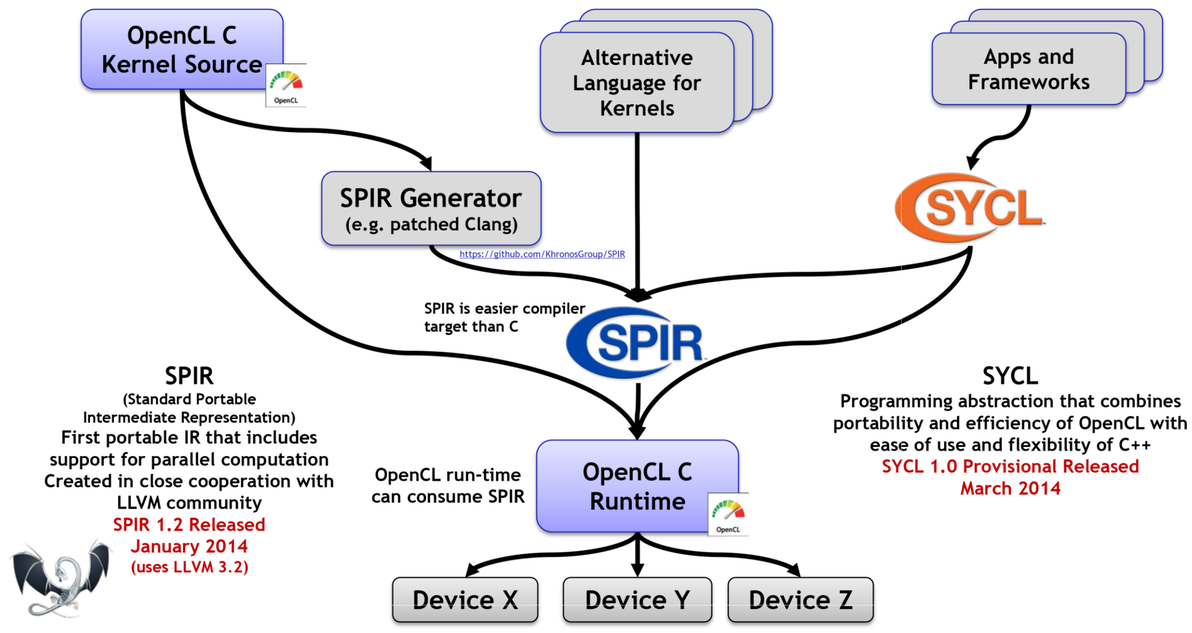


Objective

Propagate parallel interfaces exposed in the frontend (Clang) to the LLVM Backend, by designing a parallel interface in the Intermediate Representation level (LLVM IR).

Previous Work

Khronos Group OpenCL SPIR and Runtime



Provides	A parallel intermediate representation for OpenCL
Lacks	Support for other Parallel Interfaces and Runtimes

Common Parallel Interfaces

POSIX/Pthreads

- `pthread_create()`
- `pthread_join()`
- `pthread_kill()`
- `pthread_mutex_lock()`
- `pthread_mutex_unlock()`
- `pthread_cond_wait()`
- `pthread_cond_signal()`
- `int pthread_barrier_wait()`

OpenMP

- `#pragma omp parallel`
- `#pragma omp for`
- `#pragma omp sections`
- `#pragma omp teams`
- `#pragma omp single`
- `#pragma omp task`
- `#pragma omp barrier`
- `#pragma omp atomic`

Intel Cilk

- `cilk_spawn()`
- `cilk_sync()`
- `cilk_for()`
- `CILK_C_REGISTER_REDUCER()`
- `CILK_C_UNREGISTER_REDUCER()`
- `vectors`

Legion

- `Task`
- `region<int>`
- `reads()`
- `writes()`
- `Partition<>`
- `array<>`

Challenge

Translate the variety of these interfaces to a single Parallel Intermediate Representation (PIR). This PIR has to be an extension of the LLVM IR and be compatible with the LLVM Backend.

SPIRE: Sequential to Parallel IR Extension

Language	Execution	Synchronization				Memory	
	Parallelism	Task creation	Task join	Point-to-point	Atomic section	Model	Data distribution
Cilk (MIT)	—	spawn	sync	—	cilk_lock	Shared	—
Chapel (Cray)	forall coforall cobegin	begin	—	sync	sync atomic	PGAS (Locales)	(on)
X10(IBM), Habanero-Java(Rice)	foreach	async future	finish	next force get	atomic isolated	PGAS (Places)	(at)
OpenMP	omp for omp sections	omp task omp section	omp taskwait omp barrier	—	omp critical omp atomic	Shared	private, shared...
OpenCL	EnqueueND-RangeKernel	EnqueueTask	Finish EnqueueBarrier	events	atom_add, ...	Distributed	ReadBuffer WriteBuffer
MPI	MPI_Init	MPI_spawn	MPI_Finalize MPI_Barrier	—	—	Distributed	MPI_Send MPI_Recv
SPIRE	**sequential, parallel**	**spawn**	**barrier**	**signal, wait**	**atomic**	Shared, Distributed	**send, recv**

Porting to LLVM

SPIRE can be ported to LLVM IR by adding a small set of attributes to standard LLVM objects.

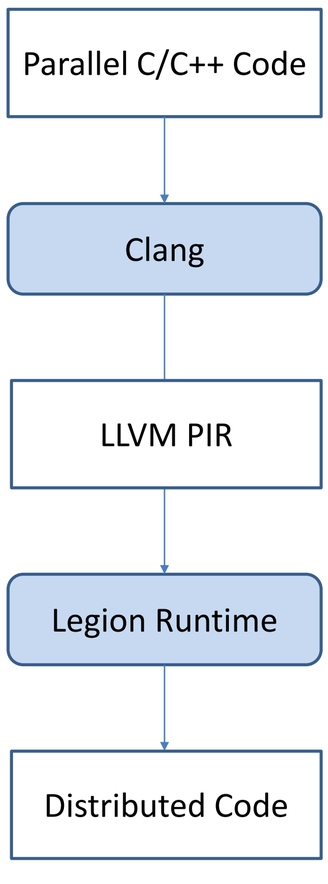
LLVM Parallel IR

This is our plan to port SPIRE to LLVM.

- An `execution` attribute is added to `function` and `block`: a parallel basic block sees all its instructions launched in parallel (in a fork/join manner), while all the blocks of a parallel function are seen as parallel tasks to be executed concurrently;
- A `synchronization` attribute is added to `instruction`; therefore, an instruction can be annotated with `spawn`, `barrier`, `single` and `atomic` synchronization attributes. When one wants to deal with a sequence of instructions, this sequence is first outlined in a function, to be called instead; this new call instruction is then annotated by the proper synchronization attribute, such as `spawn`, if the sequence must be considered as an asynchronous task. A similar technique is used for the other synchronization constructs `barrier`, `single` and `atomic`.
- As LLVM provides a set of intrinsic functions [13], SPIRE functions `newEvent`, `signal` and `wait` for handling point-to-point synchronization, and `send` and `recv` for handling data distribution, are added to this set.

Next Step: Distributed Runtime/Legion

Parallel to Distributed



Challenge

Propagate the Parallel Interfaces, through the LLVM PIR, into a distributed runtime like the Legion system developed at Stanford University.