UNIVERSITÀ DEGLI STUDI DI MILANO

RESEARCH PROJECT			
Applicant's Name	Federico Cristiano Bruzzone	PhD	Computer Science

Project title

Universal Language Server Protocol and Debugger Adapter Protocol for Modular Language Workbenches

Abstract

The rapid evolution of software development necessitates efficient tools for creating and integrating programming languages. *Integrated Development Environments* (IDEs) and *source-code editors* (SCEs) offer vital support features like syntax highlighting, code completion, and debugging, but their development is often complex and labor-intensive. **Language Server Protocol** (LSP) and **Debugger Adapter Protocol** (DAP) were introduced to simplify this process by providing a standardized API, decoupling language support implementation from specific editors. Despite these advancements, the integration of LSP and DAP remains challenging due to fragmented and inconsistent approaches. Modern language workbenches have made strides in modularization, composition, and IDE integration. However, their methods for LSP and DAP generation often lack a standardized and cohesive framework, resulting in increased complexity and reduced efficiency. By leveraging techniques like feature-oriented programming and software product lines (SPLs), there is potential to enhance modularity and reusability in language server development. This approach promotes a *bottom-up* methodology where LSP and DAP functionalities are encapsulated in feature modules, enabling a more compositional and efficient implementation process. Nowadays, *Xtext* [6] is one of the few language workbenches that support LSP generation [2]. **Neverlang**, developed at the `ADAPT-Lab` of the Università degli Studi di Milano, being a framework for language composition and modularization, presents a promising solution. By extending its capabilities to support a universal LSP and DAP, reusable, language-agnostic feature modules can be created. This approach aims to reduce development effort and complexity compared to traditional *top-down* methods. Empirical evidence suggests that a modular framework could significantly improve maintainability, extensibility, and productivity in language support tool development. Additionally, this project aims to reduce to $\mathcal{L} \times 1$ the number of combinations required to support $\mathcal{L}$ languages.

Language Workbench	Modularization Supp.	Precompiled Feature Supp.	Native IDE gen.	LSP/DAP Gen.	LSP/DAP Mod.
JustAdd	◐	○	○	○	○
Melange	●	○	3rd party (EMF)	⋆	⋆
MontiCore	◐	◐	●	○	○
MPS	●	○	●	⋆	⋆
Rascal	○	○	●	○	○
Spoofax	●	◐	●	⋆	⋆
Xtext	○	◐	●	●	○
Neverlang	●	●	○	☆	☆

Comparison of language workbenches in terms of modularization, precompiled feature support, native IDE generation, LSP generation, and LSP modularization.

Project aims and their relevance in the context of the state of the art

The primary aim of this project is to develop a Universal **Language Server Protocol**[1] (LSP) and **Debugger Adapter Protocol**[2] (DAP) for modular language workbenches (LWs). This endeavor seeks to address significant gaps and challenges developing LSPs and DAPs in the current landscape of language workbenches, particularly in the areas of modularization, composition, and interoperability. Current language workbenches such as Melange [12], MontiCore [22], Spoofax [19], and MPS [43, 44] have made significant strides in supporting modularization, composition, and IDE integration. The table above provides a comparison of various language workbenches in terms of their support for modularization, precompiled feature support, native IDE generation, LSP generation, and LSP modularization. The ● symbol indicates full support, ○ partial support, ◐ limited support and ☆my contribution, which can be extended to all LWs that support at least component modularization (identified by ⋆). The second column indicates the level of support for modularization of artifacts and language features (more detail in Project Description section). The third column indicates the level of support for precompiled features, the importance of this feature lies in the fact that an artifact can be used by several features being compiled once, and that one feature can be used among several projects without the recompilation step. The fourth column indicates the level of support for native IDE generation, this is because many LWs are supported by the existence of some IDE and thus allow IDE generation for languages developed for IDE that host them. The generation and modularizazion of LSP and DAP is trivial shown by the fifth and sixth columns, respectively. However, their approaches are often fragmented and lack a standardized method for LSP and DAP generation and modularization, as shown in table. Neverlang [39, 41], developed at the `ADAPT-Lab`[3] of the Università degli Studi di Milano, being a comprehensive framework for language composition and modularization that supports the development of language product lines [24, 8] (LPLs), is a prime candidate for the implementation of the proposed LSP and DAP. The project

[1] https://microsoft.github.io/language-server-protocol
[2] https://microsoft.github.io/debug-adapter-protocol
[3] https://di.unimi.it/it/ricerca/risorse-e-luoghi-della-ricerca/laboratori-di-ricerca/adapt-lab

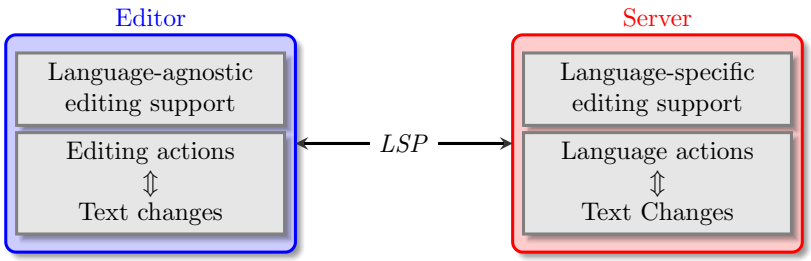

Figure 1: LSP and DAP approach for programming languages.

will leverage the existing capabilities of Neverlang to develop a universal LSP and DAP that can be used across different programming languages and IDEs. This will enable developers to create external domain-specific languages [15] (DSLs) and general-purpose languages (GPLs) more effectively and efficiently, enhancing the overall development experience and productivity.

The project aims to achieve the following objectives:

Aim 1: Improve IDE and LSP Generation
Integrated Development Environment generation and support for the *Language Server Protocol* are essential for the practical use of domain-specific languages (DSLs). While some language workbenches like Xtext [6] support LSP generation [2], many do not, limiting their usability across different editors and IDEs.
Relevance: By establishing a universal protocol for LSP and DAP, this project aims to bridge the gap, enabling language workbenches to generate IDE support and LSPs more seamlessly. This will ensure that languages developed using these workbenches can be used in any IDE that supports these protocols, enhancing their accessibility and utility.

Aim 2: Facilitate LSP and DAP Modularization
LSP and DAP modularization are not widely supported by current language workbenches [7]. This feature is crucial for allowing different language components to communicate and function cohesively within an IDE.
Relevance: Implementing support for LSP and DAP modularization will allow for better integration and interaction of various language features, thereby improving the overall development experience and capability of language workbenches. This aligns with the needs for more sophisticated and integrated language development tools as highlighted in the contemporary research and development literature.

Aim 3: Reduce to $\mathcal{L} \times 1$ the number of combinations to support $\mathcal{L}$ languages

Before the advent of LSP and DAP, developers had to implement language support for each editor separately, having the number of combinations to support $\mathcal{L}$ languages in $\mathcal{L} \times \mathcal{E}$, where $\mathcal{E}$ is the number of editors. Currently, the number of combinations to support $\mathcal{L}$ languages is $\mathcal{L} + \mathcal{E}$ [37], as the Microsoft LSP and DAP are editor-agnostic, as shown in Figure 1. This project aims to reduce the number of combinations to $\mathcal{L} \times 1$, by developing a universal LSP and DAP that can be used across different programming languages and IDEs.

Relevance: Reducing the number of combinations required to support multiple languages will simplify the development process and make it more efficient. This will enable developers to create language support more quickly and effectively, enhancing the overall productivity and usability of language workbenches.

Aim 4: Leverage Neverlang for LSP and DAP in LPL Development
Neverlang's capabilities for language composition and modularization make it an ideal platform for developing a universal LSP and DAP that caters to a variety of language needs. By leveraging Neverlang's LPL development features [14], the project will establish a reusable core for LSP and DAP functionalities, allowing for the creation of product line variations tailored to specific programming language requirements. This will significantly reduce development time and effort for creating LSPs and DAPs for new languages within the product line.
Relevance: Developing a core reusable base for LSP and DAP functionalities through Neverlang's LPL features will streamline the creation of new language support. This fosters a more efficient and scalable approach to LSP and DAP development, aligning perfectly with the core principles of software product lines.

Project description

Software languages, crucial not only in software engineering but also in various other fields [32, 10], require effective editing support for optimal use. This applies to both general-purpose languages (GPLs) and domain-specific languages (DSLs). To aid in this accomplishment, modern *Integrated Development Environments* (IDEs) and *source-code editors* (SCEs) provide a wide range of editing support (e.g., syntax and semantic highlighting, intelligent code completion, debugging, and show documentation on hovering over a primitive), but the development of such support is a complex and time-consuming task [36]. The reduction of efforts in implementing this support has paved the way for an advantageous strategy for programming language developers and maintainers, as well as those developing integration tools, when an IDE would have provided the implementation for their language and vice-versa. Then, given $\mathcal{L}$ languages and $\mathcal{E}$ editors, the number of possible combinations is $\mathcal{L} \times \mathcal{E}$ for both LSP and DAP implementations, which is a large number. It means that the development of a new language or editor would require a large amount of effort to provide support for all possible combinations, with a significant amount of duplicated work and the risk of introducing inconsistencies [34].

In contemporary times, advancements in techniques [35] such as the architecture of language infrastructures [28, 42], Language Workbenches (LWBs) [13] and the implementation of specific patterns [3, 29, 31] have been made to address this issue.

In this context, Microsoft in 2016 proposed the *Language Server Protocol* and the *Debugger Adapter Protocol* for Visual Studio Code as a promising solution to this problem, reducing from $\mathcal{L} \times \mathcal{E}$ to $\mathcal{L} + \mathcal{E}$ the number of combinations to be implemented, as it decouples the implementation of the language support from the editor (see Figure 2). Detailing, the LSP and DAP are protocols that describes a common *Application Programming Interface* (API) that the **language server** (LS) should implement, with the benefit of having only one implementation of the LS and multiple clients (IDEs and SCEs) that can consume it, essentially establishing a *client-server* relationship through a communication channel (e.g., *pipes* or *sockets*). However, the implementation of an LS and its integration with an IDE/SCEs is still a complex task, as it requires the knowledge of the LSP specification and the implementation of the language support. The implementation [16] of an LS is done entirely manually and it is a *top-down* activity, where most of the time is spent on

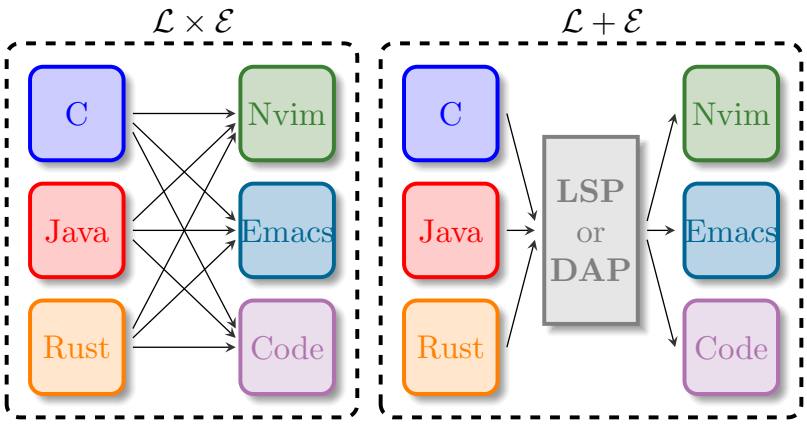

Figure 2: Traditional approach to language support in editors.

the design and implementation data structures and algorithms. Recently, researchers have started talking about the *Software Product Lines* (SPLs) [5, 14] to move towards a more modular world, where the implementation of a software system can be done in a compositional way, by composing the features of the SPL. When a SPL is applied to the implementation of a programming language, each product corresponds to a language variant [24] taking the name of *Language Product Lines* (LPLs) [24]. LPLs have been successfully used in both GPLs [9, 23, 24] and DSLs [17, 27, 40, 45, 46].

What I want to prove with this project is that the implementation of an LS could be a *bottom-up* activity, where each LSP or DAP functionality can be see as a separate *feature module* [4, 18] splitted across the language artifacts, where each artifacts can be part of one or more *language features* (see Figure 3). These units can be composed to provide a modular implementation of the LS. This approach is supported by the fact that the LSP and DAP are *language-agnostic* protocol [30, 36] (see Fig. 1), which means that it does not impose any restrictions on the implementation of the LS, as long as it respects the specification of the protocol. In *feature-oriented programming* (FOP) [1, 11, 33], a feature module is a unit of composition that encapsulates a specific functionality, and it is a first-class entity that can be composed with other feature modules to form a software system; similar to an aspect module that encapsulates a crosscutting concern in *aspect-oriented programming* (AOP) [20, 21, 26]. So, proponing a new modular approach to the implementation of an LS, based also on FOP, I want to extend Neverlang Language Workbench [39, 41] in order to give support to the implementation of the LS for any artifact of the language, and I will also implement the Neverlang LSP [25] and DAP to support the composition of the LS feature modules. In this way, the implementation of the LS is a *bottom-up* activity, where each artifact has attached a part of LSP and DAP feature module that implements the LS functionality for that action, and these units can be composed to provide a modular implementation having **variants** of the LS. I will also make it possibile write feature modules using DSLs. These DSLs will be developed in the context of the Neverlang framework, and will be specific for the implementation of the LS, and trivially they will be independent from the language for which the LS is being implemented. Furthermore, with this approach, I want to prove that it is possible to reduce the number of combinations from $\mathcal{L} + \mathcal{E}$ to $\mathcal{L} \times 1$ by generating client implementations; this will be done by implementing a *client generator* that will take as input the LS feature module and will produce the client implementation. This will

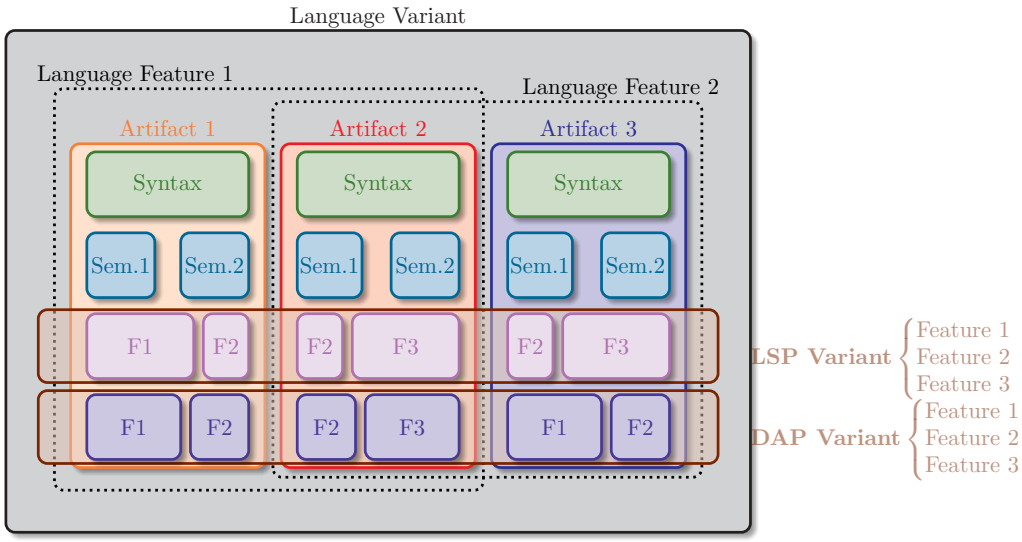

Figure 3: Proposed approach to modular implementation of LSP and DAP.

be supported by the implementation of a *client language* that will allow the developer to specify which client to generate. The client generator will be able to generate clients for different IDEs and SCEs, such as Visual Studio Code, Vim/Nvim and IntelliJ IDEA.

Methodology

The first step involves defining feature modules, which are essential components that encapsulate different functionalities of Language Server Protocol (LSP) and Debug Adapter Protocol (DAP). These functionalities include syntax highlighting, code completion, debugging, and documentation support. Each feature module is identified and defined based on its specific role within the LSP and DAP ecosystem. Following the identification of feature modules, the next phase is developing a **modular framework** within the Neverlang Language Workbench to support the implementation of these feature modules. This framework will provide the necessary infrastructure for creating, composing, and managing the feature modules effectively. This phase will involve designing and implementing the necessary data structures and innovative algorithms to support the composition. An imporant step is developing domain-specific languages (DSLs) within Neverlang. These DSLs are tailored to facilitate the **development and composition** of the feature modules, providing a structured and efficient way to create and manage them. Once the feature modules are defined and the DSLs are developed, the next step is to implement a system within Neverlang that allows for the composition of these feature modules. This system enables the integration of various feature modules into a complete and functional Language Server (**LSP/DAP variant** in Fig. 3). With the modular framework in place, the next phase involves developing Language Servers for multiple programming languages. This step demonstrates the reuse and compositional capabilities of the feature modules. By leveraging the modular design, Language Servers for different languages can be developed more efficiently and with greater consistency. To ensure the effectiveness of these Language Servers, their performance and integration within different Integrated Development Environments (IDEs) and Source Code Editors (SCEs) will be evaluated. This evaluation will focus on how well the Language

Servers perform in real-world development environments and how seamlessly they integrate with existing tools. The final phase of the methodology involves a comprehensive comparison and analysis. This includes evaluating the **effort and complexity** involved in the modular approach compared to traditional *top-down* methods. By analyzing the development process, the benefits and challenges of using a modular framework can be assessed. Additionally, the maintainability and extensibility of the modular approach will be scrutinized. This involves introducing changes and enhancements to the Language Servers and observing how easily these modifications can be implemented. The goal is to determine whether the modular approach offers superior maintainability and extensibility compared to traditional methods.

Expected Contributions

- **A Modular Framework for Language Server Development**: A comprehensive framework within the Neverlang Language Workbench that supports the modular development of Language Servers.
- **Reduction in Development Effort**: Empirical evidence demonstrating a reduction in the development effort and complexity associated with implementng Language Servers.
- **Reusable and Language-Agnostic Modules**: A library of reusable, language-agnostic feature modules for common LSP and DAP functionalities.
- **Case Studies and Practical Applications**: Detailed case studies showcasing the practical applications of the modular approach across different programming languages and development environments.
- **Evaluation and Comparison**: A comprehensive evaluation and comparison of the modular approach with traditional top-down methods, highlighting the benefits and challenges of each approach.

Timeline

In figure 4 is shown the proposed timeline for the research project. The project is divided into seven main phases:

- Literature Review
- Design and development of feature modules
- DSLs implementation for LSP and DAP
- Composing feature modules within Neverlang
- Universal Clients Generation
- Testing modularization with 3 LSs
- Evaluation comparison and analysis

Figure 4: Proposed timeline for the research project.

The **literature review** phase will be carried out in the first six months. I will start by expanding my knowledge LSP and DAP in general, and then I will perform a deeper study of all the most important approaches currently available in literature to elaborate on their pros and cons and lay a groundwork for my research work. Great attention would be given to the study of *bottom-up* and *top-down* approaches, in order to find their shared aspects. This process will lead to the drafting of a survey on feature-oriented programmin and software product lines. During the next eight months, I will **design and develop the feature modules** for the LS, and I will extend the Neverlang framework to support the implementation of the LS feature modules. This will be supported by the implementation of generic data structures, such as *Indexed Trees*, *Dependency Graphs*, and *Symbol Tables*, that will be populated by any given language artifact not known *a priori*. An additional compilation step will be added to the Neverlang framework to generate the feature modules from the language artifacts. In the following eight months, I will implement the **DLSs for the LSP and DAP**, and I will extend the Neverlang framework to support the composition of the LS feature modules through the DLSs. This will be supported by the implementation of a *multi-dimensional*

variability model [38]. One of the biggest challenges, in the next six months, will be to **compose the feature modules**. This will be done by implementing a *composition algorithm* that will take as input the splitted feature modules and the language artifacts and will produce the LS feature module. The following six months will be dedicated to the **universal clients generation**. This will be done by implementing a *client generator* that will take as input the LS feature module and will produce the client implementation. This will be supported by the implementation of a *client language* that will allow the developer to specify which client to generate. The client generator will be able to generate clients for different IDEs and SCEs, such as Visual Studio Code, Vim/Nvim and IntelliJ IDEA. In the last six months, I will test the modularization with three LSs, evaluating the feasibility of the approach. This will be done by **implementing the LS for three different languages** and by generating the client implementations. The **evaluation** will focus on the effort and complexity involved in the development of the LS, the maintainability and extensibility of the LS, and the integration of the LS with the existing tools. The evaluation will also include a comparison with the traditional approach to LS development, to assess the benefits and challenges of using the modular framework.

Conclusion

The proposed modular approach to implementing Language Servers via feature-oriented programming within the Neverlang Language Workbench represents a significant advancement in reducing the complexity and effort associated with developing Language Servers. By decomposing the LS functionalities into reusable and composable feature modules, this approach promises to enhance maintainability, extensibility, and overall efficiency in the development of language support tools. Considering the potential impact of this research, I am confident that the proposed project will yield valuable contributions to the field of programming language development and integration. By providing a modular framework for the implementation of Language Servers, this research has the potential to revolutionize the way language support tools are developed and maintained. The reduction in development effort, the increased reusability of feature modules, and the improved maintainability and extensibility of Language Servers are just a few of the benefits that this research aims to deliver. With the proposed timeline and methodology, I am confident that this research project will be completed successfully and will make a significant contribution to the field of programming languages.

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