Enable CUDA Compilation on Cppyy-Numba generated IR

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INTRODUCTION

- A third-year Computer Science & Engineering undergrad from Graphic Era University, India
- Interested in low-level systems, compilers, runtimes.
- Curious about mysteries of the universe, science and technoculture stuff
- Loves to research and explore new technologies
- Previously, contributed to different open source projects like Unikraft, KDE, Fedora

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PROBLEM STATEMENT

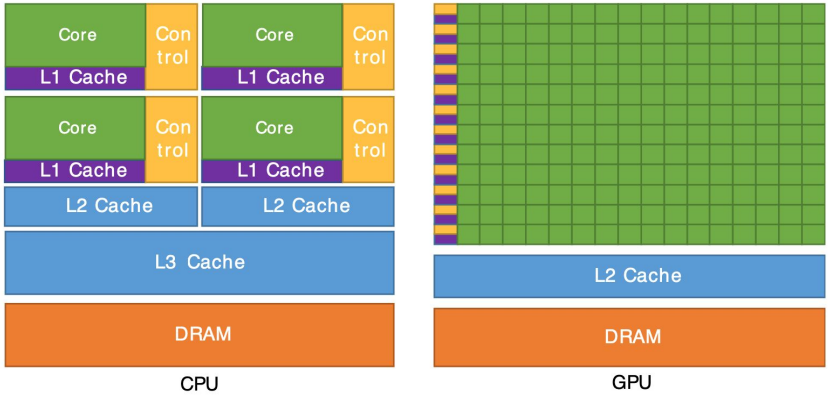
Cppyy is a tool that automatically generates Python-C++ bindings at runtime, allowing Python to call C++ code and vice versa. It has recently added support for Numba, a high-performance Python compiler that compiles looped code containing C++ objects, methods, and functions defined via Cppyy(example in the coming slides) into efficient machine code.

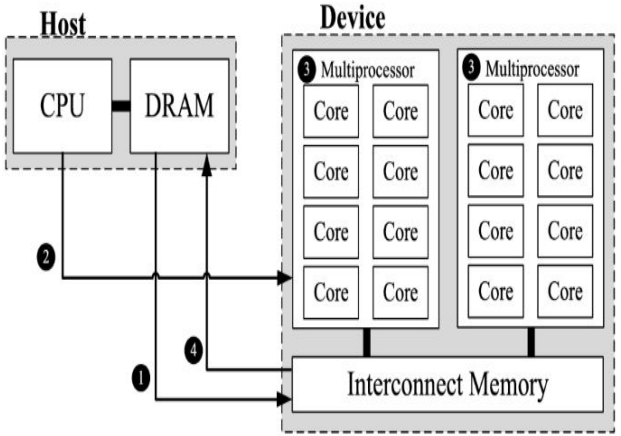
GOAL

The goal is to demonstrate that Cppyy can define CUDA kernels in C++ and launch them from Python code compiled with Numba, enabling Python users to easily utilize the power of CUDA-accelerated computing. GPUs applications spans beyond graphics in the scientific community. Examples: image processing, genetic encoding(simulation of genetic codes).

GPGPU Ecosystem & Scientific Computing

- High compute intensive workloads/code on GPU
- Normal compute intensive workloads on CPU



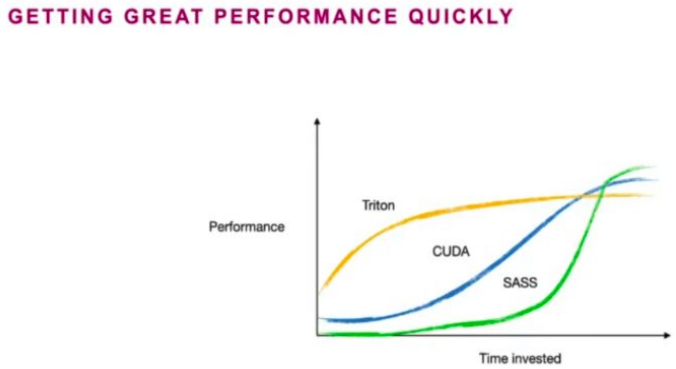


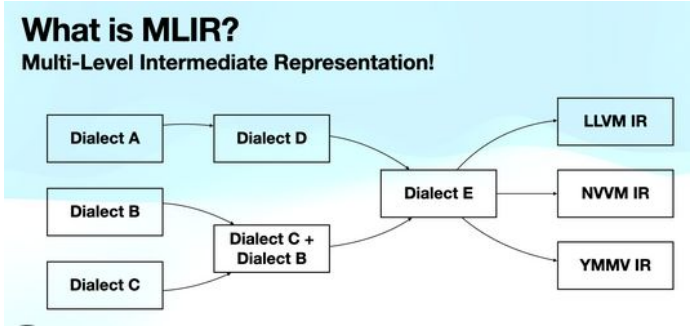
GPGPU Architecture

PAST → **PRESENT/FUTURE**

Gaming,3D Graphics GPGPUs(Scientific computation and simulation)

FUTURE- Heterogeneous Computing





"Mojo and Triton are based on MLIR dialects,

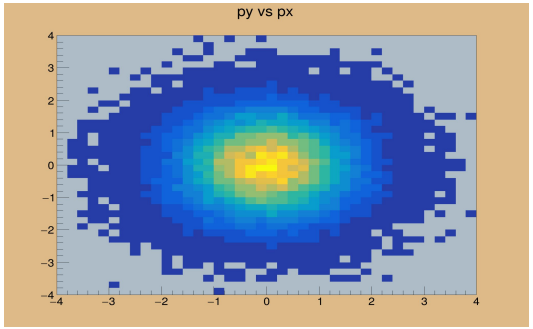
allowing compiler frontend optimizations to be reused"

Sources:

- https://mlir.llvm.org/
- https://openai.com/index/triton/
- https://www.modular.com/max/mojo

IMPORTANCE OF THIS PROJECT

- Allows scientists to leverage powerful C++ libraries from Python, combining the performance of C++ with the simplicity and rich ecosystem of Python.
- Avoids cross language overhead.
- Interoperability between static and dynamic language(Differences between C++ and Python).
- Enabling CUDA compilation of the Numba-generated code would allow Python users to easily utilize GPU acceleration when working with C++ libraries, without sacrificing performance.
- Accelerate Research and Development in Scientific Computing like Data analysis(ROOT), Machine Learning, computational sciences like simulating genetic code, protein structures, etc that rely on both languages.



Understanding Cppyy

1. Bindings/Wrappers

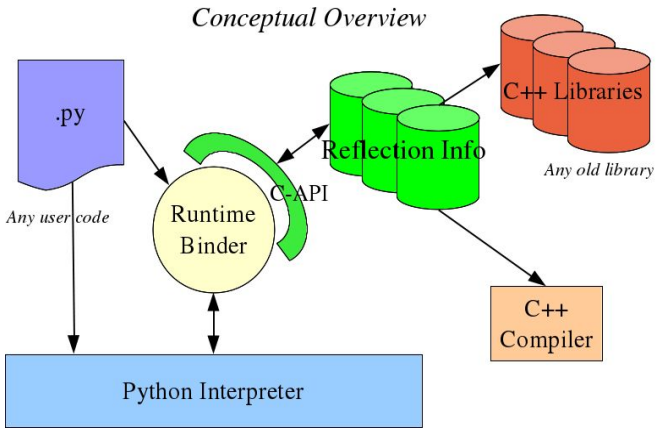
[Interaction between C++/Cuda and Python]

[Proxies exposes C++ objects and classes to Python side]

[Reflections enables advanced features like runtime

template instantiation, function callbacks,

cross-language inheritance, etc]



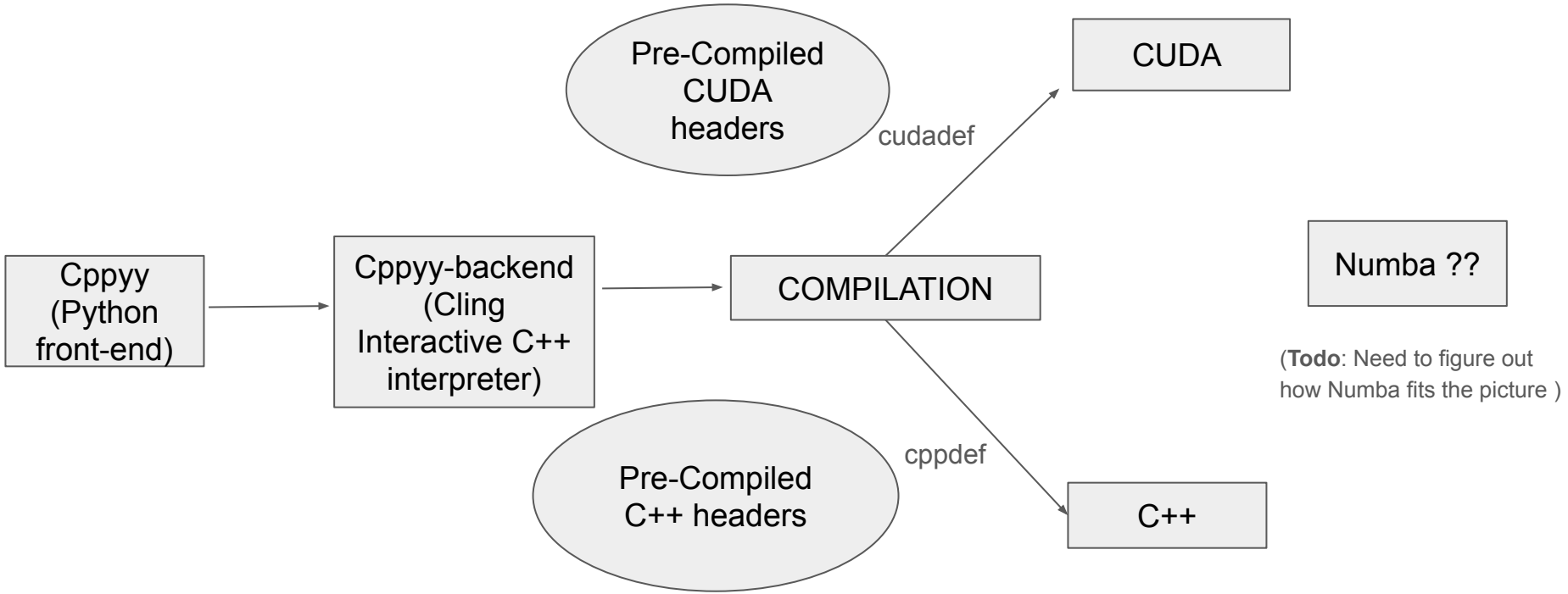
2. GPU compilation pipeline

[Enabled via Pre-Compiled CUDA headers]

[After enabling CUDA with `CLING_ENABLE_CUDA=1`, CUDA code can be used and kernels can be launched from JITed code by in *`cppyy.cppdef()`*]

Source: https://morepypy.blogspot.com/2012/06/architecture-of-cppyy.html

Cppyy-CUDA support



Why Numba?

- High performance python JIT compiler
- Numba's IR- llvmlite, based on LLVM IR

Proof of concept →

```
import cppyy
import cppyy.numba_ext

cppyy.cppdef('''
__global__ void MatrixMul(float* A, float* B, float* out) {
    // kernel logic for matrix multiplication
}
''')

@numba.njit
def run_cuda_mul(A, B, out):
    # Allocate memory for input and output arrays on GPU
    # Define grid and block dimensions
    # Launch the kernel
    MatrixMul[griddim, blockdim](d_A, d_B, d_out)
```

TASKS ACCOMPLISHED

- Project setup done(Faced issues #223 and #232 on my system- Fixed #234)
- Started a docs enhancements PR- #233
- Traced *test_numba.py* tests using PyCharm debugger(Learnt about proxies, reflections, etc)
- Tested support of Python 3.12 on Cppyy(Reported errors to the mentors)
- Tried running vector add CUDA kernel and reported my findings to the mentors

***ToDo**: Add a blogpost and presentation to compiler-research-website*

Coding period starts !!!!

- Currently: Working on implementing *cppyy.cudadef* function(similar to cppdef)

PROPOSED PLAN

August, 2024

Midterm Evaluations

Deliverables: To add some basic level of implementation. For example, use *std::vector* that contains an image. Have a piece of python that implements gaussian blur and run both on a gpu.

November, 2024

Final Evaluation

Deliverables: To replace the uniform data from the image that we showed from the previous deliverable with an irregular memory. For example, *std::vector* of some object.

Nov, 2024-Future

Future Scope

Add support for Testing and Documentation(Also, Debugging support), Research on adding support for other graphics APIs.

THANK YOU

for listening!