OPENCL COMPILER FOR CPU IN LLVM

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Objective

In 20 minutes

discover collab opportunities

within OpenCL part of LLVM community

MAPPING TO CPU

OpenCL kernel

Focus on data parallelism!

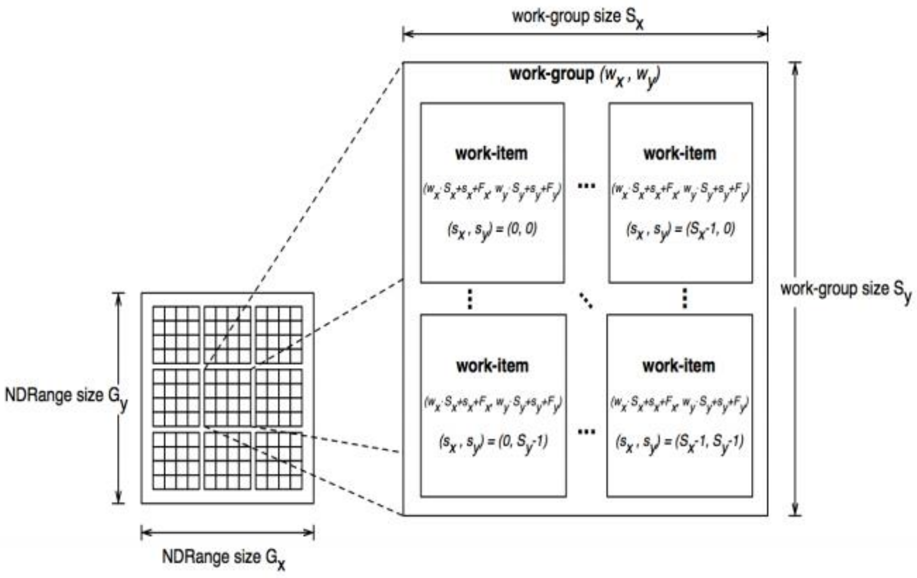
- Developer writes kernel processing a single **work item** within problem space

```
__kernel void
cl_add(__global float *a,
       __global float *b,
       __global float *res) {

  size_t gid = get_global_id(0);
  res[gid] = a[gid] + b[gid];
}
```

OpenCL kernel

Focus on data parallelism!

- Developer writes kernel processing a single **work item** within problem space
- Work-items are organized into **work-groups**
- Work-groups comprise the whole **NDRange** – problem space



OpenCL 1.2 specification, fig. 3.2

OpenCL execution on CPU

Work items in a work group are executed in an implicit loop.

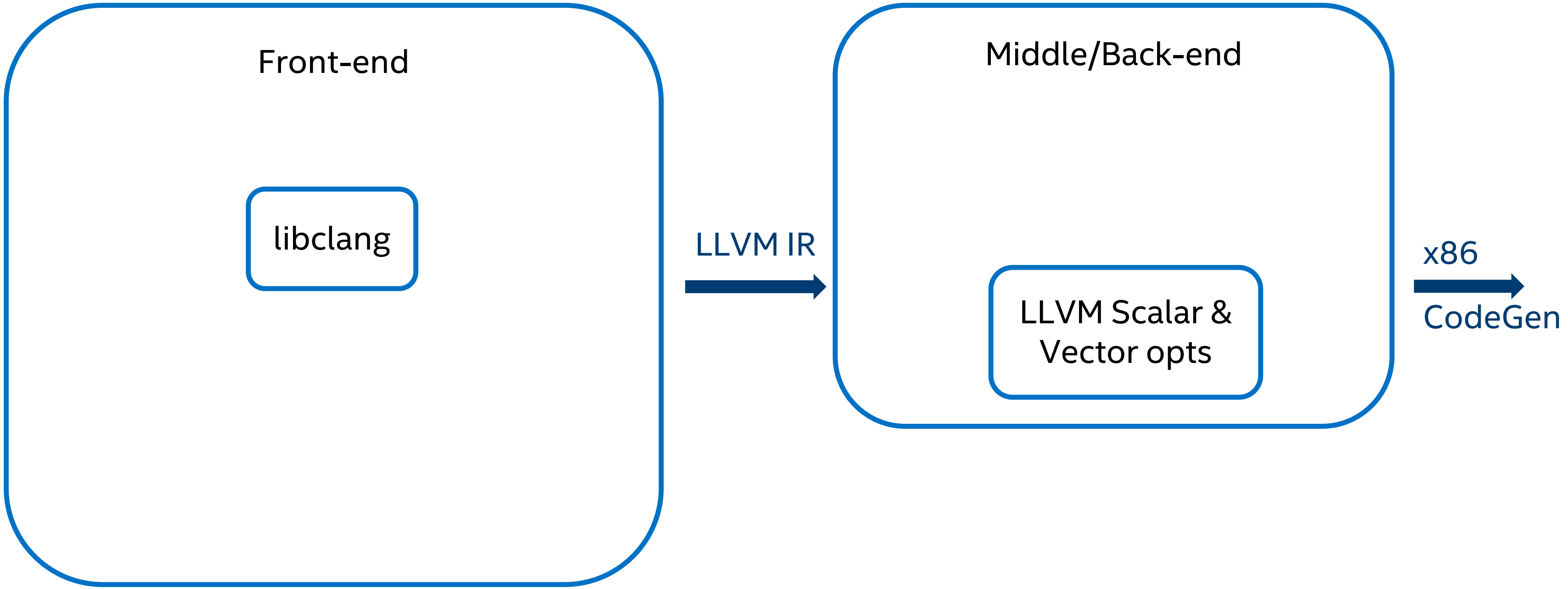
- Work item batch ⇒ **SIMD** lane
- Work group ⇒ CPU **thread**
- NDRange ⇒ CPUs

Execution of work groups is parallelized for CPU units.

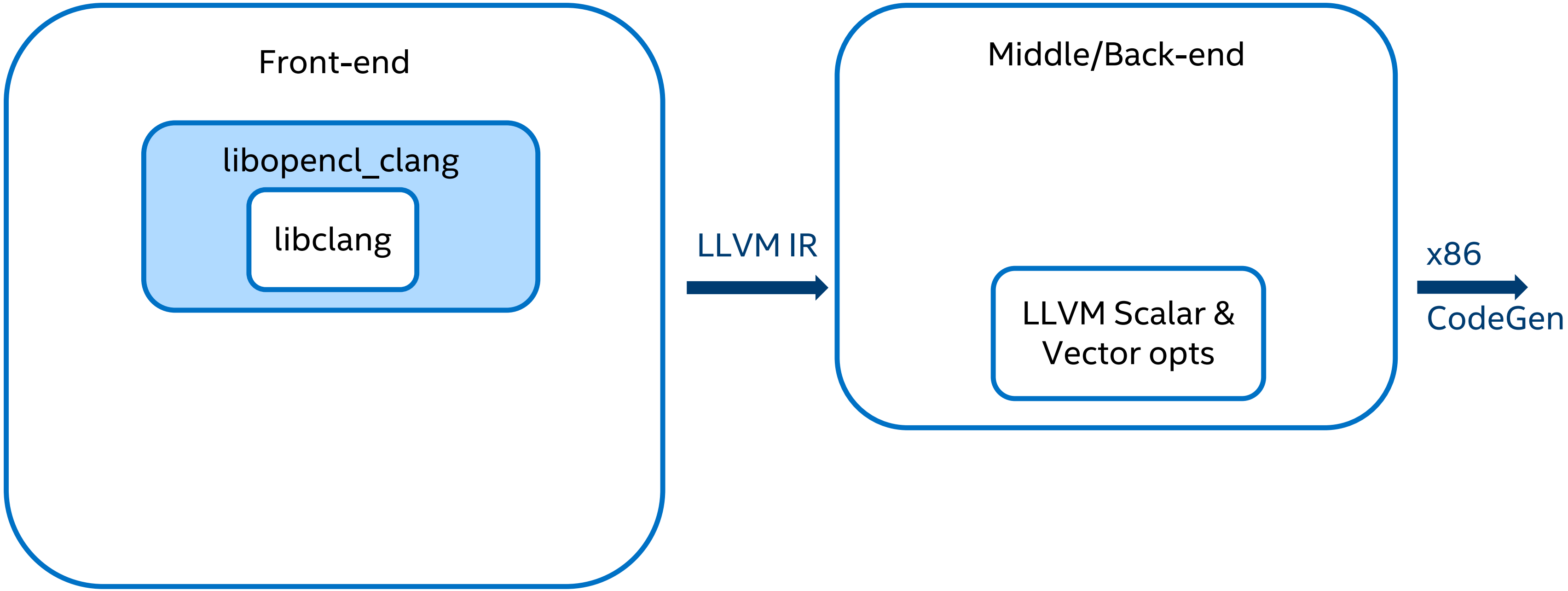
```
__kernel void
cl_mul(__global float *a,
       __global float *b,
       __global float *res) {

  size_t gid = get_global_id(0);
  res[gid] = a[gid] + b[gid];
}
```

COMPILER STACK

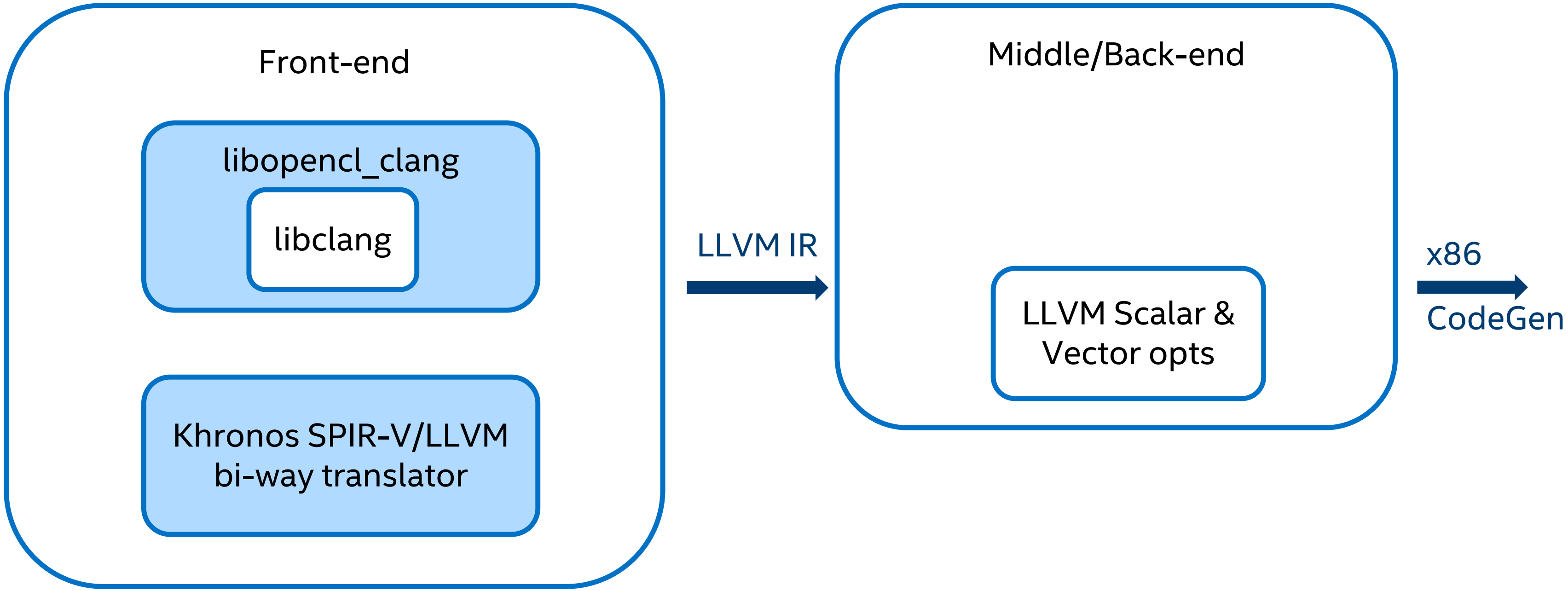
CPU Compiler components



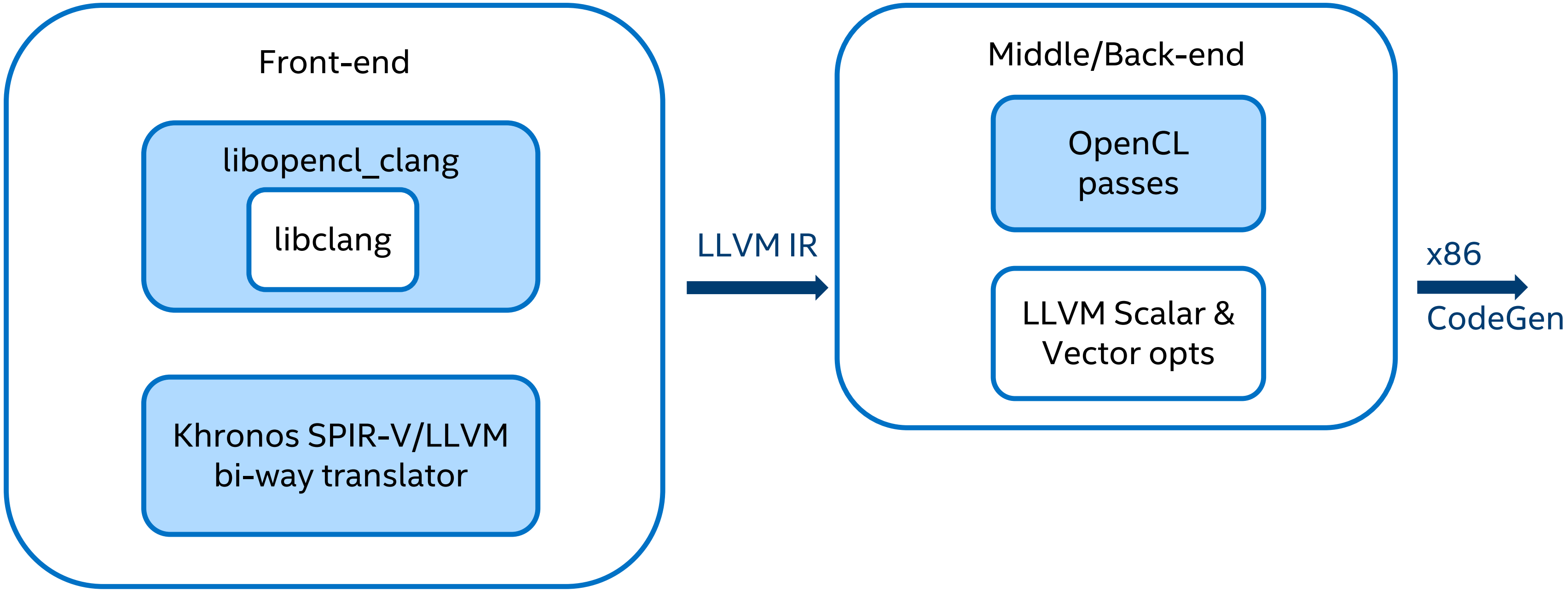
CPU Compiler components



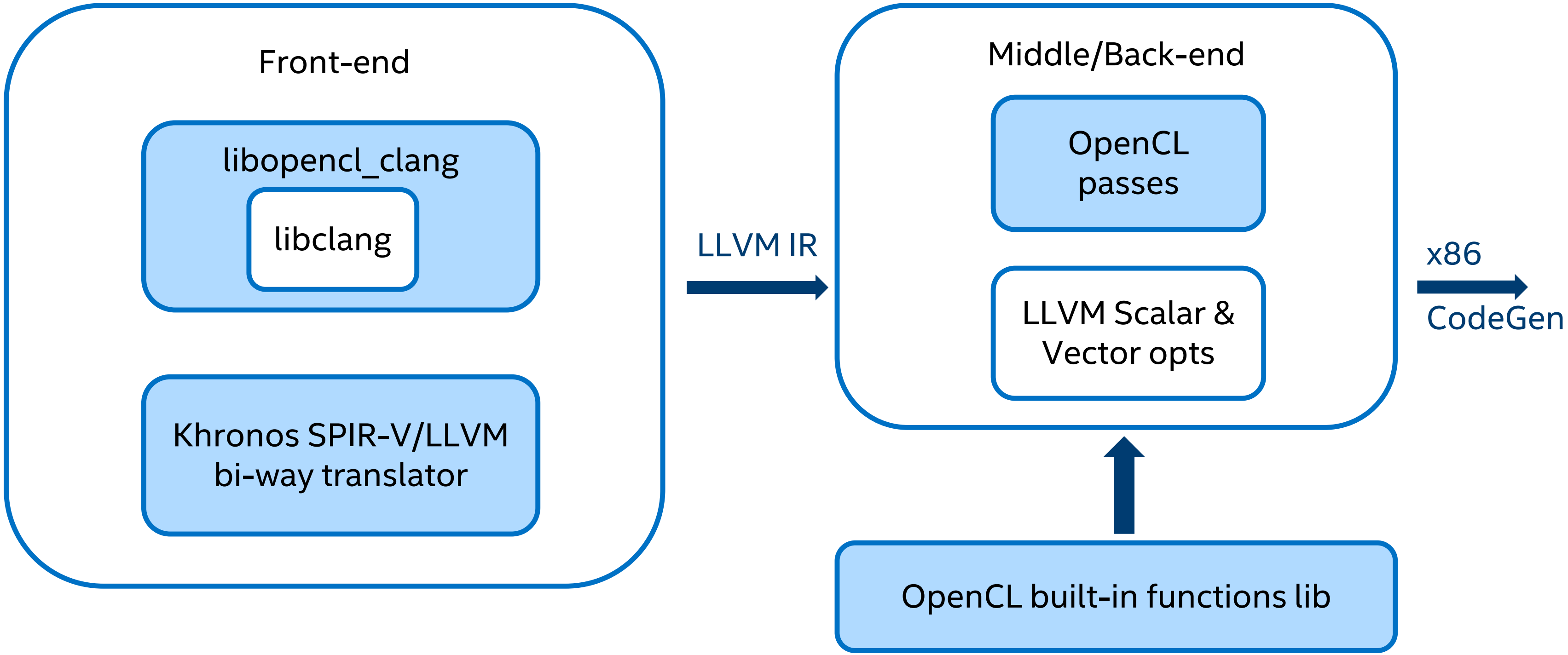
CPU Compiler components



CPU Compiler components



CPU Compiler components



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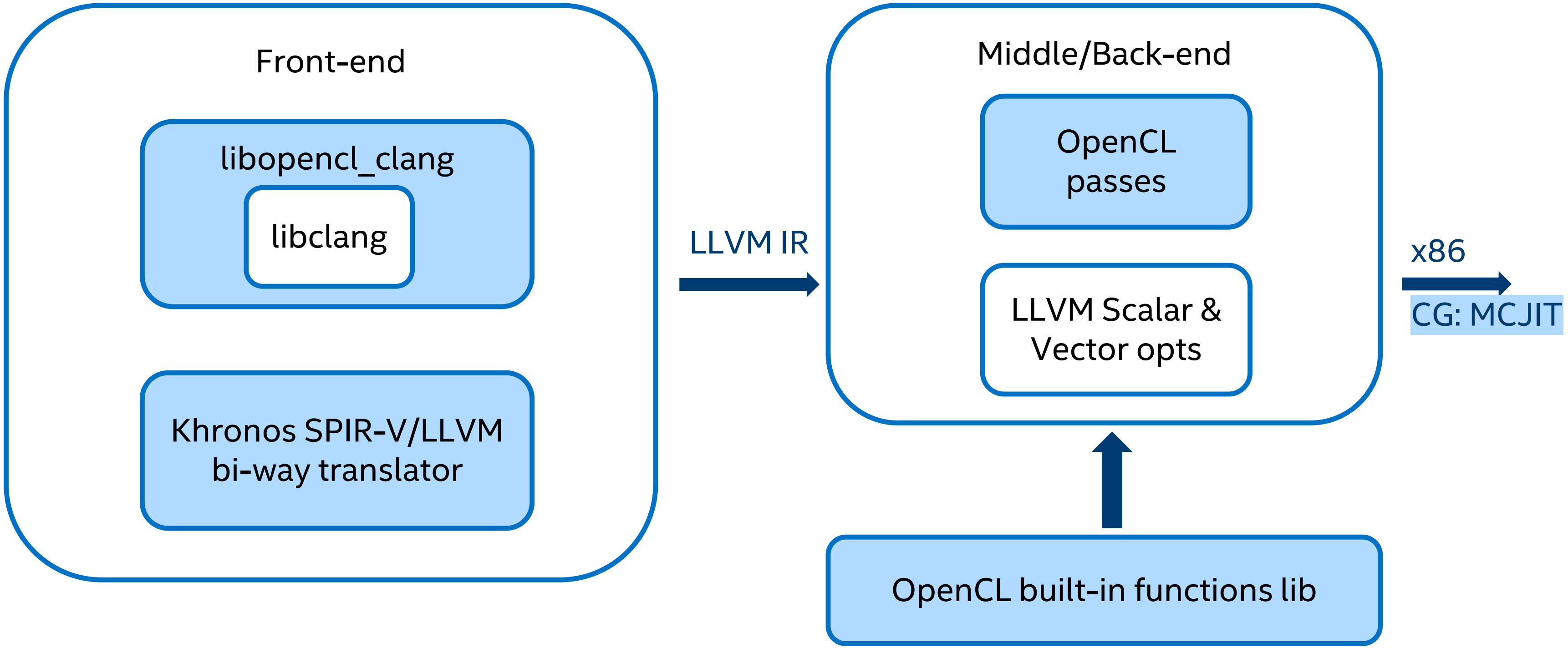

FRONTEND

Frontend challenges

OpenCL C 1.2/2.0

SPIR-V

SPIR 1.2

x86 precompiled binary

- multiple inputs
- multiple targets

Graphics ME/BE

FPGA ME/BE

DSP ME/BE

CPU ME/ BE

x86

Frontend challenges

OpenCL C 1.2/2.0

Graphics ME/BE

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SPIR-V

DSP ME/BE

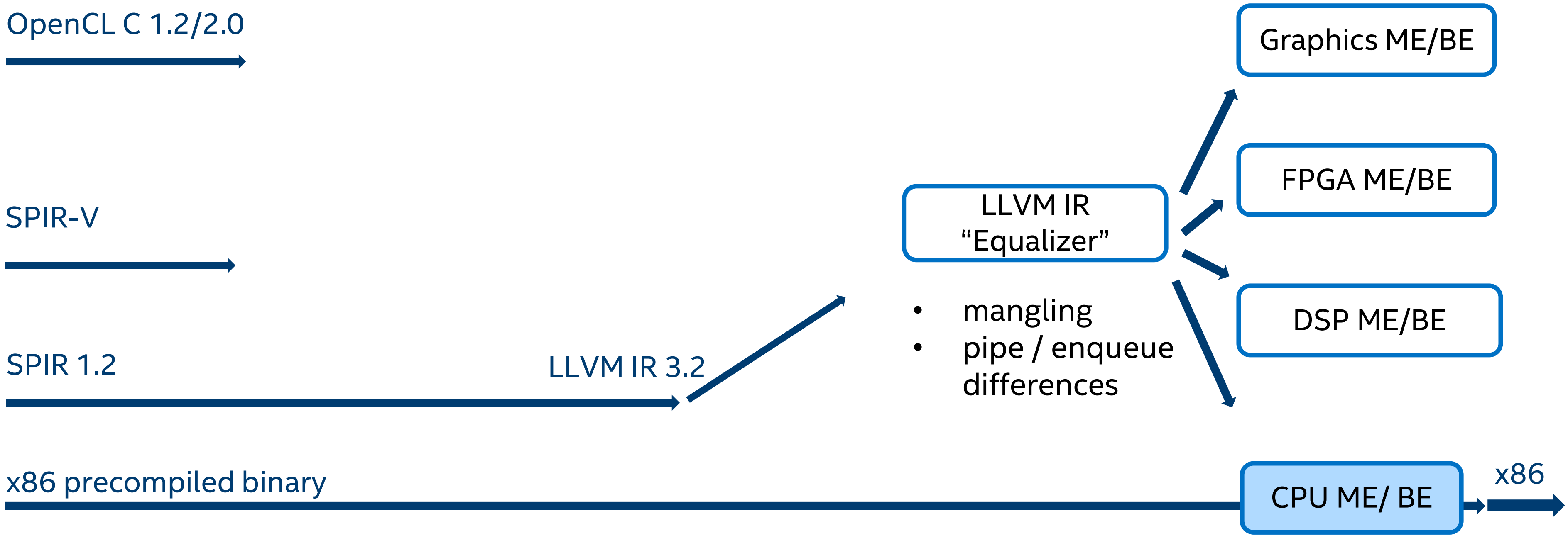
SPIR 1.2

x86 precompiled binary

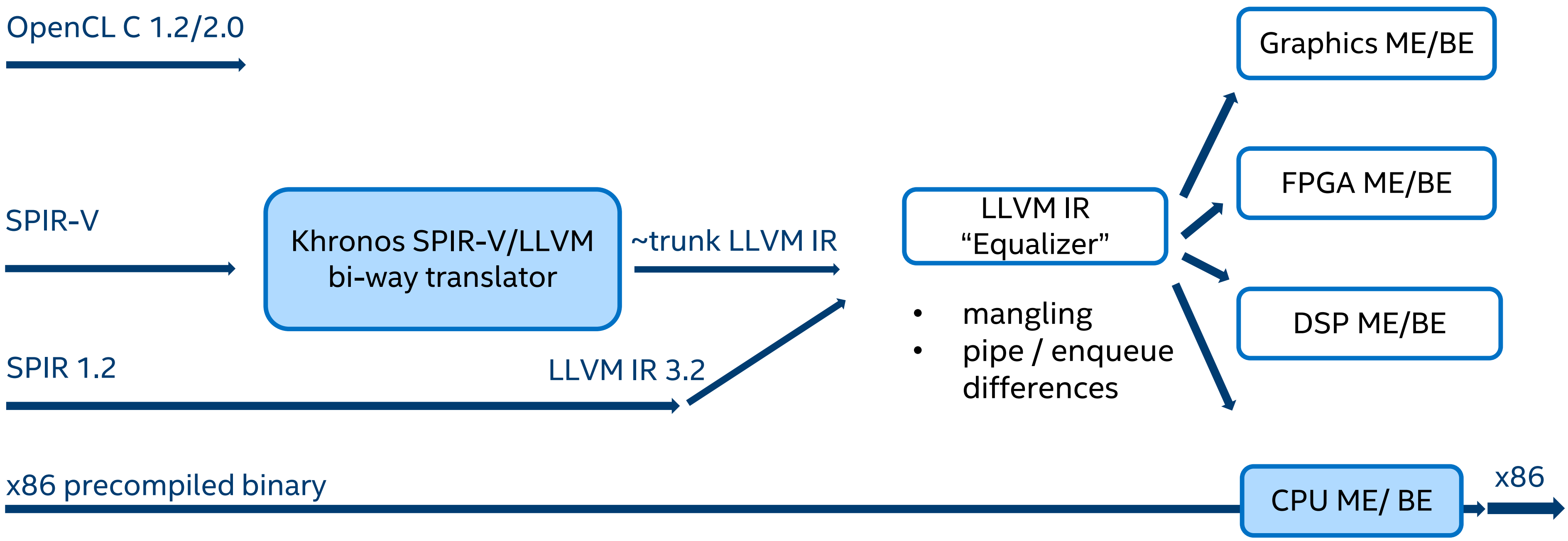
CPU ME/ BE

x86

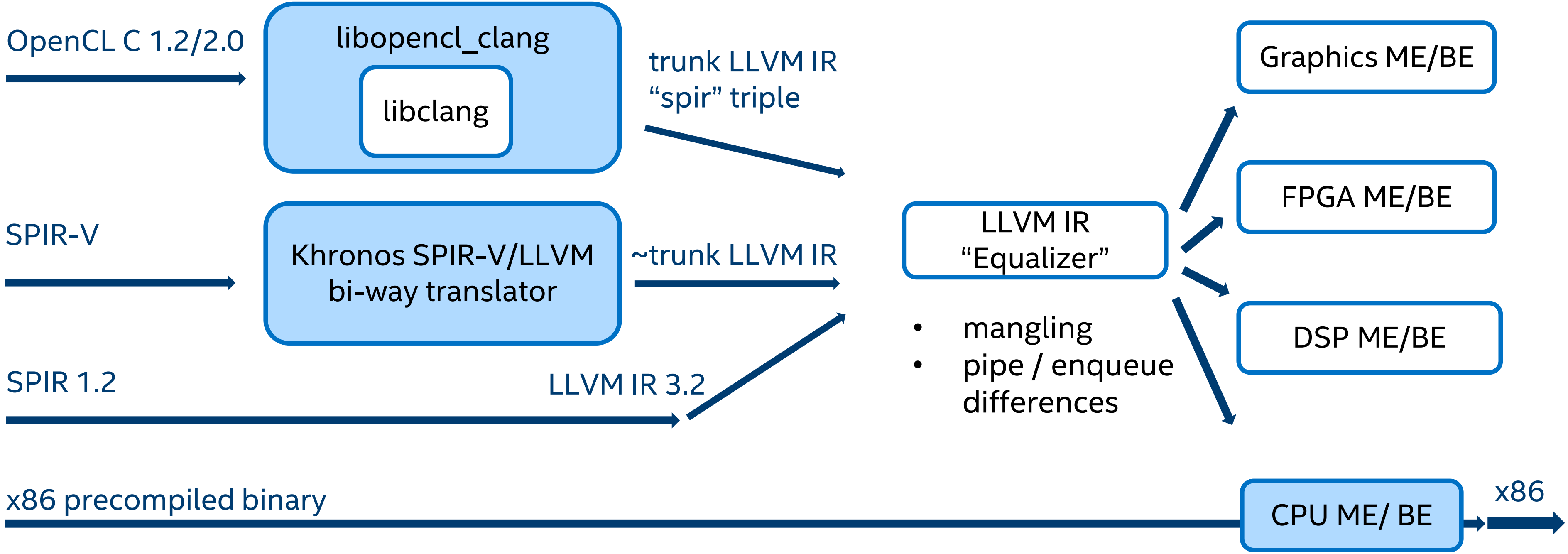
Frontend challenges



Frontend challenges



Frontend challenges



libopencl_clang

OpenCL-oriented libclang extension/wrapper

- In-memory from-source compilation
- Precompiled headers for OpenCL built-ins
- C-style APIs for actions like Compile/Link/GetKernelArgInfo
- Stable API for different device backends

libopencl_clang – example #1

```
extern "C" CC_DLL_EXPORT int Compile(
  // A pointer to main program's source (null terminated string)
  const char *pszProgramSource,
  // array of additional input headers to be passed in memory (each null
  // terminated)
  const char **pInputHeaders,
  // the number of input headers in pInputHeaders
  unsigned int uiNumInputHeaders,
  // array of input headers names corresponding to pInputHeaders
  const char **pInputHeadersNames,
  // optional pointer to the pch buffer
  const char *pPCHBuffer,
  // size of the pch buffer
  size_t uiPCHBufferSize,
  // OpenCL application supplied options
  const char *pszOptions,
  // optional extra options string usually supplied by runtime
  const char *pszOptionsEx,
  // OpenCL version string - "120" for OpenCL 1.2, "200" for OpenCL 2.0, ...
  const char *pszOpenCLVer,
  // optional outbound pointer to the compilation results
  Intel::OpenCL::ClangFE::IOCLFEBinaryResult **pBinaryResult
);
```

libopencl_clang – example #2

```
extern "C" CC_DLL_EXPORT int Link(
  // array of additional input headers to be passed in memory
  const void **pInputBinaries,
  // the number of input binaries
  unsigned int uiNumBinaries,
  // the size in bytes of each binary
  const size_t *puiBinariesSizes,
  // OpenCL application supplied options
  const char *pszOptions,
  // optional outbound pointer to the compilation results
  Intel::OpenCL::ClangFE::IOCLFEBinaryResult **pBinaryResult
 );
```

libopencl_clang

Source is available @ https://github.com/intel/opencl-clang

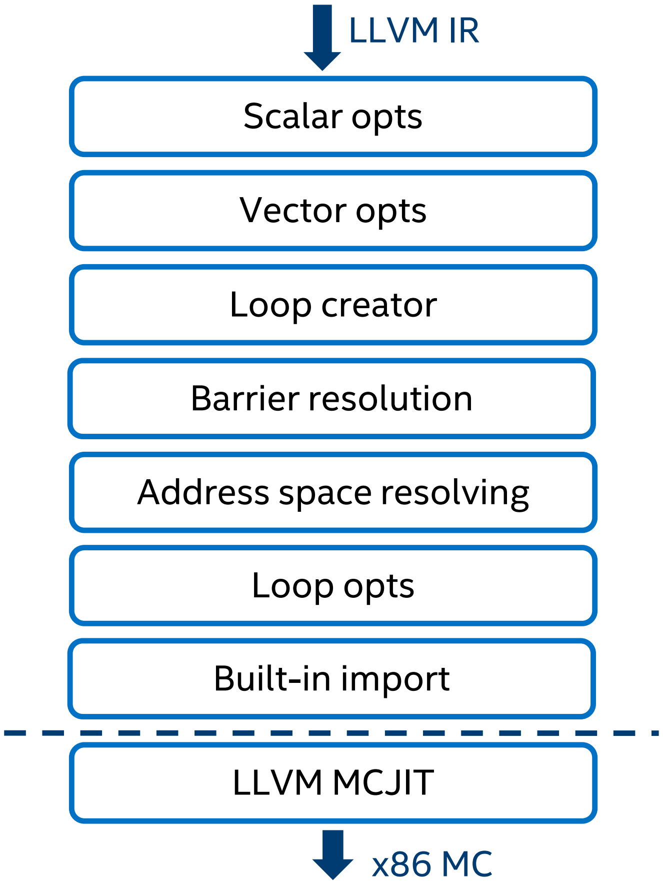
MIDDLE END

CPU middle end challenges

Optimize a hetero language!

CPU-unfriendly OpenCL features:

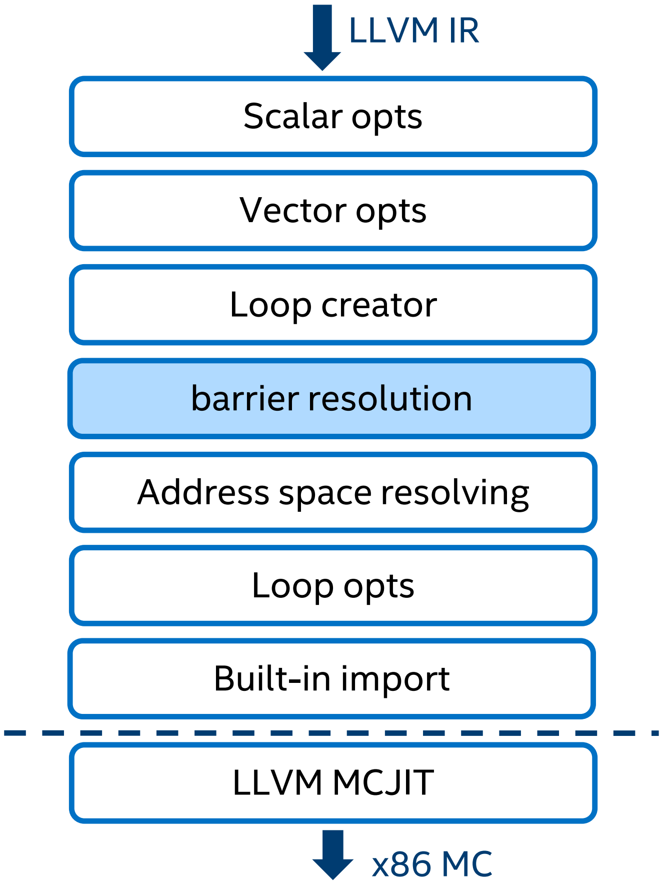
- barrier
- address spaces
- images
- pipes



OpenCL barrier

Handles barrier() built-in function

- All work-items in work-group must hit the barrier before any of them can continue execution
- Pass splits the CFG along barrier calls and creates ‘switch’-driven work-group loops to enforce the barrier



Barrier resolution

Conceptual pseudo code

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
}
```

Barrier resolution

Conceptual pseudo code

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
}
```

```
kernel void test(...)
{
  int currWI = 0;
  int currBarrier = 0;
label_0:
  ...code1
  goto label_barrier_1;
label_barrier_1:
  if (currWI < groupSize) {
    currWI++;
    switch (currBarrier) {
    case 0: goto label_0;
    case 1: goto label_1;
    }
  }
  else {
    currWI = 0;
    currBarrier = 1; //check and exit if finised
  }
label_1:
  ...code2
  goto label_barrier_1;
}
```

Barrier resolution

Let's consider this:

```
kernel void test(...)
{
  int x = b * A[wi_id];
  barrier();
  C[wi_id] = x;
}
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label_0:
  int x = b * A[wi_id];
  goto label_barrier_1;
label_barrier_1:
  if (currWI < groupSize) {
    currWI++;
    switch (currBarrier) {
    case 0: goto label_0;
    case 1: goto label_1;
    }
  }
  else {
    currWI = 0;
    currBarrier = 1; //check and exit if finised
  }
label_1:
  C[wi_id] = x;
  goto label_barrier_1;
}
```

Barrier resolution

Let's consider this:

```
kernel void test(...)
{
  int x = b * A[wi_id];
  barrier();
  C[wi_id] = x;
}
```

- values x is different for every work item;

```
kernel void test(...)
{
  int currWI = 0;
  int currBarrier = 0;
label_0:
  int x = b * A[wi_id];
  goto label_barrier_1;
label_barrier_1:
  if (currWI < groupSize) {
    currWI++;
    switch (currBarrier) {
    case 0: goto label_0;
    case 1: goto label_1;
    }
  }
  else {
    currWI = 0;
    currBarrier = 1; //check and exit if finised
  }
label_1:
  C[wi_id] = x;
  goto label_barrier_1;
}
```

Barrier resolution

Let's consider this:

```
kernel void test(...)
{
  int x = b * A[wi_id];
  barrier();
  C[wi_id] = x;
}
```

- values x is different for every work item;
- after barrier all work-items will use same value for x!

```
kernel void test(...)
{
  int currWI = 0;
  int currBarrier = 0;
label_0:
  int x = b * A[wi_id];
  goto label_barrier_1;
label_barrier_1:
  if (currWI < groupSize) {
    currWI++;
    switch (currBarrier) {
    case 0: goto label_0;
    case 1: goto label_1;
    }
  }
  else {
    currWI = 0;
    currBarrier = 1; //check and exit if finised
  }
label_1:
  C[wi_id] = x;
  goto label_barrier_1;
}
```

Barrier resolution

Pseudo code:

```
kernel void test(...)
{
  int x = b * A[wi_id];
  barrier();
  C[wi_id] = x;
}
```

- values crossing the a barrier must be preserved for each work-item;

```
kernel void test(...)
{
  int currWI = 0;
  int currBarrier = 0;
label_0:
  store x into buffer[offset];
  goto label_barrier_1;
label_barrier_1:
  if (currWI < groupSize) {
    currWI++;
    switch (currBarrier) {
    case 0: goto label_0;
    case 1: goto label_1;
    }
  }
  else {
    currWI = 0;
    currBarrier = 1; //check and exit if finised
  }
label_1:
  load x_1 from buffer[offset];
  goto label_barrier_1;
}
```

Barrier: Analysis phase

- both x and y depend on work-item ID.
- scope analysis:
  - x crosses barrier
  - y does not cross
- only x is marked and it’s size 32
- x offset will be 0
- next value’s offset will be 4

```
kernel void test(...)
{
  int x = b * A[wi_id];
  int y = B[wi_id];
  barrier();
  C[wi_id] = x;
}
```

Barrier: Analysis phase - Contd

barrier():

- Give barrier instruction a unique number [1,…,#bariers]
- Find the predecessor barriers for each barrier instruction

IR values:

- We are interested only in values that depend on work-item ID
- Find aliveness scope of such values and mark if they cross the barrier
- Find the total size in bytes of marked LLVM IR values
- Calculate the offset of each marked value with respect to the total size and with alignment consideration

Barrier: Transformation phase

- Add two new alloca variables to the beginning of the kernel
  - “currWI” initialized to 0
  - “currBarrier” initialized to 0
- for every marked LLVM value
  - Store this value to special buffer at offset given by the Analysis pass
  - For each barrier that exists in the scope of the value add a load instruction from the special buffer at same offset
  - Replace all usage of this value to use the new loaded value

Barrier: Transformation phase - Contd

- for each Barrier instruction
  - Replace it with this code:

```
if (currWI < groupSize) {
  currWI++;
  switch (currBarrier) {
    case 0: goto label_0;
    // case i: goto label_i;
    // for all "i" in barrier predecessors
  }
}
else {
  currWI = 0;
  currBarrier = #;
}
label_#: // current barrier number
__mm_mfence();
```

Barrier - Contd

- there's only one barrier
  - it's number is #1
  - barrier #0 is always the prologue of the kernel.
- predecessor of barrier #1 is #0.

```
kernel void test(...)
{
  int x = b * A[wi_id];
  int y = B[wi_id];
  barrier();
  C[wi_id] = x;
}
```

Barrier inside a function

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
  C[wi_id] = foo();
}

int foo()
{
  ...code3
   barrier();
  ...code4
}
```

Barrier inside a function

jump into the insides of a function required

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
  C[wi_id] = foo();
}

int foo()
{
  ...code3
   barrier();
  ...code4
}
```

Barrier inside a function - solution

Inline function?

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
  C[wi_id] = foo();
}

int foo()
{
  ...code3
   barrier();
  ...code4
}
```

Barrier inside a function - solution

Inline function:

- what if we cannot inline?

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
  C[wi_id] = foo();
}

int foo()
{
  ...code3
   barrier();
  ...code4
}
```

Barrier inside a function - solution

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
  C[local_wi_id] = foo();
}

int foo()
{
  ...code3
   barrier();
  ...code4
}
```

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
  barrier(); // extra
  C[wi_id] = foo();
  dummyBarrier();
}

int foo()
{
  dummyBarrier();
  ...code3
   barrier();
  ...code4
  barrier(); // extra
}
```

Barrier inside a function - solution

- For each function with barrier:
  - add dummyBarrier() at its begin
  - add barrier() at it's end.
- For each call to a function with barrier:
  - add barrier() before the function call
  - add dummyBarrier() after the function call
- dummyBarrier()
  - only counts towards barrier predecessors
  - has no barrier semantics

```
kernel void test(...)
{
  ...code1
  barrier();
  ...code2
  barrier(); // extra
  C[wi_id] = foo();
  dummyBarrier();
}

int foo()
{
  dummyBarrier();
  ...code3
   barrier();
  ...code4
  barrier(); // extra
}
```

Takeaway

Let's exchange feedback,

ask questions,

and extend collaboration beyond today's limits

Software