

POLITECNICO DI MILANO
Master of Science in Computer Science and Engineering
Dipartimento di Elettronica, Informazione e Bioingegneria



[Title of the Thesis]

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Co-supervisor: [Name]

M.Sc. Thesis by:
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Academic Year 200N-200N+1

About this template

With this template I want to give you some input on how to structure your thesis if you develop your thesis with me in Politecnico di Milano. Next to the pure structure, which you should reuse and adapt to your own needs, the document also contains instructions on how to approach the different sections, the writing and, sometimes, even the work on your thesis project itself. Sometimes you will also find boxes like this one. These are meant to provide you with explanations and insights or hints that go beyond the mere structure of a thesis.

I hope this template will help you do the best thesis ever, if not in the World, at least in your life.

Florian Daniel
October 12, 2017

Disclaimer: Sometimes I may make statements that are general, if not over-generalized, personal considerations, or give hints on how to do work or research. Be aware that these are just my own opinions and by no way represent official statements by Politecnico di Milano or its community of professors. If something goes wrong with your thesis or presentation, you cannot refer to these statements as a defense. You are the final responsible of what goes into your thesis and what not.

Acknowledgements: The original template for this document was not created by me. I would love to acknowledge the real creator, but I actually do not know who it is. The template has been passed on to me by a former student, who also didn't know the exact origin of it. It was circulating among students. However, to the best of my knowledge at the time of writing, it seems that Marco D. Santambrogio and Matto Matteucci may have contributed at some point with considerations on structure and funny citations. Both were helpful and enjoyable when preparing this version of the template. I will be glad to add more precise acknowledgements if properly informed about the origins of this template.

Supervisors and co-supervisors

If the supervisor is internal to Politecnico di Milano (a professor or researcher), then on the first page use "Supervisor" plus the titles "Prof." and "Dr." for professors and researches, respectively. If the work was co-supervised by someone else, refer to him/her as the "Co-supervisor." If the work was supervised by someone external to Politecnico di Milano, use "External supervisor" for the external supervisor plus "Internal supervisor" for the internal supervisor that mandatorily must co-supervise the work with the external supervisor.

Optionally, here goes the dedication.

Abstract

The abstract is a small summary of the thesis. It tells the reader in few words (up to one/one and a half page of total text) everything he/she needs to understand:

- ☐ the *context* of the work (e.g., chatbots),
- ☐ the specific *problem* approached by the thesis (e.g., the development of personal bots by non-programmers),
- ☐ if applicable, clearly state the *research questions* you would like to answer (e.g., “is it possible to enable non-programmers to do X using A?”),
- ☐ the three/four *core aspects of the proposed solution* (e.g., use pre-defined rules, use machine learning, assisted development, etc.),
- ☐ the *concrete outputs* produced by the thesis (e.g., a state of the art analysis, a conceptual/mathematical model, an application, middleware or API, an empirical study with/without users, etc.), and
- ☐ the *findings and conclusions* that one can draw from the evaluation of the approach (e.g., that under some very specific conditions non-programmers are indeed able to implement own chatbots effectively using the proposed technique).

Checklists

Now and there I propose checklists with items, such as the one just above this box. They are meant for you to check if you included all the content that is relevant and that should be included, in order to make your text complete. When reading your thesis, I will look for all these items.

Writing style

This is a M.Sc. thesis. It's neither Facebook nor Twitter nor an email. This is going to be an official document with legal value that will decide on the final mark of your yearlong university career and perhaps even on your future work perspectives. So, you surely don't want to be judged badly because of grammar errors, flawed/wrong vocabulary or superficial layout and/or text structure. It is a must that what you write is always *correct* content- and language-wise (no false statements or claims, no language mistakes), *readable* (no sentences that cannot be understood) and targeted at the *average-skilled reader* (professors, but also your own colleagues).

Plagiarism

This is a M.Sc. thesis. It's neither Facebook nor Twitter nor an email. This is going to be an official document with legal value that will decide on the final mark of your yearlong university career and perhaps even on your future work perspectives – yes, I plagiarized myself here a little bit. So, you surely don't want to copy/paste material from scientific articles, online resources, books, and similar without adequately acknowledging the holders of the respective intellectual property rights. If you do so, it is a must that you properly *cite* each source where you take text or inspiration from. It is fine to do so – actually, citing someone is a compliment! – but it becomes a crime if the source is not cited. Not only M.Sc. titles but also Ph.D. titles have been withdrawn for fraudulent “reuse” of others' intellectual property. Be aware that Politecnico di Milano, like most higher educational institutions that issue university degrees or scientific publishers, may use specialized software to automatically detect plagiarism.

Sommario

Here goes the translation into Italian of the abstract. If the thesis is written in Italian, no translation into English is needed. Hence, one of the following must be checked:

- ☐ Thesis written in *English*, properly proofread translation needed
- ☐ Thesis written in *Italian*, no translation needed, chapter omitted

Acknowledgements

If you would like to thank somebody for given support, this is the right place to do so.

Contents

Abstract	I
Sommario	III
Acknowledgements	V
1 Introduction	1
1.1 Context: [topic]	1
1.2 Scenario and Problem Statement	3
1.3 Methodology	4
1.4 Contributions	5
1.5 Structure of Thesis	7
2 State of the Art	9
2.1 [Topic one]	9
2.2 [Topic two]	10
2.3 Summary	10
3 Data Collection	11
3.1 Tools	11
3.1.1 Tweepy	11
3.1.2 Botometer	12
3.1.3 Hoaxy	12
3.2 Datasets	12
3.2.1 Caverlee-2011	12
3.2.2 Cresci-2017	12
3.2.3 Varol-2017	13
3.2.4 BotBlock	14
3.3 Varol clustering	14
3.4 Collection	18
3.4.1 NSFW	19

3.4.2	News-spreader	19
3.4.3	Spam-bots	21
3.4.4	Fake-followers	22
3.4.5	Genuine	22
3.5	Data visualization	23
4	Features Engineering	29
4.1	Baseline	29
4.2	Missing values filling	31
4.3	Descriptive features	31
4.4	Intrinsic features	32
4.5	Extrinsic features	33
5	[Solution aspect one]	37
6	[Solution aspect two]	39
7	Implementation and Evaluation	41
7.1	Implementation	42
7.2	Evaluation	42
7.2.1	Design of Evaluation	42
7.2.2	Metrics	43
7.2.3	Results	44
7.2.4	Discussion	44
8	Conclusion and Future Work	45
8.1	Summary and Lessons Learned	45
8.2	Outputs and Contributions	45
8.3	Limitations	46
8.4	Future Work	47
	References	49
A	User Manual	51
B	Dataset	53

Chapter 1

Introduction

The introduction is one of the core chapters of your thesis. It expands what has already been said in the abstract with additional details on the content and contribution and on the structure of the thesis. It is meant to introduce the reader to the work he/she will be reading in the rest of the document and, most importantly, to get the reader curious about reading on, knowing more about your work.

1.1 Context: [topic]

This thesis is about describing the work you are doing in your final thesis project. You have been working on it for months, and nobody knows the work better than you do. This is great and exactly how things should be: by doing your thesis project you became an expert – if not *the* expert – in this specific field of research and/or technology.

But attention: being the expert is also dangerous when it comes to explaining others what you did and why you think you did a great work that deserves attention (I give it for granted that your work does so). There are only very few people around you (your supervisor and possible co-supervisor, some friends, maybe someone else) who are as expert as you are in this topic. So, if you start in a full-impact fashion to tell that you implemented an extraordinarily cool, new algorithm to solve X, or that you discovered this extremely surprising finding Y, or that you mathematically proofed that Z, etc. (you got it), your reader will not understand anything. Therefore, before talking about what you actually did, you need to introduce the reader to the context of your work, provide the necessary core definitions that are needed to understand the terminology you will be using in the rest of the thesis (if it's not standard IT terminology).

Therefore:

- ☐ Tell the *research area(s)* your work/project focuses on. If you are doing your thesis with me, likely candidates of research areas are Web Engineering, Data Science, Crowdsourcing, Service-Oriented Computing, Business Process Management.
- ☐ Tell possible *sub-areas* that are more specifically related to what you are doing. Again, if you are doing your thesis with me, likely candidates of sub-areas are chatbots, social knowledge extraction, business process matching/modeling, quality control in crowdsourcing, etc.
- ☐ Make the *heading* of your context section self-explaining by substituting “[topic]” in heading 1.1 with the sub-area most relevant to your work. It should read like “Context: quality control in crowdsourcing” or similar.
- ☐ If needed, introduce some *key definitions* (no need to introduce everything here, but be sure that the introduction does not use terminology the reader may not be familiar with). For instance, if you are working on chatbots, this is definitely a term that needs to be introduced here; it’s not yet commonly known but it’s crucial for the understanding of the rest of the thesis and introduction.
- ☐ Use *examples* to make definitions and ideas concrete and clear.
- ☐ Throughout, make *references* to the relevant literature.

Use of tenses and pronouns

Writing a thesis is writing a scientific document like scientific articles or research publications. There are two conventions that are usually applied in this kind of publications (admittedly, they may seem somewhat odd if not used to):

First, the most used tense is the *simple present*. The thesis is meant to describe a piece of work, from problem statement, to the conception of a solution, its implementation and evaluation. Yet, it’s not a novel about your life, and it’s not meant to provide a chronological story about what you did and didn’t do. Content is presented in an order that is most effective to convey its message, not in time order. In this spirit, it’s much more effective to say “in order to get result A, first we do X, then we do Y and then Z,” instead of saying “in order to get result A, we did Y after having done X, then we went on doing Z.” The order of actions, their interconnections, inputs and outputs already tell the dependency – if properly described. Most of the times, the most effective way to describe a solution or

methodology only becomes clear after trial and error. It's enough to explain the result, not how you got there chronologically.

Second, the *pronoun* used to talk about the own work is "our" (work). That is, it is custom to say "we" instead of "I," even if you are writing your thesis alone. However, don't forget about all the people that helped you get there: your supervisor, co-supervisor, colleagues, etc. This may sound strange at the beginning, but, at the other hand, using "I" too often risks to convey the impression that you are self-focused and egoistic, which is never good.

1.2 Scenario and Problem Statement

Now that the reader got the general context of your work and has an intuition of the problem you will be solving in the rest of the thesis, it's time to be clear about which *specific problems* your thesis project is going to solve. One way of doing so is by describing a *scenario* (a description of a real situation, with all its actors, roles, tasks, instruments, etc.) that provides evidence that there are one or more real problems right now that, with the current technology and understanding of the domain, are hard to solve or not solvable at all. If instead the problem(s) can be solved already, it should be evident from the scenario that this is possible only at a prohibiting cost or with unsatisfying guarantees on the quality of the result or not within useful time for the target user.

It's important that the scenario is written in such a way that the reader, after reading it, agrees with you that the problem you are focusing on is a relevant one, one that deserves being studied and solved. Consider that if you convince the reader here that your thesis is needed (after all, that's what this section is about), he/she will be very open to possible solutions and happy to see how you solve it. If instead you fail to convince the reader – let me be harsh – the whole rest of your thesis is useless in the eyes of the reader. This is the worst outcome you want.

Conclude this section by explicitly stating which of the problems evident in the scenario you are approaching. Don't raise false expectations! Never ever tell the reader there are five core problems and then solve only two of them in the thesis, without telling upfront that this is what you intended to do in the first place. As soon as you list problems, the reader wants to see a solution, unless you stop him/her immediately from thinking so by telling that out of the described problems you focus on a subset only, usually because this subset is already a huge research and development problem in its own.

In summary:

- ☐ Describe a *real scenario* that provides evidence of *real problems*.
- ☐ Convince the *reader* that the problems need to be solved.
- ☐ Use an *illustration* or *figure* to help the reader understand.
- ☐ If possible, provide *references* to literature that backs your assessment of the problem.
- ☐ Provide a clear *problem statement* that summarizes what came out of the scenario and your specific focus.

1.3 Methodology

Fixed the problem(s) you want to approach, you can approach it/them in thousands of different ways. Your way is just one of the thousands, and the reader may have (and very likely will have) a very different intuition of how to solve the problem(s) you just pointed out. So, clarify how you intend to proceed:

- ☐ Tell if you follow an existing *methodology* or not; if yes, name it and provide a reference to literature, if available. For example, Design Science [?] is a likely methodology to cite here.
- ☐ Tell which of the following *procedures, techniques, methods* you use in your work and for which purpose (put them also into the right order, so that their application or use makes immediate sense to the reader):
 - ☐ *Systematic literature review, survey*
 - ☐ *Statistical hypothesis formulation and testing*
 - ☐ *Software prototyping*
 - ☐ *Iterative development*
 - ☐ *Participatory design*
 - ☐ *Performance evaluation*
 - ☐ *Comparative studies*
 - ☐ *User studies*
 - ☐ *Expert interviews*
 - ☐ *Simulation/emulation*

- ☐ *Live experiments*
 - ☐ *Case studies*
 - ☐ *Mathematical theorem proving*
 - ☐ *Mathematical modeling*
 - ☐ *Pseudocode*
 - ☐ *Graphical modeling* (e.g., UML, ER)
 - ☐ *Model-driven development*
 - ☐ *Automatic code generation*
 - ☐ ...
- ☐ Tell if you use some special *software instruments* that help you in your work. We are of course not talking about Word or Google Search. Perhaps you can tell that you used R for data analysis or some specific modeling instrument for automated code generation or simulation.

1.4 Contributions

Now that the reader knows what you want to solve and how you intend to proceed, you can anticipate the contributions your thesis makes to the state of the art. Attention, a thesis project may produce lots of different *outputs* (e.g., a software prototype, a set of registrations and transcripts of interviews, datasets collected during experiments) and *contributions* (e.g., a demonstration that some software solutions solves a given problem under well defined conditions, a formal proof that some property holds, empirical evidence that something works as expected). The former are all the artifacts produced throughout the work. The latter refer to *new knowledge* (if you are doing a full thesis) or the most important, *final output* (if you are doing a tesina). Sometimes, outputs and contributions overlap, but not necessarily.

Typical contributions are (multiple choices may apply to your thesis):

- ☐ A *systematic literature review* of the state of the art providing evidence for some argument
- ☐ The design of a *model* (mathematical, graphical, algebraic, etc.) describing how to solve a real world problem in a reusable fashion
- ☐ The drawing of *conclusions* (findings) from the analysis of a dataset describing some physical or virtual phenomenon

- ☐ The implementation of a *software prototype* solving a real world application problem
- ☐ The design of a *language* (textual, graphical) enabling others to solve own problems or to solve them easier
- ☐ *Formal proofs* of correctness, completeness or other properties of the proposed models or theorems
- ☐ *Objective evidence* from empirical studies (e.g., performance analyses or simulations) that demonstrate that the proposed prototype or solution works / works better than existing software or solutions that solve the same/similar problem(s)
- ☐ *Subjective evidence* from user studies or expert interviews backing the claims of viability of the proposed problem or solution/artifact
- ☐ A reasoned *argumentation*, e.g., based on a detailed case study, supporting the viability of the proposed problem or solution/artifact

Thesis vs. Tesina

Let me spend some words on the difference between these two. Before that, however, it is important to clarify the very purpose of your final project, be it a thesis or a tesina (a small thesis). The purpose of it is giving you the possibility to show that, after years of attending classes and giving exams, you are also able to *apply* the knowledge you acquired during your studies. In short, it's all about you showing that you are *mature*. Mature from a knowledge perspective, mature from an application perspective, mature from a work/teamwork perspective, mature from an ethical perspective.

It is common that a thesis project is not very well defined in its beginning and that even the supervisor does not really know how to approach a given problem or which problem to focus on in the first place. This may even be annoying to you, but attention: there is no intention behind it. Your supervisor is not withholding information from you to test you or to see if you get something. It's just the nature of real *problem solving*. If things were clear from the beginning, there wouldn't be any problem! Fledging out the problem and agreeing on a solution and methodology is a core part of you demonstrating your maturity – if not the most important one. *How* you proceed from the inception of the thesis idea to the final solution is as important as *what* you find and/or produce in the end.

This being said, a *thesis* in Politecnico di Milano usually requires you to make a contribution to the literature (the so-called state of the art). Making a contribution – from a science point of view – means creating new *knowledge*, that is, finding something that nobody knew before, demonstrating a property that nobody showed

before, improving the performance of a given system with a new algorithm, and similar. For a thesis, it is therefore not enough to produce a perfectly engineered solution. It is key that you also demonstrate, provide empirical evidence or proof that your solutions performs as claimed. Well, for a *tesina* this last demonstration is usually not required, and the focus is on the engineering of the solution. In addition, perhaps in the case of the *tesina* the solution to be engineered is also less complex then for a thesis, but this depends on the context and on how you want to measure complexity.

1.5 Structure of Thesis

Here you explain the structure of the thesis, so that the reader knows how to read it. Consider that not every reader wants to read through the whole thesis to find some specific information. Actually, only few will do so (your supervisor and co-supervisor, and the possible reviewer for sure). Many more will just leaf through it and look for specific types of information (e.g., the context of your work, your findings, how you implemented something, which technologies you used). It is your duty to accommodate them all. How? By telling them how your thesis is structured.

Therefore, in this section you provide a brief description (2-3 sentences) for *each* chapter that follows this introduction. Use an itemized or numbered list to structure the text, like this:

- ☐ Chapter 2 introduces the state of the art and...
- ☐ Chapter 3 provides...
- ☐ ...

Structuring text

Besides telling the reader how the content of your thesis is organized into chapters, it is important that you master some basic text structuring techniques. To organize your text there are lots of instruments you can use: chapters, sections, sub-sections, paragraphs, itemized lists, numbered lists, code examples, figures, images, screen shots, captions below figures, tables, and so on. Use them all! Don't write text without structure. Never.

Be aware that the structure of your text, that is, how you present your work, conveys a lot of information about how well you actually understand what you are writing about, how much you care about being clear and helping your reader understand, and how much value you give yourself to your own thesis. A well

structured presentation of content that the reader can understand and agree with is a huge plus in this respect. Text that lacks proper paragraphs, does not use lists where needed, etc. is a minus and also much harder to read (think about how much a well structured text can help you go back ten pages and find concepts you know you read about compared to a text that comes without an easy to memorize formatting and structure). When writing, think about some of your textbooks. Since you are doing an engineering degree, I'm sure these are textbooks that make exemplary use of the different formatting instruments available.

Chapter 2

State of the Art

This chapter discusses the state of the art that is relevant for your own work. What does that mean? It means that it provides the reader with all the relevant references he/she may need to know in order to understand better three things: (i) the context of your work, (ii) the problem and the need for a solution, and (iii) the value of your contribution. You achieve this by citing works or scientific papers that solved the same or similar problems in the past. Citing does not just mean adding a references to the bibliography and printing a number here; it means you tell the reader about the merits and possible demerits of each of the references you feel relevant. Of course, doing so requires you to first read each reference and, most importantly, to understand it. There should be lots of references in this chapter.

It is advisable that you structure the chapter into sections in function of the topics you treat. If you do so, before starting with the first section of the chapter, explain the reader how you structure your discussion in one paragraph.

- ☐ *Read* relevant literature and or *test* related software or tools.
- ☐ *Summarize* your reading.
- ☐ Provide correct *references* (the bibliography in the end of this document).

2.1 [Topic one]

...

2.2 [Topic two]

...

2.3 Summary

Close the state of the art chapter with some words that connect the discussion of the references to your thesis. Pay attention that the reader understands why you discussed the works/topics you discussed and how they are related to what you do.

- ☐ Show that in the state of the art the *problem* you want to solve has not yet been solved or not been solved in an as efficient / effective / easy to use / cost-saving fashion as you target with your work.
- ☐ If your work has similarities with some *specific references*, point them out here and explain why these are particularly important to you. Perhaps you started your investigation from the outputs of a specific paper or you want to improve the performance of an algorithm studied earlier; it's good to mention this here.
- ☐ Attention: this is not yet the place where to anticipate *your solution*. You may give hints, but it's too early to make a comparison between your work and the state of the art, as the reader does not yet know anything about your work. This discussion can go into the final chapter.

Chapter 3

Data Collection

In this chapter we will present all the available datasets containing bot accounts, with all the tools and methodologies used to collect new data. The final dataset contains:

ilRight Data from existing datasets

- ⇒ Data collected with different approaches
- ⇒ Hand-labeled data

3.1 Tools

Different tools were used in order to both collect the data and to enrich existing ones. This stage was essential to gather additional features. Here we present all the instruments involved in this section.

3.1.1 Tweepy

Tweepy is a python wrapper for the Twitter API. Two main methods were used to collect all the default features of users and tweets:

Method	Input	Output
API.get_user	[id/user_id/screen_name]	User object
API.user_timeline	[user_id][, count]	list of Status object

A User object contains all the features that describe the user's profile and his utilization of Twitter. A Status object contains the details of a single tweet, such as the full text, number of retweets and replies.

3.1.2 Botometer

Botometer (<https://botometer.iuni.iu.edu>) checks the activity of a Twitter account and gives it a score based on how likely the account is to be a bot. Using their dataset they tested most classification algorithm and highlighted Random Forest as their final classifier, since it gained the highest accuracy. Its accuracy was 98.42% and 0.984 F1 measure[2]. Botometer provides API to check Twitter accounts genuinity.

3.1.3 Hoaxy

Hoaxy is a tool that visualizes the spread of articles online. Articles can be found on Twitter, or in a corpus of claims and related fact checking. Hoaxy only checks the news sources and compares them with a list of unreliable URLs.

3.2 Datasets

3.2.1 Caverlee-2011

This dataset is composed by content polluters, detected by a social honeypot, and legitimate users sampled from Twitter. For each content polluter, they save their 200 most recent tweets, their following and follower graph, and the temporal and historical profile informations. In order to collect genuine users, they randomly sampled about 20.000 Twitter ids and monitored them for three months, to see if they were still active and not suspended by the social platform moderation service.[2].

3.2.2 Cresci-2017

Cresci Dataset is composed by genuine accounts and bots. In this dataset there is a deeper differentiation for the bots, which are precisely labeled according to different categories.

Dataset	Description	#Users	#Tweets	Year
genuine accounts	verified accounts that are human-operated	3,474	8,377,522	2011
social spambots #1	retweeters of an Italian political candidate	991	1,610,176	2012
social spambots #2	spammers of paid apps for mobile devices	3,457	428,542	2014
social spambots #3	spammers of products on sale at Amazon	464	1,418,626	2011
traditional spambots #1	training set of spammers used by Yang[1]	1,000	145,094	2009
traditional spambots #2	spammers of scam URLs	100	74,957	2014
traditional spambots #3	automated accounts spamming job offers	433	5,794,931	2013
traditional spambots #4	automated accounts spamming job offers	1,128	133,311	2009
fake followers	accounts inflating followers of other accounts	3,351	196,027	2012

- **Genuine accounts** are those users who correctly answered to a simple question, posed in natural language, so they represent accounts with no automatization.
- During Rome majoral election in 2014, one of the candidates used a set of automated accounts to publicize his policies. These accounts were gathered to be part of the **Social spambots #1**.
- **Social spambots #2** are accounts that promotes mobile app, using popular hashtags for months.
- **Social spambots #3** promotes products on sale on Amazon, by tweeting products URL and descriptions.

All these accounts were manually checked to verify their automated nature.

- The **Traditional spambots #1** dataset is the training set used in [1].
- **traditional spambots #2** are users that mention other users in tweets containing scam URLs. They usually invite users to claim a prize.
- **Traditional spambots #3** and **traditional spambots #4** are bots that continously tweet job offers.
- **Fake followers** are account involved in increasing popularity of other users. In order to collect them, they bought followers from fastfollowerz.com, intertwitter.com and twittertechnology.com. [5]

3.2.3 Varol-2017

This dataset contains a list of Twitter accounts, labeled as bots (1) or humans (0). The construction of the Varol dataset starts with the indentification of a representative sample of users, by monitoring a Twitter stream for 3 months, starting in October 2015. Thanks to this approach it is possible to collect data without bias; in fact other methods like snowball or breadth-first need an initial users set. During the observation window about 14 million user accounts has been gathered. All the collected users must have at least 200 tweets in total and 90 tweets during the three month observation (about one tweet per day).

Using the classifier trained on the honeypot dataset in [2], they computed

the classification scores for each of the active accounts. Then the samples were grouped by their score and 300 accounts from each bot-score decile were randomly selected. The 3000 extracted accounts were manually labeled by some volunteers. They analyzed users profile, friends, tweets, retweets and interactions with other users. Then they assigned a label to each user. Of course the final decision is conditioned to personal opinion[3].

3.2.4 BotBlock

Botblock (<https://github.com/dansarie/Botblock>) is a Twitter block list containing the user ids of a large number of known porn bot accounts. They are mainly used to aggressively market porn sites.

3.3 Varol clustering

At first try, we wanted to understand if different kinds of bots were easy to distinguish, using their profile features only. er, we didn't know what kinds of bots populate Twitter for the most. So, an unsupervised approach could have helped us to highlight different categories. We relied expectations on clustering techniques, hoping to get a solid help in automatizing the labeling process of the data. We used the Varol dataset[3], that contains a plain list of bots and humans. It was not possible to use all the data, because we needed to scrape from the web browser all the possible features. Some of the listed accounts were already been deleted, so, for this work, we had to consider only those accounts that were still active. The first step was the knee-elbow analysis based on a hierarchical clustering with single linkage and euclidean distance. The data must have been preprocessed and cleaned. Here we illustrate what kind of preprocess operations were performed for that purpose:

feature	type	preprocess operation
id	int	delete
name	str	replace with len(name)
screen_name	str	replace with len(screen_name)
statuses_count	int	/
followers_count	int	/
friends_count	int	/
favourites_count	int	/
listed_count	int	/
url	str	replace with hasUrl (0/1)
lang	str	one hot encoding
time_zone	str	one hot encoding
location	str	one hot encoding
default_profile	int	replace with hasDefaultProfile (0/1)
default_profile_image	boolean	boolean to int (0/1)
geo_enabled	boolean	boolean to int (0/1)
profile_image_url	str	delete
profile_use_background_image	boolean	boolean to int (0/1)
profile_background_image_url_https	str	delete
profile_text_color	str	delete
profile_image_url_https	str	delete
profile_sidebar_border_color	str	delete
profile_background_tile	boolean	boolean to int (0/1)
profile_sidebar_fill_color	str	delete
profile_background_image_url	str	delete
profile_background_color	str	delete
profile_link_color	str	delete
utc_offset	int	delete
is_translator	boolean	boolean to int (0/1)
follow_request_sent	int	delete
protected	boolean	boolean to int (0/1)
verified	boolean	boolean to int (0/1)
notifications	boolean	delete
description	str	replace with hasDescription (0/1)
contributors_enabled	boolean	boolean to int (0/1)
following	boolean	delete
created_at	str	string to int (year)

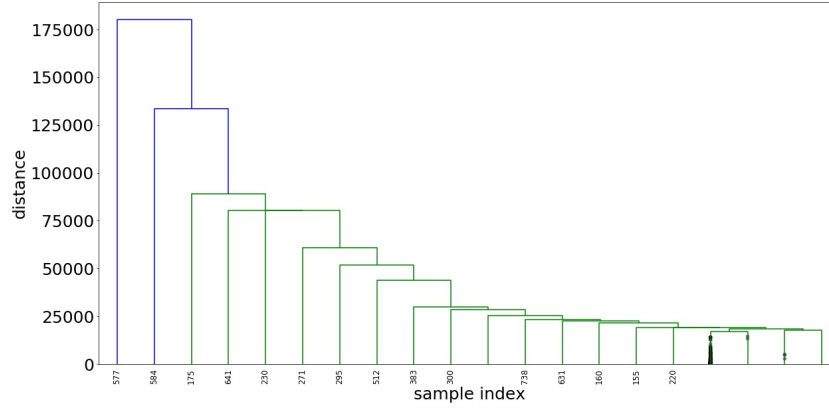


Figure 3.1: Hierarchical Clustering Dendrogram (truncated to the last 20 merged clusters)

Since we didn't know how many categories of bots were listed in this dataset, the first step consisted in understanding which was the optimal number of clusters to look for. To achieve that goal, we applied *hierarchical clustering*. In figure (3.1) you can see the dendrogram of the algorithm.

In order to select the optimal number of clusters, we plotted the knee-elbow figure (3.2). It shows the variation of WSS (within cluster sum of squares) and BSS (between cluster sum of squares) as the number of clusters increase.

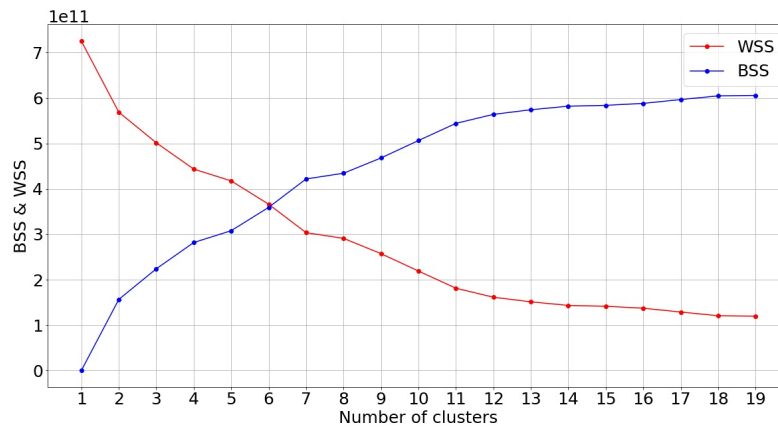


Figure 3.2: Hierarchical Clustering - knee-elbow

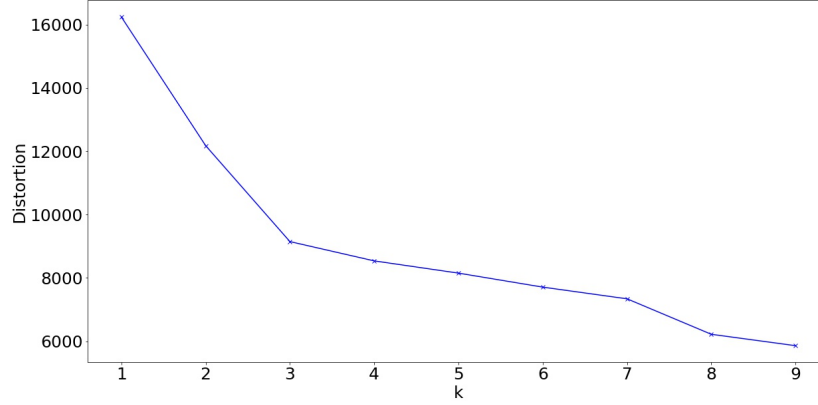


Figure 3.3: The Elbow Method showing the optimal k

It is clear that there are no well-defined elbows or knees, both curves seems to be "smooth", so it were hard to pick a reasonable k (number of clusters) for the algorithms to come.

Then we tried another approach. We applied the *K-means* algorithm and we plotted the elbow method (3.3). In this figure there is an elbow between $k=3$ and $k=4$, so the most accurate solution were represented by four clusters.

As this process came to an end, we manually inspected the resulting clusters.

cluster	size
cluster 1	82
cluster 2	648
cluster 3	2
cluster 4	16

Cluster 2 contains most of the samples, while the others have fewer elements. We observed the Twitter profile of all the elements belonging to cluster 1, 3, 4 and a small sample of profiles for cluster 2.

Unfortunately there was no correlation among accounts in the same cluster, so this technique didn't seem to fit the speeding up of the labeling process, nor to create useful features for a classifier.

3.4 Collection

The clustering approach did not help us, but the manual inspection of the clusters allowed us to get in touch with some existing bots, making us understand which categories of bots are most common on the social network. In particular we detected 4 main classes:

- ⇒ NSFW bots
- ⇒ News-spreader
- ⇒ Spambots
- ⇒ Fake-followers

We started with a hand-labeling of the Varol dataset [3]. For each account we analyzed its profile and tweets and we assigned it a label according to the categories we identified. We have faced some unexpected behaviors among bot accounts, that didn't fit the above-mentioned categories. In these cases, they were temporarily signed as "general purpose". We also found genuine users, who we thought that had been incorrectly added to the dataset. This task culminated with the collection of the following bots:

category	labeled account
NSFW	31
news-spreader	71
spambots	418
fake-followers	5
general purpose	63
genuine	104

"General purpose" accounts are sometimes bots with no goal, they aim to emulate human behavior and often they were recognizable just because their description informs other users about their own nature. Sixtythree users were not enough to represent a class and it was not possible to find a large list of those accounts who act like them, so we added all these ids to the "genuine" group. Even if this choice brought some noise to our data, that allowed us to provide our data more heterogeneity. "NSFW" accounts are only thirtyone elements, anyway the problem of pornography is a known issue on Twitter. In [3] they clusterize users too. "These bot clusters exhibit some prominent properties: cluster C0, for example, consists of legit-looking

accounts that are promoting themselves (recruiters, porn actresses, etc.)” [3]. This kind of users are often banned by Twitter, so it is likely that the accounts that we were not able to scrape, used to belong to this category. Therefore we firmly believed that obtaining further accounts of this class was fundamental. Finally it is clear that even fake-followers were few, since they were not considered in the Varol research, but they are important in [5], so we decided to expand this category too.

All these samples were not enough to train a classifier, hence we needed to collect more data. We perform this task by focusing on one category at a time.

3.4.1 NSFW

Not safe for work is a tag used on internet to mark all that URLs, web pages, e-mails that contain nudity, intense sexuality, profanity or violence. In particular we wanted to collect a specific sub-category: the pornbots. In order to collect them, we used the BotBlock dataset. BotBlock contains thousands of pornbot ids. We wanted to gather about 6000 samples, an amount that would have been enough for the final dataset, with regards to its balance. Since they were sorted according to their creation date, we shuffled the whole list. Then, using the Twitter API, we looked for accounts that weren’t deleted yet. We needed to scrape profile features and tweets, so we couldn’t consider banned accounts. The user list was initially shuffled to allow us to collect users with different ages. This emerged as a very useful setup, because we gathered both more long-lived accounts and more extreme accounts (which probably have shorter lives). We finally obtained 6903 users.

3.4.2 News-spreader

Many bots on Twitter are news-spreader. The goal of these users is to spread politics, sports or actuality news. Often their behavior is not harmful, they just retweet statuses from newspapers accounts. However, there are users created to diffuse fake news. In the last few years Twitter has been used to boost politics propaganda. During elections or political campaigns, ad hoc accounts are created to divulgate specific political idea. As a recent study highlighted, about the 80% of these ”pre-elections bots” are still alive [4]. We think that part of our news-spreader dataset includes some of those accounts.

We started gathering these ids by exploring Hoaxy. We used two different approaches. The first way (in figure 3.4) consisted in collecting the twenty

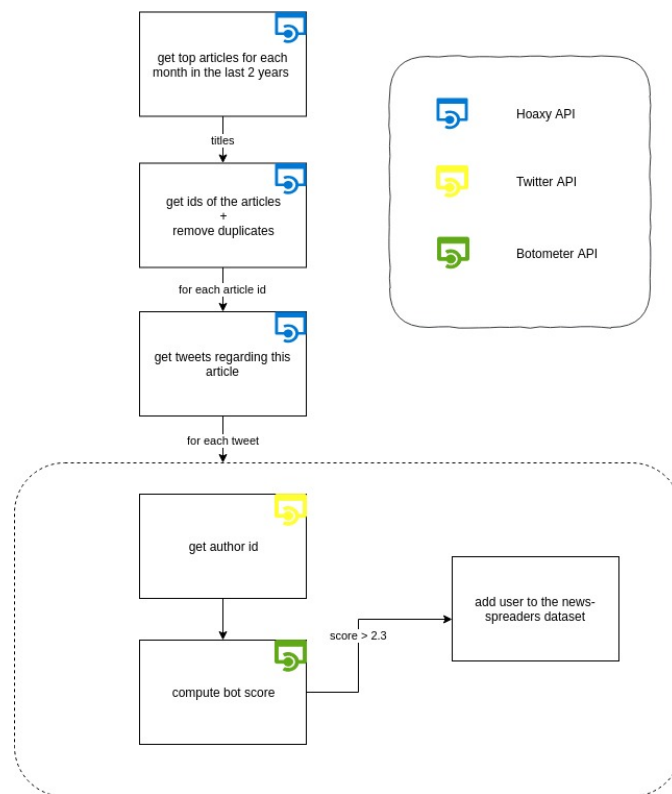


Figure 3.4: Collection of news-spreading bots, approach 1

top popular fake news, for each month, in the last two years. We performed this task using the Hoaxy APIs. Thanks to this service, we obtained all the tweet ids that have spread the considered claim. With the official Twitter APIs we collected all the users involved in this spreading activity. We finally passed all these accounts to the Botometer API, since many of the retrieved users were humans.

We set a threshold, in order to classify a user as a bot. That threshold is 2.3 due to the willing of including some false positives in our data, increasing the heterogeneity in their behaviors and the challenge level for the classifiers. We think that a high intra-homogeneity among classes could lead the models to perform well on the training data, but worse over unseen ones. The second approach just consisted in collecting the most popular news-spreaders according to Hoaxy. In consistency with the mentioned threshold, profiles with a Botometer score lower then 2.3 were still discarded. Finally we checked every profile added to this dataset and removed all that users who didn't tweet enough statuses to be included in this class. This hand-made analysis made us know that there are no bots who only spread fake-news. Usually they tweet a lot of verified news and some fake ones, to keep their credibility. We reached 3590 accounts.

3.4.3 Spam-bots

As seen before, spambots were already collected in [5]. Authors allowed us to access to their dataset, so we obtained the spambots list by sampling their data. Due to homogeneity reasons, we needed to perform scraping again, since we needed different features compared to the available ones. We selected users from:

- ⇒ traditional spambots 1
- ⇒ social spambots 2
- ⇒ social spambots 3

We chose this categories because they contain the most popular kinds of spambots, that are the ones who advertise products, services or mobile applications. We ignored "social spambots 1", since they are italian news-spreaders and "traditional spambots 3 and 4", since we retrieved enough job-offer spammers during the hand-made labeling. If we had stored too many bots of this category, we would not have been able to generalize on generic spambots. Finally we gathered 4943 accounts.



Figure 3.5: Collection of fake-followers bots

3.4.4 Fake-followers

The collection of this class was quite easy. We initially performed scraping of the data collected by the Cresci research [5]. Many of these accounts had already been banned, so we could not collect their features. In order to enrich our dataset, we created a new Twitter account (figure 3.5). Then we bought fake followers from two different services:

- 🔗 instakipci.com/
- 🔗 rantic.com/buy-legit-twitter-followers/

Instakipci provides low-quality followers. Usually they have no tweets, no followers and a they have a lot of followings. Rantic, on the other hand, ensures more realistic followers. They seem to have a real network of friends and, sometimes, they tweet too. By using both services, we gathered a more miscellaneous dataset. We collected 6307 users.

3.4.5 Genuine

Finally we needed genuine accounts. We used again the Cresci dataset [5] and we filled it with all the Varol users labeled as humans. We again performed scraping on the existing accounts and we collected 3661 users in total.

3.5 Data visualization

As the collection of the data was completed, we explored our final dataset. A first look (3.6) shows us how many user accounts we collected (y axis) for each class and how many tweets we could scrape (diameter). It is easy to observe that fake-followers and nsfw bots have less tweets than the others, while news-spreaders have a lot of tweets, but we collected less profiles.

category	target id
NSFW	0
news-spreader	1
spambots	2
fake-followers	3
general purpose	4

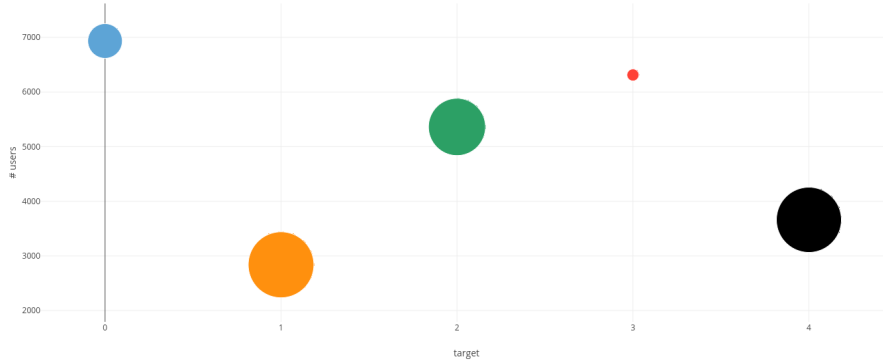


Figure 3.6: users amount and tweets

Then we plotted the heatmap of the correlation matrix (3.7). We wanted to understand if some feature was more useful to predict the correct target. This plot suggested us that there were no feature highly correlated to the target.

Moreover in figure (3.8) it is possible to see the distribution of the missing values. This is fundamental for the features engineering step.

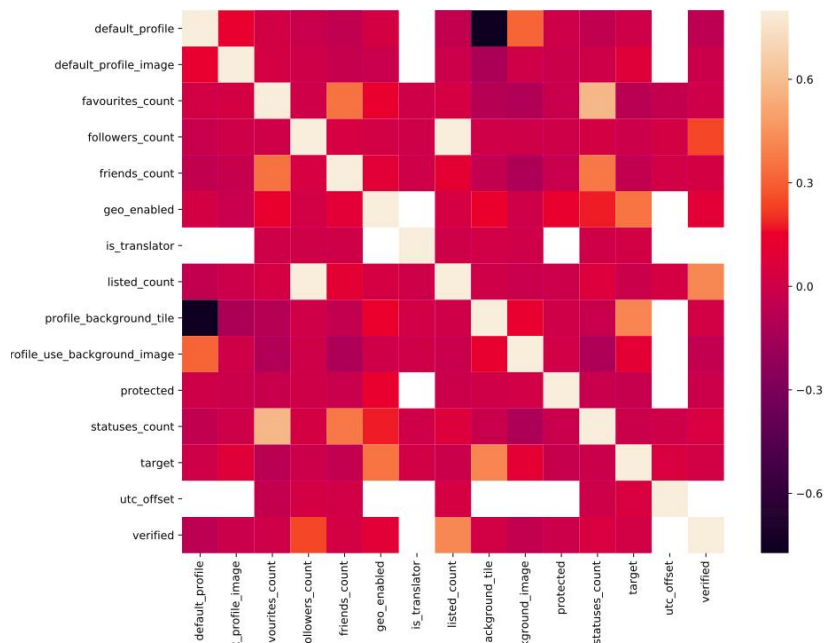


Figure 3.7: heatmap

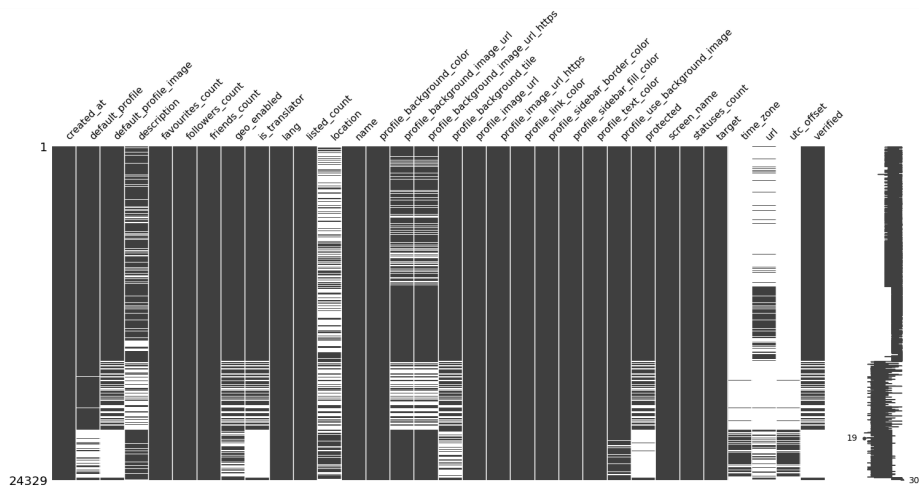


Figure 3.8: heatmap

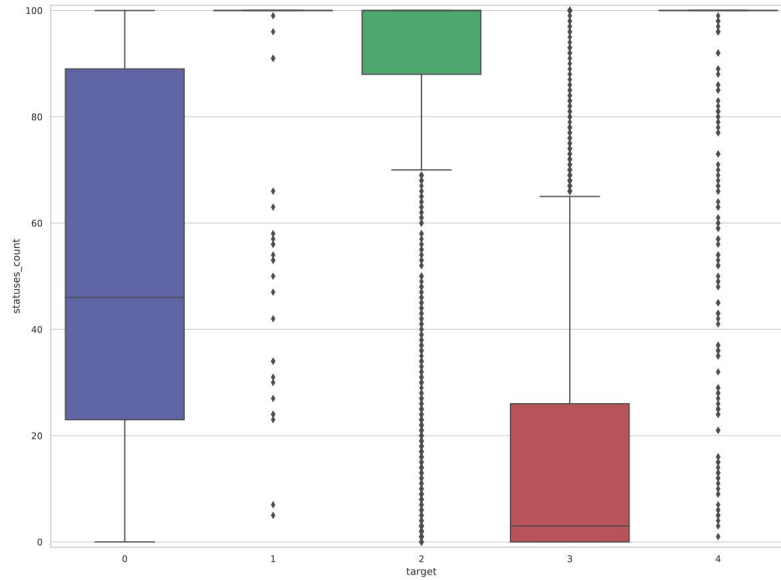


Figure 3.9: boxplot statuses_count

Finally we performed three further analisys. With the heatmap we could not detect which features were more important. Anyway,during the hand-labeling step, we understood that some of these features were instead very usefull to identify a few classes of our dataset. These attributes are "followers_count", "friends_count" and "statuses_count". For each of them we plotted a boxplot. It is a method used to represent groups of numerical data through their quartiles. In figure 3.9 we can analyze the statuses count for each target. We collected up to 100 tweets for each user, so this chart is limited to 100. Here we can notice an interesting behavior: "news-spreaders" and "spambots" are the classes with more tweets, while "fake-followers" have less statuses. By reflecting on the gols of the bots, this result is exactly what we expected to see. In fact "fake-followers" don't need to tweet, they just need to exist, while other types of bots have to publish many statuses, to draw attention on their contents.

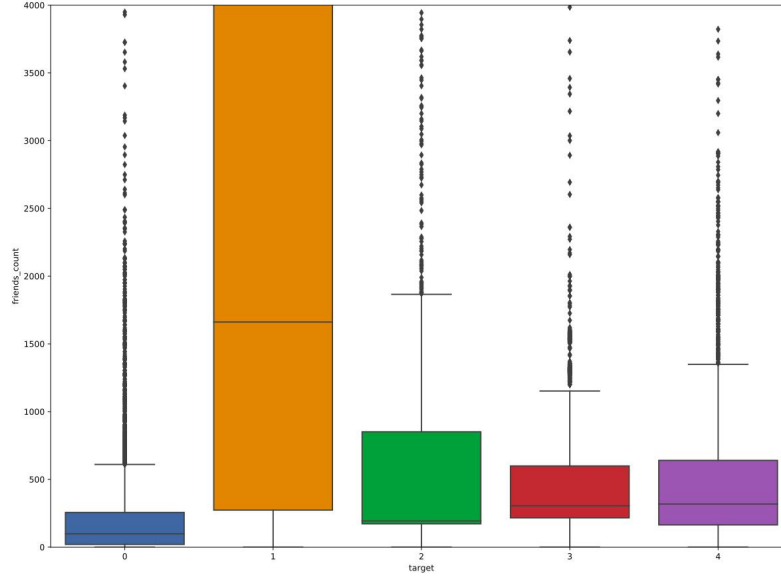


Figure 3.10: boxplot friends_count

In figure 3.10 and 3.11 we performed the same analysis considering the "friends_count" and "followers_count" features. We limited the charts to 4000 and 2000 to keep them understandable. These two figures show us that "news-spreaders" usually have a bigger network, while "fake-followers" just follow few users. "News-spreaders" network may depend on the popularity of the news media. Other categories are more balanced and their differences can be attributed to the data and not to a different behavior between them. For the genuine accounts we need to make an extra observation. Of course there are a lot of human users on Twitter and they have very different behaviours. In our dataset we included profiles with an average popularity (3.11), so they are neither VIPs nor fresh users without followers. Furthermore they have a smaller network of friends (3.10), which is in the average of the other categories. Finally they actively use twitter (3.9) since we were able to collect about 100 tweets for each of them.

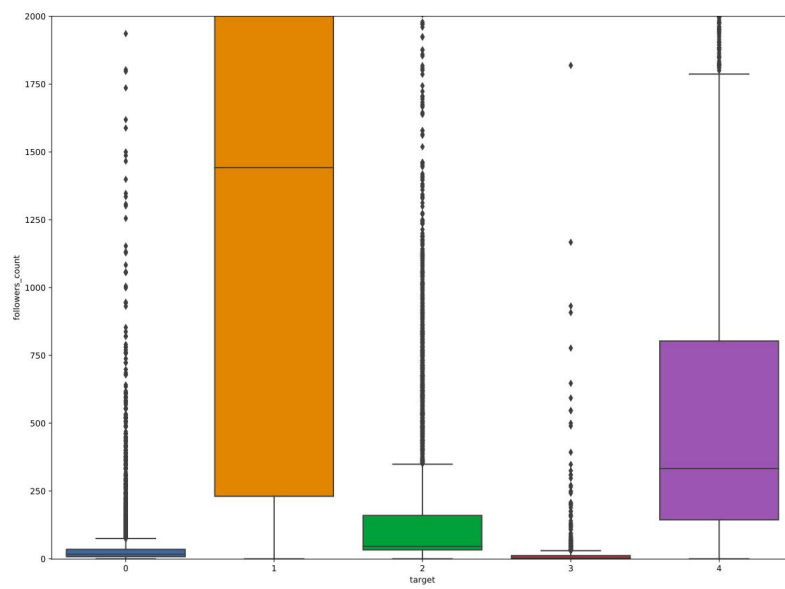


Figure 3.11: boxplot followers_count

Chapter 4

Features Engineering

In this chapter we want to analyze the set of available features and expand it with new ones, based on the properties of tweets and pictures.

4.1 Baseline

Some features are ready to be used in a classifier, while other ones need to be pre-processed to allow them to be more expressive. In this section we analyze the complete set of default profile features and which kind of pre-processing operation we applied. With this default set we trained a classifier to define a baseline and this allowed us to evaluate the improvements made by the features engineering step.

feature	type	preprocess operation
id	int	delete
name	str	delete - non-numeric feature
screen_name	str	delete - non-numeric feature
statuses_count	int	/
followers_count	int	/
friends_count	int	/
favourites_count	int	/
listed_count	int	/
url	str	replace with hasUrl (0/1)
lang	str	delete - non-numeric feature
time_zone	str	delete - too many missing values
location	str	delete - too many missing values
default_profile	int	delete - too many missing values
default_profile_image	boolean	boolean to int (0/1)
geo_enabled	boolean	delete - too many missing values
profile_image_url	str	delete - non-numeric feature
profile_use_background_image	boolean	boolean to int (0/1)
profile_background_image_url_https	str	delete - non-numeric feature
profile_text_color	str	delete - non-numeric feature
profile_image_url_https	str	delete - non-numeric feature
profile_sidebar_border_color	str	delete - non-numeric feature
profile_background_tile	boolean	boolean to int (0/1)
profile_sidebar_fill_color	str	delete - non-numeric feature
profile_background_image_url	str	delete - non-numeric feature
profile_background_color	str	delete - non-numeric feature
profile_link_color	str	delete - non-numeric feature
utc_offset	int	delete - too many missing values
is_translator	boolean	delete - too many missing values
follow_request_sent	int	delete - relative feature
protected	boolean	delete - too many missing values
verified	boolean	delete - too many missing values
notifications	boolean	delete - relative feature
description	str	replace with hasDescription (0/1)
contributors_enabled	boolean	delete - too many missing values
following	boolean	delete - relative feature
created_at	str	delete

Features processed as "delete - relative feature" are those ones related to the user who performed the scraping. So we didn't need them.

4.2 Missing values filling

4.3 Descriptive features

The feature engineering process started with this idea: we aimed to enhance our data with informations driven by the tweets that our users made.

The choice over the amount of tweets that would have been considered was a trade-off between performance and prediction speed.

We finally chose to retrieve up to the latest 100 tweets for each user, because further material led us to a slower, but equivalent, prediction over test samples. In order to enrich our attributes and to provide support to our algorithms, we decided to add some descriptive "meta" features, such as synthesis statistics and counters.

Their purpose is to describe the tweets in a statistical way, adding ranges and means to the attributes provided by the official APIs.

Each of these new values were been added to the users feature vector, in order to append new informations for each account. Here is the list of this first 18 brand new features, introduced by our work:

feature	description
avg_len	average lenght of the tweets (words)
max_len	lenght of the longest tweet (words)
min_len	lenght of the shortest tweet (words)
avg_ret	average amount of retweets (by other users) per tweet
max_ret	highest amount of retweets (by other users) on a tweet
min_ret	lowest amount of retweets (by other users) on a tweet
avg_fav	average amount of favourites (by other users) per tweet
max_fav	highest amount of favourites (by other users) on a tweet
min_fav	lowest amount of favourites (by other users) on a tweet
avg_hash	average amount of hashtags involved in tweets
max_hash	highest amount of hashtags involved on a tweet
min_hash	highest amount of hashtags involved on a tweet
freq	amount of tweets per day (up to 100)
ret_perc	percentage of retweets, made by the user, over its retrieved tweets
media_perc	percentage of media content incorporated in tweets
url_perc	percentage of URL links placed inside tweets
quote_perc	percentage of quotes, made by the user, over its retrieved tweets

4.4 Intrinsic features

Due the multiclass nature of our dataset, it was impossible to rely on the descriptive meta features only.

We faced the need of better capturing some behaviors, that could have helped us distinguish between targets.

We spent a lot of time analyzing Twitter timelines by ourselves. This was one of the most useful phases of our work.

Indeed, we have learnt a lot about bots acting like humans on the social platform. One thing that was easy to notice was the monotony, in terms of words or URLs involved in tweets, met with Spam-bots, as well as the opposites, for Genuine accounts or Fake-Followers. We tried to encapsule this distinctive behavior by adding 2 intrinsic features to the training vector, along with the descriptive ones.

How to portray such monotony?

We though about different approaches, like complex sentiment analysis or entity recognition, but then, we chose to rely on a weighting technique and the euclidean distance.

We looked inside every retrieved tweets for each user, then we encoded each of them with TF-IDF weighting.

Every term (word) of every tweet was represented by a numeric weight, according to TF-IDF.

This weighting formula is a combination of Term Frequency (TF) and Inverse Document Frequency (IDF).

$$TF_{i,j} = \frac{n_{i,j}}{|d_j|}$$

The term frequency factor counts the number n of the i_{th} term inside the j_{th} document (the tweet, in our case), dividing it by the lenght of the latest, in order to give same importance to both short and long collections of texts.

$$IDF_i = \log \frac{|D|}{|\{d : i \in d\}|}$$

Where d is the document (tweet). The invers document frequency factor aims to highlight the overall magnitude of the i_{th} term in the collection which it belongs. The collection D , in our work, is represented by all the gathered tweets of the examined user.

$$(TF - IDF)_i = TF_{i,j} \times IDF_i$$

After the encoding process, we wanted to map the resulting vectors into an euclidean space, in order to compute the distance of each weighted text,

from the total centroid of the collection.

We decided to add each user a measure of the average intra-distance of its tweets.

In order to achieve this goal, we relied on the WSS metric used in K-means clustering, but trying to soften its magnitude. We didn't want huge ranges in our features, in order to minimize the normalizations along the process.

The resulting formula for this brand new attribute is the following:

$$IntraDistance(U) = \frac{1}{N} \sum_{\mathbf{x} \in U} \|\mathbf{x} - \boldsymbol{\mu}\|^2$$

Where N is the number of tweet for user U , x is the encoded tweet and μ is the centroid of the tweet collection for that user. This formula, as well as the whole process, has been used both for tweet words and URLs inside of them. The resulting 2 features are

feature	type
tweet_intradistance	float
url_intradistance	float

We expected low values for Spam-bot accounts in both features, as well as we expected the opposite for Genuine and Fake-Follower accounts.

4.5 Extrinsic features

Once we have modeled the personal twitting actions, in terms of words and links dissimilarity, we needed to look for those parameters that could be compared with all the users in our dataset. We wanted the users to get out of their shells, and to match their timelines with each others.

Once again, sentiment analysis came to our mind. We found lots of paid or limited services that could have only partially supported us during this stage.

We couldn't think about implementing our own semantic analysis, as it is meant to be, due to the effort and time it would had taken.

For simplicity sake, we had the idea to look for the most meaningful words in tweets, that are common to all the users belonging to the same class.

We tried this approach, hoping to find a robust help in separating topics among targets.

The idea was to build five not overlapping dictionaries, one for each class of users, containing the most popular words used by them in their retrieved tweets. Each dictionary is ordered according to the occurrence of each word, in order to have a proper ranking for the terms and to give each of them a score. We gathered the 300 most common words for each category of

accounts, in order to average about 250 terms, once the overlapping elements would have been discarded. Considering more than 300 words led us to uninfluent performance boost, instead it required lot of time to process a single user, so we decided to stop early.

We have listed 5 dictionaries:

dictionary	size
NSFW_main_words.csv	209
spam_bots_main_words.csv	230
news_spreders_main_words.csv	237
fake_followers_main_words.csv	233
genuine_main_words.csv	223

The overall scores are normalized, so that the most common word, for each class, is associated with a unitary weight, the least common one with a value similar to zero (it depends on the final amount of words included in the dictionary).

In terms of representation, this *keywords score* is built with 5 different values, one for each class.

The dictionaries aren't totally disjointed with each others. We decided to strip, from each list, only the top 50 words belonging to the other collections, since the most relevant scores reside in that zone of the ranking. We didn't want to give the user high scores, for the same word, but in different categories.

If some user hit a word that is placed inside more than a dictionary, we wanted to let the relative weights speak and assign scores to each of the targets that contain that word, knowing they are less relevant, as they don't fall in the highest positions.

So we have

feature	type
NSFW_words_score	float
spam_bots_words_score	float
news_spreders_words_score	float
fake_followers_words_score	float
genuine_words_score	float

When we process a new user and infer on him, we scan every words of every tweets and match them with all the dictionary. Every time that we hit a listed word, we assign the user the score of that word.

For instance, If the word we are comparing matches with the most occur-
rent for NSFW accounts (the top position in its dictionary), we update
the *NSFW_words_score* of our user, summing 1 to its current value for that
feature. We expected to capture patterns about the choice of the words in-
volved in tweets, for each of our categories. This extrinsic attributes revealed
themsevles as very useful, lately.

Chapter 5

[Solution aspect one]

Elaborate here better on the first aspect.

Chapter 6

[Solution aspect two]

Elaborate here better on the second aspect.

Chapter 7

Implementation and Evaluation

Yes, you got it: finally, let's talk technology! If you are an attentive reader, you will have noticed that so far I restrained from talking about technology and implementation stuff. And that was intentional: doing a thesis is first and foremost a *conceptual* effort, meaning an effort that should require a lot of brainwork, thinking, reasoning, discussing, drawing sketches of ideas, constructing tables for making informed choices, and so on.

And you know what? If that is well done and well described, your reader, even if he/she is not tech-savvy or an expert in your topic, will understand you and be able to follow your reasoning and agree/disagree with the choices you propose. If instead you start too early talking about technologies, programming languages, protocols, fancy frameworks that your reader does not know and, even worse, explain your solution in function of these technologies, you will lose the attention of your reader. And there is nothing as bad as that.

Once you lose the attention of your reader due to too much geek talk, you will not be able to get the attention back. The consequence is that, even if you did the best project ever and come up with Nobel Prize worthy findings, your reader (perhaps your reviewer) will not notice, and you will not get the credit you actually deserve.

The lesson learned is: *defer* the tech talk as long as possible (too early = too dangerous), *single it out* from the rest of the work (so that who is not interested in the low-level details can skip it), and make it *self-contained* (so that who instead wants to read it gets all the details necessary).

7.1 Implementation

Here you can describe the technologies you use, put code example, describe all the details you feel are needed to enable the reader (with the necessary tech background) to understand. The goal of this section should be to enable your reader to re-implement what you did, perhaps with different technologies.

- ☐ Describe the *technologies* you use in your solution.
- ☐ *Motivate* possible technology choices.
- ☐ Copy and paste here the *architecture figure* you should already have included in Section ?? and extend it with the technologies you use for each of the modules.
- ☐ Provide insight into the most important *implementation problems* and how you solve them.
- ☐ If available, provide a link to an *online repository* holding the code of your prototype (ideally released as open-source software on GitHub or the like).
- ☐ Maybe you also want to share here some *UML diagrams* you drew before starting with the coding of the software.
- ☐ Provide evidence that your prototype *works*, e.g., screen shots, produced outputs, or similar.

7.2 Evaluation

This is a section that may be missing in a tesina, while for a thesis it is of fundamental importance. Even more: in some projects, the evaluation may even be a major contribution of the work and deserve an own chapter. If this is your case, then do so. For example, if you do an elaborated user study that requires careful literature study, design, planning, execution, data collection, data analysis, then you may want to make this effort also evident in the structure of the thesis by giving it an own chapter (remember that the structure of the thesis should already tell the reader a story).

7.2.1 Design of Evaluation

Explain here how you evaluate your solution, e.g., you do a controlled performance study in the lab using a cluster of 50 computers in a network, or

you do a simulation of an algorithm for which you first do some probing of some environment to fine-tune some parameters of the algorithm to have the simulation represent as real as possible situations, or you may do a user study, or... Here some options:

- ☐ *Theorem proofing*: if your work is of pure theoretical nature, you may want to accompany your theorems and corollaries with suitable proofs. Doing so requires good mathematical and/or algebraic skills.
- ☐ *Data analysis*: if you work on a topic that is related to Data Science, likely you will have a lot of data to analyze. Explain which data you are considering, how it is collected and prepared for the analysis, which kind of statistical analyzes you intend to use, why, etc.
- ☐ *Performance test*: if instead you develop a software prototype and claim that it works better than some exiting algorithm/software, explain which is your baseline to back your claim, tell how you want to compare your solution to the existing ones, which results you consider a success and which instead represent a failure, etc.
- ☐ *User study*: if your work involves real users in the evaluation of your work, explain how you select the participants, if they have to sign a consent form or not, if they need to obtain some form of prior training, which data you collect, how you guarantee their privacy and the security of the collected data, how you analyze the data, etc.
- ☐ *Simulation*: if you are not able to run your solution in a real environment and instead have to fall back to a simulation, explain how you set up the simulation environment, which assumptions you make, how you configure the simulation environment so that it resembles real situations, which exact data you collect, how you analyze it, etc.
- ☐ *Case study*: if the nature of your work does not allow a systematic data collection to back your claims, perhaps you want to elaborate on a case study that showcases the use of your solution in a real or fictitious application scenario. Explain the requirements of the case study, tell how realistic the case study is, show how your solution helps.
- ☐ ...

7.2.2 Metrics

Remember when I talked about the requirements and that ideally it would be good if the reader in the end of the thesis was able to use the list of

requirements as a checklist and to tick boxes? Well, this is where the reader should get the necessary tools to tick the boxes. Most likely, some of the requirements, claims and evaluation designs will need some specific metric to be able to tell if a requirement is satisfied or not. For example, you may want to measure response time for a time-critical service, or precision/recall for works on information retrieval, or individual quality attributes in crowd-sourcing, or...

- ☐ Define all the *metrics* needed by your evaluation designs.
- ☐ Tell how to *assess* the requirements and claims of your thesis.

7.2.3 Results

In this subsection you report on the results of the experiments/evaluation you perform. Report on all the important numbers for each of the metrics, on possible issues with running the code, etc. This is however not yet the place where to go into lengthy considerations on the meaning of values, this is for the next subsection. It's good to explain comparative results (A better than B in condition X, while in condition Y B is better), outliers (in one very specific situation A has an extraordinarily low/high performance), general statistics.

7.2.4 Discussion

Finally, here you discuss your results. That is, you discuss the *meaning* and *impact* of your result for the goals of your thesis. In other words, you *interpret* the results in light of your goals, expectations, intuitions, hypotheses. Did the prototype meet the expected performance? Is the achieved statistical significance reached to draw conclusions you would not be afraid of defending in front of a commission? Was the problem solved? Too slow? Too fast? Give the reader a feeling (as well as convincing arguments and numbers) for why you think some requirements are met while others may be missed.

Chapter 8

Conclusion and Future Work

So far so good. We are almost done. What is left is, well, just one of the most important chapters of the whole thesis, i.e., the conclusion. The purpose of this section is not to “conclude” the thesis in the sense to “stop” here. It’s rather to draw conclusions, that is, tell how well your work actually meets the requirements identified, answers the research questions, advances the state of the art. As such, this is perhaps the most important section! It may seem easy to just summarize a bit what you did and tell again what your objectives were when starting the work. But be aware that this can be much more difficult than it sounds, and you can expect your supervisor iterating with you several times over this same chapter. It is important that you show again your personal and professional maturity and your understanding of the topic. As you will see, some healthy self-criticism too is needed to make this chapter good.

8.1 Summary and Lessons Learned

Summarize here your work in about one page.

- ☐ Start from the initial *problem statement* or *research questions*.
- ☐ Summarize your *approach* and *methodology*.
- ☐ Recap the *lessons learned*.

8.2 Outputs and Contributions

Provide an overview of the outputs your project/work produced and then state what you think are the (research) contributions that advance the state of the art.

- ☐ List all the concrete *outputs* you produced (remember the discussion in Section 1.4).
- ☐ Copy/paste here the *list of contributions* you already anticipated in Section 1.4 (attention: outputs and contributions are two different lists; don't mix them).
- ☐ For each of the contributions, provide suitable *evidence*, drawing from the body of your thesis. For instance, if you claim that you did a formal proof of something, provide the exact number or name of the proof. If you promised subjective evidence for something, link this claim to the user studies you did. Etc. One or two sentences are enough for each of the contributions.

8.3 Limitations

This is where your self-criticism is needed. By now, I am confident you did a great work with your project and the writing of your thesis. So, compliments for that! You're almost done. But let's be frank: the work is not perfect. It simply cannot be, it never is. If it is, then not only I but also the whole commission of your defense will give you a standing ovation (I really would like to see this once). But in general there are just so many aspects of a research/thesis project that one would have to control or test, and with the limited time and resources available for these kinds of final projects it is just not possible to do everything.

In this section, you therefore tell the reader which aspects of your work may limit the impact or generalizability of your findings or contributions. As said, be frank. If you tell that you did a user study with only 10 people instead of 30 (which would make the findings stronger), you don't risk to give the impression you didn't do it well enough. Actually the opposite is true: if you don't tell it, your reader, who by now will anyway have gotten that there were 10 and not 30 people involved in the study, will instead think either (i) that you *didn't know* that a higher user involvement would have been better to back your claims or (ii) that you intentionally want to *hide* information or even *cheat*. None of these are good for you, and for sure worse than telling straightaway. Keep this in mind.

Here some typical limitations of research. Check if any of them apply to your work:

- ☐ Small *sample size* (e.g., the number of users in the study or the amount of data collected in an experiment).

- ☐ For experiments that involve multiple *independent variables*, likely you will not have tested them all (e.g., in a crowdsourcing experiment, you fixed a reward for all experiments and did not study if that too affected your results).
- ☐ You may have *promised* something in the beginning of the thesis; if you didn't achieve everything either you drop the very promise or you mention it here as a limitation.
- ☐ When you collected data, there may have been some *bias* in the data (e.g., if you implement a prototype and do a user study yourself where there participants know that you actually implemented the software, they will give you biased answers, typically better ones).
- ☐ Collected data many have turned out being *incomplete* or of *lower quality* then initially expected. How does this impact your findings?
- ☐ Your prototype may have *crashed* or *not worked properly* in some experiments; it's important you tell the reader and explain possible implications of this on the validity of your conclusions.
- ☐ Due to time restrictions, you may have *not been able to complete* all experiments planned initially; again, explain the possible implications.
- ☐ People participating in a user study may have *dropped out* of the study, for whatever reason; if the reason is related to what you did or not did, you should mention it.
- ☐ Sometimes it is *not possible to compare* an own algorithm with other, similar algorithms, e.g., because their code is not available; this too may limit the viability of the findings.
- ☐ ...

8.4 Future Work

Finally, here you tell the reader which aspects you think would deserve further study or development. A good starting point for this is of course the list of limitations you just discussed. Not all of them may be worth investing more effort, but some will. The idea of this section is to identify where possible new effort should be invested, in order to make the work complete. Again, be frank and don't be afraid of identifying also new research directions. It's not you who will be doing what you propose here. It's meant for

the reader, the community. Everybody understands that after your defense you won't be working any longer on this project. It's all about suggesting future work, not telling that *you* will be doing it.

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Appendix A

User Manual

If you implemented a piece of software that is meant to be used by somebody else than you, then here you can provide a brief user manual that tells the target user how to use it. Part of this is the possible installation of the software and its operation and trouble shooting.

Appendix B

Dataset

If your work was based on a dataset that can be considered an output of the project, here you can describe it in detail.