FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Exploring Visual Programming Concepts for Probabilistic Programming Languages

Gabriel Cardoso Candal

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FEUP **FACULDADE DE ENGENHARIA**
UNIVERSIDADE DO PORTO

Mestrado Integrado em Engenharia Informática e Computação

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Abstract

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Resumo

O Resumo fornece ao leitor um sumário do conteúdo da dissertação. Deverá ser breve mas conter detalhe suficiente e, uma vez que é a porta de entrada para a dissertação, deverá dar ao leitor uma boa impressão inicial.

Este texto inicial da dissertação é escrito no fim e resume numa página, sem referências externas, o tema e o contexto do trabalho, a motivação e os objectivos, as metodologias e técnicas empregues, os principais resultados alcançados e as conclusões.

Este documento ilustra o formato a usar em dissertações na Faculdade de Engenharia da Universidade do Porto. São dados exemplos de margens, cabeçalhos, títulos, paginação, estilos de índices, etc. São ainda dados exemplos de formatação de citações, figuras e tabelas, equações, referências cruzadas, lista de referências e índices. É usado texto descartável, *Loren Ipsum*, para preencher a dissertação por forma a ilustrar os formatos.

Seguem-se umas notas breves mas muito importantes sobre a versão provisória e a versão final do documento. A versão provisória, depois de verificada pelo orientador e de corrigida em contexto pelo autor, deve ser publicada na página pessoal de cada estudante/dissertação, juntamente com os dois resumos, em português e em inglês; deve manter a marca da água, assim como a numeração de linhas conforme aqui se demonstra.

A versão definitiva, a produzir somente após a defesa, em versão impressa (dois exemplares com capas próprias FEUP) e em versão eletrónica (6 CDs com "rodela" própria FEUP), deve ser limpa da marca de água e da numeração de linhas e deve conter a identificação, na primeira página, dos elementos do júri respetivo. Deve ainda, se for o caso, ser corrigida de acordo com as instruções recebidas dos elementos júri.

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Acknowledgements

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The Name of the Author

*"You should be glad that bridge fell down.
I was planning to build thirteen more to that same design"*

Isambard Kingdom Brunel

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Abbreviations

ADT   Abstract Data Type
PP   Probabilistic Programming
PPL   Probabilistic Programming Language
PPAML   Probabilistic Programming for Advancing Machine Learning
ML   Machine Learning
VP   Visual Programming
VPL   Visual Programming Language

Chapter 1

Introduction

This first chapter aims to provide the reader with an overview of this dissertation. It starts by introducing the context this work is inserted in, identifying the problem which we aim to solve, how we plan on solving it, and the expected outcome. Lastly, it gives a bird's eye view of this report's structure.

1.1 Context

There is, among several domains with interesting and relevant problems to solve (computer vision [KT15], cryptography, biology, fraud detection, recommender systems [Alp10], ...), the recurring necessity to be able to make decisions in the face of uncertainty using machine learning (ML) methods.

Successful ML applications include Google's personalized advertising and context-driven information retrieval, Facebook's studies of how information spreads across a network or UC Berkeley's AMPLab contributions towards Amazon Web Service and SAP's products [BAF+15].

Typically, there are two approaches for this class of problems): either use an existing machine learning model (such as KNN, neural networks or similar) [Sch08] and try to fit your data into the model, or build a probabilistic model for your particular problem so you can leverage domain knowledge [Gri13].

In the second approach one common way to tackle it is to use bayesian reasoning, where you model unknown causes with random variables, feed the model the data you have gathered and then perform inference to reverse the story and query for the desired variables [Dow12]. The tricky issue is this last step, since it is non-trivial to write an inference method [DL].

The solution to this has been building generic inference engines for graphical models, so that modeling and inference can be treated as separate concerns and people can focus on the modeling [JW96]. However, not all models can be represented as graphical models, and that's why we now

Figure 1.1: Top 10 Analytics Tools [Pia15]

have Probabilistic Programming Languages (PPLs). Probabilistic Programs let you write your model as a program and have off-the-shelf inference [Pre03].

1.2 Problem

In spite of these examples of applications in the industry, ML has been identified by Gartner, in its Hype Cycle annual review, to be in the "Peak of Inflated Expectations" stage, still far from the "Plateau of Producitvity" [Sta15].

It has also been said that ML's applications are rarely seen outside the academia, with Wagstaff claiming that there is a "frequent lack of connection between machine learning research and the larger world of scientific inquiry and humanity" [Wag12].

Arguably the scenario is even worse for PPLs, having even lesser adoption among tech companies. One factor which may be contributing to this lack of usage, despite PP's power and flexibility, is the difficulty for data scientists to adapt to textual interface these languages provide, which lack the graphical intuiton provided by other tools they are accustomed to. In a poll made to about 2800 data scientists (see Figure 1.1), half of the top 10 tools are graphically-interactable.

1.3 Motivation and Goals

DARPA, one of the funders behind PPLs' research, has recognized some of the problems identified by Wagstaff and started a program called Probabilistic Programming for Advancing Machine

Learning (PPAML) to address the shortcomings of current ML methods [Jag13]. It identifies five strategic goals:

- Shorten machine learning model code to make models faster to write and easier to understand

- Reduce development time and cost to encourage experimentation

- Facilitate the construction of more sophisticated models that incorporate rich domain knowledge and separate queries from underlying code

- Reduce the level of expertise necessary to build machine learning applications

- Support the construction of integrated models across a wide variety of domains and tool types

The purpose of this work is to try addressing the first four. In order to do so we aim to overcome the difficulties in learning a new language, either for unexperienced developers or seasoned ones, such as learning yet another syntax or getting accostumed to the language's idioms. It is known that typical languages are difficult to learn and use [LO87] and that there are advantages in providing a language with a visual interface [AA92]. Also, studies have shown that programmers and data scientists alike resort to mental imagery when solving problems [Das02][PB99], so by providing such an interface we can approximate how people think and how they use the language to solve the problem at hand.

So, the goal of this dissertation will be to develop a Visual Programming Language (VPL) with probabilitics programming capabilities. The targeted audience are programmers and data scientists with background knowledge in statistics who aren't still comfortable with full blown PPLs, but wish to educate themselves in the topic so they can eventually leverage the power of this novel machine learning approach.

The way to do so would be developing a graphical node-based editor, similar to RapidMiner or Blender Composite Nodes, but that runs in the browser. The given editor would have the capability to compile its graph to the textual representation in the target PPL so that the user can run what it has designed, either as a standalone script or even by integrating it with his existing projects.

The hypothesis under consideration is this graphical representation is more intuitive and easy to learn that a full-blown PPL. We intend to validate such hypothesis by ensuring that classical problems solved in the literature by PPLs are also supported by our graphical representation, and then measure how quickly a group of people trained in statistics would produce a viable model in both alternatives.

1.4 Outline

Para além da introdução, esta dissertação contém mais x capítulos. No capítulo 2, é descrito o estado da arte e são apresentados trabalhos relacionados. No capítulo 3, ipsum dolor sit amet,

Introduction

consectetuer adipiscing elit. No capítulo 4 praesent sit amet sem. No capítulo 5 posuere, ante non tristique consectetuer, dui elit scelerisque augue, eu vehicula nibh nisi ac est.

Chapter 2

Background State of the Art

This chapter has two purposes: describing the foundations on which this work is built on, namely PP and ML, and enumerating

2.0.1 Machine learning

Machine learning is a field with the potential to impact a wide spectrum of different areas such as biology, medicine, finance, astronomy [Ama13], computer vision, sales forecast, robotics [Alp10], product recommendations, fraud detection or internet ads bidding [Gri13]. It can be seen as a sub-field of artifical intelligence that incorporates mathematics and statistics and is concerned with conceiving algorithms that learn autonomously, that is, without human interventention [Bri16][Sch08].

2.0.1.1   Bayesian Reasoning

2.0.1.2   Probabilistic Programming

2.0.2   Visual Programming

2.0.2.1   Visual Dataflow Programming

2.0.3   State of the Art

2.0.3.1   Stan

2.0.3.2   WinBUGS

2.0.3.3   Church

2.0.3.4   Infer.NET

2.0.3.5   PyMC

2.0.3.6   VIBES

2.0.3.7   NoFlo

2.0.3.8   RapidMiner

2.0.3.9   Weka Knowledge FLow

2.0.3.10   GoJS

2.0.3.11   Blockly

2.1   Conclusions

Chapter 3

Visualização de Sinópticos SVG

Este capítulo deve começar por fazer uma apresentação detalhada do problema a resolver[1] podendo mesmo, caso se justifique, constituir-se um capítulo com essa finalidade.

Deve depois dedicar-se à apresentação da solução sem detalhes de implementação. Dependendo do trabalho, pode ser uma descrição mais teórica, mais "arquitetural", etc.

3.1 Secção Exemplo

Neste capítulo apresentam-se exemplos de formatação de figuras e tabelas, equações e referências cruzadas.

Apresenta-se de seguida um exemplo de equação, completamente fora do contexto:

$$CIF_1: \quad F_0^j(a) \quad = \quad \frac{1}{2\pi\iota} \oint_\gamma \frac{F_0^j(z)}{z-a} dz \tag{3.1}$$

$$CIF_2: \quad F_1^j(a) \quad = \quad \frac{1}{2\pi\iota} \oint_\gamma \frac{F_0^j(x)}{x-a} dx \tag{3.2}$$

Na Equação 3.2 lorem ipsum dolor sit amet, consectetuer adipiscing elit. Suspendisse tincidunt viverra elit. Donec tempus vulputate mauris. Donec arcu. Vestibulum condimentum porta justo. Curabitur ornare tincidunt lacus. Curabitur ac massa vel ante tincidunt placerat. Cras vehicula semper elit. Curabitur gravida, est a elementum suscipit, est eros ullamcorper quam, sed cursus velit velit tempor neque. Duis tempor condimentum ante.

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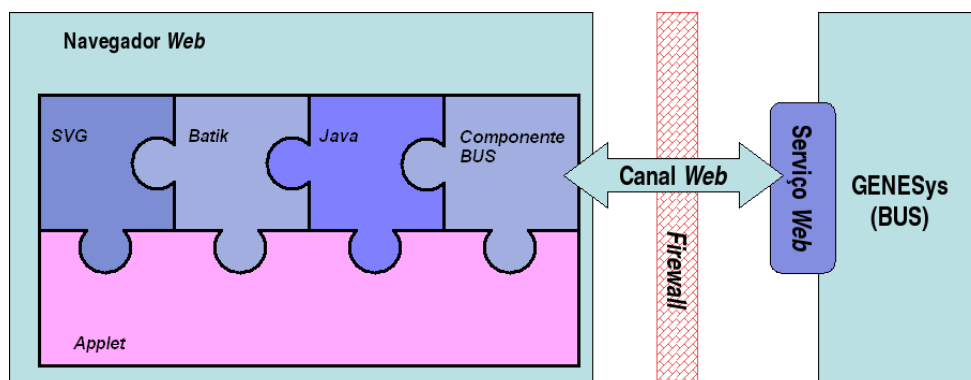[1]Na introdução a apresentação do problema foi breve.

Figure 3.1: Arquitectura da Solução Proposta

est. Sed lectus lorem, congue vel, dignissim laoreet, blandit a, nisi. Aenean nunc ligula, tincidunt eu, hendrerit vel, suscipit non, erat. Aliquam gravida. Integer non pede. In laoreet augue id leo. Mauris placerat.

A arquitetura do visualizador assenta sobre os seguintes conceitos base [?]:

- **Componentes** — Suspendisse auctor mattis augue *push*;

- **Praesent** — Sit amet sem maecenas eleifend facilisis leo;

- **Pellentesque** — Habitant morbi tristique senectus et netus.

3.1.1 Exemplo de Figura

É apresentado na Figura 3.1 um exemplo de figura flutuante.

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3.1.2 Exemplo de Tabela

É apresentado na Tabela 3.1 um exemplo de tabela flutuante e na Tabela 3.2 um exemplo de tabela flutuante, um pouco mais complicada.

Integer quis pede. Fusce nibh. Fusce nec erat vel mi condimentum convallis. Sed at tortor non mauris pretium aliquet. In in lacus in dolor molestie dapibus. Suspendisse potenti. Pellentesque

Table 3.1: Uma Tabela Simples

Acrónimo	Significado
ADT	*Abstract Data Type*
ANDF	*Architecture-Neutral Distribution Format*
API	*Application Programming Interface*

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Table 3.2: Uma Tabela Mais Complicada

		Iteração k de $f(x_n)$		
k	x_1^k	x_2^k	x_3^k	comentários
0	-0.3	0.6	0.7	-
1	0.47102965	0.04883157	-0.53345964	$\delta < \varepsilon$
2	0.49988691	0.00228830	-0.52246185	$\delta < \varepsilon$
3	0.49999976	0.00005380	-0.523656	N
4	0.5	0.00000307	-0.52359743	
$\vdots$	$\vdots$	$\ddots$	$\vdots$	
7	0.5	0.0	**-0.52359878**	$\delta < 10^{-8}$

placerat fermentum, augue nisl ultricies eros, id fringilla enim sapien eu felis. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Sed dolor mi, porttitor quis, condimentum sed luctus.

3.2 Secção Exemplo

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3.3 Resumo e Conclusões

Resumir e apresentar as conclusões que se podem tirar no fim deste capítulo.

Chapter 4

Implementação

Este capítulo pode ser dedicado à apresentação de detalhes de nível mais baixo relacionados com o enquadramento e implementação das soluções preconizadas no capítulo anterior. Note-se no entanto que detalhes desnecessários à compreensão do trabalho devem ser remetidos para anexos.

Dependendo do volume, a avaliação do trabalho pode ser incluída neste capítulo ou pode constituir um capítulo separado.

4.1 Secção Exemplo

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4.2 Mais uma Secção

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```
1   map(String key, String value):
2   // key: document name
3   // value: document contents
4   for each word w in value:
5   EmitIntermediate(w, "1");
6
7   reduce(String key, Iterator values):
8   // key: a word
9   // values: a list of counts
10  int result = 0;
11  for each v in values:
12  result += ParseInt(v);
13
14  Emit(AsString(result))
```

Listing 4.1: Example map and reduce functions for word counting

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4.3 Resumo ou Conclusões

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Chapter 5

Conclusões e Trabalho Futuro

Deve ser apresentado um resumo do trabalho realizado e apreciada a satisfação dos objetivos do trabalho, uma lista de contribuições principais do trabalho e as direções para trabalho futuro.

A escrita deste capítulo deve ser orientada para a total compreensão do trabalho, tendo em atenção que, depois de ler o Resumo e a Introdução, a maioria dos leitores passará à leitura deste capítulo de conclusões e recomendações para trabalho futuro.

5.1 Satisfação dos Objetivos

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5.2   Trabalho Futuro

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Appendix A

Loren Ipsum

Depois das conclusões e antes das referências bibliográficas, apresenta-se neste anexo numerado o texto usado para preencher a dissertação.

A.1 O que é o *Loren Ipsum*?

Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s, when an unknown printer took a galley of type and scrambled it to make a type specimen book. It has survived not only five centuries, but also the leap into electronic typesetting, remaining essentially unchanged. It was popularised in the 1960s with the release of Letraset sheets containing Lorem Ipsum passages, and more recently with desktop publishing software like Aldus PageMaker including versions of Lorem Ipsum [**?**].

A.2 De onde Vem o Loren?

Contrary to popular belief, Lorem Ipsum is not simply random text. It has roots in a piece of classical Latin literature from 45 BC, making it over 2000 years old. Richard McClintock, a Latin professor at Hampden-Sydney College in Virginia, looked up one of the more obscure Latin words, consectetur, from a Lorem Ipsum passage, and going through the cites of the word in classical literature, discovered the undoubtable source. Lorem Ipsum comes from sections 1.10.32 and 1.10.33 of "de Finibus Bonorum et Malorum" (The Extremes of Good and Evil) by Cicero, written in 45 BC. This book is a treatise on the theory of ethics, very popular during the Renaissance. The first line of Lorem Ipsum, "Lorem ipsum dolor sit amet. . . ", comes from a line in section 1.10.32.

The standard chunk of Lorem Ipsum used since the 1500s is reproduced below for those interested. Sections 1.10.32 and 1.10.33 from "de Finibus Bonorum et Malorum" by Cicero are also reproduced in their exact original form, accompanied by English versions from the 1914 translation by H. Rackham.

A.3 Porque se usa o Loren?

It is a long established fact that a reader will be distracted by the readable content of a page when looking at its layout. The point of using Lorem Ipsum is that it has a more-or-less normal distribution of letters, as opposed to using "Content here, content here", making it look like readable English. Many desktop publishing packages and web page editors now use Lorem Ipsum as their default model text, and a search for "lorem ipsum" will uncover many web sites still in their infancy. Various versions have evolved over the years, sometimes by accident, sometimes on purpose (injected humour and the like).

A.4 Onde se Podem Encontrar Exemplos?

There are many variations of passages of Lorem Ipsum available, but the majority have suffered alteration in some form, by injected humour, or randomised words which don't look even slightly believable. If you are going to use a passage of Lorem Ipsum, you need to be sure there isn't anything embarrassing hidden in the middle of text. All the Lorem Ipsum generators on the Internet tend to repeat predefined chunks as necessary, making this the first true generator on the Internet. It uses a dictionary of over 200 Latin words, combined with a handful of model sentence structures, to generate Lorem Ipsum which looks reasonable. The generated Lorem Ipsum is therefore always free from repetition, injected humour, or non-characteristic words etc.