

SHORT TITLE

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BY
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Lay Abstract

A lay abstract of not more 150 words must be included explaining the key goals and contributions of the thesis in lay terms that is accessible to the general public.

Abstract

Abstract here (no more than 300 words)

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Acknowledgements

Acknowledgements go here.

Contents

Lay Abstract	iii
Abstract	iv
Acknowledgements	vi
Notation, Definitions, and Abbreviations	xi
Declaration of Academic Achievement	xiii
1 Introduction	1
1.1 Background	2
1.2 Problem Statement	5
1.3 Thesis Outline	6
2 Drasil Printer	7
2.1 How documents are printed in Drasil?	8
2.2 Notebook Printer	11
3 Lesson Plans	19
3.1 Language of Lesson Plans	20

3.2	A Case Study: Projectile Motion	26
4	Code Block Generation	31
4.1	Unit of Contents	32
4.2	title	37
5	Conclusion	38
A	Your Appendix	39

List of Figures

3.1	Review Chapter Created Manually	30
3.2	Review Chapter Generated using Drasil	30
A.1	drasil-printer Dependency Graph	40

List of Tables

2.1	Summary of Packages and Modules in drasil-printers	8
3.2	Summary of Notebook Modules	26

Notation, Definitions, and Abbreviations

Notation

$A \leq B$ A is less than or equal to B

Definitions

Challenge With respect to video games, a challenge is a set of goals presented to the player that they are tasks with completing; challenges can test a variety of player skills, including accuracy, logical reasoning, and creative problem solving

Abbreviations

SRS

CSS

HTML

SCS

Declaration of Academic Achievement

The student will declare his/her research contribution and, as appropriate, those of colleagues or other contributors to the contents of the thesis.

Chapter 1

Introduction

Scientific computing (SC) is an intersection of computer science, mathematics, and science. It is a field that solves complex scientific problems by using computing techniques and tools. Writing documentation is a part of the process of developing scientific software. The role of documentation is to help people better understand the software and to “communicate information to its audience and instil knowledge of the system it describes” [1]. The significance of software documentation has been presented in many papers by previous researchers [2], [3], [4]. It is further shown by Smith et al. [5], [6] that developing scientific computing software (SCS) in a document-driven methodology improves the quality of the software .

Jupyter Notebook is a system for creating and sharing data science and scientific computing documentation. It is a nonprofit, open-source application born out in 2014, providing interactive computing across multiple programming languages, such as Python, Javascript, Matlab, and R. A Jupyter Notebook integrates text, live code, equations, computational outputs, visualizations, and multimedia resources, including images and videos. Jupyter Notebook is one of the most widely used interactive

systems among scientists. Its popularity has grown from 200,000 to 2.5 million public Jupyter Notebooks on GitHub in three years from 2015 to 2018 [7]. It is used in a variety of areas and ways because of its flexibility and added values. For example, the notebook can be used as an educational tool in engineering courses, enhancing teaching and learning efficiency [8], [9].

Even though the importance of documentation is widely recognized, it is often missing or poorly documented in SCS because: i) scientists are not aware of the why, how, and what of documentation [10], [11]; ii) it is time-consuming to produce [12]; iii) scientists generally believe that writing documentation demands more work and effort than they would likely yield in terms of the benefits of it [13].

We are trying to increase the efficiency of documentation development by adopting generative programming. Generative programming is a technique that allows programmers to write the code or document at a higher abstraction level, and the generator produces the desired outputs. Drasil is an application of generative programming, and it is the framework we use to conduct this research. Drasil saves us more time in the documentation development process by letting us encode each piece of information of our scientific problems once and generating the document automatically.

1.1 Background

1.1.1 Drasil

Drasil is a framework that can generate software artifacts, including Software Requirement Specifications (SRS), code (C++, C#, Java, and Python), README, and

Makefile, from a stable knowledge base. The goals of Drasil are reducing knowledge duplication and improving traceability [14]. Drasil captures the knowledge through our hand-made case studies. We currently have 10 case studies that cover different physics problems, such as Projectile and Pendulum. Recipes for scientific problems are encoded in Drasil, and it generates code and documentation for us. Each piece of information only needs to be provided to Drasil once, and that information can be used wherever it is needed. By defining and storing common concepts in a central repository, and case-specific concepts in their own packages, Drasil enables the reuse of information across different engineering domains and applications. This feature significantly reduces the time and effort required for software development and documentation, while also improving the consistency and accuracy of the information being used. More information and an example of how knowledge is reused can be found in Chapter 3.2.

Drasil is currently capable of generating SRS, a template for designing and documenting scientific computing software requirement decisions created by Smith et al [15], in document languages HTML and LaTeX. We are looking to extend the capability of Drasil by generating Jupyter Notebook in Drasil.

1.1.2 Jupyter Notebook

Jupyter Notebook is an interactive open-source web application for creating and sharing computational science documentation that contains text, executable code, mathematical equations, graphics, and visualizations.

Structure of a notebook document

A Jupyter Notebook has two components: front-end “cells” and back-end “kernels”. The notebook consists of a series of cells, which can be code cells, Markdown cells, or raw cells. A cell is a multiline text input field. The notebook follows a sequential flow, where users enter a piece of information, either in the form of text or programming code, into the cells from the web page interface. This information is then sent to the back-end kernels for execution, and the results are returned to the user [16].

The Value of Jupyter Notebook

There are several advantages of Jupyter Notebook: sharable, all-in-one, and live code. First of all, the notebook is easy to share because it can be converted into other formats such as HTML, Markdown, and PDF. Secondly, it combines all aspects of data in one single document, making the document easy to visualize, maintain and modify. In addition, Jupyter Notebook provides an environment of live code and computational equations. Usually, when programmers are running code on some other IDEs, they have to write the entire program before executing it. However, the notebook allows programmers to execute a specific portion of the code without running the whole program. The ability to run a snippet of code and integrate with text highlights the usability of the notebook.

1.2 Problem Statement

Since both Jupyter Notebook and Drasil focus on creating and generating scientific computing documentation, we are interested in extending the values of Jupyter Notebook to Drasil and the kind of knowledge we can manipulate. Following are the three main problems we are trying to solve with Drasil in this paper:

1. Generate Jupyter Notebooks. To achieve this, we will have to generate documents in notebook format. Jupyter Notebook is a simple JSON document with a .ipynb file extension. Notebook contents are either code or Markdown. Therefore, non-code contents must be in Markdown format with JSON layout. Drasil can only write in HTML and LaTeX. We are building a notebook printer in Drasil for generating documents that are readable and writable in Jupyter Notebook.
2. Develop the structure of lesson plans and generate them. As mentioned, Jupyter Notebook is used as an educational tool for teaching engineering courses. When it comes to teaching, lesson plans are often brought up because they help teachers to organize the daily activities in each class time. We are interested in teaching Drasil a “textbook” structure by starting with generating a simple physics lesson plan and expanding Drasil’s application. We aim to capture the elements of textbook chapters, identify the family of lesson plans, and classify the knowledge to build a general structure in Drasil, which will enable the lesson plan to generalize to a variety of lessons.
3. Generate notebooks that mix text and code. Jupyter Notebook is an interactive application for creating documents that contain formattable text and executable

code. However, Drasil doesn't support interactive recipes. There is no code in SRS documents, and text and code are generated separately in Drasil. We are looking for the possibility of generating a notebook document that incorporate both text and code, thereby enhancing the capabilities of Drasil and its potential to solve more scientific problems.

1.3 Thesis Outline

Thesis outline here.

Chapter 2

Drasil Printer

To generate Jupyter Notebooks in Drasil, the first step is to build a printer that can handle notebook generation. As explained in Chapter 1, a notebook is a JSON document composed of code and Markdown contexts, such as text and images. Drasil is currently capable of generating SRS documents in HTML and LaTeX, which are handled by the HTML and TeX printers, respectively. We are adding a JSON printer to Drasil for generating SRS documents in notebook format.

Once we have the user-encoded document (i.e., recipes of the scientific problem), the contents are passed to Drasil’s printers for printing. The printer is located in the **drasil-printers**, which contains all the necessary modules and functions for printing software artifacts. The **drasil-printers** is responsible for transferring the types and data defined in Drasil’s source language to printable objects and rendering those objects in desirable formats, such as HTML, LaTeX, or JSON. A list of packages and modules of the printers and their responsibilities can be found in Table 2.1. It is worth noting that the majority of the **drasil-printers** already existed before this research, and we only added a JSON printer and made a few changes to it for better

notebook printing.

This chapter explains how the contents are printed, how the printer works, and the implementation of the JSON printer.

Table 2.1: Summary of Packages and Modules in **drasil-printers**

Package/Module	Responsibility
Language.Drasil.DOT	Defines types and holds functions for generating traceability graphs as .dot files.
Language.Drasil.HTML	Holds all functions needed to generate HTML files.
Language.Drasil.JSON	Holds all functions needed to generate JSON files.
Language.Drasil.Log	Holds functions for generating log files.
Language.Drasil.Markdown	Holds functions for generating GOOL code.
Language.Drasil.Plain	Holds functions for generating plain files.
Language.Drasil.Printing	Transfers types and datas to printable objects and defines helper functions for printing.
Language.Drasil.TeX	Holds all functions needed to generate TeX files.
Language.Drasil.Config	Holds default configuration functions.
Language.Drasil.Format	Defines document types (SRS, Website, or Jupyter) and output formats (HTML, TeX, JSON, or Plain).

2.1 How documents are printed in Drasil?

In Drasil, a document that is meant to be printable includes a title, authors, and contents. The contents consist of various types of layout objects, as illustrated in Code 2.1. In Drasil’s document source language, these contents are categorized into

different types and dealt with explicitly. Code 2.2 shows the definition of contents we defined in source code. For instance, a **Paragraph** is comprised of sentences, and an **EqnBlock** holds an expression that is of type `ModelExpr`¹. These contents are then transformed into printable layout objects, defined in Code 2.3 in the **Language.Drasil.Printing**. Although the types of these layout objects are similar to the types of the contents, they are more appropriate for printing. Once the conversion is done, the layout objects can be targeted to produce the desired format in various document languages using language printers.

Code 2.1: Pseudocode for Definition of a Printable Document

```
1  data Document = Doc Title Author [LayoutObj]
```

Code 2.2: Source Code for Definition of RawContent

```
1  -- | Types of layout objects we deal with explicitly.
2  data RawContent =
3      Table [Sentence] [[Sentence]] Title Bool
4      | Paragraph Sentence
5      | EqnBlock ModelExpr
6      | DerivBlock Sentence [RawContent]
7      | Enumeration ListType
8      | Defini DType [(Identifier, [Contents])]
9      | Figure Lbl Filepath MaxWidthPercent
10     | Bib BibRef
11     | Graph [(Sentence, Sentence)] (Maybe Width) (Maybe
        ↳ Height) Lbl
```

Here is an example of how an expression is encoded and printed: Equation 2.1.1 represents the velocity obtained by integrating constant acceleration with respect to

¹Modelling expression is a mathematical expression language.

Code 2.3: Source Code for Definition of LayoutObj

```

1      -- | Defines types similar to content types in
2      -- "Language.Drasil" but better suited for printing.
3      data LayoutObj =
4          Table Tags [[Spec]] Label Bool Caption
5      | Header Depth Title Label
6      | Paragraph Contents
7      | EqnBlock Contents
8      | Definition DType [(String,[LayoutObj])] Label
9      | List ListType
10     | Figure Label Caption Filepath MaxWidthPercent
11     | Graph [(Spec, Spec)] (Maybe Width) (Maybe Height)
12         ↪ Caption Label
13     | HDiv Tags [LayoutObj] Label
14     | Cell [LayoutObj]
15     | Bib BibRef

```

time in one dimension, which is used in the case study **Projectile**:

$$v = v^i + ac^t \quad (2.1.1)$$

To encode the equation (**rectVel**), we might write it as shown in Code 2.4, where the type **pExpr** is a synonym used for **ModelExpr**. Once the equation is defined, it can be used in a **Sentence**² (Code 2.5) or other content types that contain expressions, such as **DerivBlock**³. Alternatively, expressions can also be converted directly to **Contents** (Code 2.6).

After encoding the equation and creating the sentence, the printers take over and convert the expression to a printable **EqnBlock**, which can then be generated in a specific document language. In Code 2.7, we can see how an **EqnBlock** is converted

²In Drasil, some content types are manipulated into a **Sentence** to form printable **Contents**.

³DerivBlock is a type of contents representing a derivation block.

Code 2.4: Pseudocode for Encoding rectVel

```

1  speed'  :: PExpr
2  speed' = sy QP.iSpeed `addRe` (sy QP.constAccel `mulRe
    ↪ ` sy time)
3
4  rectVel :: PExpr
5  rectVel = sy speed $= speed'

```

Code 2.5: Pseudocode for Converting rectVel to Sentence

```

1  equationsSent :: Sentence
2  equationsSent = S "From Equation" +:+ eS rectVel
3
4  -- | Lifts an expression into a Sentence.
5  E :: ModelExpr -> Sentence
6
7  eS :: ModelExpr -> Sentence
8  eS = E

```

from a [RawContent](#) to a printable [LayoutObj](#) and rendered in LaTeX.

For more details on how to create a project using Drasil and how information is encoded, please refer to Chapter 3 and the [Drasil Wiki: Creating Your Project in Drasil](#).

2.2 Notebook Printer

Since [LayoutObj](#) is the key to handling different types of contents, each document language’s printer is responsible for rendering layout objects in that particular language and generating necessary information for the document. For example, CSS describes the style and presentation of an HTML page, so generating the necessary CSS selectors in HTML documents is handled by the HTML printer. In the case of a

Code 2.6: Source Code for Converting ModelExpr to Contents

```

1      -- | Displays a given expression and attaches a '
      ↪ Reference' to it.
2      lblExpr :: ModelExpr -> Reference -> LabelledContent
3      lblExpr c lbl = llcc lbl $ EqnBlock c
4
5      -- | Same as 'lblExpr' except content is unlabelled
6      -- (does not attach a 'Reference').
7      unlblExpr :: ModelExpr -> Contents
8      unlblExpr c = U1C $ ulcc $ EqnBlock c

```

Jupyter Notebook document, metadata⁴ is required. To implement a well-functioning notebook printer, our focus is on rendering contents in JSON format and generating necessary metadata.

2.2.1 Rendering LayoutObjs in notebook format

Code 2.10 is the main function for rendering layout objects into a notebook. This function works similarly to the ones used by the HTML and TeX printers, and is responsible for generating content in the appropriate format. Each type of layout object is handled explicitly, taking into account how notebook users add content by hand in Jupyter Notebook, in order to reproduce it accurately. To help us properly render content in notebook format, we also created a few helper functions. For instance, `nbformat` (Code 2.8) helps create the necessary indentations for each line of content and encode them into JSON. We take advantage of the `encode` function from the Haskell package `Text.JSON`, which takes a Haskell value and converts it into a JSON string [18].

⁴Information about a book or its contents is known as metadata. It's often used to regulate how the notebook behaves and how its feature works [17].

Code 2.7: Source Code for Rendering EqnBlock to LaTeX

```

1      -- Line 2-15 is handled by Language.Drasil.Printing
2      -- | Helper that translates 'LabelledContent's to a
3      -- printable representation of 'T.LayoutObj'.
4      -- Called internally by 'lay'.
5      layLabelled :: PrintingInformation -> LabelledContent
6                  ⇔ -> T.LayoutObj
7      layLabelled sm x@(LblC _ (EqnBlock c)) =
8          T.HDiv ["equation"] [T.EqnBlock
9              (P.E (modelExpr c sm))] (P.S $ getAdd $ getRefAdd x)
10
11     -- | Helper that translates 'RawContent's to a
12     -- printable representation of 'T.LayoutObj'.
13     -- Called internally by 'lay'.
14     layUnlabelled :: PrintingInformation -> RawContent ->
15                   ⇔ T.LayoutObj
16     layUnlabelled sm (EqnBlock c) = T.HDiv ["equation"]
17         [T.EqnBlock (P.E (modelExpr c sm))] P.EmptyS
18
19     -- Line 18-28 is handled by Language.Drasil.TeX
20     -- | Helper for rendering 'LayoutObj's into TeX.
21     lo :: LayoutObj -> PrintingInformation -> D
22     lo (EqnBlock contents) _ = makeEquation contents
23
24     -- | Prints an equation.
25     makeEquation :: Spec -> D
26     makeEquation contents = toEqn (spec contents)
27
28     -- | toEqn inserts an equation environment.
29     toEqn :: D -> D
30     toEqn (PL g) = equation $ PL (\_ -> g Math)

```

Code 2.8: Source Code for Converting contents into JSON

```

1   import qualified Text.JSON as J (encode)
2
3   -- | Helper for converting a Doc in JSON format
4   nbformat :: Doc -> Doc
5   nbformat s = text ("    " ++ J.encode (show s ++ "\n")
                     ↪ ++ ",")

```

In addition, because non-code contents in Jupyter Notebook are built in Markdown, some types of contents require special treatment for Markdown generation, such as tables. Although Jupyter Notebook supports HTML tables (where we would be able to reuse the function from the HTML printer), we want to make the generated documents more “human-like” and reflect how people create contents in Jupyter. Therefore, instead of generating HTML tables, we create tables in Markdown format. The function `makeTable` from Code 2.9 generates a table in Markdown and converts it to the notebook format.

To handle the various types of contents, we break them down into different types and handle each type individually in our code. When we encounter a more complex case, we create a specific `make` function to deal with it in order to reduce confusion in the main `printLO` function. For instance, we have `makeTable`, which handles table generation, and `makeList`, which generates a list of items. These functions are then called by `printLO`. We carefully consider how contents are created in the notebook and render each type of layout object in notebook format to ensure that the generated document is a valid Jupyter Notebook document.

Code 2.9: Source Code for Rendering a Markdown Table

```

1  -- | Renders Markdown table, called by 'printL0'
2  makeTable :: [[Spec]] -> Doc -> Doc
3  makeTable [] _      = error "No table to print"
4  makeTable (l:lls) r = refID r $$ nbformat empty $$
5      (makeHeaderCols l $$ makeRows lls) $$ nbformat empty
6
7  -- | Helper for creating table rows
8  makeRows :: [[Spec]] -> Doc
9  makeRows = foldr (($) . makeColumns) empty
10
11 -- | makeHeaderCols: Helper for creating table header
12 -- (each of the column header cells)
13 -- | makeColumns: Helper for creating table columns
14 makeHeaderCols, makeColumns :: [Spec] -> Doc
15 makeHeaderCols l = nbformat (text header) $$
16     nbformat (text $ genMDtable ++ "|")
17     where
18         header = show(text "|" <> hcat(punctuate
19             (text "|") (map pSpec l)) <> text "|")
20         c = count '|' header
21         genMDtable = concat (replicate (c-1) "|:--- ")
22
23 makeColumns ls = nbformat (text "|" <> hcat(punctuate
24     (text "|") (map pSpec ls)) <> text "|")

```

2.2.2 Metadata Generation

There are two types of metadata in a Jupyter Notebook: the first type is for the notebook environment setup (line 9-30 in Code A.1), while the second type (line 3-7 in Code A.1) is used to control the behavior of a notebook cell, where we define the type of cell (i.e, Code or Markdown). Generating the first type of metadata is straightforward since the metadata for setting up the environment is identical across all notebooks. We built a helper function called `makeMetadata` to generate

Code 2.10: Source Code for Rendering LayoutObjs into JSON

```

1  -- | Helper for rendering LayoutObjects into JSON
2  printLO :: LayoutObj -> Doc
3  printLO (Header n contents l) = nbformat empty $$ nbformat
4    (h (n + 1) <> pSpec contents) $$ refID (pSpec l)
5  printLO (Cell layObs) = markdownCell $ vcat (map printLO
6    ↪ layObs)
7  printLO (HDiv _ layObs _) = vcat (map printLO layObs)
8  printLO (Paragraph contents) = nbformat empty $$
9    nbformat (stripnewLine (show(pSpec contents)))
10 printLO (EqnBlock contents) = nbformat mathEqn
11   where
12     toMathHelper (PL g) = PL (\_ -> g Math)
13     mjDelimDisp d = text "$$" <> stripnewLine (show d) <>
14       ↪ text "$$"
15     mathEqn = mjDelimDisp $ printMath $ toMathHelper $
16       TeX.spec contents
17 printLO (Table _ rows r _ _) = nbformat empty $$
18   makeTable rows (pSpec r)
19 printLO (Definition dt ssPs l) = nbformat (text "<br>") $$
20   makeDefn dt ssPs (pSpec l)
21 printLO (List t) = nbformat empty $$ makeList t False
22 printLO (Figure r c f wp) = makeFigure (pSpec r) (pSpec c)
   ↪ (text f) wp
23 printLO (Bib bib) = makeBib bib
24 printLO Graph{} = empty

```

the necessary metadata of a notebook document, as shown in Code 2.11. This function is called when a notebook document is being built, and the metadata is printed at the end of the document.

The second type of metadata is more complex. We need to break down our contents into units and differentiate them in order to generate the right type of cells. We will discuss this further in Chapter 4 [after introducing a new case study](#) in Chapter 3. For now, since there is no code in the SRS, all contents should be in Markdown. To generate the metadata for a Markdown cell, we use the helper

Ch4
link

Code 2.11: Source Code for Making Metadata

```

1      -- | Generate the necessary metadata for a notebook
      ↪ document.
2      makeMetadata :: Doc
3      makeMetadata = vcat [
4          text " \"metadata\": {",
5              vcat[
6                  text " \"kernel_spec\": {",
7                      text " \"display_name\": \"Python 3\",",
8                      text " \"language\": \"python\",",
9                      text " \"name\": \"python3\"",
10                     text " },",
11                 vcat[
12                     text " \"language_info\": {",
13                         text " \"codemirror_mode\": {",
14                             text " \"name\": \"ipython\",",
15                             text " \"version\": 3",
16                             text " },",
17                         text " \"file_extension\": \".py\",",
18                         text " \"mimetype\": \"text/x-python\",",
19                         text " \"name\": \"python\",",
20                         text " \"nbconvert_exporter\": \"python\",",
21                         text " \"pygments_lexer\": \"ipython3\",",
22                         text " \"version\": \"3.9.1\"",
23                         text " },",
24                     text " },",
25                 text " \"nbformat\": 4,",
26                 text " \"nbformat_minor\": 4"
27             ]
28      ]

```

function `markdownCell` function from Code 2.12. This function creates the necessary metadata and a cell for the given unit of content. An example implementation can be found in Code 2.13.

While the JSON printer implemented so far is not without flaws, there is always room for improvement. Nevertheless, the current implementation already enables

Code 2.12: Source Code for markdownCell

```

1      -- | Helper for building markdown cells
2      markdownB', markdownE :: Doc
3      markdownB' = text "    {\n    \"cell_type\": \"markdown
4          \",\n \"metadata\": {},\n    \"source\": [\"
5      markdownE  = text "        \"\\n\"\\n    ]\n    },\"
6
7      -- | Helper for generate a Markdown cell
8      markdownCell :: Doc -> Doc
9      markdownCell c = markdownB' <> c <> markdownE

```

Code 2.13: Source Code for Calling markdownCell

```

1      printL0 (Cell layoutObs) = markdownCell $ vcat (map
        ↪ printL0 layoutObs)

```

Drasil to generate Jupyter Notebooks and expand the generated document to include SRS in JSON format. This makes it possible to edit and share Drasil-generated documents with Jupyter Notebook, thereby increasing their value.

For detailed implementation of the JSON printer, please refer to the Appendix . [link](#)

Chapter 3

Lesson Plans

With the addition of a JSON printer capable of generating Jupyter Notebooks, we are now looking to expand Drasil’s application by generating educational documents. As discussed in Chapter 1, Jupyter Notebooks are commonly used in teaching engineering courses due to their characteristics and advantages. One of the educational practices to enhance education is conducting lesson plans [19, 20], which provide a guide for structuring daily activities in each class period. A lesson plan outlines the learning objectives, methods and procedures for achieving them, and the measurement of how student progress. Lesson plans are an ideal starting point for generating educational documents in Drasil because they are more accessible than academic papers. In addition, we are able to work with real examples in a lesson plan. This chapter will cover the structure of a lesson plan, how we define the language of lesson plans in Drasil, and a new case study on Projectile Lesson.

3.1 Language of Lesson Plans

To generate a new type of document, lesson plans, in Drasil, we must define its language first. Drasil’s document language has SRS, and we are creating a language for lesson plans. As discussed in Chapter 2, a Drasil document has a title, authors, and sections, which hold the contents of the document. The definition of a document is defined in **drasil-lang**¹ as shown in Code 3.1², where **Document** is the type for SRS document and **Notebook** is for Jupyter Notebook, specifically lesson plans at this moment. The reason why we define them separately is because we print the SRS and lesson plans differently. We are able to pattern match the way we print the document in the printer.

Code 3.1: Pseudocode for Definition of Document

```

1  data Document = Document Title Author ShowToC [Section]
2                  | Notebook Title Author [Section]

```

Before defining the language for lesson plans, we need to understand the components and categorize the knowledge to create a universal structure within Drasil. We analyzed the similarities and differences of elements in textbook chapters in **Discussion of Projectile Lesson: What and Why** using online resources. Based on our analysis, we narrowed down the elements and defined a structure that fits our lesson plans the most. It’s worth noting that this structure may be subject to future modifications to better suit our needs. Following is the structure of our lesson plans:

- Introduction: an introduction of the lesson plan or the topic.

¹**drasil-lang** holds the higher level language for Drasil.

²ShowToC is ShowTableOfContents in the source code, which is to determine whether to show the table of contents in the document.

- Learning Objectives: what students can do or will learn after the lesson.
- Review: a recap of what has been covered previously.
- A Case Problem: a case problem that link the topic to a real world problem.
- Example: an example of the case problem.
- Summary: a summary of the lesson plan.
- Bibliography: references that support the lesson plan.
- Appendix: additional resources or information of the lesson.

With the lesson plan structure in place, we can now define helper types and functions to create the document language for generating lesson plans. Our first step is to define the types and data for the lesson and its chapters in Drasil’s document language, **drasil-docLang**. Code 3.2 is the core declaration of the lesson plan. A [LsnDesc](#) type represents a lesson description (line 1), which consists of lesson chapters (line 3), including an introduction, learning objectives, review, case problem, example, summary, bibliography, and appendix. The detail structure of each chapter is defined in line 12-31. At present, [Contents](#) is the only defined elements as the chapter structure has not yet been fully understood. We intend to further develop the chapter structure in the future.

The [LsnDecl](#) type, as shown in Code 3.3, is used to declare all the necessary chapters for a lesson plan. It is similar in definition to [LsnDesc](#), but in a more usable form. It is meant to be a semantic rendition of a lesson plan document, while [LsnDesc](#) is intended to be a general description and more suitable for printing [21]. They are

link
to fu-
ture
work

Code 3.2: Source Code for Notebook Core Language

```

1  type LsnDesc = [LsnChapter]
2
3  data LsnChapter = Intro Intro
4                      | LearnObj LearnObj
5                      | Review Review
6                      | CaseProb CaseProb
7                      | Example Example
8                      | Smmry Smmry
9                      | BibSec
10                     | Apndx Apndx
11
12  -- ** Introduction
13  newtype Intro = IntrodProg [Contents]
14
15  -- ** Learning Objectives
16  newtype LearnObj = LrnObjProg [Contents]
17
18  -- ** Review Chapter
19  newtype Review = ReviewProg [Contents]
20
21  -- ** A Case Problem
22  newtype CaseProb = CaseProbProg [Contents]
23
24  -- ** Examples of the lesson
25  newtype Example = ExampleProg [Contents]
26
27  -- ** Summary
28  newtype Smmry = SmmryProg [Contents]
29
30  -- ** Appendix
31  newtype Apndx = ApndxProg [Contents]

```

identical at this point because the chapter structure is not well understood, but they might evolve differently as we gain more understanding of our lesson plans.

Next, we need functions to generate chapters. We can use the [Section](#) type that

Code 3.3: Source Code for LsnDecl

```

1  type LsnDecl  = [LsnChapter]
2
3  data LsnChapter = Intro NB.Intro
4                  | LearnObj NB.LearnObj
5                  | Review NB.Review
6                  | CaseProb NB.CaseProb
7                  | Example NB.Example
8                  | Smmry NB.Smmry
9                  | BibSec
10                 | Apndx NB.Apndx

```

Code 3.4: Source Code for Section and the Constructor

```

1  data Section = Section
2                  { tle    :: Title
3                    , cons  :: [SecCons]
4                    , _lab  :: Reference
5                    }
6  makeLenses ''Section
7
8  -- | Constructor for creating 'Section's with a title
9  -- ('Sentence'), introductory contents, a list of
10 -- subsections, and a shortname ('Reference').
11 section :: Sentence -> [Contents] -> [Section] ->
12         ↳ Reference -> Section
13 section title intro secs = Section title (map Con
14         ↳ intro ++ map Sub secs)

```

is used for creating SRS sections, which consists of a title, a list of contents, and a short name, as shown in Code 3.4. We can also take advantage of the `section` smart constructor to build our own chapter constructors, as illustrates in Code 3.5. Once we have these constructors, we can use them to build each chapter (Code 3.6).

When building lesson plans, the document and chapters are encoded in the `LsnDecl`

Code 3.5: Source Code for Chapter Constructors

```

1   learnObj, review, caseProb, example :: [Contents] ->
2       [Section] -> Section
3   learnObj cs ss = section (titleize ' Doc.learnObj) cs
        ↳ ss learnObjLabel
4   review    cs ss = section (titleize Doc.review)    cs
        ↳ ss reviewLabel
5   caseProb  cs ss = section (titleize Doc.caseProb)  cs
        ↳ ss caseProbLabel
6   example   cs ss = section (titleize Doc.example)   cs
        ↳ ss exampleLabel

```

Code 3.6: Source Code for Making Chapters

```

1   -- | Helper for making the 'Learning Objectives'.
2   mkLearnObj :: LearnObj -> Section
3   mkLearnObj (LrnObjProg cs) = Lsn.learnObj cs []
4
5   -- | Helper for making the 'Review'.
6   mkReview :: Review -> Section
7   mkReview (ReviewProg r) = Lsn.review r []
8
9   -- | Helper for making the 'Case Problem'.
10  mkCaseProb :: CaseProb -> Section
11  mkCaseProb (CaseProbProg cp) = Lsn.caseProb cp []
12
13  -- | Helper for making the 'Example'.
14  mkExample :: Example -> Section
15  mkExample (ExampleProg cs) = Lsn.example cs []

```

type, which is then converted to `LsnDesc` for printing. In Code 3.7, the `mkNb` function takes the user-encoded list of chapters (i.e., `LsnDecl`) and **System Information**³ to form a lesson plan document.

All types and functions mentioned in this chapter are declared in **drasil-docLang**.

³System Information is a data structure designed to contain all the necessary information about a system for the purpose of generating artifacts.

Code 3.7: Source Code for mkNb

```

1  mkNb :: LsnDecl -> (IdeaDict -> IdeaDict -> Sentence)
2      -> SystemInformation -> Document
3  mkNb dd comb si@SI {_sys = s, _kind = k, _authors = a} =
4      Notebook (nw k `comb` nw s) (foldlList Comma List $
5          map (S . name) a) $ mkSections si l where
6          l = mkLsnDesc si dd
7
8  -- | Helper for creating the lesson plan sections.
9  mkSections :: SystemInformation -> LsnDesc -> [Section]
10 mkSections si = map doit where
11     doit :: LsnChapter -> Section
12     doit (Intro i)      = mkIntro i
13     doit (LearnObj l)   = mkLearnObj l
14     doit (Review r)     = mkReview r
15     doit (CaseProb c)   = mkCaseProb c
16     doit (Example e)    = mkExample e
17     doit (Smmry s)      = mkSmmry s
18     doit BibSec         = mkBib (citeDB si)
19     doit (Apndx a)      = mkAppndx a
20
21 mkLsnDesc :: SystemInformation -> LsnDecl -> NB.LsnDesc
22 mkLsnDesc _ = map sec where
23     sec :: LsnChapter -> NB.LsnChapter
24     sec (Intro i)       = NB.Intro i
25     sec (LearnObj l)    = NB.LearnObj l
26     sec (Review r)      = NB.Review r
27     sec (CaseProb c)    = NB.CaseProb c
28     sec (Example e)     = NB.Example e
29     sec (Smmry s)       = NB.Smmry s
30     sec BibSec          = NB.BibSec
31     sec (Apndx a)       = NB.Apndx a

```

Table 3.2 summarizes the responsibility of each module for the language of lesson plans.

Table 3.2: Summary of Notebook Modules

Module	Responsibility
Drasil.DocLang	
Notebook.hs	Contains constructors for building chapters.
Drasil.DocumentLanguage.Notebook	
Core.hs	Contains general description functions for lesson plans.
DocumentLanguage.hs	Holds functions to create chapters and form a lesson plan.
LsnDecl.hs	Contains declaration functions for generating lesson plans.

3.2 A Case Study: Projectile Motion

In Chapter 3.1, we discussed the language of lesson plans to introduce a new case study on projectile motion. We chose projectile motion as a starting point for our lesson plans for several reasons: i) it is often one of the initial concepts taught when students are introduced to the study of dynamics; ii) the developed model is considered relatively straightforward as it solely incorporates kinematics, which pertains to the geometric characteristics of motion [22]; iii) Drasil already captures the knowledge of projectile, allowing us to showcase the reuse of knowledge. In this chapter, we are going to reproduce the **Projectile Motion Lesson**, authored by Dr. Spencer Smith, and generate a Jupyter Notebook version with Drasil.

3.2.1 Knowledge Reusability

In Drasil, we store commonly used knowledge, such as physics concepts (e.g., acceleration) and mathematics ideas (e.g., Cartesian coordinates), in a package named

drasil-data. Additionally, each case study has its own package that contains concepts specific to that study. For example, “Projectile Motion” is an idea in the Projectile case study. Once these ideas and concepts are defined in Drasil, they can be utilized whenever needed. Since there is an overlap in knowledge between the Projectile SRS and Projectile Motion Lesson, we can reuse the information without the need to encode it again.

For example, the following equation is the position of a particle moving in straight line as a function of time, given that the object experiences a constant acceleration:

$$p = p^i + v^i t + \frac{a^c t^2}{2} \quad (3.2.1)$$

The left side p (**scalarPos**) is a physical quantity defined in **drasil-data** with units as a [UnitalChunk](#)⁴, where the right side expression (**scalarPos'**) is a [PExpr](#) declared in the Projectile package in **drasil-example**, as shown in Code 3.8.

Code 3.8: Source Code for scalarPos

```

1      scalarPos  :: UnitalChunk
2      scalarPos  = uc CP.scalarPos 1P Real metre
3
4      scalarPos' :: PExpr
5      scalarPos' = sy iPos `addRe` (sy QP.iSpeed `mulRe`
6      sy time `addRe` half (sy QP.constAccel `mulRe`
      ↪ square (sy time)))

```

The information of Equation 3.2.1 was already available prior to the development of Projectile Motion. By utilizing the definitions of both **scalarPos** and **scalarPos'** as a reference, we can incorporate this information into our own usage for the lesson

⁴UnitalChunks are concepts with quantities that require a definition of units. A ‘UnitalChunk’ contains a ‘Concept’, ‘Symbol’, and ‘Unit’.

plan. The implementation of this can be seen in Code 3.9. The expression is defined in a `LabelledContent` because we are adding a label to it, allowing us to cross-reference it in the document.

Code 3.9: Source Code for `lcreatPos`

```

1   lcreatPos :: LabelledContent
2   lcreatPos = lbldExpr (sy scalarPos $= scalarPos') (
      ↪ makeEqnRef "rectPos")

```

Drasil offers a powerful way to store and reuse knowledge across different domains and aspects of the case study. By growing our knowledge database in this way, we believe that we can save time and effort while also ensuring consistency and accuracy in the use of concepts and ideas. This has the potential to greatly enhance the efficiency and effectiveness of engineering projects, and we are excited to continue exploring the possibilities of Drasil in the field of engineering.

3.2.2 Reproduce the Lesson

In accordance with the lesson plan structure discussed in Chapter 3.1, we divided the `Projectile Motion Lesson` into four chapters: learning objectives, review, a case problem, and examples. Each chapter is composed of a variety of content types, such as sentences, equations, or figures. To combine these contents into a chapter, we convert them to the `Contents` type and map them together. We provide smart constructors like `lbldExpr`⁵ for transferring different kind of contents to `Contents`. In Code 3.10, we demonstrate how information and contents of the review chapter are encoded in Drasil.

⁵This converts a `ModelExpr` into a `Contents`.

Code 3.10: Source Code for Encoded Review Chapter

```

1  reviewContent :: [Contents]
2  reviewContent = [reviewHead, reviewContextP1,
3    LlC E.lcrectVel, LlC E.lcrectPos, LlC E.lcrectNoTime,
4    reviewEqns, reviewContextP2]
5
6  reviewHead, reviewContextP1,
7    reviewEqns, reviewContextP2 :: Contents
8  reviewHead = foldlSP_ [headSent 2 (S "Rectilinear
9    Kinematics: Continuous Motion")]
10 reviewContP1 = foldlSP_
11   [S "As covered previously, the", plural equation, S
12     "relating", phrase velocity, sParen (eS (sy QP.speed)
13     ) `sC` phrase position, sParen (eS (sy QP.scalarPos))
14     `S.and_` phrase time, sParen (eS (sy QP.time))
15     `S.for` phrase motion `S.in_` S "one dimension with",
16     phrase QP.constAccel, sParen (eS (sy QP.constAccel))
17     +:+ S "are as follows:"]
18
19 reviewEqns = foldlSP [S "where", eS (sy QP.iSpeed)
20   `S.and_` eS (sy QP.iPos), S "are the initial",
21   phrase velocity `S.and_` phrase position,
22   S ",respectively"]
23
24 reviewContP2 = foldlSP
25   [S "Only two of these", plural equation, S "are
26     independent, since the third" +:+ phrase equation, S
27     "can always be derived from the other two"]

```

A lesson plan is represented in the `LsnDecl` type, which is a collection of chapters (see Code 3.11). We then use the `mkNb` function (presented in Code 3.7) to convert the lesson plan into a Drasil document. The resulting document can be printed and produced as a Jupyter Notebook with the Drasil printer, as discussed in Chapter 2.

Figures 3.1 and 3.2 display the review chapter of the lesson plan created manually and using Drasil, respectively.

Code 3.11: Source Code for Forming a Notebook

```

1  mkNB  :: LsnDecl
2  mkNB  = [
3      LearnObj $ LrnObjProg [learnObjContext],
4      Review $ ReviewProg reviewContent,
5      CaseProb $ CaseProbProg caseProbCont,
6      Example $ ExampleProg exampleContent,
7      BibSec
8  ]

```

Figure 3.1: Review Chapter Created Manually

Rectilinear Kinematics: Continuous Motion (Recap)

As covered previously, the equations relating velocity (v), position (p) and time (t) for motion in one dimension with constant acceleration (a) are as follows:

$$\begin{aligned}
 v &= v' + at & (\text{Eq_rectVel}) \\
 p &= p' + v't + \frac{1}{2}at^2 & (\text{Eq_rectPos}) \\
 v^2 &= (v')^2 + 2a(p - p') & (\text{Eq_rectNoTime})
 \end{aligned}$$

where v' and p' are the initial velocity and position, respectively.

Only two of these equations are independent, since the third equation can always be derived from the other two.

Figure 3.2: Review Chapter Generated using Drasil

Review**Rectilinear Kinematics: Continuous Motion**

As covered previously, the equations relating velocity (v), position (p) and time (t) for motion in one dimension with constant acceleration (a) are as follows:

$$\begin{aligned}
 v &= v' + a't \\
 p &= p' + v't + \frac{a't^2}{2} \\
 v^2 &= v'^2 + 2a'(p - p')
 \end{aligned}$$

where v' and p' are the initial velocity and position, respectively.

Only two of these equations are independent, since the third equation can always be derived from the other two.

For a complete demonstration of how the lesson plan is created using Drasil, including the implementation and generated document, we recommend referring to the appendix. [link](#)

Chapter 4

Code Block Generation

Jupyter Notebooks are valued for their effectiveness in writing and revising code for data research. They allow code to be written in discrete blocks (or “cells”), which can be executed separately, as opposed to writing and running a whole program [23]. This allows for a mix of content types with code to better present information.

In Chapter 2, we cover two types of metadata in Jupyter Notebooks: one type is necessary for forming the notebook, while the other is required to create cells for the contents. We explain how to generate the metadata and create a Markdown cell. When generating SRS, we do not need to worry about generating code blocks since SRS does not include any code. However, when creating lesson plans, we may want to integrate real examples that involve code. As we are now combining text and code in a document, we need to address the following questions before generating the right type of cell: i) what type of cell should we use, Markdown or code? and ii) how do we know when to end a cell and start a new one? That is, how do we determine where to split the contents into cells?

To begin, we need to consider the conceptual definition of a cell in Jupyter Notebooks. A cell is essentially a standalone unit of information or code that can be executed independently. In other words, it is a unit of content within the notebook [24]. A cell can contain either text or code and can span multiple lines. Understanding the relationship between cells and their contents is crucial for implementing an effective splitting strategy. By identifying natural boundaries within the text or code and recognizing the unit of the contents, we can determine where to split the contents into cells.

In this chapter, we will discuss different approaches and implementations for splitting the contents and generating the appropriate type of cells.

4.1 Unit of Contents

4.1.1 Section-level

When considering what would be the appropriate unit of content for splitting, one might first think of paragraphs or sections. In the source language of Drasil, since a document is made up of sections (as seen in Code 3.1), it may appear reasonable to split these sections into individual cells. However, the nested structure of Drasil documents, where each [Section](#) is composed of a list of [Contents](#) and [Sections](#) (as demonstrated in Code 3.4), does not align well with the sequential flow of a Jupyter Notebook. To address this issue, we flatten the structure of the Drasil document by making each section and subsection an independent [Section](#).

For example, Code 4.1 defines the Introduction section, where the original nested structure (lines 1-12) comprises a list of subsections, while in the flattened version

(lines 13-21), each subsection is self-contained and has its own type. Code 4.2 further illustrates that each section is independent after the changes.

Code 4.1: Source code for Definition of Introduction

```

1  -- Nested Structure
2  -- | Introduction section. Contents are top level
3  -- followed by a list of subsections.
4  data IntroSec = IntroProg Sentence Sentence [IntroSub]
5
6  -- | Introduction subsections.
7  data IntroSub where
8      IPurpose    :: [Sentence] -> IntroSub
9      IScope    :: Sentence -> IntroSub
10     IChar     :: [Sentence] -> [Sentence] -> [Sentence] ->
        ↳ IntroSub
11     IOrgSec   :: Sentence -> CI -> Section -> Sentence ->
        ↳ IntroSub
12
13 -- Flatten Structure
14 -- | Introduction section.
15 data IntroSec = IntroProg Sentence Sentence
16
17 -- | Introduction subsections.
18 newtype IPurpose = IPurposeProg [Sentence]
19 newtype IScope = IScopeProg Sentence
20 data IChar = ICharProg [Sentence] [Sentence] [Sentence]
21 data IOrgSec = IOrgProg Sentence CI Section Sentence

```

While flattening the structure of a document can allow for it to be split into individual cells by sections, there are limitations to this approach. Splitting the contents at the section level might not always be the most effective approach. It's possible that certain sections might be too long to fit comfortably in a single cell. Moreover, when working with documents that combine text and code (such as lesson plans), section-level splitting may not be appropriate due to the different types of

Code 4.2: Pseudocode for Definition of DocSection

```

1      -- Nested Structure
2      data DocSection = TableOfContents
3                          | RefSec RefSec
4                          | IntroSec IntroSec
5                          | StkhldrSec StkhldrSec
6                          ...
7
8      -- Flatten Structure
9      data DocSection = TableOfContents TableOfContents
10                         | RefSec RefSec
11                         | TUnits TUnits
12                         | TSymb TSymb
13                         | TAandA TAandA
14                         | IntroSec IntroSec
15                         | IPurposeSub IPurposeSub
16                         | IScopeSub IScopeSub
17                         | ICharSub ICharSub
18                         | IOrgSub IOrgSub
19                         ...

```

cells needed for text and code. Therefore, a better approach is needed.

4.1.2 LayoutObj-level

In Jupyter Notebook, a cell can be seen as a self-contained unit of information, and it can contain multiple types of content, such as text, code, and figures. To determine the appropriate unit of content for splitting, we need to consider the content itself and what makes sense in terms of its structure and organization. Although a cell might not always be the most appropriate unit of content for splitting, it is somehow the lowest level of “display content” that conveys a coherent piece of information [24]. Therefore, splitting the content based on logical units of information might be a more

effective approach rather than using sections as the sole criterion.

In previous chapters, we discussed how Drasil handles different types of content through the use of the `RawContent` data type, which includes paragraphs, figures, equations, and other content types (Code 2.2). A Drasil `Section` can consist of a list of `RawContent`, allowing for the inclusion of different types of contents within a single section. Additionally, as we saw in Chapter 2, the document is printed in a specific document language using `LayoutObj`, which is derived from `RawContent`. Because each content type is handled explicitly by `LayoutObj`, we can take advantage of this and split each type of content into its own cell.

To implement this approach, we first need to ensure that each layout object is generated independently and is not nested with other layout objects. In Chapter 2, we discussed how `RawContent` is translated to a printable `LayoutObj`. The `printLO` function in Code 2.3 demonstrates how the printer renders each content type into a notebook format. However, it's worth noting that the current format of `LayoutObj` is designed for SRS and may not be suitable for lesson plans. For instance, the `HDiv` type wraps sections and creates an HTML `<div>` tag, and even an equation block is translated into the `HDiv`, as seen in Code 2.7. Moreover, the `Definition` type is designed for the definition or model defined in SRS and may not be required for lesson plans. To better accommodate lesson plan content types, we may need to create a new `LayoutObj` in the future when we have a better understanding of the lesson plan structure.

Currently, we are using the existing `LayoutObj` to translate our lesson plan contents into printable layout object. Since these contents are not code and should be in Markdown, we print each required content type independently into a Markdown

future
work

cell. To accomplish this, we use the `markdownCell` function from Code 2.12. This function generates the necessary metadata and creates the Markdown cell for each layout object, which is our unit of content.

Code 4.3 illustrates how each content type is rendered in notebook format in a Markdown cell. For layout objects that are not needed in lesson plans, we make them empty. We also separate equation blocks from `HDiv` with the equation tag to have more control over the structure.

Code 4.3: Source Code for `printLO'`

```

1  -- printLO' is used for generating lesson plans
2  printLO' :: LayoutObj -> Doc
3  printLO' (HDiv ["equation"] layObs _) = markdownCell $
4    vcat (map printLO' layObs)
5  printLO' (Header n contents l) = markdownCell $ nbformat
6    (h (n + 1) <> pSpec contents) $$ refID (pSpec l)
7  printLO' (Cell layObs) = vcat (map printLO' layObs)
8  printLO' HDiv {} = empty
9  printLO' (Paragraph contents) = markdownCell $ nbformat
10    (stripnewLine (show(pSpec contents)))
11  printLO' (EqnBlock contents) = nbformat mathEqn
12    where
13      toMathHelper (PL g) = PL (\_ -> g Math)
14      mjDelimDisp d = text "$$" <> stripnewLine (show d) <>
15        ↪ text "$$"
16      mathEqn = mjDelimDisp $ printMath $ toMathHelper $
17        TeX.spec contents
18  printLO' (Table _ rows r _ _) = markdownCell $
19    makeTable rows (pSpec r)
20  printLO' (Definition dt ssPs l) = empty
21  printLO' (List t) = markdownCell $ makeList t False
22  printLO' (Figure r c f wp) = markdownCell $ makeFigure
23    (pSpec r) (pSpec c) (text f) wp
24  printLO' (Bib bib) = markdownCell $ makeBib bib
25  printLO' Graph{} = empty

```

4.2 Code Block

Chapter 5

Conclusion

Every thesis also needs a concluding chapter

Appendix A

Your Appendix

Figure A.1 shows the dependency between modules in **drasil-printers**. The arrow points to the module that is being relied on.

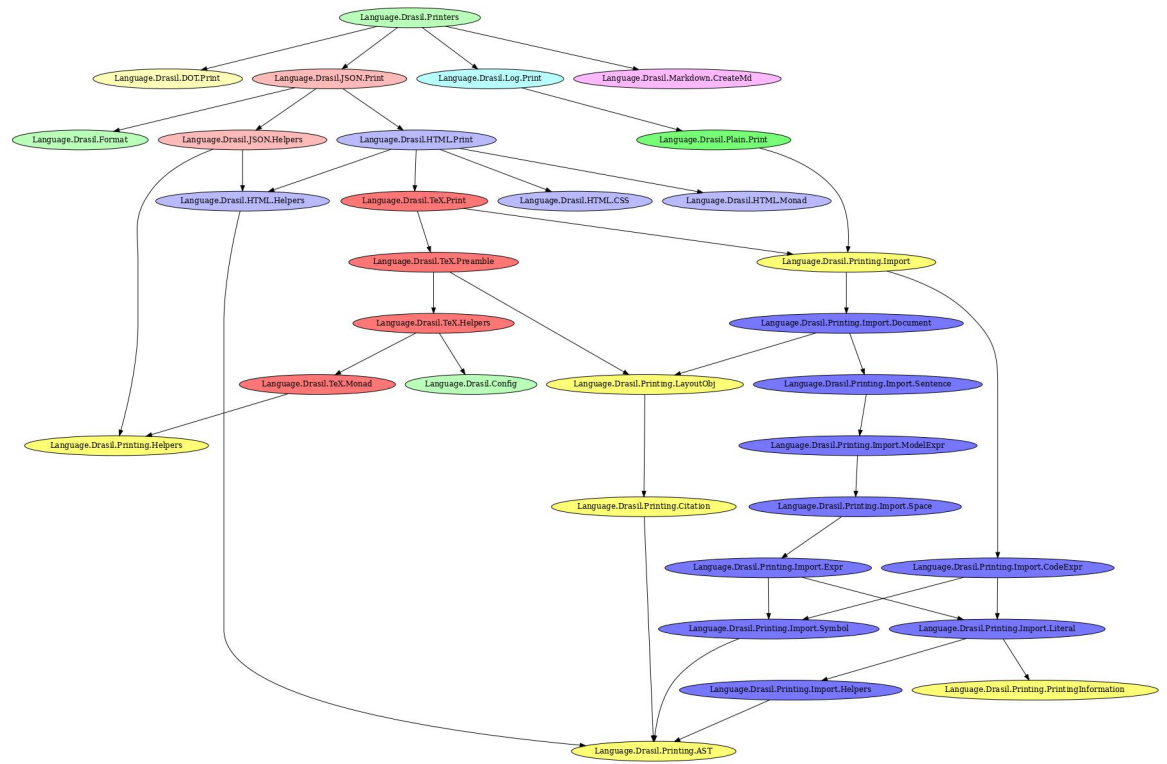


Figure A.1: drasil-printer Dependency Graph

Code A.1: JSON Code of A Notebook Document

```
1  {
2    "cells": [
3      {
4        "cell_type": "markdown",
5        "metadata": {},
6        "source": []
7      }
8    ],
9    "metadata": {
10     "kernelspec": {
11       "display_name": "Python 3",
12       "language": "python",
13       "name": "python3"
14     },
15     "language_info": {
16       "codemirror_mode": {
17         "name": "ipython",
18         "version": 3
19       },
20       "file_extension": ".py",
21       "mimetype": "text/x-python",
22       "name": "python",
23       "nbconvert_exporter": "python",
24       "pygments_lexer": "ipython3",
25       "version": "3.9.1"
26     }
27   },
28   "nbformat": 4,
29   "nbformat_minor": 4
30 }
```

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