

Features; unlimited features; but no features

Developing a zero-core modular IDE

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Abstract

This paper introduces a modular, *zero-core*, application, to serve as an Integrated Development Environment (IDE) for experimental programming languages, addressing limitations in traditional IDEs. While standard IDEs are crucial in software development, their support for experimental languages is often inadequate. This can be solved by extensively using the module architecture of existing IDEs. Relying on *niche* modules or functionality is not beneficial for the longevity of the software. By analyzing the essential features of traditional IDEs a need for adaptability by IDEs to new paradigms and tools is highlighted. The solution, proposed by this paper, is to utilize a modular architecture to extend its lifespan and enhance support for experimental languages. Magnolia, a research programming language developed at the University of Bergen, serves as a case study, highlighting its unique characteristics and the necessity for a modular IDE. The primary research question explores how modularization facilitates the design and implementation of experimental programming languages. To showcase the usefulness of a modular approach, the modules needed to extend the core application to an IDE will be implemented.

Keywords: Modularization · IDE · Magnolia.

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Contents

1	Introduction	1
1.1	Modular Architecture	2
1.2	Zero-core Application	2
1.3	Thesis Outline	2
2	Background	4
2.1	Magnolia	4
2.1.1	Magnolia Concept	4
2.1.2	Magnolia Implementation	7
2.1.3	Magnolia Satisfaction	8
2.1.4	Mathematics and Programming	9
2.1.5	Logging example in Java, Rust, and Magnolia	10
2.1.6	Editor example in Java, Rust, and Magnolia	12
2.1.7	Abstract Algebra	13
2.1.8	Java: Magma to Group	15
2.1.9	Rust: Magma to Group	16
2.1.10	Magnolia: Magma to Group	16
2.2	Reusable Software	18
2.2.1	Reuse in Magnolia	18
2.3	Integrated Development Environment	19
2.3.1	Syntax Highlighting	20
2.3.2	Code Autocompletion	21
2.3.3	Go-To-Definitions	21
2.3.4	Formatting and Linting	21
2.3.5	Boilerplate Code Generation	22
2.3.6	File Explorer	22
2.3.7	Version Control System Integration	24
2.3.8	Module Market & Installation	25
2.4	Module Architecture	25

2.4.1	Compile Time Module	26
2.4.2	Runtime Module	26
2.4.3	Modular Architecture in IDEs	26
2.4.4	Module Ecosystem	26
2.4.5	Granularity	27
2.4.6	Module Family	28
2.5	Language Workbench	28
2.6	Language Server	29
2.7	Zero-core IDE	30
2.8	Existing Magnolia IDE	31
2.9	Challenges imposed by Magnolia	31
2.9.1	Renaming	32
2.9.2	Dependency Cycles	33
2.9.3	External software dependency	33
3	Magnolia IDE	34
3.1	User Perspectives	34
3.2	Module Developer	35
3.2.1	Language Agnostic Modules	35
3.2.2	Existing Third Party Libraries	37
3.2.3	Module Development Experience	37
3.3	IDE Users	37
3.3.1	Developer	38
3.4	Maintainer	38
4	Implementation	39
4.1	Tech Stack	39
4.1.1	Low level languages	40
4.1.2	Application Binary Interface (ABI)	40
4.1.3	Rust	41
4.1.4	Tauri	43
4.1.5	Security	44
4.2	Module V.1	45
4.3	Module V.2	45
4.3.1	The Elm Architecture	46
4.3.2	Module Architecture	46
4.3.3	IDE lifecycle	48
4.3.4	Module v2 Cons	49

4.4	Module V.3	51
4.4.1	Zero core architecture and microservice architecture	51
4.4.2	Vanilla TypeScript	52
4.4.3	Core Modifications	52
4.4.4	Tree Manipulation	53
4.4.5	Backend Agnostic Frontend	55
4.4.6	Making the Core evaluate modifications asynchronously	55
4.5	Testing	56
4.5.1	Mocking	56
4.5.2	Unit Testing	56
4.5.3	Module Family Testing	57
4.5.4	Automating Contract Testing	58
4.5.5	End-To-End-Testing	58
4.6	Module Developer Tools	58
4.6.1	Module Dependency Visualization	58
4.6.2	Module Isolation Testing	58
4.6.3	Module Boilerplate Generation	59
4.7	Modules	59
4.7.1	Magnolia Dependency Graph Visualizer	61
4.7.2	IDE Module Family	67
4.7.3	Caching	67
4.7.4	IDE Framework	68
4.7.5	Editor Module Family	68
4.7.6	Magnolia Language Server	68
5	Related Work	69
5.1	Multi-way Dataflow Constraint System	69
5.2	Automated Testing	70
5.3	Abstract Algebra	70
5.4	Syntactic Theory Functor	71
6	Conclusion	72
6.1	Modular Development	72
6.2	Making an IDE is hard	72
6.3	Cons	73
7	Future Work	74
7.1	Technical Debt	74

7.2	Modular Language Server	74
7.3	Modular Editor	74
	Glossary	75
	Acronyms	76
	Bibliography	78
A	Optimizing instructions sets	81
B	Magnolia library parser module	86

List of Figures

2.1	Syntax Highlighting (\LaTeX in Neovim)	20
2.2	No Syntax Highlighting (\LaTeX in Neovim)	21
2.3	Visual Studio Code (VS Code) suggesting appropriate methods (Rust) .	21
2.4	Window for generating boilerplate code for a unit test (Kotlin in IntelliJ)	23
2.5	File explorer in VS Code showing the Nmid source code	24
2.6	File explorer in Neovim showing that the <i>result</i> folder is not Version Control System (VCS)-controlled (grey), and that the thesis folder have un-committed changes, (purple), the files who have changes are marked (yellow), and there is one file which has a committed, but a non-pushed change, (green checked checkbox).	24
2.7	Module market window in IntelliJ showing popular modules that the user can install by clicking on the <i>install</i> button. Also seen in the window is that the user can disable already installed modules, or uninstall them. .	25
2.8	Text Editor Module Family	28
3.1	Foreign modules being invoked by a singular Translation-module	36
3.2	Foreign modules being invoked by an individual Translation-module . . .	36
4.1	Elm Architecture (Figure adapted from [8])	46
4.2	Module state initialization stage	47
4.3	Module view initialization stage	47
4.4	Magnolia basic library dependencies visualized. Each colour represents a package, which contains several modules. The size of the nodes vary depending on the amount of dependents, (indegree), a module has. . . .	65
4.5	Control panel, with buttons and sliders for controlling the graph view .	66
4.6	List of packages in the graph, that can be toggled	66
4.7	Magnolia basic library, with just the <i>Fundamentals</i> package highlighted.	67
6.1	Text Editor Module Family	73

List of Tables

2.1	Module Ecosystem per IDE	27
2.2	IDE features enabled by Language Language Server (LS) (LS)	29

Listings

2.1	Natural numbers (Magnolia)	5
2.2	List concept (Magnolia)	6
2.3	NonEmptyList concept (Magnolia)	6
2.4	Natural numbers implementation (Magnolia)	7
2.5	Invalid implementation (Magnolia)	7
2.6	Natural numbers implementation (C++)	7
2.7	Invalid implementation (C++)	8
2.8	Satisfaction of the natural numbers (Magnolia)	8
2.9	Logging structure (Java)	11
2.10	Logging structure (Rust)	11
2.11	Logging structure (Magnolia)	11
2.12	Magnolia logging satisfaction, the implementation is left out for brevity .	11
2.13	Editor structure (Java)	12
2.14	Editor structure (Rust)	12
2.15	Editor structure (Magnolia)	12
2.16	Magma concept (Java)	15
2.17	Semigroup concept (Java)	15
2.18	Monoid concept (Java)	15
2.19	Group concept (Java)	15
2.20	Magma (Rust)	16
2.21	Semigroup (Rust)	16
2.22	Monoid (Rust)	16
2.23	Group (Rust)	16
2.24	Magma (Magnolia)	17
2.25	Semigroup (Magnolia)	17
2.26	Monoid (Magnolia)	17
2.27	Group (Magnolia)	17
2.28	Logging example (Magnolia)	19
2.29	Editor example (Magnolia)	19

2.30	String concatenation (Magnolia)	32
2.31	String concatenation (Magnolia)	32
4.1	Ownership example (Rust)	41
4.2	Ownership example with reference (Rust)	42
4.3	Counter Module (Haskell)	48
4.4	Core Modifications (Rust)	52
4.5	Instruction (Rust)	53
4.6	UI Builder (Rust) showcasing how to add an empty HyperText Markup Language (HTML) div element to the root HTML element.	54
4.7	State Builder (Rust) showcasing how to add a <i>count</i> field to the state, also showcasing how Rust can infer that the i32 type 0 is a Value::Int type.	55
4.8	Module Event (Rust)	59
4.9	Module trait (Rust)	60
4.10	Core trait (Rust)	60
4.11	Magnolia library parser Module <i>subscribing</i> to an <i>get_magnolia_graph</i> Event (Rust)	61
4.12	Simplified magnolia library parser Module (Rust)	62
4.13	Magnolia library parser response (TypeScript)	63
4.14	Dependency visualiser module (TypeScript)	64
A.1	Instruction (Rust)	81
A.2	Opt method (Rust): Uses a match statement and a guard to match on a <i>slice</i> , (reference to a Vec). The guard lets us add a predicate to our branch, in this case, if y <i>matches</i> an NoOp. If it is an empty slice, it's a NoOp, otherwise, it will be an Instruction with all NoOps recursively removed.	82
A.3	Flatten method (Rust): Not the lack of return statements, this is because the last expression in a function in Rust, is returned, if it doesn't end with a semicolon.	82
A.4	Modification counting (Rust)	83
A.5	Instruction folding (Rust)	84
B.1	Magnolia library parser module (Rust)	86
B.2	Graph visualisation module (TypeScript)	91

Chapter 1

Introduction

Standard IDEs are indispensable tools in modern software development, offering features like early bug reporting, project outline visualization, code highlighting, and code completion, however, these IDEs may not adequately support the unique demands of experimental programming languages. Experimental languages could introduce new concepts like Abstract Semantic Representation (ASR) Transformation, Term Algebras, Mathematics of Arrays (MoA), Syntactic Theory Functor (STF), or other novel programming features. These are concepts from the academic community, and are not common in *mainstream* languages, and as such, have little to no support in modern IDEs. To solve this, researchers need ad hoc solutions for existing IDEs, adding the needed functionality to test out their language features. If this ad hoc solution is too extreme; outside the standard functionality supported by the developers of the IDE, it might be short-lived. As the IDE is maintained, updated and improved, the features used to solve the niche needs of the experimental language might be deprecated.

However, if the IDE has integrated support for extending the standard functionality of the application, then the ad hoc solution will be more stable. Such a system is known by many names. Plug-in architecture, extension Application Programming Interface (API), or add-on system, to name a few. The common factor amongst these systems, is that some component, be it a plug-in, an extension, an add-on, or a module, can extend the functionality of the application. This is a modular approach to extending the lifetime of an application; extending its software longevity. In many of these systems, said components, are composable, allowing for multiple components to work together in a modular fashion to add extra features to an application. This way of adding functionality to an application is commonly used in IDEs.

1.1 Modular Architecture

A modular IDE would assist in these ad hoc solutions. Even if a new feature from an experimental language is introduced, it is unlikely that this feature has no relation to existing features, and as such, it is easier to extend the application in such a manner to facilitate this new feature, with help of existing modules. However, if it is the case that this feature is paradigm-shifting, then there will still be existing functionality that can be used, re-used or extended to facilitate this.

Hypothesis 1.1.1. When an application is designed to be modular from the start, then features not thought of, by the original developers can be integrated into the application, and be stable. If an experimental research language introduces some paradigm shifting concept, then this can easily be tested in a modular IDE.

1.2 Zero-core Application

Taking the modular architecture design to the extreme, the core application has no base features, everything is enabled by an external module. We call such a highly modular application, a *zero-core* application. To qualify for a *zero-core* application, the default application has no functionality; everything is acquired by modules. Such a design facilitates a modular approach, enabling a module-developer to only focus on the functionality they want to extend, not the entire core.

1.3 Thesis Outline

Traditional IDEs encompass essential features such as syntax highlighting, code navigation, and hover-help, all of which play a crucial role in the software development process. However, their limitations become apparent when working with experimental languages. This paper advocates for modularization and composability as key design principles, demonstrating their ability to extend the operational lifespan of software by allowing for ease-of adoption to new paradigms and tools. The discussion revolves around Magnolia, an experimental research programming language developed by Bergen Language Design Laboratory (BLDL) at the University of Bergen. Magnolia is a way to experiment with

novel language features. It will therefore be a case study illustrating the need for a specialized IDE. To achieve this in a sufficient manner, a more specialized IDE is required.

The focus point of this paper is to design a zero-core architecture, to develop and implement a modular IDE, where the target language will be Magnolia.

In chapter 2, we will introduce Magnolia, and features this language introduces that are difficult to encompass using standard IDEs. In chapter 3 we will explore the use case of the aforementioned IDE, focusing on the different users of such an application. Chapter 4 the design and implementation of the IDE, mentioning different designs that were considered, and some challenges that were encountered.

Chapter 2

Background

2.1 Magnolia

Magnolia is designed to support a high level of abstraction and ease of reasoning. With Bagge [1], we can summarize a Magnolia program to three fundamental ideas.

- *Concept*: A set of operations, type declarations and axioms.
- *Implementation*: Implementation of a concept.
- *Satisfaction*: Satisfaction of an implementation.

While Magnolia is inspired by things like abstract algebra and institution theory, it is quite trivial to understand on a conceptual level. Developers quite often work with sets of operations, type declarations and axioms, namely APIs.

2.1.1 Magnolia Concept

Commonly, the term API is used specifically for Representational State Transfer (REST) APIs, but it also covers concepts, like those in Magnolia, interfaces in Java, traits in Rust, or type-classes in Haskell. What all of these variations have in common, is that they specify a method for two different procedures to communicate with each other. In a REST API this could be a microservice architecture, where several servers send and receive requests and responses, or in a programming project, it could be the **List** interface in Java, which informs consumers of that interface, which methods are needed to qualify

as a **List**. In Magnolia a concept concepts declare types, functions and properties which those functions need to uphold. A simple example of this would be a concept for addition with natural numbers.

```
concept NaturalNumbers = {
  type N;
  function zero(): N;
  function succ(number: N): N;
  function _+_ (a: N, b: N): N;
  axiom unit(a: N) {
    assert zero() + a == a;
    assert a + zero() == a;
  };
};
```

Listing 2.1: Natural numbers (Magnolia)

In the listing 2.1, we are specifying concept called *NaturalNumbers*, which declares a type **N**, and three methods that act upon the type **N**. We have the function, (also called a constructor), **zero**, which takes zero arguments, and should return something of type **N**. With this constructor, we can instantiate our numbers. To get new numbers, we have the function **succ**, which should give the *successor* to the passed number. That way, we can represent 0 as **zero()**, 1 as **succ(zero())**, and 2 as **succ(succ(zero()))**. The final function, is an infix operator. **+** takes two arguments, of type **N**, and returns an **N**. Of course, this should be interpreted as addition, meaning **succ(zero()) + succ(succ(zero())) = succ(succ(succ(zero())))**, or using numbers: $1 + 2 = 3$. Finally, the last statement in the concept, is an axiom, stating that given any *a*, if we add **zero()** to *a*, we should get *a*.

This axiom is what allows for us to put constraints on our concepts, which allows for improvement in our API. Unlike other APIs, like traits or REST, such specific constraints can only be achieved by using unit tests, which is not enforced on the implementor. But with axioms, this is possible in Magnolia. This pattern is quite useful, since it allows for *reuse* of logic. The listings 2.2 specifies a list interface, we can instantiate a list, and do operations on it, such as getting adding an element to the list, or by concatenating two lists. We can also fetch the first element of the list, by using **head**, note the *guard* attached to the function statement, this guard ensures that when this method is invoked, the list we get the first element from, cannot be empty, (equal to **nil()**), which means

that our function is not *total*, but *partial*. This means that for any argument, we might not have a corresponding result. If we did not have this guard, then what would happen if we *took* **head** of a list with no elements? In languages like Java, we would get null, but this does not exist in Magnolia. We could expand upon the list API by creating a non-empty variant of list, as shown in 2.3, which is the same as list, except to instantiate it, we need to supply an element, ensuring when we have a **NonEmptyList** variant, we can safely get an element from it, since there will at minimum, be one element in the list.

```
concept List = {
  type T;
  type List;
  function nil(): List;
  function cons(xs: List, x: T): List;
  function head(xs: List): T
    guard xs != nil();
  function concat(xs: List, ys: List): List;
};
```

Listing 2.2: List concept (Magnolia)

```
concept NonEmptyList = {
  use List;
  type NonEmptyList;
  function build(t: T): NonEmptyList;
  function cons(xs: NonEmptyList, x: T): NonEmptyList;
  function head(xs: NonEmptyList): T;
  function concat(xs: NonEmptyList, ys: NonEmptyList): NonEmptyList;
  function concat(xs: List, ys: NonEmptyList): NonEmptyList;
  function concat(xs: NonEmptyList, ys: List): NonEmptyList;
  axiom notEmpty(xs: NonEmptyList) {
    assert xs != nil();
  }
};
```

Listing 2.3: NonEmptyList concept (Magnolia)

However, this interpretation depends on our implementation of the concept.

2.1.2 Magnolia Implementation

As one can see in listing 2.4, we have implemented the concept specified in 2.1, by using concrete values for \mathbf{N} . There is an implementation for all the functions, giving us the functionality we set out to specify with our concept, but there is nothing stopping us from straying away from the specification, by implementing it incorrectly. Since we are using primitive types, (integers), we have to use external code, which is another feature of Magnolia. In the listings 2.4 and 2.5, we are using an external implementation of numbers, from C++.

```
implementation implNaturalNumbers
= external C++ CxxNaturalNumbers signature(NaturalNumbers);
```

Listing 2.4: Natural numbers implementation (Magnolia)

```
implementation implNaturalNumbersInvalid =
= external C++ CxxNaturalNumbers signature(NaturalNumbersWrong);
```

Listing 2.5: Invalid implementation (Magnolia)

We have defined zero correctly in listing 2.6, and incorrectly in 2.7, here it returns 1 instead of 0.

```
struct CxxNaturalNumbers {
  struct CxxNaturalNumbers_impl {
    typedef int N;

    N zero() {
      return 0;
    }

    N succ(const& N number) {
      return number + 1;
    }

    N plus(const& N a, const &N b) {
      return a + b;
    }
  };
};
```

Listing 2.6: Natural numbers implementation (C++)

```

struct CxxNaturalNumbers {
  struct CxxNaturalNumbers_impl {
    typedef int N;

    N zero() {
      return 1;
    }

    N succ(const& N number) {
      return number + 1;
    }

    N plus(const& N a, const &N b) {
      return a + b;
    }
  };
};

```

Listing 2.7: Invalid implementation (C++)

This is where the *satisfaction* comes in, it is what ties the concept and implementation together, by ensuring our axiom are upheld.

2.1.3 Magnolia Satisfaction

```

satisfaction implNaturalNumbersIsValid
= implNaturalNumbers models NaturalNumbers;

```

Listing 2.8: Satisfaction of the natural numbers (Magnolia)

When implementing a concept in Magnolia, one could do so incorrectly. In other programming languages, one might still have *imparted* some meaning in an interface, like that in the interface **Action** in listing 2.13, is an associative operation. To detect this, one would have to create a unit test for each implementation of the interface, while in Magnolia one writes a satisfaction as shown in listing 2.8, which in turn is *transpiled* to a format understandable by an Satisfiability modulo theories (SMT) solver.

Satisfiability Modulo Theories solvers

A SMT solver is a program that takes our implementation, and say whether our implementation satisfies our concept. In [18], Skogvik lays out different SMT solvers and compare them against each other, with the Magnolia library as input. One of Skogviks conclusions are that while verification of some program is good to have, some features needed for a new IDE would be to integrate it with this functionality.

2.1.4 Mathematics and Programming

Mathematics is everywhere, and useful. It's not always easy to notice this, but one thing that helps, is knowing the names of the concepts one encounter. One can easily understand that knowing simple operations like addition, multiplication, etc. is useful but for more abstract mathematics, this is harder. An example of this is abstract algebra, which is the study of algebraic structures, which are often seen in programming. A programmer will use these structures more often than not, knowingly or unknowingly, and a good programmer will explicitly seek these structures out.

An important aspect of development, is logging. Knowing what actions have taken place is an essential tool when hunting down bugs. A common way to structure logs, would be composing logs, depending on when they occurred. As a concrete example, let's say we are making a text editor, and are in the need of a logging manager, which, among other things, should compose different log statements. Assuming we have some type $\mathbf{Log(A)}$, where the type \mathbf{A} , is the result of the computation of a given function, we want to be able to compose different, related, computations. But, importantly, the order of composition of the $\mathbf{Log(A)}$ -type matters. Representing the composition of the $\mathbf{Log(A)}$ -type as \odot , doing, and letting a, b, c be of type $\mathbf{Log A}$:

Definition 2.1.1 (Log Composition).

$$a \odot (b \odot c) = (a \odot b) \odot c \tag{2.1}$$

Now we have a good logger, as the logs of the entire call stack is available for us to read when something goes wrong. Moving on, a good feature of a text editor, is being able to undo and redo actions. These are the actions that a user should be able to do:

- Insert text at a position

- Delete text from a position
- Redo an action
- Undo an action

Same as in the logging example, composing is a reasonable thing to implement, and should result in another action. Similarly, the order matters; deleting text and then inserting, is not the same as inserting and then deleting. But what is different between the logging and editor example, is that we also want the *inverse* of an action, so for every action we want an opposite action that undoes an action. Then our composition of actions has an edge case. Say, a is some action, and c is some opposite action, then our composition looks like this:

Definition 2.1.2 (Action Composition).

$$a \odot c = U \tag{2.2}$$

Where U is an action representing *no-operation*. This could be inserting the empty string at any position, deleting the empty string at any position, or redoing or undoing any of the aforementioned actions.

Both of these examples are relatively easy to implement, but harder to verify, to satisfy our properties; that the *logic* holds. In Java and Rust, to ensure that we have implemented something correctly, one would create a unit test. But there is nothing to ensure that we create this test correctly, that we cover all the edge cases, or if we are testing the correct thing.

2.1.5 Logging example in Java, Rust, and Magnolia

In the Java listing (2.9) and Rust listing (2.10) we have implementations which might not uphold our constraints. We can add unit tests, that ensure the implementations satisfy the definition 2.1.1, but this safeguard only exists in our project, and once our API can be implemented by third-party developers, we have no guarantee they will follow our constraints.

```

interface Log<T> {
    public Log<T> appendLogs(Log<T> a, Log<T> b);
}

```

Listing 2.9: Logging structure (Java)

```

trait Log {
    fn appendLog(self, other: Self) -> Self;
}

```

Listing 2.10: Logging structure (Rust)

In Magnolia, however, it is possible to constraint a consumer of our API. In the 2.11 listing, we can add an axiom, which is the same as our requirement definition 2.1.2. For implementers, *consumers* of our API, we can now ensure they implement correctly, as long as they add the simple declaration showed in listing 2.12. This will be ensured, because in a standard Magnolia work routine, a developer will invoke an SMT solver, which will ensure the concepts, that the implementations implementing concepts are sound; that they are satisfiable.

```

concept Log = {
    type Log;
    function appendLog(first: Log, second: Log): Log;
    axiom logComposition(a: Log, B: Log, c: Log) {
        assert
            appendLog(appendLog(a, b), c)
            ==
            appendLog(a, appendLog(b, c));
    }
};

```

Listing 2.11: Logging structure (Magnolia)

```

satisfaction loggingImplSatsLog = loggingImpl models Log;

```

Listing 2.12: Magnolia logging satisfaction, the implementation is left out for brevity

2.1.6 Editor example in Java, Rust, and Magnolia

The Java and Rust listings, (2.13, 2.14), also have no method of ensuring the satisfiability of future implementations. But what is more interesting, is that we can see, clearly in the case of the Magnolia listing 2.15, that there is some kind of relation between these APIs.

```
interface Action {
    public Action addText(String s);
    public Action removeText(String s);
    public Action redoAction(Action action);
    public Action undoAction(Action action);
    public Action combineAction(Action first, Action second);
}
```

Listing 2.13: Editor structure (Java)

```
trait Action;

trait Editor {
    pub fn addText() -> Self;
    pub fn removeText() -> Self;
    pub fn redoAction(&self) -> Self;
    pub fn undoAction(&self) -> Self;
    pub fn combineAction(self, second: Self) -> Self;
}
```

Listing 2.14: Editor structure (Rust)

```
concept Editor = {
    type Action;
    function noop(): Action;
    function addText(): Action;
    function removeText(): Action;
    function redoAction(a: Action): Action;
    function combineAction(first: Action, second: Action): Action;
    axiom noop(a: Action) {
        assert combineAction(noop(), a) == a;
    }
}
```

```

};
axiom combineAction(a: Action, b: Action, c: Action) {
  assert
    combineAction(a, combineAction(b, c))
    ==
    combineAction(combineAction(a, b), c);
};
};

```

Listing 2.15: Editor structure (Magnolia)

Both the logging example, and the text editor example, are some binary operation over some set. In the first example, our set was all different log statements of the type **Log A**, and composing these logs, gave us another **Log A** type. While in the second example, we were working on the set of actions, which we could compose, which also gave us another action, but we also had an action representing no-operation, and an *inverse* operation, undoing an action. This is related to mathematics, specifically abstract algebra, the study of algebraic structures.

2.1.7 Abstract Algebra

In the first example, we are working with a *semigroup*, and in the second example, we are working with a *group*. These are known as algebraic structures, which is just some set, with a function, (operation), that takes two inputs, and outputs one result, (binary), and some property on that function, (binary operation). The trivial example, is known as *magma*, and is defined by 2.1.4. The closure 2.1.3 simply specifies that we only work with one set.

Definition 2.1.3 (Closure). For a set M , with a binary operation \oplus , $\forall a, \forall b, \exists c \in M$, such that $a \oplus b = c$.

Closure Addition with the integers, (\mathbb{Z}), is a kind of closure, as per the definition 2.1.3, since no matter what integer you put into the equation, you will still get a positive integer. And since this is the only requirement a magma has, this example is also a magma.

Definition 2.1.4 (Magma). A magma is a set M , with a binary operation \oplus , which is *closed* by definition 2.1.3

We can *extend* the definition of magma, by adding associativity on the binary operation. The definition 2.1.5, as shown in the examples, simply specifies that the order we evaluate our composition matters.

Definition 2.1.5 (Associativity Law). For any binary operation \oplus , on a set M , $a, b, c \in M$. $a \oplus (b \oplus c) = (a \oplus b) \oplus c$, must hold.

This associativity gives us a semigroup, as shown in the definition 2.1.6, which is the structure that we modeled in our logging example.

Definition 2.1.6 (Semigroup). A semigroup is a set M , with a binary operation \oplus , and \oplus must uphold the definitions 2.1.3 and 2.1.5.

Example 2.1.1. Multiplication with the positive integers, (\mathbb{N}) , is associative, since no matter where we put parentheses; what order we evaluate this equation: $2 * 3 * 4$, we will get the same answer.

By simply requiring the identity law (2.1.7), we get a monoid (2.1.8), and adding the inverse law (2.1.9), we get a group.

Definition 2.1.7 (Identity Law). For any binary operation \oplus , on a set M , $\forall a, \exists U \in M$, such that $a \oplus U = a$, and U is unique.

Definition 2.1.8 (Monoid). A monoid is a set M , with a binary operation \oplus , and \oplus must uphold the definitions 2.1.3, 2.1.5, and 2.1.7.

Example 2.1.2. To make a monoid, we can choose the binary operation to be \times , and our set to be the natural numbers, (\mathbb{N}) . We know addition is closed, and associative, so choosing $U = 1$, we get a monoid. Any number from our set \mathbb{N} multiplied with 1, gives us the number we choose.

Definition 2.1.9 (Inverse Law). For any binary operation \oplus , on a set M , $\forall a, \exists U \in M$, such that $a \oplus U = a$, and U is unique. And $\forall a, \exists b \in M$, such that $a \oplus b = U$, and the mapping for $a \rightarrow b$ is one-to-one.

Definition 2.1.10 (Group). A group is a set M , with a binary operation \oplus , and \oplus must uphold the definitions 2.1.3, 2.1.5, 2.1.7, and 2.1.9.

The definition 2.1.10, of course is identical to the structure we used to model undo-redo, in our text editor example. We have our *combine* operator, which takes two variants

of the *action*-type, and return another variant of the same type. Its therefore a closed binary operation. We also specified that *combine* is associative, it does not matter where one puts the parentheses, the resulting *actions* are equivalent. *NoOp* gives us the *unit*, meaning our binary operation upholds the identity law. Finally, we have an inverse *action* variant, that is unique, for all other variants.

This, of course, is dependent on our implementation. It is quite common to make mistakes when developing. These mistakes are usually tackled by developing good unit tests. However, this can get quite tedious, as for everytime we re-implement these algebraic structures, we would have to re-create the unit tests. To avoid these common mistakes when implementing these structures, it would behoove a developer if they could encode these properties in something like an interface or a trait, however, this is not possible in either Java nor Rust. We cannot enforce things like the definition 2.1.5 on our operators.

2.1.8 Java: Magma to Group

This structure could *technically* be implemented in something like Java, an Object-Oriented Language, as shown in listings 2.16, 2.17, 2.18, and 2.19. But not practically. Note the empty interfaces; there is nothing that enforces the different laws on the properties. This can only be done by unit testing, which is not enforced on an external consumer of the API.

```
interface Magma<T> {  
    public T binop(T a, T b);  
}
```

Listing 2.16: Magma concept (Java)

```
interface Semigroup<T> extends Magma<T> {}
```

Listing 2.17: Semigroup concept (Java)

```
interface Monoid<T> extends Semigroup<T> {  
    public T unit();  
}
```

Listing 2.18: Monoid concept (Java)

```
interface Group<T> extends Monoid<T> {}
```

Listing 2.19: Group concept (Java)

2.1.9 Rust: Magma to Group

The same issue with property enforcement exists in Rust.

```
trait Magma<A> {  
    fn op(a: A, b: A) -> A  
}
```

Listing 2.20: Magma (Rust)

```
trait Semigroup<A>: Magma<A> {}
```

Listing 2.21: Semigroup (Rust)

```
trait Monoid<A>: Semigroup<A> {  
    fn identity() -> A;  
}
```

Listing 2.22: Monoid (Rust)

```
trait Group<A>: Monoid<A> {}
```

Listing 2.23: Group (Rust)

2.1.10 Magnolia: Magma to Group

However, in Magnolia this can be required on the *interface*-level. The example code shown in listing 2.24, showcases a concept representation a binary operation, which has one function, *binop*, which takes in two values of type *T*, and returns *T*. Note that the actual implementation of this function is missing. This is because a concept encodes the properties of a users code. The actual implementation of the binary function needs to uphold the properties of the concept that is being implemented. Note that this is unlike the Java and Rust example, in which we have no way to encode the property of our binary function. So any consumer of our API would not be explicitly bound to our restriction of the associativity law 2.1.5, identify law 2.1.7, and the inverse law 2.1.9, required by semigroup and group. The closure definition, 2.1.3, however, can be encoded by the type system in Java and Rust.

```

concept Magma = {
  type T;

  function binop(a: T, b: T): T;
};

```

Listing 2.24: Magma (Magnolia)

In the example code shown in listing 2.25, the *magma* concept has been expanded upon, still following the same rules as before, but with the added property of associativity.

```

concept Semigroup = {
  use Magma;

  axiom associative(a: T, b: T, c: T) {
    assert
      binop(a, binop(b, c))
      ==
      binop(binop(a, b), c);
  };
};

```

Listing 2.25: Semigroup (Magnolia)

```

concept Monoid = {
  use Semigroup;

  function unit(): T;

  axiom identity(a: T) {
    assert binop(a, unit()) == a;
  };
};

```

Listing 2.26: Monoid (Magnolia)

```

concept Group = {
  use Monoid;

```

```

axiom inverse(a: K, b: K, c: K) {
  assert binop(a, b) == unit();
  assert binop(a, c) != unit();
};
};

```

Listing 2.27: Group (Magnolia)

So Magnolia facilitates reuse, and extension of logic. In Magnolia we can build upon existing proven algebraic structures like a group, and reuse their properties. For instance, with the editor example, we can do optimizations on the actions. Since the user of the editor reacts slower than our code, we can batch several actions together, and evaluate them together. If the user keeps writing and deleting the same sentence over and over again, we could evaluate them as an "NoOp", and not do the expensive IO operation.

2.2 Reusable Software

One of the most important features in any programming language, is the notion of *reusability*. From the invention of the GO-TO-statement, with which we could repeat code statements N times instead of writing them N times, to functions, where we could run the same piece of code several times in a program, with different inputs, reuse has been an essential tool for a programmer. It avoids *re-inventing the wheel*, as common functionality can be externalized and reused in several different places. This ensures fewer points of failure. Instead of having to test several different places in a project, we can test the function being used different places.

2.2.1 Reuse in Magnolia

Reusability is also an important feature in Magnolia, but this reusability is in the entire language. In libraries in other languages, functions are reused, in an attempt to avoid common logical mistakes, but these mistakes could still be there, hiding in plain view. In Magnolia, one can re-use the *logic* of a function. The logging and group example can be rewritten using Magnolia concepts as shown in listing 2.28 and 2.29 respectively, by reusing the concepts we created for semigroup in listing 2.25 and group in listing 2.27.

```

concept Logging = {
  type Log;

  use Semigroup[binop => combine, T => Log];
};

```

Listing 2.28: Logging example (Magnolia)

```

concept Editor = {
  type Action;

  use Group[binop => compose, T => Action, unit => noOp];

  function addText() : Action;
  function removeText() : Action;
  function redoAction(action: Action) : Action;
  function undoAction(action: Action)
};

```

Listing 2.29: Editor example (Magnolia)

Indeed, reuse is so useful, that in Magnolia one can rename concepts one use. In the listings 2.28 and 2.29, we have renamed the type and function into something that makes more sense in the specific use case. While it is useful for us developing the concept, to know that our logging concept is a semigroup, when using an implementation, this is less relevant. If a consumer of the logging API read that logs where used everywhere in the project with `binop(log_a, log_b)`, it would be confusing, but when using context specific names, as renaming allows us to do, we could rename `binop` to `combine`, which makes the code easier to read.

2.3 Integrated Development Environment

Before IDEs where the standard development tool, all a developer had, was a terminal, an editor, and a compiler/interpreter. An editor to change the source code, a compiler/interpreter to compile/interpret, and a terminal to invoke them. But not all projects can be

```
\begin{center}  
  \includegraphics{./pics/syntax-highlighting.png}  
  \caption{Syntax Highlighting (\latex)}  
  \label{pic:stx}  
\end{center}
```

Figure 2.1: Syntax Highlighting (L^AT_EX in Neovim)

handled this way. In larger projects other programs like Make¹ for C/C++, or Gradle² for Java/Kotlin, was needed to build, test and package the project. So instead of manually adding each new C file to the compiler argument list, or manually compiling and zipping Java class files, an external program was used. But for C/C++ or Java/Kotlin, external libraries are used, which meant that among different developers, the environment could vary. This meant that onboarding new developers took time, to ensure they had all the necessary dependencies to develop the project. Which could be as simple as downloading some library or program, to ensuring specific environment variables existed during compile time. Eventually all of these different dependencies, programs, environment variables and such where all integrated into a single application.

An IDE, aids a developer, as all the needed tools for development are integrated into one application. Some are more specialized than others, targeting specific language, like Eclipse and IntelliJ. Others are more generic, like VS Code. We will use the terms generic and specialized IDEs to differentiate the two variants.

An IDE that claims to support a language, is expected to with certain features. So a specialized IDE should contain the following features:

2.3.1 Syntax Highlighting

Highlighting important keywords, identifiers and more, makes the language easier to read for the developer, allowing them to spot easy to miss errors, like misspelling of keywords, functions, and variables. In the pictures 2.1, and 2.2 we can see the difference between having syntax highlighting. In 2.1 we can clearly see what is, and is not a latex command, if we wrote

begn instead of

begin, we can notice the discrepancy, as we expect it to, in this case, be purple. We are using visualization to make developers notice issues.

¹<https://www.gnu.org/software/make/>

²<https://gradle.org/>

```

\begin{center}
\includegraphics{./pics/syntax-highlighting.png}
\caption{Syntax Highlighting (\LaTeX)}
\label{pic:stx}
\end{center}

```

Figure 2.2: No Syntax Highlighting (L^AT_EX in Neovim)

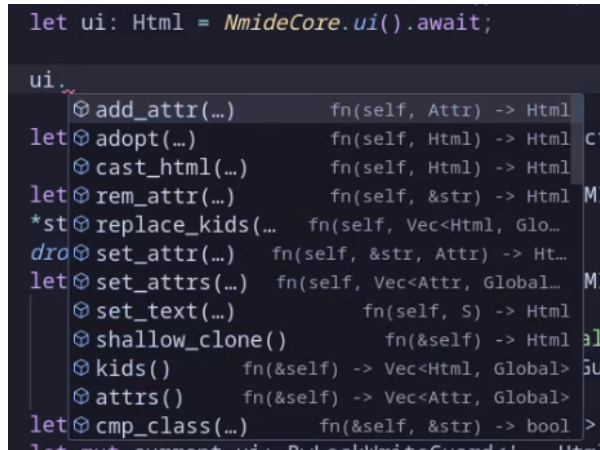


Figure 2.3: VS Code suggesting appropriate methods (Rust)

2.3.2 Code Autocompletion

Suggesting keywords, method names or even entire code snippets, is a powerful tool an IDE can have. This is possible to achieve, in some form, without being specialized, by for example, suggesting text that already exist in the document, but is most useful if it is specialized, and can suggest built-in methods. This allows a developer to not having to remember exactly how methods are named, is the method to split a string by some delimiter, *split_by* or *split_on*? As long as the developer writes *split*, the correct method name will be suggested.

2.3.3 Go-To-Definitions

Being able to quickly navigate to methods and read their implementation is a useful tool for a developer, as less time has to be spent navigating the project structure, to figure out where some method was implemented, and more time can be spent actually developing.

2.3.4 Formatting and Linting

When developing, an important process is code review, another developer ensuring that the suggested improvement is up to some standard, specified by the language and/or

development team. Things like naming conventions, code style, unused variables, dangling doc-strings, bad variable names and commented out code, have no effect on the resulting program. Unused variables and comments are optimized away by the compiler, while variable names are mangled (unless they are constants). But for developers reading the source code, these issues can hide bugs because there is a lot of *noise*. Luckily, IDEs can detect these common issues, by the help of a *linter*, which can, on the invocation of the user, fix these issues. Linters are opinionated, since programming language specifications specify conventions on how the source code should look. In Rust for example, the compiler has a built-in formatter and linter, which, during compilation, warns the user of these mistakes, and can re-arrange the source code by formatting it to fit the standard.

2.3.5 Boilerplate Code Generation

An important process in development, are ensuring your code is correct. A good way to ensure this, is with unit testing. For object oriented programming, this is done by testing the methods on a class, and creating the necessary unit tests for this can be tedious. Luckily, IDEs like IntelliJ come with boilerplate code generation, creating a *skeleton* unit test, containing the empty tests ready to fail. An example for this can be seen in 2.4, where we are prompted with a checkbox for each method on the class; whether we want to include it in our unit test or not.

For unit tests, getters and setters, (where relevant), and similar.

These are features also within a generic IDE, but most are available through the IDE module architecture. A generic IDE contains the features that are common among development across any programming language. But the following features are not exclusive to generic IDEs.

2.3.6 File Explorer

Most project nowadays is larger than one file, so being able to visualize the project in a tree-like-structure, and navigate that, is useful. Similarly to syntax highlighting, it adds icons to showcase what is a file or folder, but also what file extension is used. In the picture 2.5, one can see how all the Rust files, the files ending with *rs*, have a crab, (called *Ferris*), visually showing the developer that this file is a Rust source file. This makes it easier for a developer working on a polyglot project. This feature also comes

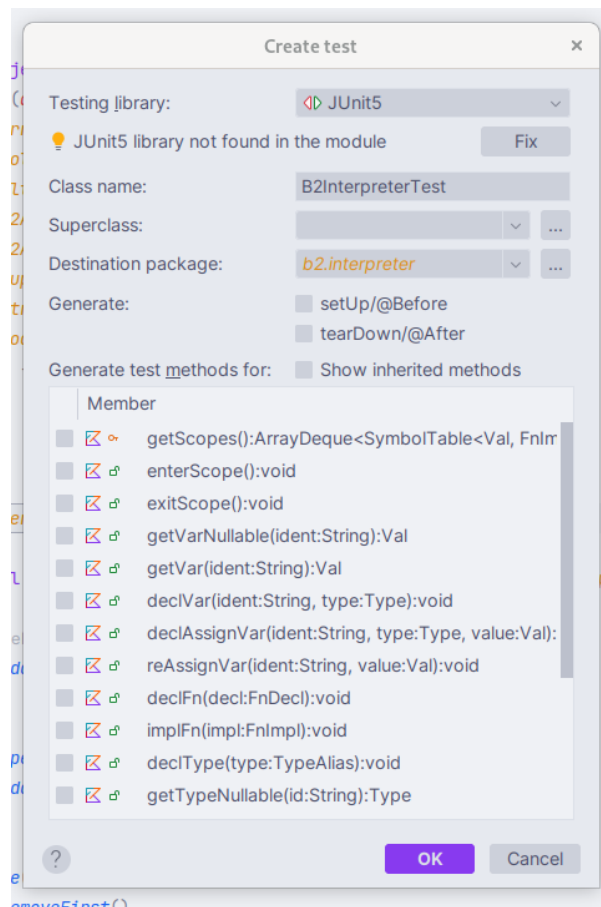


Figure 2.4: Window for generating boilerplate code for a unit test (Kotlin in IntelliJ)



Figure 2.5: File explorer in VS Code showing the Nmide source code

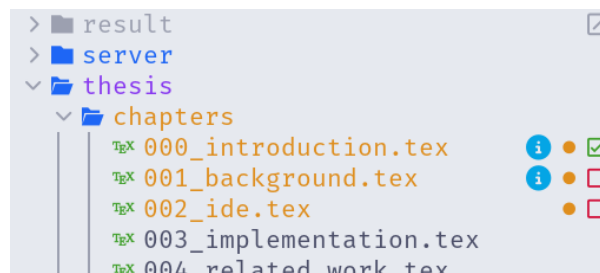


Figure 2.6: File explorer in Neovim showing that the *result* folder is not VCS-controlled (grey), and that the *thesis* folder have uncommitted changes, (purple), the files who have changes are marked (yellow), and there is one file which has a committed, but a non-pushed change, (green checked checkbox).

with the ability to manipulate the project structure, by adding files, folders, moving files around, and deleting them, but most importantly, being able to open the file. By clicking on a file, it opens up in an editor, to be edited.

2.3.7 Version Control System Integration

VCS is an integral part of development. Being able to sync ones work between different machines and developers is essential. It allows for cooperation between different programmers.

In the picture 2.6, we can see an example of this in action. There, we are using Git to version control our project, (this IDE). Neovim can detect changes made to the project, with the help of Git, adding colours to our files based on their state, (not controlled, uncommitted changes, marked changes, committed change).

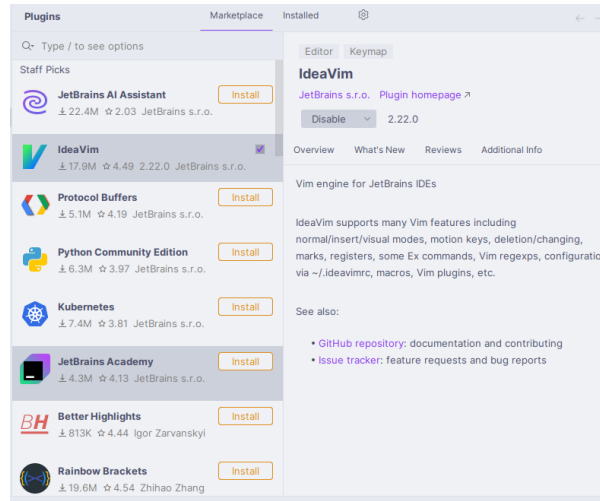


Figure 2.7: Module market window in IntelliJ showing popular modules that the user can install by clicking on the *install* button. Also seen in the window is that the user can disable already installed modules, or uninstall them.

2.3.8 Module Market & Installation

An important part of the user experience in a modular IDE, is being able to seamlessly add, install and use modules. An integral part of this is the module marketplace. This is a term for the place where a user can find modules, and with the click of a button, install them. Depending on what feature this module adds, the installation process could be as simple as adding it during the runtime, or if it's a more complex or integrated feature to the IDE, requires a restart of the IDE. In the picture 2.7, we can see this in action.

2.4 Module Architecture

A modular application, is an application which can be extended by other pieces of software. This extensibility is useful as features that the original developers of the application did not think about, can be added. If this module architecture is well-designed, then this extension can be added without changing the core application.

There are different ways an application can be extended. The most common one uses so-called *live-reload*, in which, if a module drastic changes the functionality of an application, the application has to be restarted, or if it is a *minor* change, the module is simply loaded. This method is extending the application during runtime, which is the method most users expect. Another method would be *compile-time-extension*, in which modules are added before the application itself is compiled. There are some advantages and disadvantage in both approaches.

2.4.1 Compile Time Module

As an example, a standard user of any application will expect the application to come bundled with all the needed functionality. This is best achieved with the *compile-time-extension* method, since the application can be installed with the expected modules during compile time, ensuring the resulting binary contains all the wanted features. This also comes with the benefit of the compiler being able to optimize the module-core interactions, since the module is directly integrated into the source code of the core application.

2.4.2 Runtime Module

Runtime modules are usually also interpreted, but they can still be a library, same as in a compile time module. The benefit with a runtime module, is that a user can easily test out different modules, as compiling the entire application before being able to test a module is a hassle. But it comes with some drawbacks, like having to do extra verifications on top of the module, ensuring invoking the module won't crash the entire IDE.

2.4.3 Modular Architecture in IDEs

IDEs are one of the most common application that supports extensions by third-party code. IDEs like Eclipse and IntelliJ are specialized for working with Java, but they can still support other languages with the help of modules. A module in Eclipse for instance, could extend Eclipse with functionality like syntax highlighting, code completion, Go-to-definitions, debugging, and more, for standard programming languages. A lot of this functionality, comes from module-to-module extension, as in Eclipse modules can extend modules, with the use of the Eclipse Rich Client Platform [16].

2.4.4 Module Ecosystem

In modern IDEs, with an extensive module architecture, there exists a vast module ecosystem. From simple modules that change the color scheme, or add file icons to more complex modules that add support for other languages. A good variety of a module

Table 2.1: Module Ecosystem per IDE

IDE	Module count
Eclipse	~ 1200
IntelliJ	~ 9500
VS Code	~ 71700

ecosystem can help ensure the longevity of an IDE. In the table 2.1, we can see that IDEs have an extensive module ecosystem.³

VS Code is a popular IDE [5], and this could be due to the amount of modules it has to offer. The amount of modules attributed to VS Code could be the cause of a positive feedback loop. VS Code is popular because it has many modules to extend the functionality, making it able to cover many use cases. Since VS Code is popular, developers use, and make modules for VS Code. All of which strengthen the longevity of the IDE.

Module Marketplace

Having modules is all well and good, but if a user cannot easily get the module, it's not useful. The top IDEs mentioned, Eclipse, IntelliJ, and VS Code all have access to their respective *module marketplace*, a dedicated webpage to find modules, integrated into the application. This is the most user-friendly method for a user to search for and find modules, as they can simply do a keyword search for the language they are wanting support for, say Haskell, and get the necessary modules available to use with a simple click of a button.

2.4.5 Granularity

When designing modules, the *granularity* of the combined modules has to be considered. As an example, if one where to extend the zero-core application with the needed functionality for it to be considered an IDE, this could be achieved by creating a singular module which does all the work. However, this is not a modular approach, as if one wants to change some specific feature in the IDE-module, one would have to re-create

³Data found by looking at the marketplace for the modules, in order:<https://marketplace.eclipse.org/content/welcome-eclipse-marketplace>,
<https://plugins.jetbrains.com/>,
<https://marketplace.visualstudio.com/search?target=VSCode&category=All%20categories&sortBy=Installs>

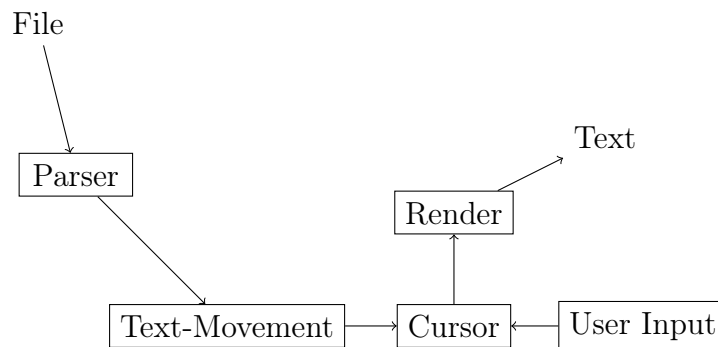


Figure 2.8: Text Editor Module Family

the whole module with that specific feature implemented. Instead, if this functionality was granular, that is to say, split into several modules, that together enable the needed features, then it would be *simpler* to modify the needed modules to achieve the wanted feature.

2.4.6 Module Family

A module family are several modules enabling a single *feature*. A user of the IDE might think that being able to browse the project using a file explorer integrated into the IDE as a single feature, in a modular system, that facilitates reuse, this would be made up of several different modules.

In figure 2.8, an input file is parsed to some structure which is used to translate user actions, into cursor movements. The cursor being the place in the file where text is written to by the user.

This is a feature that naturally shows up in a *true* modular system. If several modules together enable some feature, then those modules can be treated as a singular module by an external module developer, depending on what they want to extend.

2.5 Language Workbench

Language workbenches are environments for simplifying the creation and use of computer languages. [10]

Expand

Table 2.2: IDE features enabled by LSP

IDE Feature	LSP-method
Go to Declaration	textDocument/definition
Go to Implementation	textDocument/implementation
Auto-completion	textDocument/completion
Hover	textDocument/hover
Warnings	textDocument/publishDiagnostics
Rename	textDocument/rename

2.6 Language Server

The most important features in a modern IDE are possible due to the LSP. LSP is a protocol for a language server and editor, (the client), in which they communicate, allowing for many of the features mentioned in section 2.3, and explicitly mentioned in table 2.2. LSP being the standard since the 2020s, is a sign of modularity being preferred, as now a single LSP can be created, and used across several different applications, like IntelliJ, VS Code and Vi Improved (Vim). While useful for *standard* language, this is the limiting factor when it comes to supporting experimental languages, as not only does a new set of protocols need to be appended to a language server, the editor itself needs to be changed to actually use these protocols. This creates a lot of work, for both the IDE developer and for the compiler developer. Here is where a modular approach can help both. If some new functionality or feature is added to the experimental language, this off course means the compiler/interpreter has to be expanded and/or modified, but for the IDE, a module could be added and/or modified to utilize this change, instead of having to change the entire application.

An example of this in action, say a developer is working on a file *main.ts*, in their Typescript project. They hover over a type imported from, and defined in *types.ts*. This is what happens:

1. The editor detects the user is hovering over a *special* word
2. The editor sends a request to the Typescript LS
3. The LS responds
4. The editor formats the response into a small window showcasing the documentation and implementation of the type

2.7 Zero-core IDE

A zero-core IDE takes the modular architecture that is standard IDEs and takes it to its extreme. When all features are modules, and modules interact by invoking each other, it can mimic a microservice architecture. A module invocation is some *request*, which the invoked module *responds* to. There is a provider-consumer dynamic. There is also a provider, some module providing data, and some consumer, some module using the data. If either the consumer or the provider is maintained by a third party, then there is some informal *contract* between them. The consumer expects the outputs of a provider to be in some certain format, which in the case for REST APIs usually is JavaScript Object Notation (JSON), but with specification formats like OpenApi [19], one can also specify the structure of the JSON response, with what fields and values it can have. One can also specify what values are valid in a request. But even if one does use such a format, changes in scope can require the provider to change the API, which could affect the consumer, because the consumer assumed something about their informal contract, that all numbers provided are integers. And if suddenly the provider changes, and returns floating point numbers, the consumer could crash trying to parse a string as an integer.

The same concept applies to a zero core IDE. Modules have an implicit, and informal contract between them. So the same measures, used in microservice architecture, to mitigate these issues, can be used in this zero core IDE. Unit testing of code is essential in software development, especially when developing against third party systems. Instead, invoking these third party systems at test time, mocking is used. This mocking is part of how a consumer assumes a provider should act. Mocking of modules is trivial, as all one needs to mock is the state, the User Interface (UI), or that some event happens. At a larger scale we test the module family, to see if its change has affected the other modules. This can be done with contract testing, as discussed by Gross and Mayer [12]. They propose a module architecture, where each module expose some testing interface. However, in the architecture propose by us, all modules composing the IDE can be loaded in a test environment, where all interactions are recorded, and used to generate a dependency graph, showing what modules depend on whom. This can show that certain modules are more tightly connected than assumed, meaning they are in the same module family, it can also show what module families communicate with other module families, showing module communities.

2.8 Existing Magnolia IDE

The current IDE for Magnolia [2], is a many-years-old version of Eclipse, using modules and functionality from the core Eclipse application, that has since been outdated. The IDEs lifetime was limited by a dependency on external modules and features that were not maintained by the IDE-developers. This meant that for future development of Magnolia, an outdated IDE was needed, with outdated tooling. Furthermore, the Magnolia compiler was implemented as an Eclipse module, which means that development is limited to Eclipse, and only Eclipse, as a developer cannot compile Magnolia code without it.

Modularization will help to mitigate some of the issues with the current Magnolia IDE. Instead of maintaining an entire application, the needed and wanted features of the application can be maintained instead.

Experimental languages might have features which are not possible to be fully used in current IDEs. This is also the case for the current Magnolia IDE. The compiler for Magnolia, syntax highlighting, error reporting, and hover-functionality are functionality made in the Eclipse IDE, by using its plug-in architecture. Some of the functionality and plug-ins this implementation used, have been deprecated in later version of Eclipse. This means the Magnolia IDE is locked to an old version of Eclipse, which, as time passes, increases the complexity of installation, as the surrounding tooling and libraries needed by this version of Eclipse also becomes deprecated. Currently, in INF220, at the university, two weeks are set aside for students to be able to install it.

2.9 Challenges imposed by Magnolia

In most programming languages, any type has a singular definition, so invoking the *go-to-definition* endpoint implemented by an LSP results in a singular response. The actual response of the LSP is a list, but this is *always* a singleton. However, in Magnolia a singular type could have multiple definitions, and resolving this can be complex.

2.9.1 Renaming

String concatenation is a monoid, so is list concatenation. Given our definition of a monoid (2.1.8), one can trivially see that string concatenation and list concatenation falls under this definition, and are therefore related.

Even though they are related, it is more useful to have specific names for each concept. In 2.30 and 2.31 we are importing the monoid, (from listing 2.26), and renaming the **unit** and **binop** operation to something that are specific to the concepts, **emptyString**, **+** and **emptyList**, **++** respectively.

```
concept StringConat = {  
  use String;  
  use Monoid[  
    T => String,  
    unit => emptyString,  
    binop => _+_  
  ];  
}
```

Listing 2.30: String concatenation (Magnolia)

```
concept ListConat = {  
  use List;  
  use Monoid[  
    T => List,  
    unit => emptyList,  
    binop => _++_  
  ];  
}
```

Listing 2.31: String concatenation (Magnolia)

Since renaming is heavily used, being able to visualize the *flattened* and *unflattened* ASR-tree is useful.

2.9.2 Dependency Cycles

Programming languages have different ways to avoid the problem of imports of modules forming a cyclic graph. The easiest, is to simply disallow such import structures, which is something the Magnolia compiler does. All imports have to be Directed Acyclic Graphs (DAG)'s. In most programming languages this is trivial to solve for developers, as if suddenly a project has a cyclic import, it can be solved quite easily. However, due to the heavy reuse in Magnolia, the cycles could be quite large and harder to reason about without a tool to visualize the dependency graph.

2.9.3 External software dependency

Magnolia depends on a compiler, like all compiled programming languages, but also an SMT solver. While the new compiler for Magnolia, at the time of writing is still under development, [22], but once released will be quite stable. This is in contrast to the SMT solver environment. Skogvik [18] noted the different competitions for developers of SMT solvers, this means there might be a new and better SMT solver, which means it needs to be easy for a user of the IDE to change the SMT solver they are using to validate their program with.

Chapter 3

Magnolia IDE

This section will discuss the new Magnolia IDE, the different users of the IDE, and their possible experiences which was under consideration when developing the application.

3.1 User Perspectives

This application has to consider different users. In IDE's like Eclipse or IntelliJ, there is the primary user base, the developers who are using the IDE to develop, and then there are the secondary user base, the developers whom develop *plugins* for the IDE. Being the primary user base, most of the new features implemented by either IDE are related to the development experience. There are still changes to that the *plugin* developers are interested in, namely API changes. IntelliJ for example, lists their *incompatible API changes* [14]. Breaking changes between IDE versions is something normal users of the IDE do not worry about. As usually when a new version is released, it means more features for the developer to utilize. While *plugin* developers have to ensure their *plugins* still work. One of the reasons behind IDE version changes can break a *plugin*, is due to how they interact with their IDE. In IntelliJ a *plugin* is created by implementing a Java interface for the functionality one wants.

If one wanted IntelliJ to recognize that a file with the extension "rs", is a Rust source file, and give it a certain icon, one would have to implement the **Language** interface and override the **getIcon** method to return the wanted icon.

So a change in the IDE architecture could break a *plugin* for the newer version of the IDE, as with Bagge's Magnolia IDE [2]. While in this zero core IDE module developers are quite important, as they are the ones who add the functionality to the IDE. Therefore, the core API has to be more stable, and it is by virtue of not having much functionality.

3.2 Module Developer

Being a zero core application; all functionality comes from modules, the module developer experience is the most important. To achieve this, documentation is important. If a module developer has a question about how the core might react, it should be answered by the documentation. In Eclipse, this is in the form of *Javadocs*, which specify, with examples how the Eclipse runtime handles *plugins*.¹

The documentation for *plugin* developers, in both IntelliJ and Eclipse has to be large, due to of how *plugins* interact with the IDE; it is a large API. In a zero core IDE it is smaller, simply due to the fact that the core IDE offers fewer features, as features necessarily come from a module.

3.2.1 Language Agnostic Modules

The largest limiting factor in module oriented applications, is the *language barrier*. Most applications limit what language one can extend an application with, like in VS Code, where its JavaScript/HTML/CSS. Or IntelliJ, where one can use Java or Kotlin. But what does language agnostic mean in the context of programming languages? It is, and always will be C. Rust, the language chosen to implement this IDE, also has bindings to C. This means that Rust can invoke C libraries. This is important for language agnosticism, as any language that has bindings to C, has then, through C, bindings to Rust. This is called an Application Binary Interface (ABI), specifically the C-ABI.

This module could be a singular one, acting as a translator, translating the data flowing between the core and foreign-modules as shown in figure 3.1, or each foreign-module could have their own translator as shown in figure 3.2. But this language agnosticism also means that translating from one language to another should be trivial. This is achieved by the models used in the core. The *primitive* types, are the same as in JavaScript, the notion of an empty value, numbers, strings, lists and *objects*, can be serialized/deserialized to/from any language. So the manipulation on these types can be extracted and rewritten in another preferred language.

¹<https://help.eclipse.org/latest/rtopic/org.eclipse.platform.doc.isv/reference/api/org/eclipse/core/runtime/Plugin.html>

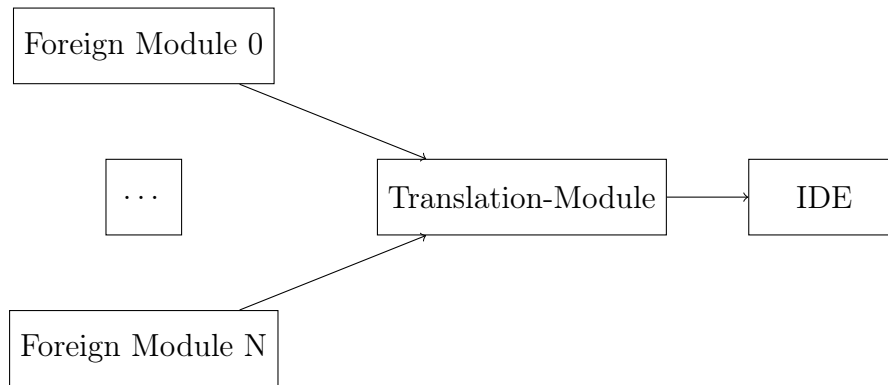


Figure 3.1: Foreign modules being invoked by a singular Translation-module

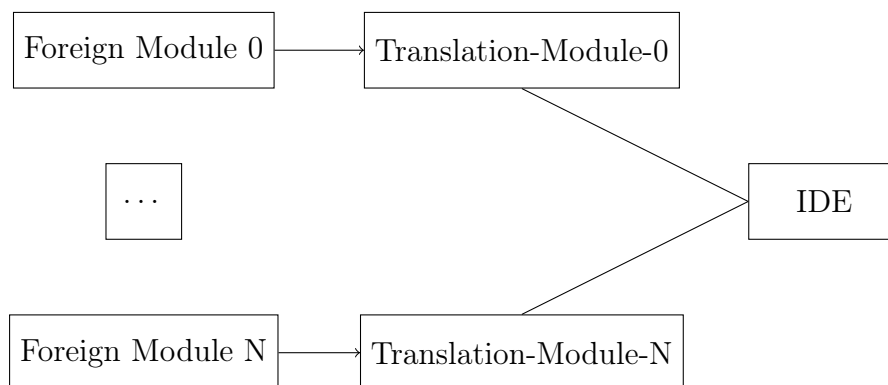


Figure 3.2: Foreign modules being invoked by an individual Translation-module

3.2.2 Existing Third Party Libraries

Since the core can support different languages, one can use the libraries written for these languages to make an IDE. This could be achieved by creating a module, acting as a wrapper around the library. For example, by using JavaScript and since the core application is designed to be an IDE, one could use existing JavaScript libraries, like *Monaco*, which is the text editor used by Visual Studio Code. It comes with an integrated LSP-client, which would enable the application to easily support existing popular languages.

However, being zero core, this application could be anything, from an audio editing program, to a game emulator. Simply using the *JS-DOS* library, would allow the application to run video games like Doom.

3.2.3 Module Development Experience

A module developer can invoke the module-developer-Commandline Interface (CLI)-tool to create boilerplate modules for JavaScript, TypeScript or Rust. After they have implemented a module, they can test it out, again by invoking the CLI-tool. When they are satisfied with their implementation, they can add it to the compile time configuration for the IDE, and compile it. They can now use the module in the IDE.

Implement
this

3.3 IDE Users

As mentioned in chapter 2, modern IDEs come with an integrated module architecture. Which is used to extend/change the IDE, from as simple as to change the theme, to more drastic changes, like changing all key binds to *vim-motions*. In any case, a user expects certain functionality to already exist in an IDE, like text editing. A maintainer of a zero core IDE could supply modules added at compile time, meaning the expected functionality is there out of the box, while more thematic modules could be supplied as runtime modules.

3.3.1 Developer

Most users just want an IDE, and do not spend, nor want to spend, much time configuring their IDE. This can be achieved by adding the necessary modules to qualify as an IDE at compile time. If one is a lecturer, teaching something that is used by a *niche* programming language, the lecturer can add the needed modules to a configuration file, *Modules.toml*, and then compile it to an IDE. Before the IDE is compiled, it finds the mentioned modules in the configuration file, and directly integrates them into the core, ensuring that the resulting binary is a fully fledged IDE. And then this IDE can be distributed to the students, who can still extend the IDE with runtime modules at their own digression.

3.4 Maintainer

To make the maintainer of the core application most comfortable, good documentation is needed. The same documentation a module developer wants, so it's important for them and the maintainer that the documentation is up-to-date. But how good is documentation if it is not updated when the code being documented is changed? This is where Rust's doc-test system comes into play. Any function annotated with a doc string, can contain code examples. If these code examples are written as Rust code, and use assert statements, then this code is run, during testing, as if it was an actual test. Meaning the saying *code is documentation*, is *documentation is code* in Rust.

Chapter 4

Implementation

This section will focus on the implementation of the zero core IDE. In section 4.1, we will mention technologies used, and why they were chosen. In section 4.2 and 4.3, we will discuss the different iterations the application architecture had, and why they were subpar, compared to section 4.4, which is the implementation of the zero core IDE. Section 4.5 will explain the necessity of testing when using such a modular design, and explore the ease of which functionality can be tested.

4.1 Tech Stack

A module can extend an application at either compile time, or during runtime. This could be achieved by using an interpreted language like JavaScript or Python. The issue with using a dynamically typed language like Python or JavaScript, is that it enhances the risk for runtime issues occurring, and when dealing with scenarios like writing to files, or running long processes like compiling a program, it is important to avoid such issues. So using a typesafe language, that can *transform* runtime errors into compile time errors, is preferred. Furthermore, being able to support runtime modules, in a language agnostic manner, necessarily means that the core IDE needs good ABI support, and therefore should be implemented in a low level language. But what does *low level* language mean? And what is an ABI?

4.1.1 Low level languages

Programming languages has changed over time. In the beginning, a program was a series of ones and zeros, representing instructions a computer should do. Since then, we have moved several abstraction layers above what is commonly referred as *bare metal* programming. From writing in hexadecimal instead of binary, to machine instructions, to more generic programming language, like C. What was different with C, compared to writing direct machine instructions, was that an external program, a compiler, could translate C code to machine instructions specific to the computers' Central Processing Unit (CPU) architecture, this meant a single program, written in C, could be compiled to many different computers. So, at the time C came out, it was considered a *high level* programming language, because the language a developer was writing in, had a higher level of abstraction. Today this notion of *low* and *high* level languages has changed. A *low level* language is close to how a CPU *thinks*, which has traditionally meant that C is a low level programming language, but some authors [6] argue that this is no longer the case. In any case, we will use *low level* to mean a programming languages like C, where direct memory manipulations is a feature of the language.

4.1.2 Application Binary Interface (ABI)

An ABI is an low-level interface, a kind of API, between two programs. Such as C program and its dynamic library dependencies. The ABI defines how data is laid out in memory, how functions are invoked, and other machine level details. Both the C program and the dynamic libraries must agree on the ABI, otherwise misinterpreted data or invalid function calls could lead to Undefined Behavior (UB).

Undefined behavior In programming UB occurs when a program violates the language specification in a manner that is not defined by the specification. This can be the results of ABI mismatch, like if the layout of a struct in memory differs between the parties, in a manner which leads to breaking of type safety, or direct violations of the language rules, like null pointer dereference. UB is dangerous because the compiler might optimize the binary unpredictably or the program may behave arbitrary. It is also a vector of attack for hackers.

Why not C? C has good parts, like the C-ABI, which most languages have bindings too. Using C would mean allowing those languages to interface with our project, meaning, one step closer to a language agnostic module architecture. But C has issues, like being the number one cause in security issues. (This is just because so much of our infrastructure is written in C, but y’know.) These security issues are mostly caused by memory management. Would be cool if the C compiler could notify a developer if they were developing something that could cause an issue in the future. Enter, Rust.

4.1.3 Rust

Rust is a general purpose programming language, designed for, amongst other things, type safety, memory safety, and concurrency. When programming in Rust, the bugs common in other languages, like null pointers, buffer overflow and data races are detected at compile time. Most of these are features of Rusts ownership rules. These rules, enforced by the compiler, ensure that values are safely dropped, (freed), this ensures that all variables referenced in Rust have a value, and can be safely evaluated. It works by simply dropping values when they are out of scope. The example in listing 4.1, the **name** variable is declared, and used as an argument in the **greeting** function. We cannot call the function again with **name**, since at the end of **greeting**, before it returns, **name** is dropped, since once we called **greeting**, the **main** method no longer *owned* **name**, as the ownership was transferred to **greeting**. We could *fix* this by changing the argument type from *name: String*, to *name: &String*, (commonly written as *name: &str*), and adding the borrow symbol to the argument in the method invocation, as shown in listing 4.2.

```
fn main() {
    let name: String = "Nils".to_string();
    greeting(name);
    // Not allowed
    greeting(name);
}

fn greeting(name: String) {
    println!("Hello, {}", name);
}
```

Listing 4.1: Ownership example (Rust)

```

fn main() {
    let name: String = "Nils".to_string();
    greeting(&name);
    // Now this is allowed
    greeting(&name);
}

fn greeting(name: &str) {
    println!("Hello, {}", name);
}

```

Listing 4.2: Ownership example with reference (Rust)

This same principle ensure the other mentioned features of the language, including performance, as with the borrow checker, there is no need for a garbage collector. Another Rust feature are so-called *macros*. A macro is some code that is evaluated and executed at compile time, that may change the source code. An example of this, can be seen in listing 4.1. The **println!** is a macro invocation. **println!** is used so that the developer doesn't have to format the expressions being used, this is handled by the macro. This is helpful because redundant work can be automated.

Furthermore, Rust has good cross-platform support, ensuring we can write OS-agnostic code, and compile it to specific targets, without much hassle. Since Rust is low-level, it has good bindings to C, ensuring compatibility with future models, made in other languages, by use of the Rust ABI.

Rust Application Binary Interface

Rust's ABI is not stable! Because it is not supported by their semantic versioning. This means even a bug fix in the compiler, could break the ABI. So if an application, written in Rust, is compiled in version 1.8.0, if this application relies on a Rust library that is compiled in version 1.8.0, everything is okay. But if the application is later recompiled with a compiler in version 1.8.1, then *undefined* behavior could occur. One of the ways undefined behavior was avoided, was using the *abi_stable*-crate, which enables *safe* loading of external libraries, meaning modules. This is only an issue for runtime modules, which means they need to be handled differently than compile time modules.

If the types in the core application change, either by expansion or renaming or such, the crate would crash the application during startup, because the existing module would have a different expectation of what types existed, which again, could lead to undefined behavior. But, this due to the implementation of a runtime module using the *abi_stable*-crate, as one could design a module to be expanded in the future, but due to the stability of the API, this was deemed unnecessary.

4.1.4 Tauri

Tauri is a framework for Rust, which enables us to create a cross-platform application. Any frontend framework that compiles to HTML, JavaScript and Cascading Style Sheets (CSS) can be used as the Graphical User Interface (GUI). Such a GUI is commonly referred to as a *web view*. This framework also adds support for invoking Rust methods in the frontend framework, and vice-versa. This allows for support of JavaScript modules, without much fuzz. Tauri archives with Inter-Process Communication (IPC), which allows for isolated processes to communicate securely. For JavaScript to Rust, this is achieved with something called *Commands*, which acts as an abstraction on top of the IPC, which turns the invocation to a frontend-backend architecture.

TypeScript

Any frontend framework that compiles to HTML, JavaScript and CSS can be used with Tauri, so TypeScript was chosen. TypeScript offers a lot of features over JavaScript, amongst them being able to *type* functions, ensuring null/undefined-safety. Furthermore, by using crates like *ts-rs*, Rust types can be annotated with attribute macros, which create a one-to-one mapping between the Rust type, and the serialized JSON object, to be used in TypeScript, allowing for even more type safety, and ensuring that the types used in the IDE only have to be defined one place.

Allowing for any JavaScript library to be used, enabled a low development time of UI components, since this is something that a lot of UI and user experience designers have looked into. So existing code for this already exists and can be used. Node Package Manager (NPM), for example, is a package registry for JavaScript. It contains around *34 million* libraries, all of which are usable in this architecture. If the functionality that these libraries are useful for the application, is another question. This functionality allows for quick development time for modules, which means features that are standard in IDE can be quickly and easily added.

4.1.5 Security

This framework gives a lot of security which is needed in an application which runs third party code.

Look
into
isol-
ation
pattern
from
Tauri

Module Validation

Running third-party-code can dangerous. If this code is not validated or does not come from a trusted source, it could be an attack vector. Luckily, Tauri does some of this work for us, allowing us to analyze all module to core communication, but even if we have validated that a module is wanted, there is still the remaining use that has been the reason for 100% of all CVE's, human error.

The Rust compiler can ensure that the Rust modules are valid during compile time, for runtime this is a bit trickier. But for JavaScript modules, which the IDE supports out-of-the-box, this is a bigger issue. This lead to the development of two systems. Rust Module System (RSMS) and JavaScript Module System (JSMS).

It was necessary to distinguish the different module systems, due to the way they would be loaded and invoked by the core application. Since the core is written in Rust, the RSMS doesn't have to do any validation or translation when communicating with compile time modules. With runtime modules this also ended up being trivial, but will be discussed more in depth later.

In the JSMS, managing of modules can lead to exceptions being thrown. Since third party code is being run, nothing can be trusted. All module invocations and outputs needs to be sanitized before it can be used in the core application. This is achieved by wrapping all invocations in a *try-catch*, and using the *io-fp* library to decode types during runtime. This enables us to safely invoke modules, as we can translate all computations into a product type, where it is either an success, giving us the wanted computation from the module, or an error. But even with types, we cannot verify functions. Since during runtime, we are in the JavaScript environment, we can only validate if something is a function, using the `typeof` operator. It is possible to do *some* verification on functions in JavaScript, but this is only a) Is it a function, and b) does it have the correct amount of arguments. In this case, one. Nothing about the typing of the function can be ascertained at runtime, without explicitly invoking the function.

4.2 Module V.1

We did not attempt at first, to create a zero core application; this was a *natural* conclusion to the existing problem. The first attempt was a simple generic IDE, in which the module architecture was a concern from day one of development. The general plan was this:

1. Create an IDE
2. Extend the IDE, to allow for a module architecture
3. Modules call the application using some DSL

Since any JavaScript frontend framework could be used, React was chosen, one of the reason for this choice was due to its popularity, which again, would speed up the development time of the application, but also due to the way React renders the HTML. Between two different re-renders of the application, React can check the difference between the Virtual Document Object Model (VDOM), which is React's representation of the Document Object Model (DOM). It then only changes what is needed in the DOM, instead of re-creating the entire DOM, which makes the render time quick.

This was the more straight forward way to work, because as we could model it of existing IDEs, like *Visual Studio Code* or *Eclipse*. Another advantage is that when implementing the application, one necessarily gets a better understand of how eventual modules should extend the application.

This approach did unfortunately not lead to a truly modular application. Similar issues to existing IDEs, how does one allow for *everything*? Furthermore, anything created this way, would be subpar to existing software, which would lead to the next maintainer having to fix the core application. This in turn, would add a lot of complexity, which the maintainers would have to deal with.

4.3 Module V.2

1. Everything is a module

Instead of developing features that make up an IDE, and attempting to ensure it is implemented in such a manner that it can be modified in the future, make everything modular. The only thing the IDE can do, is to manage modules. All features, from the file explorer to the text editor, everything is a module that can be enabled or disabled.

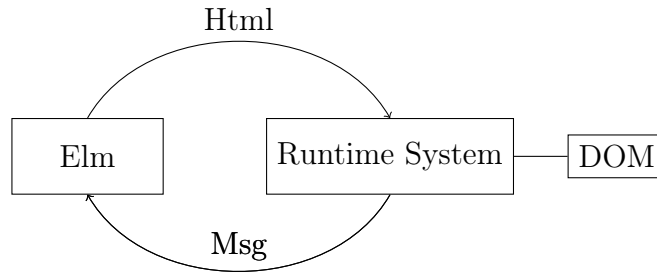


Figure 4.1: Elm Architecture (Figure adapted from [8])

4.3.1 The Elm Architecture

An inspiration for the new module architecture is Elm-Lang [7]. Elm is a functional language, aimed at frontend web development, but its architecture is quite interesting. As one can see in figure 4.1, is used by the Elm-runtime, which translates the Elm code into DOM manipulations, and translates DOM events into *Msg* which is handled by the Elm code. This was the inspiration for the new module architecture. A module is managed by the runtime, which is the *core* application. But with some inspiration from Model-View-Controller (MVC), where instead of the module keeping its own state, this is again managed by the core, allowing for multiple modules to read and react to states updated by other modules, allowing for more interactivity between modules, and therefore being more modular.

4.3.2 Module Architecture

In this application, the Elm-box is a module, while the runtime system, is the core itself. The core invokes all modules, all of which, should have these three functions, `init`, `update`, and `view`.

Init Returns a collection of key-value-pairs, which represent the state of the core.

Update Returns a collection of key-value-pairs, which overwrite existing key-value-pairs in the state, or are appended to the state. Invoked every time a *Msg* is sent.

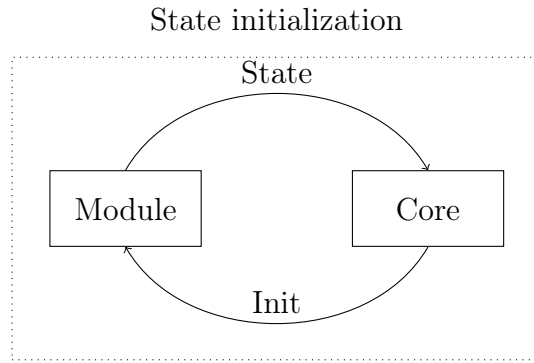


Figure 4.2: Module state initialization stage

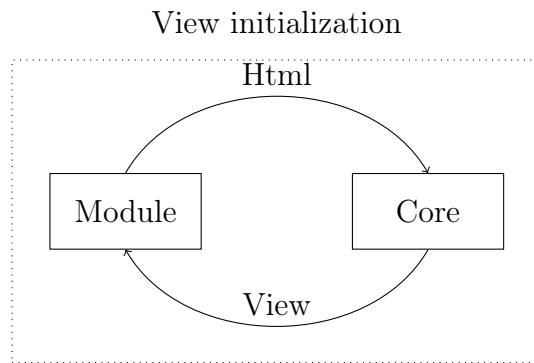


Figure 4.3: Module view initialization stage

View Returns a collection which represents HTML, which is rendered by the core.

A module is initialized by invoking the **init** method, which returns a state. This can be seen in figure 4.2. After the state initialization, the modules' **view** method is invoked, which initializes the UI for the user, which can be seen in figure 4.3.

Since the IDE is written in both TypeScript and Rust, a method of encoding type information when crossing between the TypeScript and Rust environment was needed. It was achieved by simply typing JSON objects, so while the state could be represented as any JSON object, it was instead represented as nested JSON objects, where, all values, except **null**, were encoded as an object with one field, being the type of the object, and then the value. So an int would be **{ int: 0 }**.

The reason for representing a JSON object as key-value pairs, is that this could be easily translated to a Rust representation of the same type, using the *Serde* crate. This allows for creating Rust structs which represents JSON objects, and creates an automatic encoder/decoder between Rust and JSON. Using the *ts_rs*, we could also automatically create the TypeScript type that represents the automatically encoded/decoded JSON. This ensures a good cooperation between the *frontend* and *backend*.

4.3.3 IDE lifecycle

The general idea was that for each possible DOM-event, there would exist a way to send a `Msg`. Each `Msg` contains a `Msg` name, and some value, which enabled pattern matching on `Msg`, similar to `Elm`, for modules, so each module could choose to act on a `Msg` or not. So, after the initialization of the IDE, any time the user interacted with the GUI the modules would react to the `Msg`. The trivial plugin, would simply return an empty state on **init** and **update**, while on **view**, it would return a *frag* element, which is a `React` element that evaluates to no DOM change.

In listing 4.3, an example of a counter module can be seen. This module initializes a state, containing the field **"counter"**, with the value **VInt 0**.

The *update* function the module exposes, matches on a **"counter"** msg, with a **VInt i** value. If the given `Msg` matches this, then the module adds to the **"counter"**-field, the value from the `Msg`, which is 1.

Finally, the *view* function renders a button, which when pushed by a user, sends the *counter-Msg*.

```
init :: State
init = [("counter", VInt 0)]

update :: Msg -> State -> State
update (Msg { msg: "counter", val: VInt i }) model =
  case lookup "counter" model of
    Just (VInt j) ->
      insert "counter" (VInt (j + i)) model
    Nothing -> insert "counter" (VInt 0) model
update _ m = m

view :: State -> HTML
view model = Div [] [Text "Hello, World!"
  , Btn [OnClick $ Msg { msg: "counter", val: VInt 1 }] []
  , Text $ putStrLn $ lookup "counter" model
```

Listing 4.3: Counter Module (Haskell)

Module purity

One important thing in this architecture, is the pureness of module. The state of a module needs to be kept in the core application, and not in the module itself. The reason for this is twofold. It allows for the possibility of the core to be optimized in the future, as modules which do not react to a certain msg-state combination, can be noticed, and ensure modules are not unnecessarily invoked. It also lowers the complexity for module developers, as it is easier to reason about modules if *all* they do is read or write to some state.

If we have the modules A and B , where their relationship is $A \rightarrow B$, meaning A *invokes* B by sending some *Msg*, which B reacts too, and we want something to happen before B reacts, we can add a new module, C , which also reacts to the same *Msg*, but if we know the name of the module B , we can set the name of module C to be *above* the order, relative to B , ensuring that C always triggers before B .

4.3.4 Module v2 Cons

Not modular This setup is also not really modular, as a single module cannot invoke another module without being impure. The only way to invoke/trigger another module, is to throw a *Msg*, which would trigger an update \rightarrow view \rightarrow cycle. So a module cannot *listen* for a single message, all modules are triggered by the same *Msg*, and handled accordingly, synchronously.

Synchronous Module Invocation If a *Msg* triggers a computational heavy method, the IDE will *hang*, and act *sluggish* until the computation has finished. This would also affect *all* modules, since they are invoked in order, regardless of if they actually change the state or view.

Ever-growing State There was no way to remove a field on the state, the state is appending/overwriting -only, which was a side effect of the *solution* to state collisions.

State Collision

A state collision occurs when two or more modules updates the same field, during the same update-cycle. This issue also occurs when folding two states. After any update-cycle, we were left with a list of states, which needed to be coalesced into a singular one. There are several different ways to correct a collision between two states:

1. If the states are of same type:
 - 1.1. If the value from one of the colliders are unchanged from the previous state:
 - i. Keep the new value OR Keep the old value
 - 1.2. Else
 - i. Apply the types' semigroup operator to the fields.
2. Else
 - 2.1. If the value from one of the colliders are unchanged from the previous state:
 - i. Keep the new value OR Keep the old value
 - 2.2. Else
 - i. Keep the left-hand side value OR Keep the right-hand side value

Since the states are ordered by the name of the module they come from, we have a consistent ordering of left-hand side and right-hand side. Due to the fact that module invocation is synchronous, and ordered. If the same modules gives a collision on the same input, (given that all modules are pure), the resulting state will be the same every time. The problem is that applying some function on the values could be an unwanted way to resolve collisions. The standard way will be to log the collision, and then drop both states. Even if two states have A and B amount of fields, and just one collision, we will drop $A + B$ amount of fields.

This problem of resolving state collision only occurs because each module returns a subtree of the state. We then have to analyze the new coalesced tree for each new subtree that is added, to figure out if there occurs any collision. And then notifying the module developer of which field this collision occurred on, and which modules tried to modify that field.

4.4 Module V.3

The third and hopefully final, plan:

1. Everything is a module
2. Modules can *invoke* modules

A module only exposes two functions:

Init Returns nothing

Handler Returns nothing

In the previous architecture version, each module directly changed the state, which caused issues. Instead, each modification a module does, *acts*, as a direct modification, but is in fact, translated to a DSL which can be analyzed for possible collisions. This was discovered to be a need, as in the new version, the UI was also restructured, to allow for less re-rendering, and this restructuring, made it clear that changing the state, or changing the UI is just tree manipulations, which will be discussed more later.

4.4.1 Zero core architecture and microservice architecture

The new plan came with a change of viewpoint. Think of *everything being a module*, this pushed for a modularization between the then tightly coupled parts, the *frontend* and *backend*. As mentioned, having two different languages could allow for easier support of modules written in different programming languages, but for this to work in an optimal way, both the *frontend* and *backend* should be loosely coupled. This is an equivalent architecture to microservices.

Add
dia-
grams
and ex-
amples

4.4.2 Vanilla TypeScript

Instead of using React as the frontend framework, TypeScript was chosen, which simplified the integration between the backend and frontend, as the complexity of React's state management could be avoided, along with React's hydration. Given the rendering was now more *hands-on*, the core could expose a lot of the functionality for rendering, which modules could change. This would increase the difference between the JSMS and RSMS, as the backend was not privy to this API, but this was not seen as an issue, as this API would turn module non-pure.

Removing abstractions

It became prudent, due to the change of architecture, to change the entire frontend, moving away from React, and using *bare-bones* TypeScript. This would enable easier integration into the JSMS.

4.4.3 Core Modifications

Learning from the issues outlined in section 4.3.4, instead of a module returning the new core, it will rather return a set of instruction on *how* the core is to be modified, resulting in what the module developer wants the core to be. The reason for turning it around in this manner, is that, the new architectural change also came with a change on how the UI is modeled, as it is now up to the core to figure out an inexpensive way to do rendering. Since the core has UI-structure which is a representation of what the DOM should be, it can be treated as a Virtual-DOM, similar as to how React does it. This also means that there could be a collision on UI-change, as well as on a state-change. Instead of solving the equivalent problems twice, it was decided to try to treat the issues with collisions in state and UI as the same issue; its some form of tree-manipulation. We could then reduce the amount of needed methods on the module instance, to two. One for initializing the state, and one for handling events. In 4.4, we have a **CoreModification** type, which has two fields, one for the state, and one for the UI.

```
pub struct CoreModification {  
    state: Instruction<Value>,  
    ui: (Instruction<Html>, Instruction<String>, Instruction<Attr>),  
}
```

Listing 4.4: Core Modifications (Rust)

4.4.4 Tree Manipulation

This restructure changes the way the view is rendered. Instead of the view being re-rendered for each state-update, the view, or UI-hierarchy, is only modified by modules. This modification is similar to the earlier state modification, so a unified algorithm to solve this can be used. If there is an easy way to translate a UI modification to a state modification, and back again. To solve this, instead of having a module return the actual modifications, meaning, the updated core, a module returns a set of instructions of what to do with the core.

```
pub enum Instruction<T> {  
    /// No Operation, results in no change to the state  
    #[default]  
    NoOp,  
    /// Adds the given T where the id and/or class is found.  
    Add(String, T),  
    /// Removes the given T where the id is found.  
    Rem(String, T),  
    /// Combines two instruction into one  
    Then(Box<Instruction<T>>, Box<Instruction<T>>),  
}
```

Listing 4.5: Instruction (Rust)

In the listing 4.5, it is clear how the **Instruction**-set makes the modification of the core, a kind of group, as given by the definition 2.1.10. Intuitively, for any **Instruction**, there exists an *inverse* one, such that the definition 2.1.9 is upheld. If we add some value to the state, we can find an remove instruction that removes that field from the state, as shown in listing 4.5, in the **combine** method.

Remark. The **combine** method does not recursively check the **Then** instruction for **Instructions** that lead to a **NoOp**, but in the core IDE, there is an optimization step that does this.

To formalize this, that the **Instruction**-set is an group, we can look at a subset, since **Instruction** is parameterized by some type **T**, we will look at it when **T** is **Value**, noted by the subscript **val**.

Theorem 4.4.1 (Instruction Group). Let Σ be the set of all strings, Val be the set of all **Values**, $HtmL$ be the set of all **HtmL** variants, and $Inst_{val}$ be the set of all **Instruction** defined as:

$$NoOp = \{noOp\}$$

$$NoOp \in Inst_{val}$$

$$Add_{val} = \{(x, y, z) | x \in \Sigma, y \in \Sigma, z \in Val\}$$

$$Add_{val} \in Inst_{val}$$

$$Rem_{val} = \{(x, y, z) | x \in \Sigma, y \in \Sigma, z \in Val\}$$

$$Rem_{val} \in Inst_{val}$$

$$Then_{val} = \{(x, y) | x, y \in Inst_{val}\}$$

$$Then_{val} \in Inst_{val}$$

For any $x \in Add_{val}$ there exist a unique $y \in Rem_{val}$, such that:

$$x \oplus y = noOp$$

The theorem 4.4.1, unfortunately, cannot be encoded in Rusts type system, but when implementing *combine*, we can map the variants along with the specific fields being added (*Add*), modified (*Mod*), or removed (*Rem*), to get a more optimized instruction set. If we are modifying a value on field *foobar*, but in the same instruction set, remove it, then the modifying instruction is an *NoOp*. This optimization can be found in appendix A.

Like writing direct binary to develop a program, writing **instructions** to change the core is quite abstract for most developers so to facilitate development of modules, a helper class was created, which *translates* modifications to instructions. As shown in listing 4.6 and 4.7, a module developer simply invokes different methods on the builder, eventually building a **CoreModification**, to be sent.

```
async fn init(&self, core: Box<dyn Core>) {
    let mod = CoreModification::default()
        .set_state(UIBuilder::new().add(None, None, HtmL::Div()));
    core.get_sender().await.send(mod).await.unwrap();
}
```

Listing 4.6: UI Builder (Rust) showcasing how to add an empty HTML div element to the root HTML element.

```

async fn init(&self, core: Box<dyn Core>) {
    let mod = CoreModification::default()
        .set_state(StateBuilder::new().add("count", 0));
    core.get_sender().await.send(mod).await.unwrap();
}

```

Listing 4.7: State Builder (Rust) showcasing how to add a *count* field to the state, also showcasing how Rust can infer that the i32 type 0 is a **Value::Int** type.

This allows for an ergonomic way for module developer to create modifications on the core, without having to understand the syntax of the **Instruction-set**.

4.4.5 Backend Agnostic Frontend

Since we are using the framework Tauri to implement the IDE, the IDE is split to two, loosely coupled parts. The *frontend* and *backend*. The frontend acts as a thin wrapper around the core API, enabling different *runtimes* to handle module management, while the frontend waits for events, and renders the GUI. This structure allows for future maintainers of the IDE to be able to *trivially* switch runtime, if they wanted to use some other language to implement the runtime system in, like PureScript, Gleam or Haskell, all of which can target JavaScript, then they could.

4.4.6 Making the Core evaluate modifications asynchronously

Due to Rust first class focus on concurrency, it was trivial to make the core modifications run asynchronously. In previous iterations, the core evaluated one event at a time, waiting until all modules had finished their computations, before emulating the change and allowing for the next event to be evaluated. But this caused a noticeable *lag* if an event was long. This was solved by changing the core modification evaluation from a simple method to be invoked, to an Multi Provider Single Consumer (MPSC) channel system. Using *tokio*, a Rust crate for asynchronous development, a channel for core modifications was created, and instead of the core collecting all modifications, each module is invoked and *awaited* for in a separate thread, where in each module, if they have a core modification, sends the modification to the core channel, which works on a first come, first server basis. Here the core can evaluate the changes, also on a separate thread.

4.5 Testing

A zero-core IDE is equivalent to a microservice architecture, in that testing is important to ensure changes in one module does not inadvertently affect another. This is commonly achieved by using *pipelines*, a part of the Continuous Integration and Continuous Delivery (CI/CD) process, where we run several *jobs* whenever we make a change to our application. If we are bundling different modules together, and serving that as an IDE, we want to ensure that a change to a module does not negatively affect the other. This is where *pipeline jobs* come in, as each *job* test some part of our IDE. While it is cheaper to *spin* up an instance of the IDE in a pipeline, than an application dedicated to serve millions of users, we still want to avoid doing this unnecessarily. This is why we split up our testing into different stages.

4.5.1 Mocking

Due to the *pureness* of modules, mocking can be achieved easily, and therefore, modules can be tested alone, which is good, because testing a singular module is inexpensive.

4.5.2 Unit Testing

A module developer should create unit tests for their module. This can easily be done, and tested many times, due to the light-weightiness of a module. This, together with mocking, ensures we can test our modules, as if they were in an IDE. This means we can ensure changes made to a module is non-breaking.

UI Testing

We can also combine this with existing testing libraries, like *Playwright*¹, which can enable us to create tests specifically for UI behavior.

¹<https://playwright.dev/>

4.5.3 Module Family Testing

If a module changes some feature, let's say in the editor functionality, the module family tree encompassing this functionality needs to be tested, to ensure nothing breaks.

Contract Testing

As a module developer, one is designing some kind of API, but the developer has no say in how a consumer of the API consumes it. In a microservice architecture, the common way to work around this, is to version control the API by prefixing v^* in front of all endpoints in the API, where star, (*), is the version of the API. This way, the API designer can develop new APIs, without worrying about breaking functionality that consumers of the API depend on. This, however, usually means having to maintain equivalent APIs in parallel, until one decides to deprecate an older less used version, forcing consumers to move on to the newer version of the API.

Instead of relying on such a versioning system, module developers could use *contract testing*.

Contract Testing Imagine some API, and several consumers, A, B, C , The API developer is serving some data, in this case an integer number, which all the consumers use. One day, the developer finds out that using integers is not optimal, and want to move on to using floating point numbers instead. Changing the API outright could bring issues, as the consumers might rely on the API being an integer, instead of a float. But the change is needed, or wanted, at least. In this scenario, it is *easy* to inform all the consumers of the API, but if the consumer count increases tenfold, this is more difficult. A notice can still be sent, but it is not feasible to ensure all consumers commit time to change their ways. Contract testing ensures that, if a change like this occurs, the maintainer of the API is notified by which consumer this change breaks.

The issue is to create these contracts. Using frameworks like Pact [11], a developer creates a Domain Specific Language (DSL) test, where they describe how the provider or consumer reacts to certain interactions. But since everything is a module, we can automate this.

4.5.4 Automating Contract Testing

This process could be partially automated, as all modules have to register the event they want to handle. Furthermore, all events thrown are also explicitly done through the core instance, meaning a *test-core* could be created, which registers which event is thrown from what module, and all dependencies between modules can be noted.

4.5.5 End-To-End-Testing

The final step in the testing pipeline, is to test the entire application together. This is known as End-To-End (E2E). E2E is expensive, compared to the other steps, as we have to load the entire application in the pipeline, and test all interactions. This, of course, is the easiest way to cover all edge-cases, but since it is the whole application being tested, harder to figure out what caused a failure. Our IDE can be saturated with events in the E2E step of a pipeline, as all user interactions are translated into events, this ensures a module developer can narrow down what modules are at fault, by what modules *subscribe* to that event.

4.6 Module Developer Tools

The module developer experience is an important aspect of a zero-core architecture. A good way to improve this experience, is by providing good tooling.

4.6.1 Module Dependency Visualization

Still
being
de-
veloped

4.6.2 Module Isolation Testing

Still
being
de-
veloped

This is as simple as creating a minified version of our IDE, that has extra tools for mocking Events.

4.6.3 Module Boilerplate Generation

Still
being
de-
veloped

This CLI-tool enables a developer to quickly get started on developing modules, as the tedious work of setting up a project can be automated away.

4.7 Modules

Event Type In listing 4.8, one can see the structure of an event type. This allows for modules to pattern match on specific events, and unlike, as in the previous version, modules can *subscribe* to specific events to react to. This changes the structure of the module architecture to go from one wherein the core is a terminal object, to a more *complicated* one, in which module families can form.

```
pub enum Event {
    Event {
        event: String,
        args: Option<Value>,
    },
    DialogEvent {
        event: String,
        kind: Option<DialogEvtKind>,
        message: String,
        btn: Option<DialogBtn>,
        title: Option<String>,
    },
    DialogFile {
        event: String,
        title: Option<String>,
        file_kind: DialogFileKind,
        filter_ext: Vec<String>,
        create_dirs: bool,
    },
    #[serde(rename = "nmide://post-init")]
    PostInit,
    #[serde(rename = "nmide://pre-exit")]
```

```

    PreExit,
    CoreResponse {
        event: String,
        args: Option<Value>,
    },
}

```

Listing 4.8: Module Event (Rust)

This forms our *request* and *response* type, making the equivalence with a REST API obvious. The clients and consumers of the API, are the modules which can be seen in listing 4.9.

```

pub trait ModuleWrapper: Send + Sync {
    fn module_name(&self) -> String;
    async fn init(&self);
    async fn handler(&self, event: Event);
}

```

Listing 4.9: Module trait (Rust)

A module can interact with the core, by getting the state, UI, *throwing* an event, registration themselves to *handle* an event, or to *send* a **CoreModification**. In listing 4.10, we can see this core trait.

```

pub trait Core: Send + Sync {
    async fn state(&self) -> State;
    async fn ui(&self) -> Html;
    async fn throw_event(&self, event: Event);
    async fn add_handler(&self, event: String, handler: String);
    async fn send_modification(&self, modification: CoreModification);
}

```

Listing 4.10: Core trait (Rust)

Since a module updates the core by *choosing* to send a **CoreModification**, through a MPSC-channel, a module can run an expensive computation on another thread, while *ending* their invocation, ensuring a smooth IDE experience.

Here are some examples of modules implemented using the proposed architecture.

4.7.1 Magnolia Dependency Graph Visualizer

In Magnolia, as in many other languages, one cannot have a cyclic dependency. This means that the dependency graph of a Magnolia project should be a DAG. And since Magnolia has such a focus on reuse, the dependency graphs in a Magnolia project could be quite large. Which means the cycles could be quite long, which would make resolving the cyclic dependency issue complicated. One way to help a developer, would be to give them a tool to visualize the dependency graph, so that they could see what modules are connected. Using the Magnolia library as the input, we can create a visualization of the dependencies in Magnolia. Using two modules, one for *parsing* the Magnolia library, finding all packages, and their dependencies, and another for visualizing this.

```
async fn init(&self, core: Box<dyn Core>) {  
    core.add_handler("get_magnolia_graph".to_string(), MODULE_NAME.  
        to_string())  
        .await;  
}
```

Listing 4.11: Magnolia library parser Module *subscribing* to an *get_magnolia_graph* Event (Rust)

In listing 4.11, the module is invoking the *add_handler* method on an object that implements the *Core* trait, (4.10), and passing *get_magnolia_graph* and *MODULE_NAME*. This means that Events with the event name *get_magnolia_graph*, will trigger this module. It's *this* module, because we have to pass the name of the module handling the event.

We can therefore invoke this Module by simply triggering the subscribed Event.

Due to Rust's type safety, there is a lot of *noise*, especially because we are working with recursive data structures, with optional values. In listing 4.12, we can see a simplified version of the module handler, but this is not valid Rust code, the full code for the module can be found in appendix B.


```

1  async fn handler(&self, event: Event, core: Box<dyn Core>) {
2      match event.event_name() {
3          "get_magnolia_graph" => {
4              let path = event.args();
5              let key = format!("graph:{path}");
6              match core.state().get(&key) {
7                  Some(existing_graph) => {
8                      core.throw_event(Event::new("graph", existing_graph));
9                  }
10                 None => {
11                     let graph = get_graph(&path);
12                     core.throw_event(Event::new("graph", graph));
13                     let mods = CoreModification::state(
14                         StateBuilder::add(key, graph)
15                     );
16                     core.send_modification(mods);
17                 }
18             }
19         }
20         _ => (),
21     }
22 }

```

Listing 4.12: Simplified magnolia library parser Module (Rust)

The above code (4.12), we are handling Events with the name *get_magnolia_graph*, (line 3), and getting the path that is supplied in the Event argument, (line 4). In line 4 we then create a *key*, which we use to check if this graph has been created yet, by checking the state (line 6). If this graph does exist, we *respond* by throwing an Event with the existing graph (line 7 to 9). If it does not exist, we create it by calling the *get_graph* function, (left out for brevity), which recursively finds files in the supplied path, using RegEx to find the packages, and their dependencies. We then end by *responding* with the created graph, (line 12), and store it in the state, with the key (line 13 to 16). The resulting response can be seen in listing 4.13

```

{
  event: {
    event: "graph",
    args: {
      list: [
        {
          obj {
            name: { str: string },
            dependencies: { list: [{ str: string }] }
          }
        }
      ]
    }
  }
}

```

Listing 4.13: Magnolia library parser response (TypeScript)

The module responsible for rendering the graph, uses *d3*², a visualization library for JavaScript. *d3* expects *nodes* and *links*, specified in listing 4.7.1.

```

type Node = { id: string, name: string };
type Link = { source: string, target: string };

```

But due to how types are encoded in our *Value* type, as seen in 4.13, some translation is necessary. We have to go from the type *Value*, to *list of objects, with two fields, name and dependencies, of type string and list of string, respectively*. This translation can be seen in 4.14. Left out, are the steps verifying that the event has an argument, (since its optional to pass one), and that the argument is of the list variant of *Value*. The full source code can be found in appendix B. Since the list variant can contain any *Value* variant, we filter the list by whether it is an object variant, (line 2), we then transform each element in the list, into a intersection of the types *d3* expects, (4.7.1). The questionmark syntax on line 4, where we declare the *id* variable, means that if any of the expressions on the left are undefined, the resulting expression is undefined. Since the object variant of *Value* does not necessarily contain the *name* field, or is of the kind *str*. On line 9 to 13, we are getting all the dependencies from the object, with a helper method, *tObjLookupOr*. This method does a *lookup* on the supplied field on an object, and a typecheck. If the object does not exist, or is not of the correct type, the passed fallback value is returned instead, in this case, an empty list (line 10). Since we know the value is an list, we can

²<https://d3js.org/>

safely access it, (line 11), and filter by the string variant, and transforming the *Value* to a string primitive, (line 11 to 13).

```
1  const data = args.list
2  .filter(v => isTObj(v))
3  .map((obj) => {
4    const id = obj["name"]?.["str"];
5    return {
6      id,
7      name: id,
8      source: id,
9      targets: tObjLookupOr<ValueList>("dependencies")
10         (tList([]))
11         (obj).list
12         .filter(v => isTStr(v))
13         .map(s => s.str),
14   };
15 });
```

Listing 4.14: Dependency visualiser module (TypeScript)

In the picture 4.4, we can see the finished rendering of the dependency graph of the Magnolia basic library. As mentioned earlier, Magnolia has a lot of re-use, and therefore dependencies. That makes this visualization quite *noisy*, as there are a lot of crossing between the dependencies.

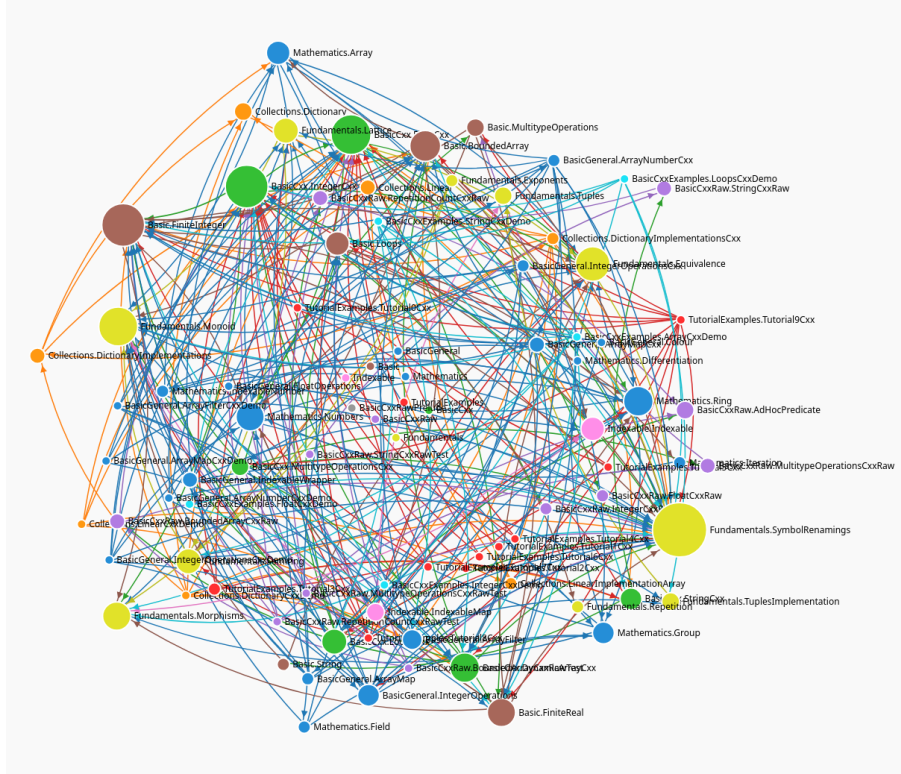


Figure 4.4: Magnolia basic library dependencies visualized. Each colour represents a package, which contains several modules. The size of the nodes vary depending on the amount of dependents, (indegree), a module has.

Luckily, with *d3*, we can mitigate some of the noise. In the picture 4.5, we can see the control-panel that our graph module has created. With the control panel, we can zoom in and out on the graph, (this can also be done with the mouse), reset our view. This is done with the help of *d3*, while the final button, find cycles, is implemented by simply checking the input data for a cycle, and colouring it red with the help of basic JavaScript and CSS. The remaining sliders are specifically for the graph ordering itself, where force strength, is with how much force nodes exert on each other, and link distance is how far a link between two nodes can/*wants* to be. This, along with the node size scale, scaling how big a node is depending on how many dependents it has, ensures this visualisation tool can be used for other programming libraries, not just Magnolia.

Furthermore, we can highlight the packages we care about, using the filter panel the module created. In picture 4.6, all the different Magnolia packages have been detected, and their corresponding colour has been added. We can then enable, or disable them.

In the picture 4.7, we can see the graph after we have disabled all other packages, except the *Fundamentals* package.

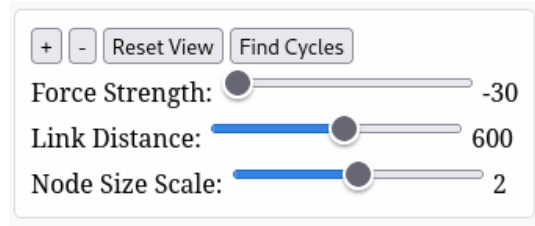


Figure 4.5: Control panel, with buttons and sliders for controlling the graph view

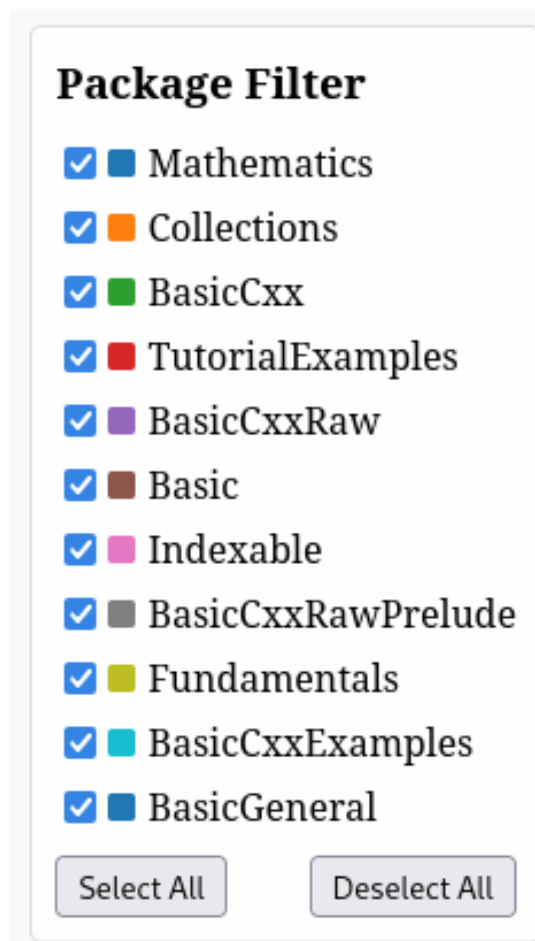


Figure 4.6: List of packages in the graph, that can be toggled

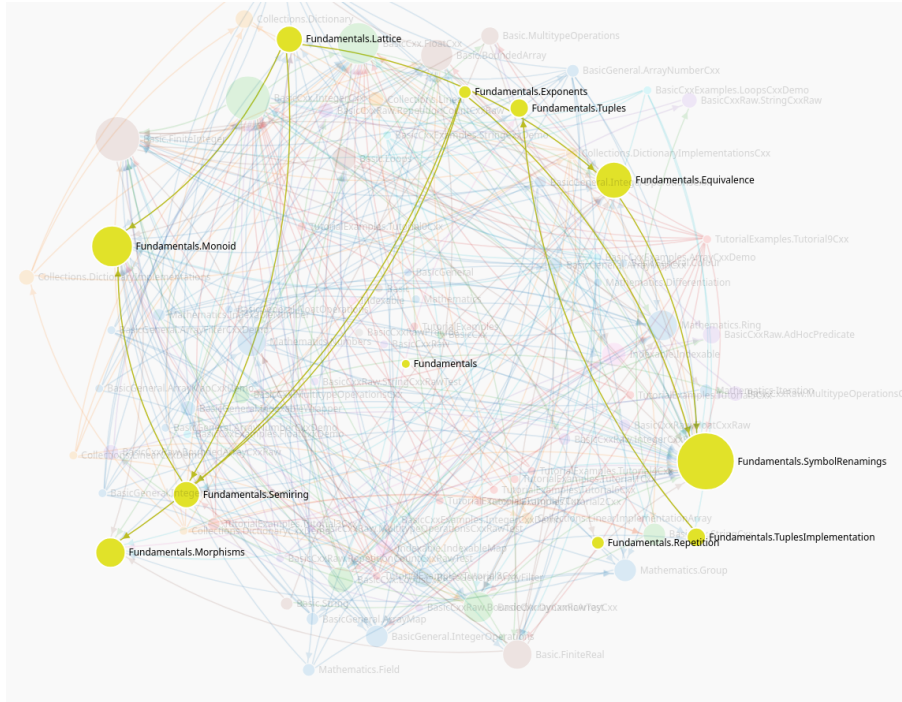


Figure 4.7: Magnolia basic library, with just the *Fundamentals* package highlighted.

4.7.2 IDE Module Family

4.7.3 Caching

There are two difficult problems in computer science³. Cache invalidation, naming things and off-by-one errors. Compiler for programming languages stores compiled code, such that it is not unnecessarily re-compiled. Similarly, IDEs like IntelliJ or VS Code store the application state between sessions, what files where opened, where in the files one where, etc. In this IDE, something similar can be done, by using the *ide_cache* module. This module declares a field on the state, *ide-cache*, which everytime the IDE exits, it writes to a file the contents of the field, which it reads and adds to the state during the *PostInit*-event. That way, if existing modules are doing some state change, they can be trivially refactored to use the cache field instead, by simply pre-fixing all their paths with *ide-cache*. In the dependency visualizer, we can prefix the graph storing, with this, and then the generated graph would be stored across sessions, ensuring a speedier visualisation process, as we don't have to wait for an, relatively, expensive IO operation.

³<https://martinfowler.com/bliki/TwoHardThings.html>

4.7.4 IDE Framework

An important aspect development, is separation of concerns. This is also relevant for module development. A module that renders a DAG, should not also be responsible for parsing a library and retrieving the data to be rendered. The same principle has been applied when developing prototype modules for this IDE, the following modules are responsible for the *view* of the IDE:

1. *ide_explorer*: Responsible for the file explorer
2. *ide_framework*: Responsible for general layout
3. *ide_pm*: Responsible for the menu bar
4. *ide_tabs*: Responsible for the tabbing system
5. *ide_errors*: Responsible in displaying module errors

In the figure ??, we have layed out the naming convention we use when referring to different *places* in the IDE.

The module *ide_pm*, being responsible for the menu bar at the top of the IDE, has an *easy* job, as it just simplifies the creation of interactive UI elements for other modules. With the dependency graph visualisation module, we can create a module which sends the initial Event that triggers the graph visualisation, and have the button be under the *View* dropdown content.

4.7.5 Editor Module Family

4.7.6 Magnolia Language Server

Create
the fig-
ure

Show
the
code
for this

Implement
a rudi-
ment-
ary
editor

Implement
a rudi-
ment-
ary
Magno-
lia LS

Chapter 5

Related Work

5.1 Multi-way Dataflow Constraint System

One thing this application does not provide a solution for, is the difficulty in designing good GUI. Following the MVC-pattern, GUIs can represent structures such as lists, which users might want to manipulate in some fashion, like appending or rearranging the items in the list. Managing such a change, especially one that involves GUI widgets can be a challenge, since a change in the view should be reflected in the model, and encoding this can be very involved. Luckily, there exists frameworks that make this task easier. *WarmDrink*, [20], [15] is a JavaScript framework that allow a developer to declarative specify structural changes in an application. This can be achieved, since the IDE exposes a simple API for runtime systems. A runtime system specifically for a Multi-way Dataflow Constraint System (MCDS) could be implemented for JavaScript modules. This could also be done for the Rust modules, by utilizing the crate developed by Svartveit. [21] The module developer experience is important, so it's good that there exist MCDS tooling to ease a module developers experience. [13]

Another issue in GUIs is optimizing performance in regard to events triggered by user actions, such as scrolling, resizing or typing. These events could happen many times in a second, while in theory user speed is trivial for a computer to keep up with, there are instances where a module family could be quite large, meaning many different modules are triggered by the same event many times. There are techniques, called event coalescing, for handling this, like debouncing and throttling.

Debouncing Debouncing is a technique where you delay the sending of an event until after some time period T has passed. Once the event is triggered T_0 starts counting down. If the same event is re-triggered while $T_0 > 0$, T_0 is reset by $T_0 = T$. If $T_0 = 0$, then the event is sent. Ensuring that T is not too large, is important, as if T is above some threshold, the user of the GUI will notice, and it will make the application *feel* slow.

Throttling Throttling is a similar technique to debouncing, except instead of delaying the event by some time T , the event is only sent when $T_0 = 0$. Meaning the event is sent at regular intervals, and could be sent at the exact same point in time when the user triggered the event, or it could happen at most, T units after the user action.

Debouncing and throttling work in less complex GUI structures, but as the amount of features in an application increases, the complexity will also increase. These event-coalescing-strategies are a source of subtle bugs, as event coalescing can easily break modularity. In a JSMS, this issue could be solved by using *flushable promises* [4].

5.2 Automated Testing

Due to the extensive modularity of the application, all modules can be tested individually, by *mocking* the expected state and events. This means that breaking changes in one module can be detected before E2E testing, which is expensive. But this can only verify the general logic of a module and module family, not the UI. To achieve such automation, one could rely on an automated testing framework, like the one in [3]. Or if one is working with a *simple* JavaScript runtime, one could use third party software like *Playwright* for creating tests, as it can auto generate the DSL, while the developer uses the module or entire IDE if it is an E2E test. This would help a module developer to discover behavior that a user might not expect [17].

5.3 Abstract Algebra

Magnolia is a kind of algebraic specification language, like CafeOBJ [9]. An algebraic specification language, is a language where one can develop similarly as to how one might create an algebraic structure. As shown in the development of this IDE, this can be quite useful way of thinking.

5.4 Syntactic Theory Functor

STF is used by the compiler [22] for stuff. Amongst them being resolving renaming, and flattening the ASR to be shown to the developer.

Chapter 6

Conclusion

The hypothesis 1.1.1 is right, source? Me.

6.1 Modular Development

In this thesis, we have shown that developing against a zero-core modular architecture is trivial. By utilizing separation of concerns, a module developer need to only understand the feature they want to extend, or if it is an entirely new feature, find out what has been done before.

6.2 Making an IDE is hard

An IDE has many features, which are needed to enhance the developer experience. To achieve this, the modular approach enables future users to enhance the application.

In the figure 6.1, the *cursor* is the place at which text is placed when the user writes. If the user clicks someplace in the document, the cursor *jumps* to that place. If the user uses the arrow-keys to move around, the cursor moves one character to left or right, or one line up and down, depending on which arrow-key was pressed.

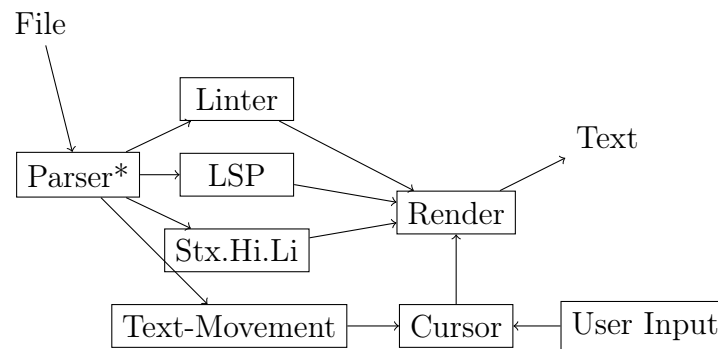


Figure 6.1: Text Editor Module Family

6.3 Cons

If you are the one developing every module, it get's very complex.

If you have a problem, and try to solve it with concurrency, now problems two have you.

Chapter 7

Future Work

Would've, could've, should've.

7.1 Technical Debt

It just piles and piles and piles on.

7.2 Modular Language Server

Once the compiler [22] is implemented, a proper LS can be created.

7.3 Modular Editor

The prototype editor module develop for this IDE is subpar compared to existing ones. A new one should be developed, in tandem with a LS client. This will ensure that this IDE can support more languages.

Glossary

Eclipse Eclipse is an IDE for Java.

Git Git is a VCS for tracking changes in computer files and coordinating work on those files among multiple people.

IntelliJ IntelliJ is an IDE for Java.

Neovim Fork of Vim.

Acronyms

ABI Application Binary Interface.
API Application Programming Interface.
ASR Abstract Semantic Representation.
BLDL Bergen Language Design Laboratory.
CI/CD Continuous Integration and Continuous Delivery.
CLI Commandline Interface.
CPU Central Processing Unit.
CSS Cascading Style Sheets.
DAG Directed Acyclic Graphs.
DOM Document Object Model.
DSL Domain Specific Language.
E2E End-To-End.
GUI Graphical User Interface.
HTML HyperText Markup Language.
IDE Integrated Development Environment.
IPC Inter-Process Communication.
JSMS JavaScript Module System.
JSON JavaScript Object Notation.
LS Language Server.
LSP Language LS.
MCDS Multi-way Dataflow Constraint System.
MoA Mathematics of Arrays.
MPSC Multi Provider Single Consumer.
MVC Model-View-Controller.
NPM Node Package Manager.
REST Representational State Transfer.

RSMS Rust Module System.
SMT Satisfiability modulo theories.
STF Syntactic Theory Functor.
UB Undefined Behavior.
UI User Interface.
VCS Version Control System.
VDOM Virtual Document Object Model.
Vim Vi Improved.
VS Code Visual Studio Code.

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Appendix A

Optimizing instructions sets

To optimize an instruction set, these are the steps taken:

1. Flatten the Instruction
2. Register how many times a field is modified
 - 2.1. Turn unnecessary Instructions into NoOps
3. Filter out NoOps
4. Unflatten the Instructions

```
#[derive(Debug, Default, Clone, Deserialize, Serialize, TS, PartialEq)]
#[serde(rename_all = "camelCase")]
pub enum Instruction<T> {
    /// No Operation, results in no change to the state
    #[default]
    NoOp,
    /// Adds the given T where the id and/or class is found.
    Add(String, T),
    /// Removes the given T where the id is found.
    Rem(String, T),
    /// Combines two instruction into one
    Then(Box<Instruction<T>>, Box<Instruction<T>>),
}
```

Listing A.1: Instruction (Rust)

Instruction is a recursive data type, parameterized by **T**. In Rust we can have generic data types, as shown in A.1, by the type parameter, *T*, but we have to restrict the type *T* to a type that implements the trait **PartialEq**, which means we can use equality on it. We need this restrictions, because the attribute macro **Instruction** has. These macros generate the needed code to implement the different traits:

- Debug: Enables the implementer to be printed to *stdout*
- Default: Implements a default variant of the implementer type, in this case, NoOp
- Clone: Implements a simple **clone** method, to create an owned instance of a borrowed value
- Deserialize & Serialize: Implements the needed methods for encoding and decoding a variant to a JSON representation
- TS: Enables automatic TypeScript type generation of the variant

We first start the optimization step, by removing all NoOps, and then flattening the instructions, by using the **opt** and **flatten** methods, shown in listings A.2 and A.3 respectively.

```

let i = *fv_map
    .get(&key)
    .expect("Should be initialized in the previous pass");
if i > 0 {
    fv_map.insert(key, 0);
    acc.combine(Instruction::Add(f, v))
} else {

```

Listing A.2: Opt method (Rust): Uses a match statement and a guard to match on a *slice*, (reference to a Vec). The guard lets us add a predicate to our branch, in this case, if *y matches* an NoOp. If it is an empty slice, it's a NoOp, otherwise, it will be an Instruction with all NoOps recursively removed.

```

let r = other.clone().flatten();
Self::opt(&l) == Self::opt(&r)
}

pub fn is_noop(&self) -> bool {
    matches!(self, Self::NoOp)
}

```

```

pub fn flatten(self) -> Vec<Instruction<T>> {
    match &self {
        Instruction::NoOp | Instruction::Add(..) | Instruction::Rem
            (...) => vec![self],
    }
}

```

Listing A.3: Flatten method (Rust): Not the lack of return statements, this is because the last expression in a function in Rust, is returned, if it doesn't end with a semicolon.

In listing A.4, we then iterate over each instruction in the sequence, and mapping each field and value to a counter. If it's an Add instruction, the counter is incremented, if it's a Rem instruction, the counter is decremented. We don't have a way to inform the compiler that we have removed all NoOp and Then instructions, and we need complete match-statements, so we add a catch-all with an *unreachable* macro, which will *panic* with the supplied message. This is commonly used to represent a state that is unreachable, but something the compiler can't prove.

```

pub fn unflatten(mut xs: Vec<Instruction<T>>) -> Self {
    if xs.len() == 1 {
        xs.pop().unwrap()
    } else {
        xs.into_iter()
            .fold(Self::NoOp, |acc, instr| acc.combine(instr))
    }
}

```

/// Creates an optimal instruction set by flattening the instructions, and removing all

/// operations that are "NoOp"s

```

pub fn optimize(vs: Vec<Instruction<T>>) -> Instruction<T> {
    let sequence: Vec<Instruction<T>> = Self::opt(&vs)
        .flatten()
        .into_iter()
        .filter(|i| !matches!(i, Instruction::NoOp))
        .collect();

    if sequence.is_empty() {
        return Instruction::NoOp;
    }
}

```

```
}
```

```
let mut fv_map: HashMap<(String, T), i32> = HashMap::new();
```

```
for instr in sequence.clone() {  
    match instr {  
        Instruction::Add(f, v) => {  
            let key = (f, v);
```

Listing A.4: Modification counting (Rust)

Finally, in the listing A.5, we *unflatten* the sequence of instructions, and check the count for each Add and Rem Instruction. If it is above 0, then that means we have added that field-value pair more times than removing it, but we can still only add it once, so we set the count to 0, and return a Then instruction, since we have the accumulated instructions along with the current Add instruction. If the count is less than 0, then it means we are removing it more times than adding it, similarly, we can only remove it once, so we set the count to 0, and combine the accumulated instruction, with the Rem instruction. Because of our **combine** implementation, we can be sure that the initial NoOp element is removed as soon as possible.

```
        Some(v) => {  
            fv_map.insert(key, *v + 1);  
        },  
        None => {  
            fv_map.insert(key, 1);  
        }  
    }  
}  
Instruction::Rem(f, v) => {  
    let key = (f, v);  
    match fv_map.get(&key) {  
        Some(v) => {  
            fv_map.insert(key, *v - 1);  
        },  
        None => {  
            fv_map.insert(key, -1);  
        }  
    }
```

```

    }
}
- =>
    unreachable!("'Then' or 'NoOp' instruction should never occur
        in a flattened instruction set"),
}
}

```

```

sequence
    .into_iter()
    .fold(Instruction::NoOp, |acc, instr| match instr {

```

Listing A.5: Instruction folding (Rust)

Appendix B

Magnolia library parser module

```
use async_trait::async_trait;
use core_std_lib::{
    core::Core,
    core_modification::CoreModification,
    event::Event,
    state::{StateInstructionBuilder, Value},
};
use regex::Regex;
use std::collections::HashMap;
use std::fs;
use std::fs::File;
use std::io::Read;
use std::path::Path;

pub struct ModuleBuilder;

impl core_module_lib::ModuleBuilder for ModuleBuilder {
    fn build(self) -> impl core_module_lib::Module {
        Module
    }
}

pub struct Module;

const MODULE_NAME: &'static str = "magnolia_dependency";
```

```

#[async_trait]
impl core_module_lib::Module for Module {
    fn name(&self) -> &str {
        MODULE_NAME
    }

    async fn init(&self, core: Box<dyn Core>) {
        core.add_handler("get_magnolia_graph".to_string(), MODULE_NAME.
            to_string())
            .await;
    }

    async fn handler(&self, event: Event, core: Box<dyn Core>) {
        match event.event_name() {
            "get_magnolia_graph" => {
                let path = if event.args().is_some_and(|v| v.is_str()) {
                    event.args().unwrap().str().unwrap()
                } else if event.args().is_none()
                    || event
                        .args()
                        .unwrap()
                        .obj()
                        .is_some_and(|o| !o.contains_key("eventArgs"))
                {
                    "/home/nmf/magnolia-basic-library/src".to_string()
                } else {
                    let p = event
                        .args()
                        .unwrap()
                        .obj()
                        .unwrap()
                        .get("eventArgs")
                        .unwrap()
                        .str();
                    if p.is_none() {
                        return;
                    }
                }
            }
        }
    }
}

```

```

        p.unwrap()
    };
    let field = format!("graph:{path}");
    match core.state().await.get(&field) {
        Some(g) => {
            core.throw_event(Event::new("graph", Some(g.clone(
                )))).await;
        }
        None => {
            let graph = get_graph(&path);
            core.throw_event(Event::new("graph", Some(graph.
                clone()))).
                .await;
            let mods = CoreModification::default()
                .set_state(StateInstructionBuilder::default().
                    add(field, graph));
            core.send_modification(mods).await;
        }
    }
}
- => (),
}
}
}

```

```

#[derive(Debug)]
pub(crate) struct MagnoliaModule {
    #[allow(dead_code, reason = "Handy to have the path for debugging
    purposes")]
    pub path: String,
    pub name: String,
    pub dependencies: Vec<String>,
}

```

```

impl MagnoliaModule {
    pub fn new(path: &Path) -> Self {
        let re =

```

```

Regex::new(r"package\s*([\w.]+)(?:\s*/\s*.*?)(?:\s*imports\s*([\s\S]*?))
?;").unwrap();

let mut file = File::open(path).unwrap();
let mut contents = String::new();
file.read_to_string(&mut contents).unwrap();
let mut name = String::new();
let mut dependencies = Vec::new();
if let Some(caps) = re.captures(&contents) {
    let mut caps = caps.iter();
    caps.next();
    name = caps.next().unwrap().unwrap().as_str().to_string();
    dependencies = caps
        .next()
        .and_then(|p| p)
        .map(|m| m.as_str().to_string())
        .map(|p| {
            p.trim()
                .split(",")
                .map(|s| s.trim())
                .map(|s| s.to_string())
                .filter(|s| !s.contains("//"))
                .collect()
        })
        .unwrap_or_default();
}

Self {
    path: path.to_str().unwrap_or_default().to_string(),
    name,
    dependencies,
}

pub fn to_obj(self) -> Value {
    let mut mp = HashMap::new();
    mp.insert("name".to_string(), Value::Str(self.name));
}

```

```

mp.insert(
    "dependencies".to_string(),
    Value::List(
        self.dependencies
            .into_iter()
            .map(Value::Str)
            .collect::<Vec<Value>>(),
    ),
);

mp.into()
}
}

pub(crate) fn get_graph(path: &str) -> Value {
    Value::List(
        get_modules(Path::new(path))
            .into_iter()
            .map(MagnoliaModule::to_obj)
            .collect::<Vec<Value>>(),
    )
}

pub(crate) fn get_modules(path: &Path) -> Vec<MagnoliaModule> {
    fs::read_dir(path)
        .unwrap()
        .filter_map(|e| e.ok())
        .flat_map(|d| match d.file_type() {
            Ok(df)
                if df.is_file() && d.file_name().to_str().is_some_and(|p| p
                    .ends_with(".mg")) =>
            {
                vec![MagnoliaModule::new(&d.path())]
            }
            Ok(df) if df.is_dir() => get_modules(&d.path()),
            _ => Vec::new(),
        })
}

```

```

        .collect()
    }

```

Listing B.1: Magnolia library parser module (Rust)

```

import {
    cls,
    Core,
    CoreModification,
    emptyCm,
    Event,
    HtmlBuilder,
    id,
    isPostInit,
    isPrimAnd,
    isTList,
    isTObj,
    isTStr,
    primDec,
    tList,
    tObjLookup,
    tObjLookupOr,
    UiBuilder,
    ValueList
} from "@nmide/js-utils";
import { initializeGraph } from "../dag";

const controls_div = new HtmlBuilder()
    .attrs(cls("controls"))
    .kids(
        new HtmlBuilder()
            .kind("button")
            .attrs(id("zoomIn"))
            .text("+"),
        new HtmlBuilder()
            .kind("button")
            .attrs(id("zoomOut"))
            .text("-"),
    )

```

```

new HtmlBuilder()
  .kind("button")
  .attrs(id("resetZoom"))
  .text("Reset View"),
new HtmlBuilder()
  .kind("button")
  .attrs(id("resetZoom"))
  .text("Find Cycles"),
new HtmlBuilder()
  .kids(
    new HtmlBuilder()
      .kind("label")
      .text("Force Strength:"),
    new HtmlBuilder()
      .kind("input")
      .attrs(
        { type: "range" },
        id("chargeSlider"),
        { custom: ["min", "-200"] },
        { custom: ["max", "-10"] },
        { custom: ["value", "-30"] },
        { custom: ["step", "-5"] },
      ),
    new HtmlBuilder()
      .kind("span")
      .attrs(id("chargeValue"))
  ),
new HtmlBuilder()
  .kids(
    new HtmlBuilder()
      .kind("label")
      .text("Link Distance:"),
    new HtmlBuilder()
      .kind("input")
      .attrs(
        { type: "range" },
        id("linkDistanceSlider"),

```

```

        { custom: ["min", "50"] },
        { custom: ["max", "1200"] },
        { custom: ["value", "300"] },
        { custom: ["step", "10"] },
    ),
    new HtmlBuilder()
        .kind("span")
        .attrs(id("linkDistanceValue"))
    ),
    new HtmlBuilder()
        .kids(
            new HtmlBuilder()
                .kind("label")
                .text("Node Size Scale:"),
            new HtmlBuilder()
                .kind("input")
                .attrs(
                    { type: "range" },
                    id("nodeSizeSlider"),
                    { custom: ["min", "1"] },
                    { custom: ["max", "5"] },
                    { custom: ["value", "2"] },
                    { custom: ["step", "0.5"] },
                ),
            new HtmlBuilder()
                .kind("span")
                .attrs(id("nodeSizeValue"))
        ),
    );

const legend_div = new HtmlBuilder().attrs(id("packageLegend"));

const package_filter_div = new HtmlBuilder()
    .attrs(id("packageFilter"))
    .kids(
        new HtmlBuilder().kind("h3").text("Package Filter"),
        new HtmlBuilder().attrs(id("packageCheckboxes")),
    );

```



```

    new HtmlBuilder().kids(
      new HtmlBuilder().kind("button").attrs(id("selectAll")).text("
        Select All"),
      new HtmlBuilder().kind("button").attrs(id("deselectAll")).text("
        Deselect All"),
    ),
  );

const Module = {
  name: "DependencyViewer",
  init: async (core: Core): Promise<CoreModification> => {
    const script = document.createElement("script");
    script.type = "text/javascript";
    script.src = "https://cdn.jsdelivr.net/npm/d3@7"
    document.head.appendChild(script);
    await core.registerHandler("DependencyViewer", "graph")
      .catch(err => console.error("error from module: ", err));
    await core.registerHandler("DependencyViewer", "post-init")
      .catch(err => console.error("error from module: ", err));
    return emptyCm();
  },
  handler: async (evt: Event, __: Core) => {
    console.log("Dp: ", evt);
    if (isPostInit(evt)) {
      console.log("post-init");
      return new UiBuilder()
        .add(
          controls_div,
          "content"
        )
        .add(
          legend_div,
          "content"
        )
        .add(
          package_filter_div,
          "content"

```

```

    )
    .add(
      new HtmlBuilder()
        .attrs(id("visualization")),
        "content"
    )
    .build();
}

if (!isPrimAnd(evt, "graph")) return emptyCm();

const { args } = primDec(evt);

if (args === null) return emptyCm();

if (!isTList(args)) return emptyCm();

const data = args.list
  .filter(v => isTObj(v))
  .map((obj) => {
    const id = obj["name"]?.["str"];
    return {
      id,
      name: id,
      source: id,
      targets: tObjLookupOr<ValueList>("dependencies")
        (tList([]))
        (obj).list
        .filter(v => isTStr(v))
        .map(s => s.str),
    };
  });

const nodes = data.map(({ id, name }) => {
  return { id, name };
});

```

```

const links = data.map(({ source, targets }) => {
  return targets.map(target => {
    return {
      source,
      target,
    };
  });
});

.flat()
.filter(
  ({ source, target }) =>
    nodes.find(n => n.id === source) !== undefined
    && nodes.find(n => n.id === target) !== undefined
);

let graphContext = initializeGraph(nodes, links);

function handleResize() {
  if (graphContext === undefined) {
    return emptyCm();
  }

  const container = document.getElementById("content");
  if (container === null) {
    console.log("Error on graphing: could not find element with id: 'content'");
    return emptyCm();
  }
  const width = container.clientWidth;
  const height = container.clientHeight;

  d3.select("#visualization svg")
    .attr("width", width)
    .attr("height", height)
    .attr("viewBox", [0, 0, width, height]);

```

```

    if (graphContext.simulation) {
      graphContext.simulation
        .force("center", d3.forceCenter(width / 2, height / 2))
        .force("x", d3.forceX(width / 2).strength(0.05))
        .force("y", d3.forceY(height / 2).strength(0.05))
        .alpha(0.3)
        .restart();
    }

    if (graphContext.svg && graphContext.zoom) {
      graphContext.svg.call(
        graphContext.zoom.transform,
        d3.zoomIdentity.translate(width / 2, height / 2)
      );
    }
  }

  window.addEventListener('resize', handleResize);

  /*
  const resizeObserver = new ResizeObserver(entries => {
    handleResize();
  });

  resizeObserver.observe(document.getElementById("content")!);
  */

  return emptyCm();
}
};

export default Module;

```

Listing B.2: Graph visualisation module (TypeScript)