



# Differentiable Time-Varying Linear Prediction in the Context of End-to-End Analysis-by-Synthesis

Chin-Yun Yu, György Fazekas

Queen Mary University of London, UK

chin-yun.yu@qmul.ac.uk, george.fazekas@qmul.ac.uk

## Abstract

Training the linear prediction (LP) operator end-to-end for audio synthesis in modern deep learning frameworks is slow due to its recursive formulation. In addition, frame-wise approximation as an acceleration method cannot generalise well to test time conditions where the LP is computed sample-wise. Efficient differentiable sample-wise LP for end-to-end training is the key to removing this barrier. We generalise the efficient time-invariant LP implementation from the GOLF vocoder to time-varying cases. Combining this with the classic source-filter model, we show that the improved GOLF learns LP coefficients and reconstructs the voice better than its frame-wise counterparts. Moreover, in our listening test, synthesised outputs from GOLF scored higher in quality ratings than the state-of-the-art differentiable WORLD vocoder.

**Index Terms:** speech synthesis, linear prediction, differentiable DSP, source-filter model, harmonic-plus-noise model

## 1. Introduction

Efficiency and interpretability are important aspects of neural voice synthesis. Instead of building high-quality but computationally expensive black-box vocoders [1, 2, 3, 4], efforts have been made to increase controllability and reduce computational complexity while retaining the same voice quality. One promising approach is utilising synthesis components in the classic source-filter framework to split the workload of neural networks and train them jointly [5, 6]. The filter in this framework represents the response of the vocal tract, which is often modelled using linear prediction (LP) based on the varying diameters tube model [7]. The LP coefficients (LPCs) are very compact features and require low transmission bandwidth.

Although LP has a long history in voice modelling [7], its recursive computation makes end-to-end training extremely slower than non-recursive filters due to the overhead for building deep computational graph [8]. LPCNet series [5, 9] address this problem by modelling the inverse filtered speech, thus utilising parallel computation. Several works parallelise LP by frame-wise processing and overlap-add [10, 11], while Yu et al. [8] accelerate it further with custom kernels for gradient backpropagation. Other works seek to approximate the vocal tract filter using FIRs [12, 13, 14, 15]. Besides LPCs, different filter representations have been explored as well, such as linear/mel-scale spectral envelope [14, 15] or cepstral coefficients [13, 16].

This paper proposes a new differentiable vocoder based on the GOLF vocoder [8]. We extend their custom backpropagation method to work with time-varying LP, removing mismatches between training and evaluation conditions with the cost of slightly slower training speed than frame-wise approxi-

mation. We conducted an end-to-end analysis-by-synthesis experiment and compared the performance of several differentiable components with two classic synthesiser formulations. We also compare the spectral envelopes of different methods' learnt LPCs.

## 2. Background

### 2.1. Harmonic-plus-noise GOLF

Global flow LPC Filter (GOLF) is a singing vocoder proposed by Yu et al. [8]. Given mel-spectrograms as conditions, a neural network encoder converts them into synthesis parameters, which are then passed to the decoder, also known as a synthesiser. The synthesiser has the following form:

$$S(z) = G(z)M(z) + N(z)C(z), \quad (1)$$

where  $S(z)$  is the voice signal which consists of  $G(z)$  the glottal pulses filtered by a LP filter  $M(z)$  and a white noise  $N(z) \sim \mathcal{N}(0, 1)$  controlled by another LP filter  $C(z)$ . This resembles the classic harmonic-plus-noise (HpN) model [17], which has been used in several related works [13, 14, 18] with different harmonics and noise components. GOLF generate  $G(z)$  using wavetable synthesis, where the wavetables are sampled from the transformed LP model [19] with different  $R_d$ .

### 2.2. Differentiable time-invariant LP

Although the response of the vocal tract varies from time to time in speech, we can assume it is invariant in a short time. Based on this assumption, the computation of the LP filter is given by

$$\begin{aligned} s(t) &= \text{LP}_a \{e(t)\} \\ &= e(t) - \sum_{i=1}^M a_i s(t-i), \end{aligned} \quad (2)$$

where  $s(t)$  is the time-domain speech signal,  $e(t)$  the excitation signal,  $\mathbf{a} = [a_1, \dots, a_M]$  the LP coefficients with a chosen order  $M$ .  $e(t)$  and  $s(t)$  are zero for  $t < 0$ . Yu et al. and Forgiato et al. [8, 20] show that given a loss function  $\mathcal{L}$  and the gradients  $\frac{\partial \mathcal{L}}{\partial s(t)}$ , the gradients  $\frac{\partial \mathcal{L}}{\partial e(t)}$  and  $\frac{\partial \mathcal{L}}{\partial a_i}$  can be computed as

$$\frac{\partial \mathcal{L}}{\partial a_i} = \sum_{t=0}^T \frac{\partial \mathcal{L}}{\partial s(t)} \text{LP}_a \{-s(t-i)\} \quad (3)$$

$$\frac{\partial \mathcal{L}}{\partial e(T-t)} = \text{LP}_a \left( \frac{\partial \mathcal{L}}{\partial s(T-t)} \right), \quad (4)$$

where  $T+1$  is the number of audio samples and  $T-t$  means reverse indexing. As the computation only consists of

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**Michael Rajnik**



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umgang mit texten und medien sowie reflexion über sprache

**masterstudiengang fachdidaktik schulsprache deutsch phzh** - Aug 03 2022

web der masterstudiengang fachdidaktik schulsprache deutsch richtet sich an inhaber innen der folgenden schweizerischen studienabschlüsse bachelor oder master einer pädagogischen hochschule bachelor oder master einer universität in germanistik bachelor oder master einer universität in erziehungswissenschaft merkmale des studiengangs

*fachspezifität von unterrichtsqualität in der deutschdidaktik* - Nov 06 2022

web jun 4 2021 die fachdidaktik deutsch beschäftigt sich traditionell intensiv mit der frage was guter deutschunterricht ist im bemühen um einen gegenstands und lernerangemessenen unterricht entwickelt sie konzepte und methoden für das lehren und lernen in den verschiedenen lernbereichen des deutschunterrichts

*lese und literaturdidaktik fb 05 deutsches institut* - Jun 01 2022

web jul 3 2023 willkommen im arbeitsbereich lese und literaturdidaktik in der lese und literaturdidaktik geht es um die vermittlung und aneignung von literatur und medien innerhalb und außerhalb der schule literaturdidaktik als teil der deutschdidaktik verstehen wir als praktische wissenschaft in einem zweifachen sinn

*fachdidaktik deutsch institut für germanistik an der universität* - Oct 05 2022

web fachdidaktik deutsch dieser anwendungsorientierte lehr und forschungsbereich der germanistik beschäftigt sich mit den bedingungen des lehrens und lernens im unterrichtsfach deutsch als wesentlicher teil des vier säulen modells des lehramtsstudiums ist die fachdidaktik deutsch an der schnittstelle zwischen

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web unter fachdidaktik deutsch wird die wissenschaft vom fachspezifischen lehren und lernen deutscher sprache literatur und anderer medialer erscheinungsformen verstanden sie umfasst die bereiche sprach literatur und mediendidaktik deutsch sowie didaktik des deutschen als zweitsprache

**didaktik lehren und lernen cornelsen** - Feb 26 2022

web die fachdidaktik setzt sich also mit der gelungenen lehre innerhalb eines bestimmten fachbereichs auseinander z b der mathematik ziele der fachdidaktik die fachdidaktik hat zum ziel den lernenden bestmöglich in seinem fachbereich auszubilden

*ovgu fachdidaktik deutsch iger* - Jul 02 2022

web jul 14 2023 die fachdidaktik deutsch ist für die fachdidaktische ausbildung der lehramtsstudierenden an der ovgu zuständig im bereich germanistik können die studiengänge deutsch für das lehramt an berufsschulen sowie deutsch für das lehramt an gymnasien und sekundarschulen studiert werden

*zum studium der didaktik der deutschen sprache* - Mar 10 2023

web das studium der fachdidaktik deutsch an der cau orientiert sich an aktuellen bildungspolitischen rahmungen sowie an ergebnissen der aktuellen empirischen bildungsforschung zum professionswissen von lehrerinnen und lehrern sowie zum sprachlich literarischen wissen und können von schülerinnen und schülern

*fachdidaktik wikipedia* - Jun 13 2023

web fachdidaktiken sind im deutschsprachigen raum in der regel den schulfächern entsprechend organisiert etwa physikdidaktik geschichtsdidaktik es gibt aber auch didaktiken welche mehrere fächer zusammenfassen bereichsdidaktiken z b didaktik der sozialwissenschaften naturwissenschaftsdidaktik fremdsprachendidaktik oder nur

**fachdidaktik germanistik schulpädagogik fachdidaktik deutsch** - Jan 08 2023

web und systematischen aspekten der fachdidaktik deutsch und des unterrichtsfachs deutsch sowie den rahmenbedingungen des lehrens und lernens im bereich der deutschen sprache und li teratur gewidmet der zweite spezielle teil orientiert sich an der kompetenzbereichsgliederung der von der kultusministerkonfe

**deutsch institut für erziehungswissenschaft uzh** - Jan 28 2022

web dozierende fachdidaktik deutsch dr phil susanne balmer dr phil stefan hofer lic phil philippe wampfler dr phil christine weber ehemalige dozierende fachdidaktik deutsch prof dr phil ralph fehlmann bis ende hs16 prof manfred gloor bis ende hs14 prof dr phil antonie hornung bis ende fs14 dr phil eva pabst bis ende

lehrstuhl für didaktik der deutschen sprache und literatur fau - Dec 07 2022

web basismodul fachdidaktik deutsch vertiefungsmodul fachdidaktik deutsch aufbaumodul sprach und mediendidaktik deutsch mittelschule aufbaumodul literatur und mediendidaktik deutsch mittelschule aufbaumodul fachdidaktik deutsch grundschule studienbegleitendes fd praktikum deutsch examensmodul

**fachdidaktik deutsch universität oldenburg** - Aug 15 2023

web jun 6 2023 für studierende was ist fachdidaktik deutsch und wozu fachdidaktik im studium fachdidaktik deutsch ist die wissenschaftliche disziplin die fachspezifische erwerbs und vermittlungsprozessen innerhalb und außerhalb der schule untersucht

pädagogisches wissen versus fachdidaktisches wissen - Mar 30 2022

web jul 10 2017 pädagogisches und fachdidaktisches wissen gelten als zentrale kognitive elemente professioneller kompetenz von lehrkräften der erwerb entsprechenden wissens soll daher möglichst schon im lehramtsstudium erfolgen

*fachdidaktik deutsch didaktik 7 überarbeitete neuauflage* - May 12 2023

web die neuesten entwicklungen der deutsch didaktik finden sie hier fachdidaktisch reflektiert brandaktuell beispielsweise die auseinandersetzung mit den bildungsstandards für das abitur und die kommentare zum materialgestützten schreiben

