Incremental Compilation Support in Clang

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Objectives

Incremental compilation aims to support clients that need to keep a single compiler instance active across multiple compile requests. Our work focuses on:

- Enhancement – upstream incremental compilation extensions available in forks;
- Generalization – make building tools using incremental compilation easier;
- Sustainability – move incremental use cases upstream.

Introduction

Over the last decade an interactive, interpretative, C++ (aka REPL) platform has developed as part of the high-energy physics data analysis project – ROOT [1, 2]. This REPL, cling [3] supports data analysis of exabytes of particle physics data coming from the Large Hadron Collider (LHC) and other particle physics experiments.

Cling is a C++ interpreter built on top of clang and LLVM. In a nutshell, it uses clang's incremental compilation facilities to process code chunk-by-chunk by assuming an ever-growing translation unit [3]. Code is lowered into LLVM's IR and run by the LLVM jit. Cling implements language "extensions" such as execution statements on the global scope and error recovery.

Cling is also available as a standalone tool, with a growing community, including users in finance, biology and in a few companies with proprietary software. For example, there is a xeus-cling jupyter kernel [4]. One of the major challenges we face to foster this community is the set of cling-related patches to its LLVM and clang forks. The benefit of relying more heavily on the LLVM community standards for code reviews, release cycles and integration has been mentioned a number of times by our users.

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Background

Cling requires ∼100 patches to clang's incremental compilation facilities. For example, CodeGen was modified to work with multiple llvm::Module instances, and to finalize per each end-of-translation unit (cling has more than one). Tweaks to the FileManager's caching mechanism, and improvements to the SourceManager virtual and overridden files (code reached mostly from within cling's setup) were necessary.

Our research shows that the **clang infrastructure works amazingly well** to support something which was not its main use case. The grand total of our diffs against clang-9 is: *62 files changed, 1294 insertions(+), 231 deletions(-)*.

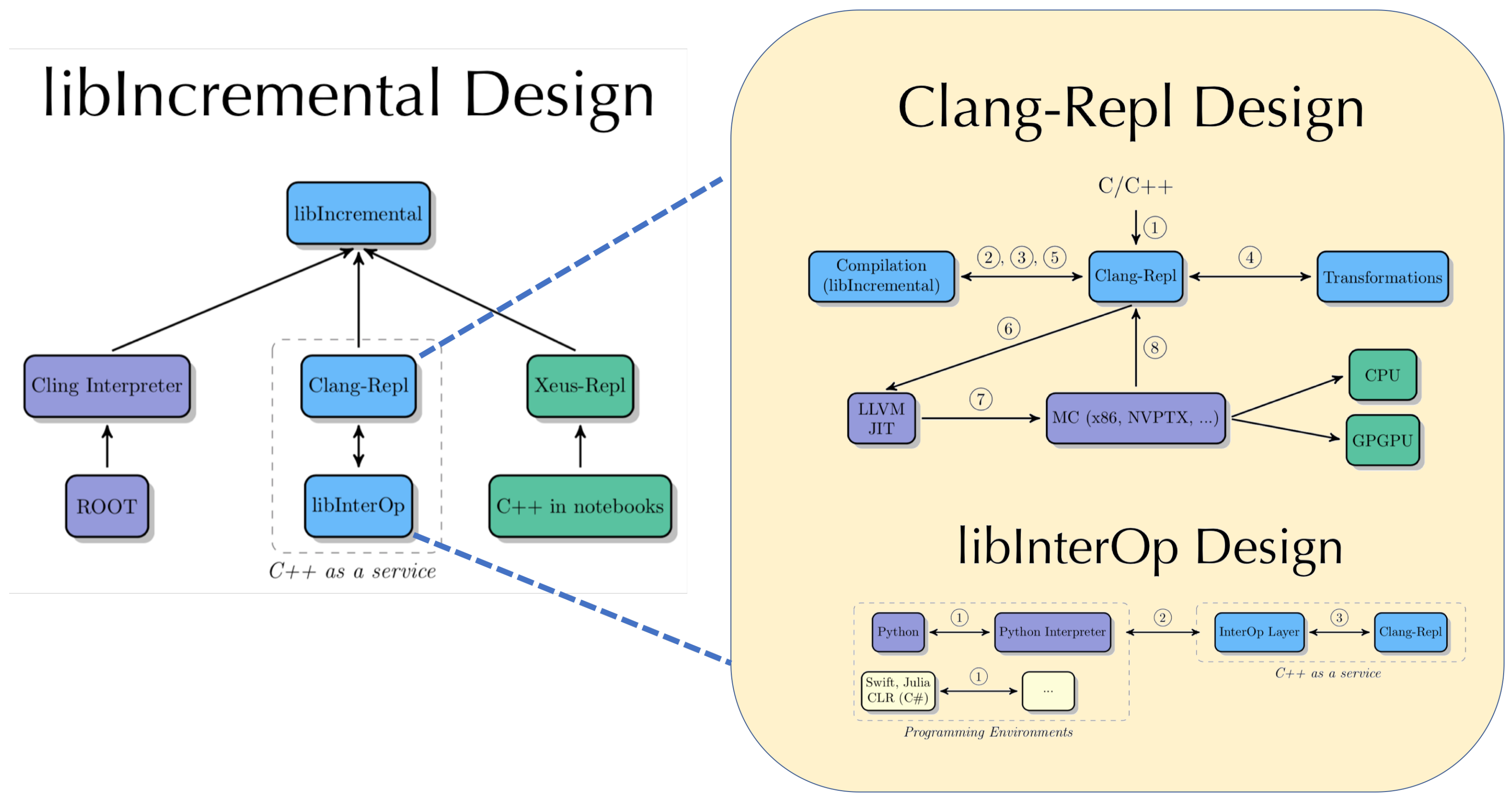
A major weakness of cling's infrastructure is that it does not work with the clang Action infrastructure due to the lack of an IncrementalAction.

Clang Incremental Action

An incremental action should enable the incremental compilation mode in clang (eg., in the preprocessor) and does not terminate at end of the main source file.

High Level Tool Design

Incremental Action allows constant compilation of partial inputs and ensures that the compiler remains active. It includes an API to access attributes of recently compiled chunks of code that can be post-processed. The REPL orchestrates existing LLVM and Clang infrastructure with a similar data flow:



The tool enabling incremental compilation (eg, Clang-Repl or cling) controls the input infrastructure by interactive prompt or by an interface allowing the incremental processing of input (①). Then it sends the input to the underlying incremental facilities in clang, for simplicity *libIncremental*, infrastructure (②). Clang compiles the input into an AST representation (③). When required the AST can be further transformed in order to attach specific behavior (④).

The AST representation is then lowered to LLVM IR (⑤). The LLVM IR is the input format for LLVM's just-in-time compilation infrastructure. The tool will instruct the JIT to run specified functions (⑥), translating them into machine code targeting the underlying device architecture (eg. Intel x86 or NVPTX). This embeddable design (⑦,⑧) offers a ***compiler as a service*** (CaaS) capability.

A *CaaS* can support various language interoperability services. For example *libInterOp* can aid a Python program unable to resolve an entity via last resort lookup request to the proposed layer (①). It performs a name lookup through for the requested entity (②). The REPL, run as a service, finds a suitable candidate(s) and returns it. Then the layer wraps the candidate into a meta object and returns to the Python interpreter as C++ entity bound to Python.

Conclusion

Over the years it has become evident that incremental processing of C++ has its users not only in the science domain but also industry. The work underway aims at making the incremental C++ facilities in clang more sustainable and easier to build tools.

The advancement of the interpretative technology for C++ in cling will be a basis for our contributions to the LLVM community. The development of clients based on clang incremental C++ and improved language interoperability will make C++ easier to use and friendlier to integrate in the trending Notebook-style programming.

Additional Information

We invite anyone interested in joining our incremental C++ activities to join our google group: compiler-research-announce.

References

[1] The official repository for ROOT: analyzing, storing and visualizing big data, scientifically. `https://github.com/root-project/root`.

[2] ROOT: analyzing petabytes of data, scientifically. `https://root.cern/`.

[3] V Vasilev, Ph Canal, A Naumann, and P Russo. Cling–the new interactive interpreter for ROOT 6. In *Journal of Physics: Conference Series*, volume 396, page 052071, 2012.

[4] Xeus is now a Jupyter subproject. `https://blog.jupyter.org/xeus-is-now-a-jupyter-subproject-c4ec5a1bf30b`.

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