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Swiss National Supercomputing Centre

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Extending the Capabilities of the Cray Programming Environment with Clang-LLVM Framework Integration

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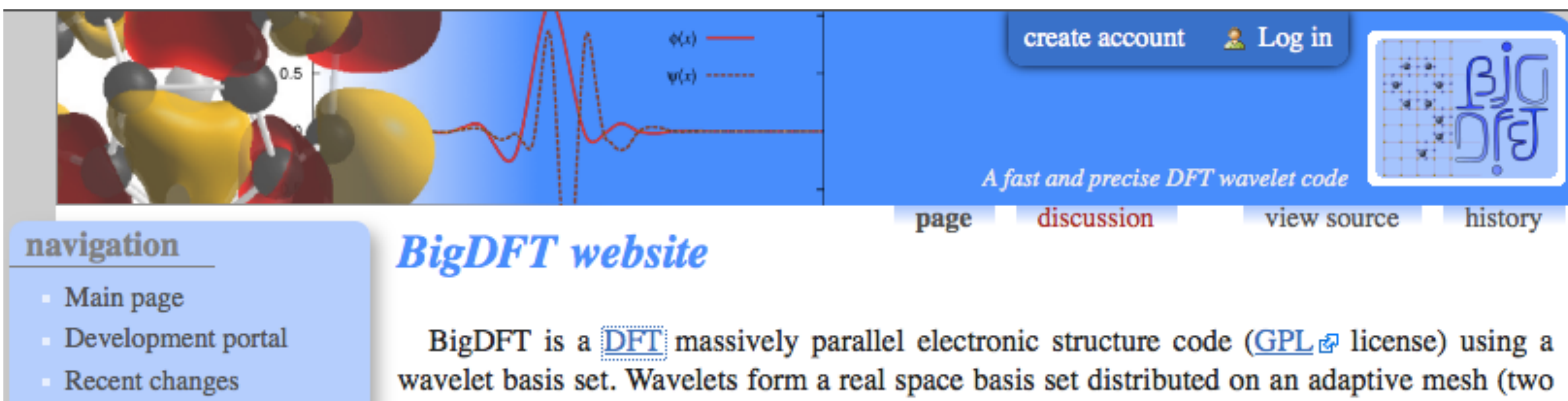
Motivation (I)

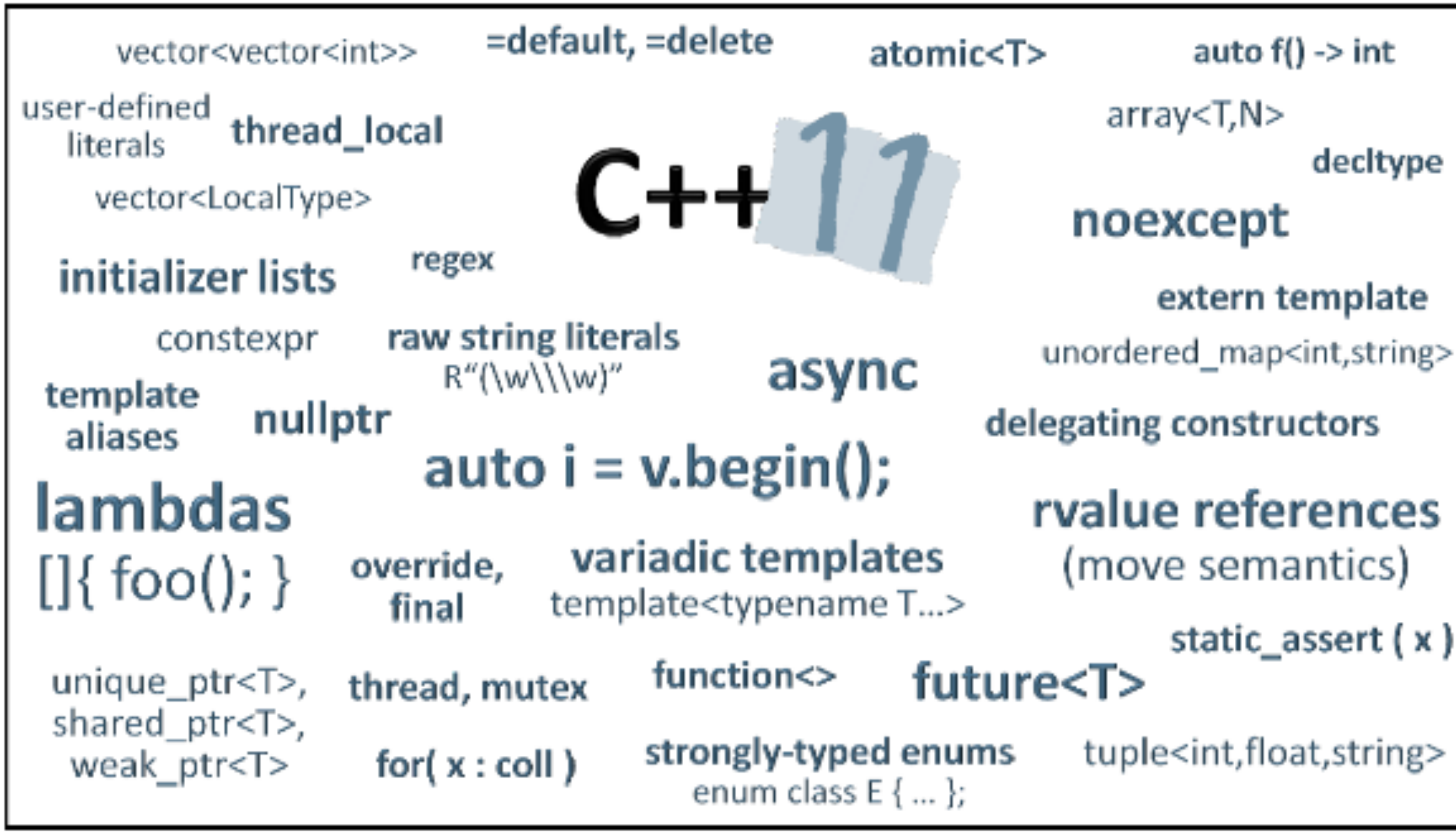
```
> cc hello.c -lOpenCL
> aprun ./a.out
Number of OpenCL GPU devices found = 1
DEVICE_NAME = Tesla K20X
DEVICE_VERSION = OpenCL 1.1 CUDA
DEVICE_VENDOR = NVIDIA Corporation
Hello, World!
…
CL_DEVICE_ADDRESS_BITS: 32
CL_DEVICE_GLOBAL_MEM_SIZE: 1744371712
```

```
Vendor: Intel(R) Corporation
Profile: FULL_PROFILE
Version: OpenCL 1.2 LINUX
Name: Intel(R) OpenCL
…
   Work item sizes: 1024 1024 1024
   Max clock freq: 2600 MHz
   Global memory: 33785212928 bytes
   Local memory: 32768 bytes
```



OpenCL accelerated application—HP2C project

Motivation (II)—C++11 -> C++1y

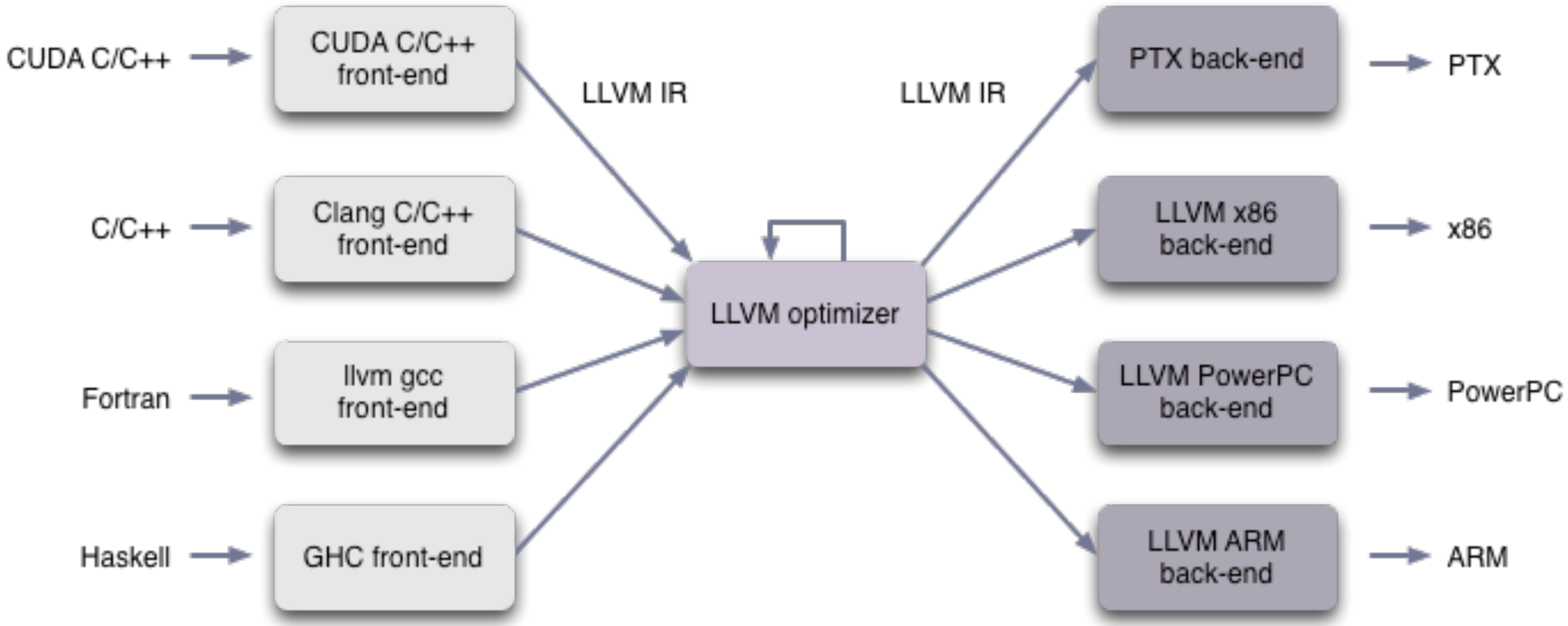


Applications use cases: COSMO, MAQUIS, DCA++, …

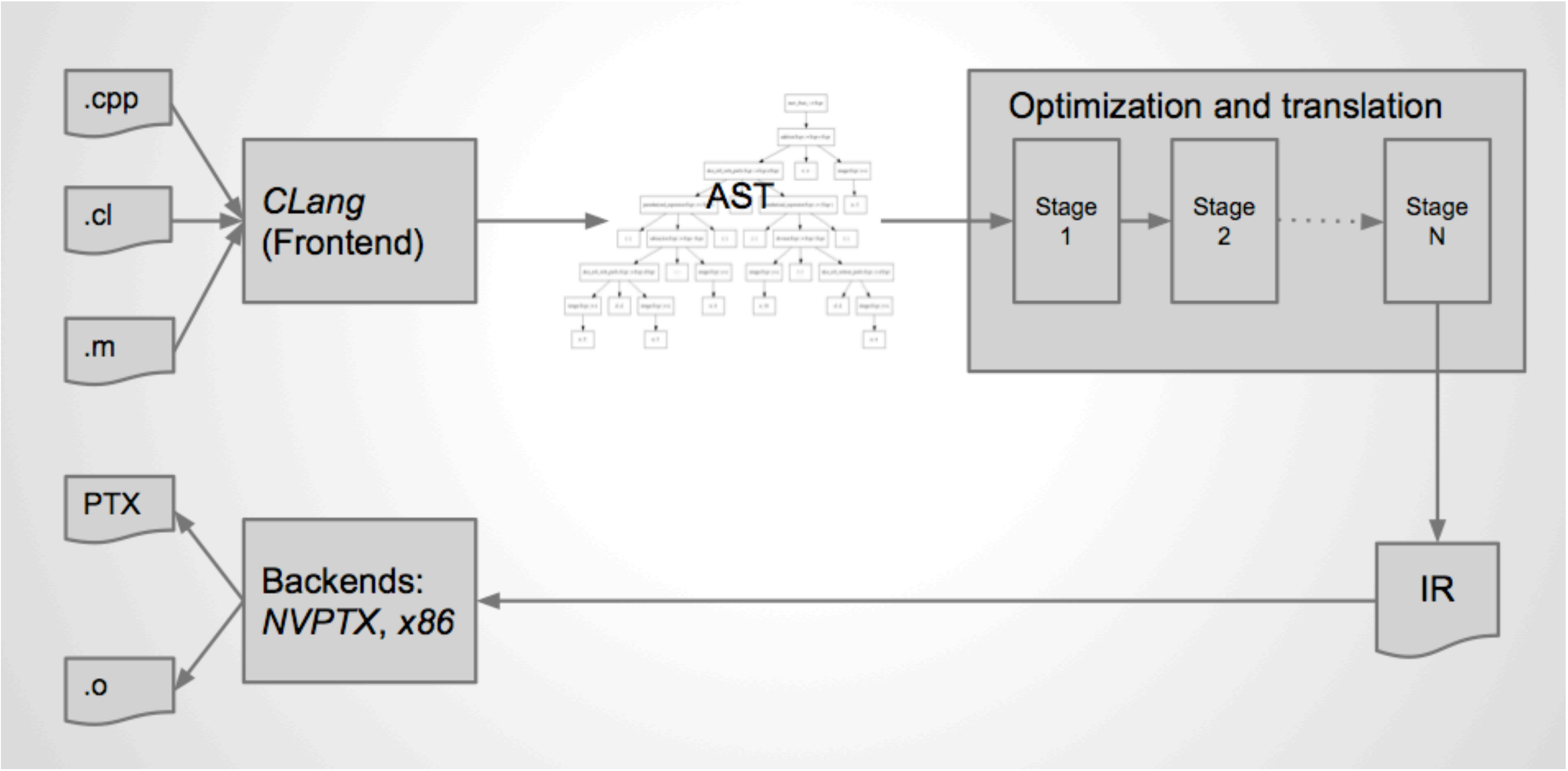
Limitations of the Current Cray PE

- OpenCL
  - Only CUDA SDK version (1.1)
  - CSCS installs CPU version
- C++1y
  - PrgEnv-cray —not up-to-date
  - PrgEnv-gnu —4.9 release made progress
  - PrgEnv-intel —gradual support
  - PrgEnv-pgi —not up-to-date
- Code development tools for OpenCL and C++1y
  - Non-existent—not sure of any roadmaps

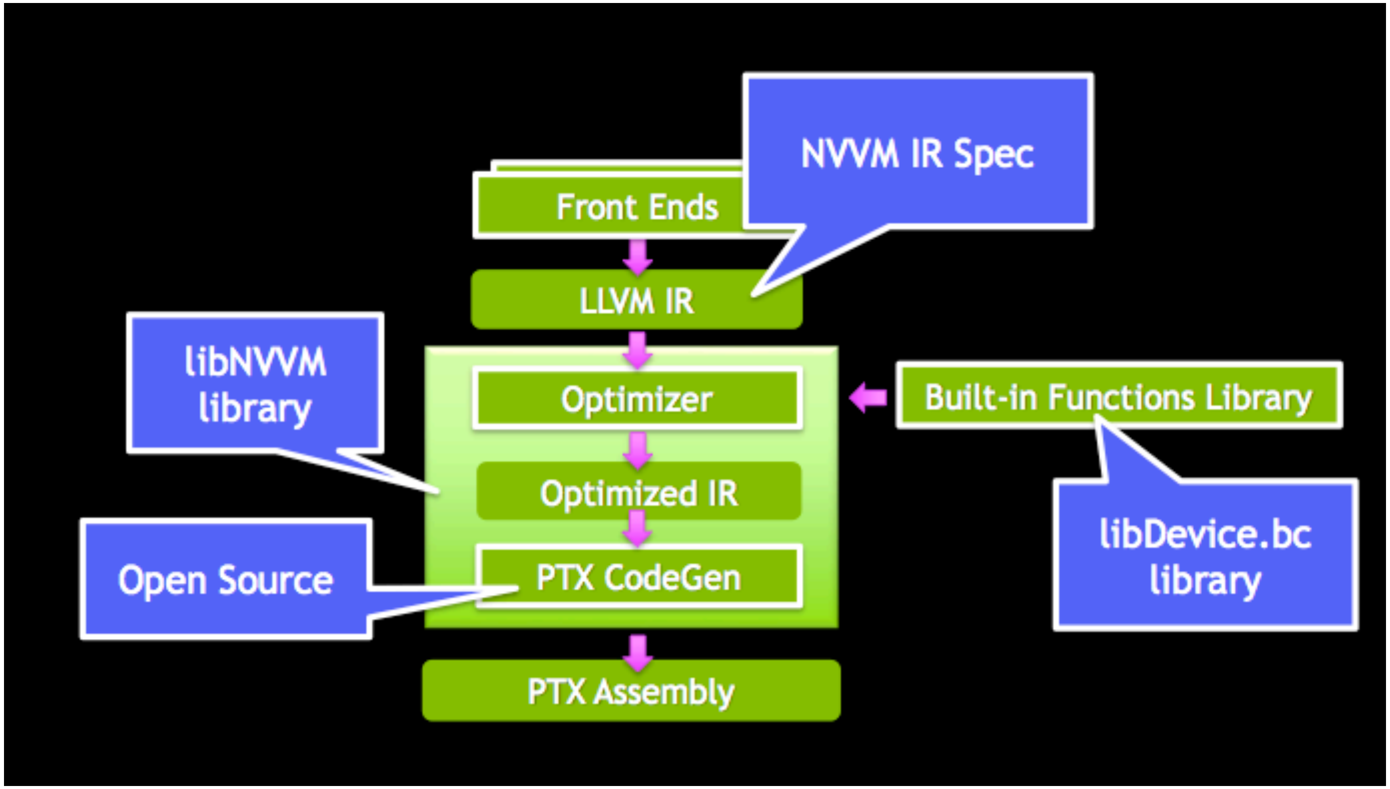
Clang-LLVM Solution



Code Generation in Clang-LLVM

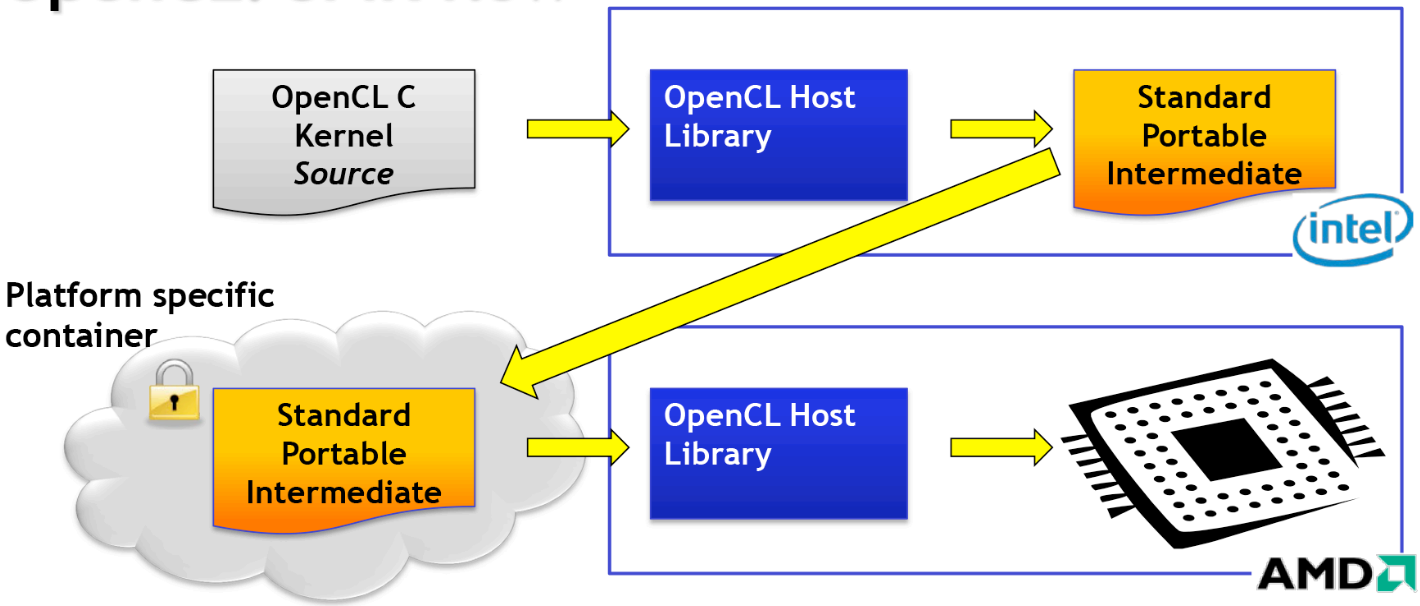


An LLVM Based Compiler Example (I)



OpenCL to IL → SPIR

OpenCL: SPIR flow



- ISV ships kernels in SPIR form
- Customer runs application on platform of their choice

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Who is using SPIR?

The following projects are known to use SPIR:

Project	Description	Project owner
Clang 3.2 patched	OpenCL C 1.2 to SPIR compiler	Khronos Group Inc
SPIR Tools	SPIR module verifier, etc.	Khronos Group Inc
PGI OpenACC	OpenACC to SPIR compiler	Portland Group Inc
Multicoreware C++AMP (on Bitbucket)	C++AMP compiler	Multicoreware Inc

SPIR portability and versioning

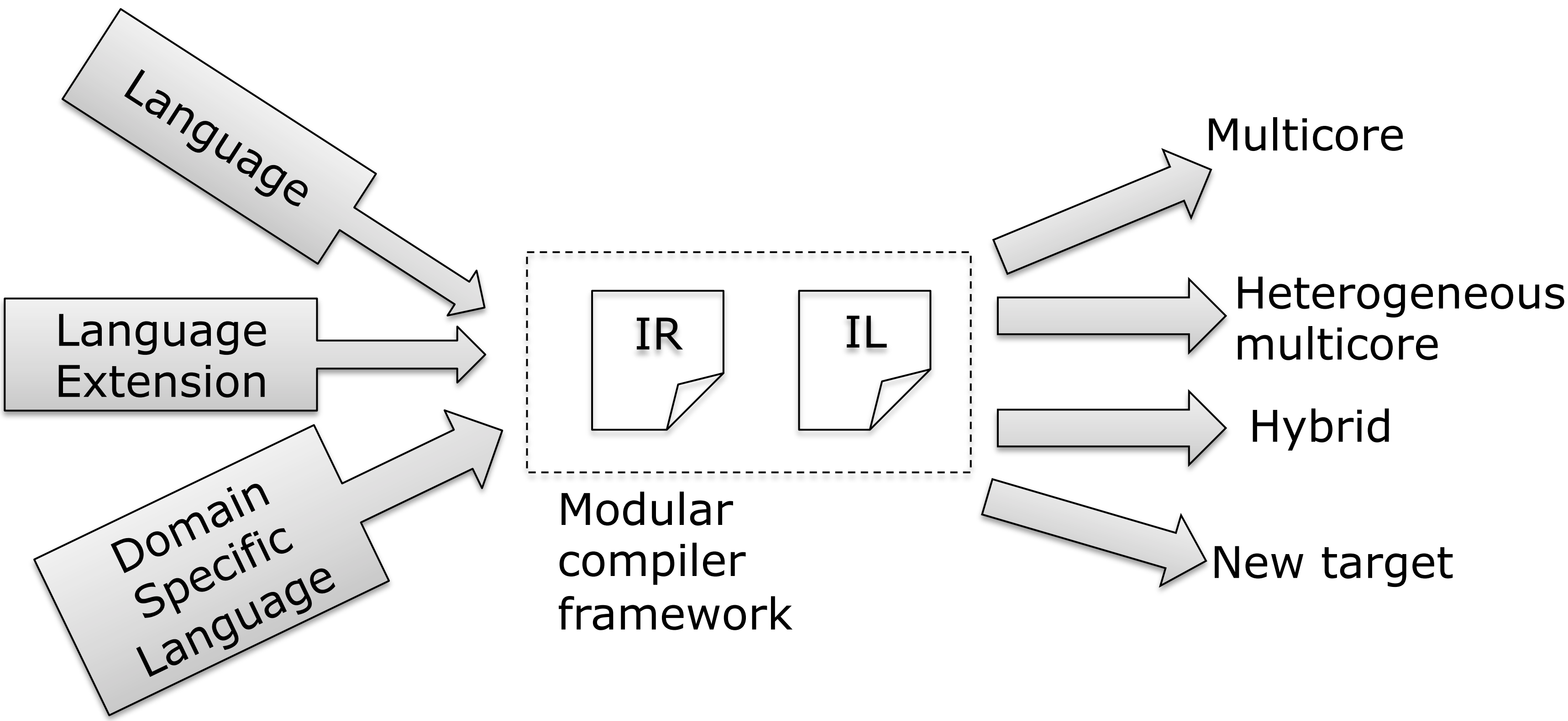
Can I generate a SPIR instance with compiler X and run it on platform Y?

The OpenCL cl_khr_spir runtime API extension assumes you can deliver a binary SPIR IR instance to the clCreateProgramWithBinary API.

The target environment may impose additional requirements before such an application can execute. For example, a target environment may require application pre-verification and cryptographically strong application signing. See the definition of Deployment Ecosystem in the Glossary below.

http://www.khronos.org/faq/spir

An Adaptive Environment



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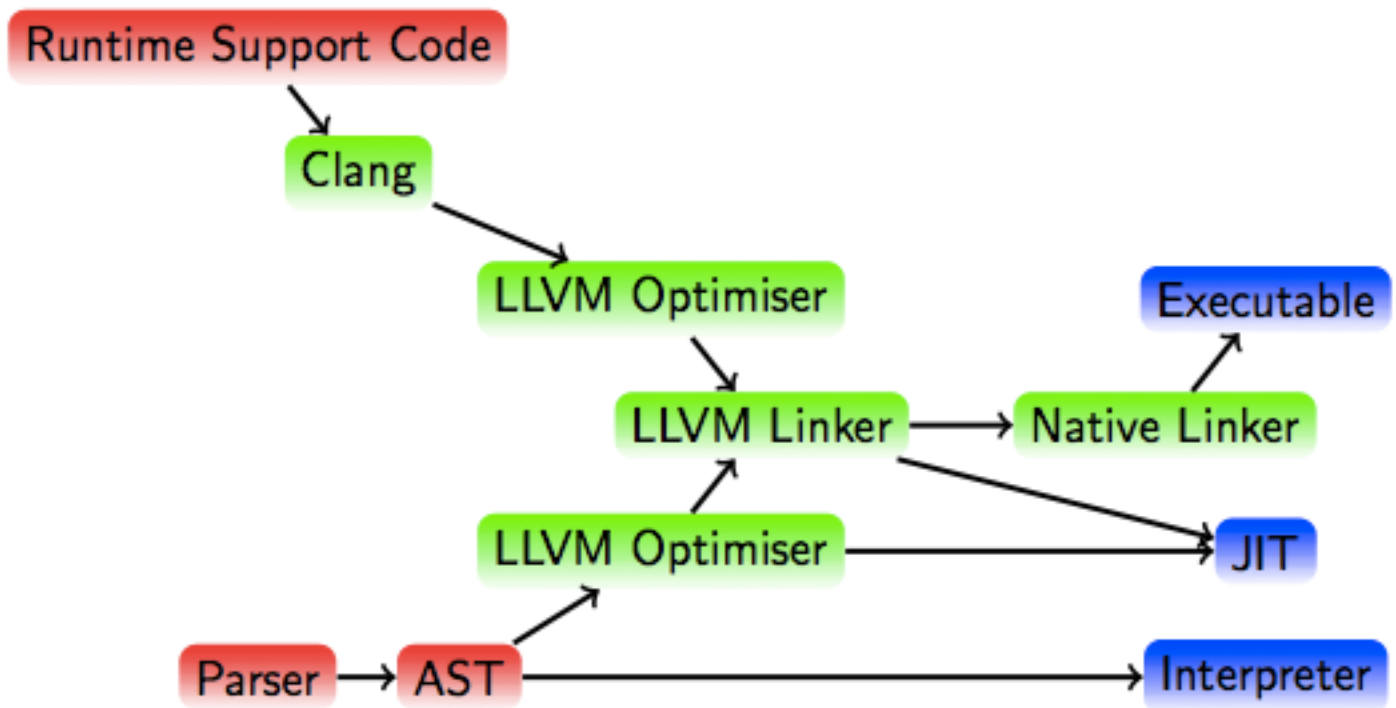
A typical DSL implemetation



FOSDEM2012 talk by David Chisnel on
"Implementing Domain Specific Languages with LLVM"

http://cs.swan.ac.uk/~csdavec/FOSDEM12/DSLsWithLLVM.pdf

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OpenCL 1.2 Code Generation (I)

Step # 1: Conversion of OpenCL code to LLVM IR using the Clang compiler

```
clang -Dcl_clang_storage_class_specifiers -isystem libclc/
generic/include -include clc/clc.h -target nvptx64-nvidia-cuda -
xcl kernel.cl -emit-llvm -S -o kernel.ll
```

Step # 2: Optional

```
llvm link libclc/built_libs/nvptx64   nvidiacl.bc kernel.ll o
kernel.linked.bc
```

OpenCL 1.2 Code Generation (II)

Step # 3: IR to PTX

```
llc -mcpu=sm_35 kernel.ll -o kernel.ptx
```

With the built-in functions:

```
clang -target nvptx64-nvidia-cuda  kernel.linked.bc -S -o
kernel.nvptx.s
```

Step # 4: Write the driver code

```
CC  sample.cpp  -o  sample  -O2  -g  -I/opt/nvidia/cudatoolkit/
5.5.20-1.0501.7945.8.2/include  -L  /opt/nvidia/cudatoolkit/
5.5.20-1.0501.7945.8.2/lib64/ -lcudart

> aprun ./sample
Using CUDA Device [0]: Tesla K20X
Device Compute Capability: 3.5
Launching kernel …
```

Integration into the Cray PE

- **Works with Cray MPI, perftools & libraries (examples in paper)**
- **Full automation tricky—hard coded paths not always discoverable by scripts**
  - E.g. LD_LIBRARY_PATH include paths
- **Binaries for compiler wrappers**
- **Must be straightforward for Cray to come up with PrgEnv-clang?**

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Other Opportunities—Developers tools

- **ClangFormat – formatting tool for C & C++ (integrated in editors)**
- **ClangCheck – performs basic error and warning checks on code snippets. For example**

```
 > cat test.c void foo() { int a = 3 }
$ clang-check test.c --
/scratch/santis/bcumming/test.c:1:23: error: expected ';' at end
of declaration
void foo() { int a = 3 }                ^
```

- **ClangModernize –automatically converts C++ code to C++11, with support for features such as converting for loops to range-based loops and using the auto keyword.**

Other Opportunities—Debug tools

- **Clang Static Analyzer – find bugs without running the code**
- **`$ scan-build make`**

```
int main(void) {
   int *ptr = nullptr;
   ptr[10]++;
}
```

```
test.cc:3:5: warning: Array access
(from variable 'ptr') results in a null
pointer dereference
   ptr[10]++;
      ^~~~~~~~~~
1 warning generated.
scan-build: 1 bugs found.
```

Other Opportunities—Debug tools

```
int main(void) {
    int *ptr = nullptr;
```

1 'ptr' initialized to a null pointer value →

```
    ptr[10]++;
```

2 ← Array access (from variable 'ptr') results in a null pointer dereference

```
}
```

Other Opportunities—Sanitizers

- **AddressSanitizer—fast memory error detector (`-fsanitize=address`)**
  - Out-of-bounds accesses to heap, stack and globals
  - Use-after-free
  - Use-after-return (to some extent)
  - Double-free, invalid free
  - Memory leaks (experimental)

- **MemorySanitizer—detects uninitialized reads (`-fsanitize=memory`)**

- **ThreadSanitizer—detects race conditions (`-fsanitize=thread`)**

RFE for Cray & collaboration opportunities with other sites

- **PrgEnv-Clang, please!**
- **OpenACC to OpenCL SPIR via Intel**
- **After PrgEnv-Clang, solution for OpenCL on GPU, CPU & beyond …**
- **Domain specific languages using LLVM**
- **OpenCL tools for parallel computing**
- **DSL (e.g. poloyglot: http://www.exmatex.org/prog-models.html)**
- **Incremental development on Cray (Co-design summer school: http://codesign.lanl.gov/summer-school/)**
  – Reduce development to deployment time on Cray systems

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Thank you