

AI for personalization: from predictive to generative modeling.

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AI for personalization: from predictive to generative modeling.

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Universiteit van Amsterdam
op gezag van de Rector Magnificus
prof. dr. G.T.M. ten Dam
ten overstaan van een door het College voor Promoties ingestelde
commissie, in het openbaar te verdedigen in
de Aula der Universiteit
op vrijdag 01 January 2024, te 14:00 uur

door

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geboren te Chavannes-Pres-Renens, Zwitserland

Promotiecommissie

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This research was (partially) funded by Bertelsmann SE & Co. KGaA and by the Hybrid Intelligence Center, a 10-year program funded by the Dutch Ministry of Education, Culture and Science through the Netherlands Organisation for Scientific Research, <https://hybrid-intelligence-centre.nl>.

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Cover by Off Page, Amsterdam

Printed by Off Page, Amsterdam

ISBN:

Certains pensent qu'ils font un voyage, en fait, c'est le voyage qui vous fait ou vous défait.

– Nicolas Bouvier

Acknowledgements

Gabriel Bénédict
Amsterdam
January 2024

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Introduction

Video streaming platforms have changed the way people consume and interact with digital media. They use machine learning to deliver personalized and recommended content to users based on their behavior and preferences. This thesis investigates how these platforms work, focusing on the different aspects of the user journey on a video streaming platform. The main goal is to understand and improve the personalization and recommendation systems that enhance the user experience. Platforms have to balance user satisfaction, content diversity, and ethical responsibility.

The *user journey* consists of several steps. First, users come to the platform with some *intents* (e.g., binge-watching a series, finding a family-friendly movie, discovering new genres, etc.). Then, they see a customized home page with various horizontal *recommendation* strips. Each strip contains videos with (sometimes personalized) *thumbnails*. Over time, users interact with the platform and leave *behavioral* signals (e.g., clicks, watch time, bookmarks, ratings, etc.). From the platform’s perspective, deciphering how these behaviors, prompted by user intents, translate into overall *satisfaction* remains a complex challenge. Besides satisfying the users, the platform also has to ensure that the content it offers is *diverse* and does not promote any biased or harmful views.

This thesis presents some novel methods and tools for improving the pipeline along this user journey. The pipeline includes collecting user data, analyzing user behavior, building predictive models, testing different strategies, and evaluating the outcomes. These steps help to capture user intent, preferences, and interaction patterns; the input for personalization tools. The tools we propose here are: a generative model for creating diverse and relevant recommendation strips for the home page; a multilabel classifier for selecting optimal thumbnails for each video; a survey-based method for predicting user satisfaction from intent and behavior; and a set of metrics for measuring content diversity and avoiding unwanted biases.

In short, we offer a comprehensive overview of the video streaming platform ecosystem, exploring the challenges and opportunities of personalization, recommendation, and user behavior analysis. By combining survey methods, content modeling, adaptive testing, and behavioral analysis, this study aims to contribute to the development of video streaming platforms that can provide better user satisfaction and engagement in a responsible way.

1.1 Research Outline and Questions

We scope the thesis around four research questions, each corresponding to a chapter in the thesis.

Personalization on streaming platforms is often seen as a way of predicting what users want to watch based on their preferences and behavior. Personalization can also be seen as a creative and ethical process that involves generating new content and experiences for users through a pipeline. Our first research question addresses the entry point of the user journey on a personalized platform, namely recommendations on the home page.

RQ1 Can we use diffusion to do recommendation in the classical user-item matrix setting?

Assuming recommendations are to be linked with a certain form of creativity, we harness the power of generative models. The emergent diffusion models field has been applied to images, music and other modalities. Unlike these, the classical recommendation setting of the user-item matrix does not entail spatial relationships between data points: contrary to pixels on an image, there is no information encoded in the allocation of users and item on a matrix. We illustrate this in RecFusion, where we first use Unets to fit data in a spatial way, before going back to the classical recommendation neural setting of feeding data user-by-user. For this one-dimensional user vector, we propose a proof and first experiments to show that a binomial (Bernoulli) diffusion process is viable. After recommendation, the next step of our pipeline caters to the display of these recommended videos via thumbnails.

RQ2 Is there a way we can generate personalized thumbnails for each item on a streaming platform?

Taking the simplifying assumption that each user has a favorite genre. We can provide a thumbnail personalized to that genre (e.g. show a romantic scene from an action movie, if the favorite genre is romance). Given editorial or automatically selected candidates for thumbnails, we wish to display the one that is most closely associated with the user's preferences. This reduces to a multilabel classification problem: given an image, predict one, or many, genre(s) they associate with. With sigmoidF1 we propose a surrogate F1 Score as a loss function, as a multilabel classification loss. At training time, we approximate step functions (i.e. confusion matrix counts: true positives, false positives etc.) with sigmoid functions and calculate an F1 score over each entire batch. We show that this improves on classical image and text benchmarks with classical backbones (CNN and transformers). Recommendations and thumbnails are what primes the users interactions with the platform. This relates to the next step in our pipeline.

RQ3 Are users' intents together with their behavioral data useful signals to predict or explain satisfaction on a video streaming platform?

By merging user behavior on the website and user surveys, we connect implicit and explicit user feedback and link them to satisfaction. We reproduce a study [6], but this time propose a transparent approach by revealing our survey design, code and simulated data. We use Bayesian multilevel modeling to reveal the relationships between intents, behavioral data and satisfaction. Finally, we close off our pipeline with a responsible approach to diversity.

RQ4 Can we formulate a divergence metric that measures the normative diversity of recommendations?

Can we empower a video/news platform to measure its ability to cater to its norms and values? We would like to account for any form of democratic norms (how a platform means to properly inform citizens) and any form of diversity metric (topic, presence of alternative voices, complexity of the text, etc.). The framework we propose caters to these normative aspects but also to the specific recommendation context: RADio is rank aware and caters any kind of discrete distribution via a our proposed rank-aware Jensen Shannon divergence. This work is focused on news recommendation but trivially generalizes to any domain that has categories (e.g. video streaming with movie genres).

Our research questions have been outlined in this section. The main contributions of this thesis will be summarized in the next section.

1.2 Main Contributions

In this section, we summarize the main contributions of this thesis. We separate theoretical from artifact (tool and experimental design) contributions.

Theoretical Contributions

- Diffusion applied on unstructured data, where there is no spatial dependency (Chapter 2).
- Diffusion for binary and/or 1D data: A demonstration that KL divergence is also suited for binary data and that the Bernoulli Markov Process has the same properties as its Gaussian counterpart (Chapter 2).
- A multilabel loss function that accounts for all examples in a batch (Chapter 3).
- An F1 score surrogate as a loss function (Chapter 3).
- An account of the current limitations and underreporting of thresholding at inference time (Chapter 3).
- a proposal of typical intents for a video streaming that we divide into explorative and decisive categories (Chapter 4).

- A diversity metric that is versatile to any normative concept and expressed as the divergence between two (discrete) distributions, rank-aware and mathematically grounded in distributional divergence statistics (Chapter 5).

Artifact Contributions

- Frequentist logistic regression model, we test Bayesian multilevel models for visualization and explanations, along with random forests for improved accuracy (Chapter 4).
- A reproducibility study from music to video streaming platforms of intent-satisfaction modeling (this time with code and synthetic data) (Chapter 4).
- In-app survey design for a medium size streaming platform (~1 million users) and corresponding synthetic data (Chapter 4).
- A metadata enrichment pipeline (e.g., sentiment analysis, named entity recognition) to extract normative concepts from news articles (Chapter 5).

1.3 Thesis Overview

This chapter introduces the main topics and goals of this thesis, and suggests some possible ways to read it. The thesis has seven chapters in total, and this is the first one. The following five chapters each address one of the research questions that we presented in Section 1.1. Each chapter is based on a paper (see Section 1.4 below), and can be read on its own. If the reader is interested in the entire thesis, we recommend following the original order of chapters, as they follow the user journey on a streaming platform. The final chapter summarizes the main findings and contributions of this thesis, and proposes some future research directions.

1.4 Origins

We list the publications that are the origins of each chapter below.

Chapter 1 is based on the following paper:

- Gabriel Bénédict, Olivier Jeunen, Samuele Papa, Samarth Bhargav, Daan Odijk, and Maarten de Rijke. Recfusion: A binomial diffusion process for 1d data for recommendation, 2023.

GB wrote the first draft, code, experiments and mathematical formulations. GB was helped all along the way via discussion with the coauthors. Coauthors then edited the first draft together with GB. GB did most of the writing.

Chapter 2 is based on the following paper:

- Gabriel B  n  dict, Hendrik Vincent Koops, Daan Odijk, and Maarten de Rijke. sigmoidf1: A smooth f1 score surrogate loss for multi-label classification. *Transactions on Machine Learning Research*, 2022. ISSN 2835-8856. URL <https://openreview.net/forum?id=gvSHaaD2wQ>.

GB wrote the first draft, code, experiments and mathematical formulations. GB was helped all along the way via discussion with the coauthors. Coauthors then edited the first draft together with GB. GB did most of the writing.

Chapter 3 is based on the following paper:

- Gabriel B  n  dict, Daan Odijk, and Maarten de Rijke. Intent-satisfaction modeling: From music to video streaming. *ACM Trans. Recomm. Syst.*, 1(3), aug 2023. doi: 10.1145/3606375. URL <https://doi.org/10.1145/3606375>.

GB wrote the first draft, code, experiments and mathematical formulations. GB was helped all along the way via discussion with the coauthors. Coauthors then edited the first draft together with GB. GB did most of the writing.

Chapter 4 is based on the following paper:

- Sanne Vrijenhoek, Gabriel B  n  dict, Mateo Gutierrez Granada, Daan Odijk, and Maarten de Rijke. Radio – rank-aware divergence metrics to measure normative diversity in news recommendations. In *Proceedings of the 16th ACM Conference on Recommender Systems, RecSys ’22*, page 208–219, New York, NY, USA, 2022. Association for Computing Machinery. ISBN 9781450392785. doi: 10.1145/3523227.3546780. URL <https://doi.org/10.1145/3523227.3546780>.

GB, together with SV, wrote the first draft, code, experiments and mathematical formulations. GB was helped all along the way via discussion with the coauthors. Coauthors then edited the first draft together with GB. GB and SV did most of the writing.

The writing of this thesis also benefited from work on the following publications:

- Gabriel B  n  dict, Ruqing Zhang, and Donald Metzler. Gen-ir @ sigir 2023: The first workshop on generative information retrieval. 2023.
- Ali Vardasbi, Gabriel B  n  dict, Shashank Gupta, Maria Heuss, Pooya Khandel, Ming Li, and Fatemeh Sarvi. The university of amsterdam at the trec 2021 fair ranking track. *TREC Fair Ranking*, 2021.
- Gabriel B  n  dict. Generative adversarial networks, 2021. URL <https://spectra.mathpix.com/article/2021.09.00009/gans>.

Generative Recommendations with Diffusion

RQ1: Can we use diffusion to do recommendation in the classical user-item matrix setting?

Reproducibility

To facilitate the reproducibility of the work in this chapter, our code is available at <https://github.com/gabriben/recfusion>.

This chapter is under submission at International Conference on Learning Representations (ICLR) under the title “RecFusion: A Binomial Diffusion Process for 1D Data for Recommendation” [?].

Metrics as Losses

In this chapter, we address the following research question:

RQ2: Is there a way we can generate personalized thumbnails for each item on a streaming platform?

Reproducibility

To facilitate the reproducibility of this work, our code is available at <https://github.com/gabriben/metrics-as-losses>.

This chapter was published at the Transactions of Machine Learning Research (TMLR) under the title “sigmoidF1: A Smooth F1 Score Surrogate Loss for Multilabel Classification” [1].

Intent, Behavior and Satisfaction

In this chapter, we address the following research question:

RQ3: Are users' intents together with their behavioral data useful signals to predict or explain satisfaction on a video streaming platform?

Reproducibility

To facilitate the reproducibility of the work in this chapter, our code is available at <https://github.com/rtnl/streaming-intent-model>.

This chapter was published at the ACM Transactions on Recommender Systems (TORS) under the title “Intent-Satisfaction Modeling: From Music to Video Streaming” [2]

Normative Diversity

In this chapter, we address the following research question:

RQ4: Can we formulate a divergence metric that measures the normative diversity of recommendations?

Reproducibility

To facilitate the reproducibility of the work in this chapter, our code is available at <https://github.com/svrijenhoek/RADio>.

This chapter was published at the ACM Conference on Recommender Systems (RecSys 2022) under the title “RADio – Rank-Aware Divergence Metrics to Measure Normative Diversity in News Recommendations” [8], , where it won a best paper runner up award.

Conclusions

In this thesis...

6.1 Main Findings

In this section, we describe our main findings across the three parts of the thesis.

The first part of this thesis focused on a generative personalization pipeline throughout the user journey on a video streaming platform. Along this pipeline, we first present RecFusion, a system that uses diffusion models to generate novel and relevant recommendations for users, as part of the emerging field of Generative Information Retrieval. To make these recommendations more appealing, we also propose a method to generate personalized stills from movies using sigmoidF1, a technique that adapts the image quality and style to the user's taste. We analyze how the user interactions on streaming platforms are influenced by not only the explicit data that is collected by web analytics, but also the implicit data that is hidden from them, using our intent-satisfaction framework. Finally, we ensure that the recommendations we generate respect the normative diversity of the users and the content providers, using RADio, a framework that measures and optimizes the fairness and diversity of the recommendations.

In Chapter 2, we asked our first research question:

RQ1 Can we use diffusion to do recommendation in the classical user-item matrix setting?

The answer to **RQ1** is yes:

In Chapter 3, we then turned to our next research question:

RQ2 Is there a way we can generate personalized thumbnails for each item on a streaming platform?

The answer to **RQ2** is yes:

In Chapter 4, we investigated the following research question:

RQ3 Are users' intents together with their behavioral data useful signals to predict or explain satisfaction on a video streaming platform?

The answer to **RQ3** is yes:

We asked our final research question in Chapter 5:

RQ4 Can we formulate a divergence metric that measures the normative diversity of recommendations?

We answered **RQ4** by ...

6.2 Future Directions

In this section, we describe some limitations of the methods proposed in this thesis and identify potential avenues for future work.

Final thoughts

Bibliography

- [1] Gabriel Bénédict, Hendrik Vincent Koops, Daan Odijk, and Maarten de Rijke. sigmoidf1: A smooth f1 score surrogate loss for multilabel classification. *Transactions on Machine Learning Research*, 2022. ISSN 2835-8856. URL <https://openreview.net/forum?id=gvsHaad2wQ>. (Cited on page 9.)
- [2] Gabriel Bénédict, Daan Odijk, and Maarten de Rijke. Intent-satisfaction modeling: From music to video streaming. *ACM Trans. Recomm. Syst.*, 1(3), aug 2023. doi: 10.1145/3606375. URL <https://doi.org/10.1145/3606375>. (Cited on page 11.)
- [3] Gabriel Bénédict. Generative adversarial networks, 2021. URL <https://spectra.mathpix.com/article/2021.09.00009/gans>.
- [4] Gabriel Bénédict, Olivier Jeunen, Samuele Papa, Samarth Bhargav, Daan Odijk, and Maarten de Rijke. Recfusion: A binomial diffusion process for 1d data for recommendation, 2023.
- [5] Gabriel Bénédict, Ruqing Zhang, and Donald Metzler. Gen-ir @ sigir 2023: The first workshop on generative information retrieval. 2023.
- [6] Rishabh Mehrotra, Mounia Lalmas, Doug Kenney, Thomas Lim-Meng, and Golli Hashemian. Jointly leveraging intent and interaction signals to predict user satisfaction with slate recommendations. In *The World Wide Web Conference on - WWW '19*. ACM Press, 2019. doi: 10.1145/3308558.3313613. URL <http://dx.doi.org/10.1145/3308558.3313613>.
- [7] Ali Vardasbi, Gabriel Bénédict, Shashank Gupta, Maria Heuss, Pooya Khandel, Ming Li, and Fatemeh Sarvi. The university of amsterdam at the trec 2021 fair ranking track. *TREC Fair Ranking*, 2021.
- [8] Sanne Vrijenhoek, Gabriel Bénédict, Mateo Gutierrez Granada, Daan Odijk, and Maarten de Rijke. Radio – rank-aware divergence metrics to measure normative diversity in news recommendations. In *Proceedings of the 16th ACM Conference on Recommender Systems, RecSys '22*, page 208–219, New York, NY, USA, 2022. Association for Computing Machinery. ISBN 9781450392785. doi: 10.1145/3523227.3546780. URL <https://doi.org/10.1145/3523227.3546780>. (Cited on page 13.)

Summary

Samenvatting
