Bachelor Thesis

Comparative effects of optimization strategies in high and low level programming languages on PBR performance

by

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Comparative effects of optimization strategies in high and low level programming languages on PBR performance

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ABSTRACT

Your Master Thesis has to be written in English and should follow the ACM style (see the Overleaf template). We also suggest a *structured abstract* following the structure below.
Context. Write this at the end
Goal. Write this at the end
Method. Write this at the end
Results. Write this at the end
Conclusions. Write this at the end

As a very rough indication, the final thesis report typically entails, excluding appendixes, between 10 and 30 pages, with an average of 15 pages. The large variation depends on many variables including the specific field, project nature, and context. We advise to ask your supervisor if you should consider which number as a reference.

1 INTRODUCTION

Rewriting software components; or entire systems; in a different language is a common practice to address various limitations caused by the original implementation language, including but not limited to performance, maintainability, and scalability. The primary motivation behind rewriting is to leverage the strengths of the new language to address the limitations of the original language. However, rewriting a large system, especially in a different language with potentially different paradigms can be a complex and time-consuming task. This study aims to asses the viability of leveraging language interoperability to simplify and expedite the rewriting process.

Most well known major software services today like Facebook, YouTube, Google, LinkedIn, Wordpress, etc. have all had either components many of them starting out with language such as PHP or Ruby on Rails because these were the popular choices back in the day and what the intial developers where likely the most familiar with. We can take YouTube as a good example, it was intially written largely in PHP, but as the platform grew this came with some key drawbacks, a key one being scalability, one reason for switching to Python (and C++) was because Python speifically had both a wider range of syntax expressions and more importantly a better optimizability. This allowed for rapid flexible development and deployment, in addition to scalability and performance at an improved maintainability over PHP.

Similar stories exist for so many other platforms, as languages evolve and the second system effect comes into play we will naturally see software evolve to adapt to new requirements and technologies as developers realize their mistakes of the past. Though the rewriting process does not come without its own set of challenges. It could be argued that a contributing factor to the downfall of the Netscape browser was the decision to do a ground up rewrite of the browser, a reason for this being that the original code base was so messy developers did not want to contribute Pogue [1]. The choice was then made to start from new, but by the time the browser released it still lacked a lot of basic features Zawinski [2].

More broadly speaking the manner in which we choose to rewrite software in a different language should preferably align with the core motivation as best as we can, while mitigating as many of the downsides as possible. This is where the concept of language interoperability could come into play. Language interoperability can potentially offer some very interesting benefits, a key one being the ability to effectively implement a gradual/iterative rewrite while still allowing for the original code to be used. The benefit here being that we can leverage the strengths of the new language, still use existing familiar infrastructure, all while allowing the system to be iteratively improved without there being any major downtime untill the rewrite is complete.

```
1   // Example of  interoperability   between C and C++
2   # include  <iostream>
3   extern "C" {
4       # include  <stdio . h>
5       void  c_function ()  {
6           printf ("Hello  from C\n");
7       }
8   }
9   int main()  {
10      c_function () ;
11      std :: cout  << "Hello  from C++" << std :: endl ;
12      return 0;
13  }
```

2 BACKGROUND

Language interoperability; or interop for short; is broadly seen as the ability of two or more different programming languages to interact with each other and function as a part of a single system. A primary motivation behind the implementation of interop mechanics is the idea that while programming languages; especially modern ones; are often designed to be somewhat general-purpose, they are not necessarily the best tool for every job. Thus it is often the case that a system will be implemented in multiple languages. A good example of this is the tendency to separate various types of systems into frontend and backend in line with the idea of separation of concerns. In the case of web development frontend generally refers to the user interface, for which a common choice is

HTML and CSS with JavaScript for interactivity. The backend on the other hand is generally responsible for the business logic and data storage, for which a common choice is Python, Java, or C#, the interoperability in this instance takes the form of a REST API.

The focus of this study however is on faster means of interoperability of which there are two important types in particular to focus on, Virtual Machines (VMs) and Foreign Function Interfaces (FFIs).

3 RESEARCH METHODS

In this section, you would provide a description of: the research strategy (well-formulated and justified); the data collection and data analysis methods; and a clear link explaining how research strategy and methods are suitable to answer the research question(s). Include a figure providing a overview of the whole thesis in terms of research strategies/methods, RQs, inputs and outputs. An example is given in Figure.

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4 DISCUSSION

Here you put your results in context (possibly grouped by research question). Usually, this section focuses on analyzing the implications of the proposed work for current and future research and for practitioners.

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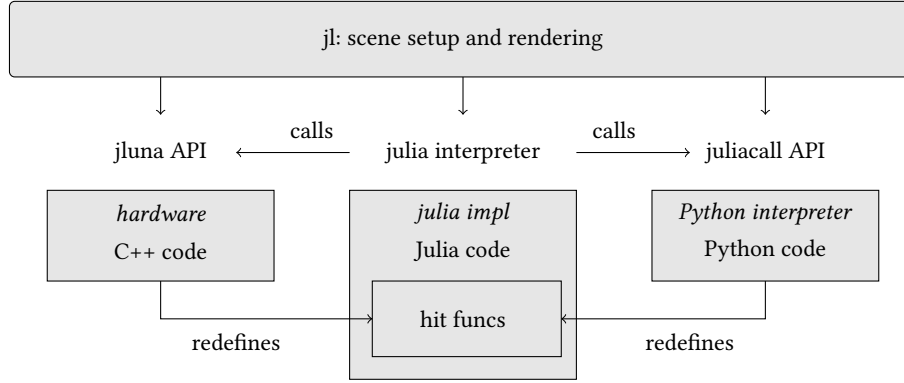
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│              jl: scene setup and rendering               │
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   jluna API  ◄──────── julia interpreter ────────► juliacall API

┌──────────────┐      ┌──────────────────┐    ┌────────────────────┐
│  hardware    │      │   julia impl     │    │ Python interpreter │
│  C++ code    │      │   Julia code     │    │  Python code       │
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Figure 1: *System architecture of multi-language PBR renderer.*

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5 RELATED WORK

Describe here scientific papers similar to your thesis work, both in terms of goal and methodology. One paragraph for each paper (we expect about 5-8 papers to be discussed). Each paragraph contains: (i) a brief description of the related paper and (ii) a black-on-white description about how your work differs from, or overlaps with, the related paper, hence emphasizing the novelty contributed by this thesis. You may place this section immediately after the Background section, if necessary.

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6 CONCLUSION

Briefly summarize your contributions, and share a glimpse of the implications of this work for future research.

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REFERENCES

[1] D. Pogue, "State of the art; netscape 6 browser: Mixed bag", *The New York Times*, Nov. 2000, See the article in its original context from November 30, 2000, Section G, Page 1. [Online]. Available: https://www.nytimes.com/2000/11/30/technology/state-of-the-art-netscape-6-browser-mixed-bag.html.

[2] J. Zawinski, *Resignation and postmortem*, © 1999 Jamie Zawinski, Apr. 1999. [Online]. Available: https://www.jwz.org/gruntle/nomo.html.