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An Online Compiler for SYCL Kernels and Some Related Ideas

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What is “online compilation”? Why do we need it?

- Applications want to customize kernels based on input data, device features, or other parameters
- Specialization constants not powerful enough
  - E.g. aren’t “constexpr”, so can’t use as template parameters
- Not practical to predefine all possible variants of kernel
  - Too many variations, leads to code explosion
- Want to dynamically generate source code for a kernel and then compile it when the application runs
- OpenCL has this feature, as does CUDA (with NVRTC)

Example usage – part 1

```
namespace syclex = sycl::ext::oneapi::experimental;

int main() {
  sycl::queue q;
  sycl::context ctxt = q.get_context();

  std::string src = /*...*/;
  auto src_bundle = syclex::create_kernel_bundle_from_source(
    ctxt, syclex::source_language::sycl, src);

  auto exe_bundle = syclex::build(src_bndl);
  sycl::kernel myiota = exe_bundle.ext_oneapi_get_kernel("myiota");

  float start = 3.14f;
  float *ptr = sycl::malloc_shared<float>(NUM, q);
  q.submit([&](sycl::handler &cgh) {
    cgh.set_arg(0, start);
    cgh.set_arg(1, ptr);
    cgh.parallel_for(sycl::nd_range{{NUM},{WGSIZE}}, myiota);
  });
}
```

String defining kernel, dynamically generated

Leverages existing SYCL "kernel bundle" framework

Gets a "kernel" object from compiled string

Can use existing SYCL APIs to launch a "kernel" object

The problem with kernel argument indices

```
cgh.set_arg(0, start);
cgh.set_arg(1, ptr);
```

Sets kernel arg #0

Sets kernel arg #1

Lambda expression captures kernel arguments, but no defined order of captures in C++.

```
float start = 3.14f;
float *ptr = sycl::malloc_shared<float>(NUM, q);

auto lambda = [=](sycl::nd_item<> it) {
  int id = it.get_global_linear_id();
  ptr[id] = start + static_cast<float>(id);
};
```

SYCL doesn't define whether this kernel has two arguments or one "struct" argument.

```
struct mykernel {
  float start;
  float *ptr;

  void operator()(sycl::nd_item<> it) {
    int id = it.get_global_linear_id();
    ptr[id] = start + static_cast<float>(id);
  }
};
```

Solve with new kernel syntax – free function kernels

Kernel is just a plain function, arguments are obvious

This "property" identifies the function as an nd-range kernel

```
SYCL_EXT_ONEAPI_FUNCTION_PROPERTY((syclex::nd_range_kernel<1>))

void myiota(float start, float *ptr) {
  sycl::nd_item<1> it = syclex::this_work_item::get_nd_item<1>();

  int id = it.get_global_linear_id();
  ptr[id] = start + static_cast<float>(id);
}
```

Need some new way to get iteration index. Functions in the "this_work_item" namespace return the iteration index. These are available as an extension even for traditional kernels.

We support this syntax for nd-range and single-task kernels (not for simple range kernels)

Putting it all together

```
namespace syclex = sycl::ext::oneapi::experimental;

int main() {
  sycl::queue q;
  sycl::context ctxt = q.get_context();

  std::string src = R"""(
    SYCL_EXT_ONEAPI_FUNCTION_PROPERTY((syclex::nd_range_kernel<1>))
    void myiota(float start, float *ptr) {
      sycl::nd_item<1> it = syclex::this_work_item::get_nd_item<1>();
      int id = it.get_global_linear_id();
      ptr[id] = start + static_cast<float>(id);
    }
  )""";

  auto src_bundle = syclex::create_kernel_bundle_from_source(ctxt, syclex::source_language::sycl, src);

  auto exe_bundle = syclex::build(src_bndl);
  sycl::kernel myiota = exe_bundle.ext_oneapi_get_kernel("myiota");

  float start = 3.14f;
  float *ptr = sycl::malloc_shared<float>(NUM, q);
  q.submit([&](sycl::handler &cgh) {
    cgh.set_arg(0, start);
    cgh.set_arg(1, ptr);
    cgh.parallel_for(sycl::nd_range{{NUM},{WGSIZE}}, myiota);
  });
}
```

Remember, this string would be dynamically generated

Digression on free function kernels

Free function kernels – not just for online compilation

```
SYCL_EXT_ONEAPI_FUNCTION_PROPERTY((syclex::nd_range_kernel<1>))
void iota(float start, float *ptr) {
  sycl::nd_item<1> it = syclex::this_work_item::get_nd_item<1>();
  int id = it.get_global_linear_id();
  ptr[id] = start + static_cast<float>(id);
}

int main() {
  sycl::queue q;
  sycl::context ctxt = q.get_context();

  auto exe_bundle =
    syclex::get_kernel_bundle<iota, sycl::bundle_state::executable>(ctxt);
  sycl::kernel myiota = exe_bundle.ext_oneapi_get_kernel<iota>();

  float start = 3.14f;
  float *ptr = sycl::malloc_shared<float>(NUM, q);
  q.submit([&](sycl::handler &cgh) {
    cgh.set_arg(0, start);
    cgh.set_arg(1, ptr);
    cgh.parallel_for(sycl::nd_range{{NUM},{WGSIZE}}, myiota);
  });
}
```

Kernel defined exactly as before, but definition is in main program (not in a string)

Get "kernel" object from function pointer template parameter

Launch kernel exactly as in online compilation case

Why?

- Consistent syntax with online compiled kernels
  - No advantage to prohibiting this syntax in “normal” (non-online-compiled) kernels
- Familiar syntax to OpenCL and CUDA programmers
  - Eases migration to SYCL

Back to the online compiler

Backends can online compile other languages

```
namespace syclex = sycl::ext::oneapi::experimental;

int main() {
  sycl::queue q;
  sycl::context ctxt = q.get_context();

  std::string src = R"""(
    extern "C" __global__
    void myiota(float start, float *ptr) {
      size_t id = blockIdx.x * blockDim.x + threadIdx.x;
      ptr[id] = start + static_cast<float>(id);
    }
  )""";

  auto src_bundle = syclex::create_kernel_bundle_from_source(ctxt, syclex::source_language::cuda, src);

  auto exe_bundle = syclex::build(src_bndl);
  sycl::kernel myiota = exe_bundle.ext_oneapi_get_kernel("myiota");

  float start = 3.14f;
  float *ptr = sycl::malloc_shared<float>(NUM, q);
  q.submit([&](sycl::handler &cgh) {
    cgh.set_arg(0, start);
    cgh.set_arg(1, ptr);
    cgh.parallel_for(sycl::nd_range{{NUM},{WGSIZE}}, myiota);
  });
}
```

Kernel defined in CUDA source code

Launching is the same

Online compilation support in the DPC++ compiler

- SYCL – Supported on all backends
- CUDA – Supported only on CUDA backend
- OpenCL C – Supported on either OpenCL or Level Zero backend

SPIR-V can also be a “language”

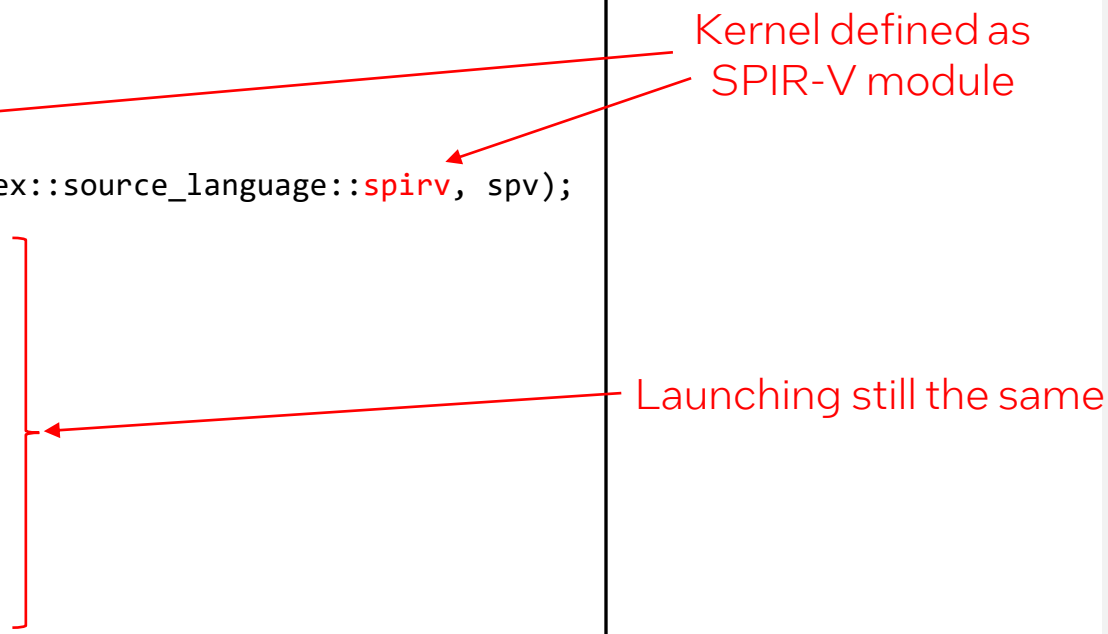
```
namespace syclex = sycl::ext::oneapi::experimental;

int main() {
  sycl::queue q;
  sycl::context ctxt = q.get_context();

  std::vector<std::byte> spv{/* binary SPIR-V module */};
  auto src_bundle = syclex::create_kernel_bundle_from_source(ctxt, syclex::source_language::spirv, spv);

  auto exe_bundle = syclex::build(src_bndl);
  sycl::kernel myiota = exe_bundle.ext_oneapi_get_kernel("myiota");

  float start = 3.14f;
  float *ptr = sycl::malloc_shared<float>(NUM, q);
  q.submit([&](sycl::handler &cgh) {
    cgh.set_arg(0, start);
    cgh.set_arg(1, ptr);
    cgh.parallel_for(sycl::nd_range{{NUM},{WGSIZE}}, myiota);
  });
}
```



- Enables ninjas to hand-code kernels in SPIR-V
- Enables any high-level compiler that generates SPIR-V (e.g. graph compiler)
- Supported on Level Zero or OpenCL backends

Experimental support in DPC++

- OpenCL C – Works now
- SPIR-V – Works now
- SYCL – In progress
- CUDA – Planned

Disclaimers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