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# My thesis

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## Abstract

- [1] summarize the motivation
- [2] problem overview
- [3] experiment
- [4] main findings and contributions.

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# Preface

# Acknowledgements

Thank my partner Thank Johan I would especially like to thank Jim O' Regan for all his thought-provoking insights, encouragement, and advice, which were crucial for me getting my bearings in a project which pushed me to grow beyond my limits. The process was deeply meaningful to me. Thank you. Thank Greg and Conchúr Thank examiner

# 1 Introduction

[5] Lead work here. Outline modern context of minority languages in nlp. Introduce Irish context in this framework. **revisit introduction, try to lead with an impactful framing of the motivation of the work.** Language competency is crucial in securing opportunities in the workplace as well as for accessing services and exercising rights in society at large. Language technologies have become central to many of the ways we interact with each other and society, for both good and ill. Such technologies are often identified as promising tools to promote language learning, but are also implicated in the coalescence of online interaction around a few dominant languages such as English. Low-resource languages struggle to keep pace with the most recent technological advancements given the relative scarcity of data they are faced with, necessitating

[6] Reiterate need for a solution, lead into research question explanation These

[7] Outline key goals of thesis In this thesis we explore the feasibility of two primary methods of overcoming the scarcity of phonetically annotated second language (L2) Irish learner data for Mispronunciation Detection (MD) applications. One approaches the problem with ensembles of monolingual automatic speech recognition (ASR) models for which data scarcity less acute, and another using a schema of data generation by leveraging established Text-to-Speech (TTS) systems to approximate learner speech: a potential low-cost alternative to large-scale phonetic annotation. By exploring these approaches, we aim to illuminate possible ways forward for low-resource language communities interested in developing automated technologies for language learning and pronunciation training.

[8] CAPT intro N. F. Chen and H. Li (2016) CAPT review, emphasis on teaching and learning, prosody

[9] ASR intro

## 2 Background & Related works

[10] Short overview of background section

In the following section we will outline the context motivating our current work with relation to Natural Language Processing (NLP) research for minority languages. We begin by exploring the different themes at play in the current work, summarizing the lay of the land, before digging into the ongoing research in these areas to rectify some thusfar recalcitrant problems hindering more equal access to the benefits of our time’s rapid advances in language technology.

### 2.1 Irish & The Predicament of Minority Languages

[11] introduce need for general-use systems. Developing language technologies that can scale beyond the language they are designed for is no new goal for NLP research. The value of such a property is apparent: transferring an existing system seamlessly to another language could potentially save significant resources for language communities without the ability to fund such system development themselves. Actually achieving this goal in practice, however, is no simple endeavor, typically requiring some level of linguistic awareness which is all-too-often lamentably absent (*inter alia*; Bender, 2011; Hedderich et al., 2021; Joshi et al., 2021). For example, success in applying supposedly language independent word-based n-gram approaches to languages rests on its level of inflectional morphology: the lower the better. Higher morphological complexity together with variations in word order raise data sparsity problems which n-gram approaches rooted in English struggle to handle (Bender, 2011). This should come as no surprise, given the relatively fixed word order and low levels of inflectional morphology present in English, but it illustrates a need for caution: systems developed for a given language may make implicit assumptions about language structure which do not generalize well. Linguistic typology can provide important clues as to what features are shared between the original development language and possible languages of extension for a system. Information of this kind has, for many of the world’s languages, already been gathered by linguists. Perhaps the most renowned database of typological information is the World Atlas of Linguistic Structure (WALS) (Dryer et al., 2024), a free, online resource currently boasting 152 chapters with detailed descriptions of 192 linguistic features spanning over 2,600 of the world’s languages. How a language is communicated through script is also a point of complication for NLP research, with Manohar et al. (2024) implicating standard normalization praxis when comparing ASR models as artificially inflating scores of languages using Indic scripts. Correctly segmenting continuous-script languages like Chinese is another area of ongoing research with clear implications for downstream performance. [get a good reference here and clean up transitions](#). By explicitly mobilizing linguistic knowledge already painstakingly gathered by linguistic typologists, we can identify where languages agree, where they differ, and hopefully identify implicit, ungeneralizable assumptions underpinning our approaches earlier in the design stage.

[12] language disparity in lang tech. Despite the claims of language-agnostic systems often touted by proponents of emerging Artificial Intelligence (AI) technologies, these systems have often fallen well short of such promise. The overwhelming majority of the world’s languages have no footprint in emerging language technologies

(Joshi et al., 2021). In the past, building neural network (NN)-based language technologies demanded immense quantities of labeled data: a high bar of entry to the language communities of those languages with limited if any access to such resources, and an ongoing issue which continues to stimulate a body of research dedicated to overcoming such issues (see Magueresse et al. (2020) for an overview). For languages where data availability is no obstacle, research and development can proceed unfettered by the prohibitive cost of curating datasets from scratch. As our daily lives grow increasingly integrated with the digital realm, language communities without the same support are obliged to switch to more digitally dominant languages (often English) to gain access to these new resources, narrowing the opportunities to engage with resources and services through the medium of their mother tongue (Ní Chasaide et al., 2019). A particularly sobering taxonomy illustrating the states of languages facing such disparities is formulated by Joshi et al. (2021) and reproduced in table 2.1 on page 8, which outlines the states and challenges faced by languages in resource terms in the digital space, and how dominant a small group of languages are within it. Of particular note for the privileged few that find themselves at the top of the heap is their typological similarity, being drawn as they are from a few dominant language families (and even dominant branches within these larger families). This state of affairs constitutes a sort of typological echo-chamber for the cutting edge of NLP developments, a point which we will return to shortly.

Class Descriptions	Example Languages	% of total languages
0 The Left-Behinds: Virtually ignored in language technology. Exceptionally limited resources available, even with respect to unlabeled data.	Dahalo, Bora	88.17%
1 The Scraping-Bys: Some unlabeled data. With organized promotion and data collection, there is hope for improvement in coming years.	Fijian, Navajo	8.93%
2 The Hopefuls: Limited labeled data. Support communities help these languages survive, and there is promise for NLP tools in the near term.	Zulu, Irish	0.76%
3 The Rising Stars: Strong web presence and thriving cultural community online. Lacking in labeled data. Good potential for NLP tool development for these languages.	Indonesian, Hebrew	1.13%
4 The Underdogs: Much unlabeled data, and less but still significant labeled data. Dedicated investment from NLP communities.	Russian, Dutch	0.72%
5 The Winners: Dominant online presence with massive investment and resources.	English, German	0.28%

**Table 2.1:** Data availability & status taxonomy of languages adapted from work by Joshi et al. (2021).

[13] set the Irish case in this context, outline challenges currently undertaken by developers

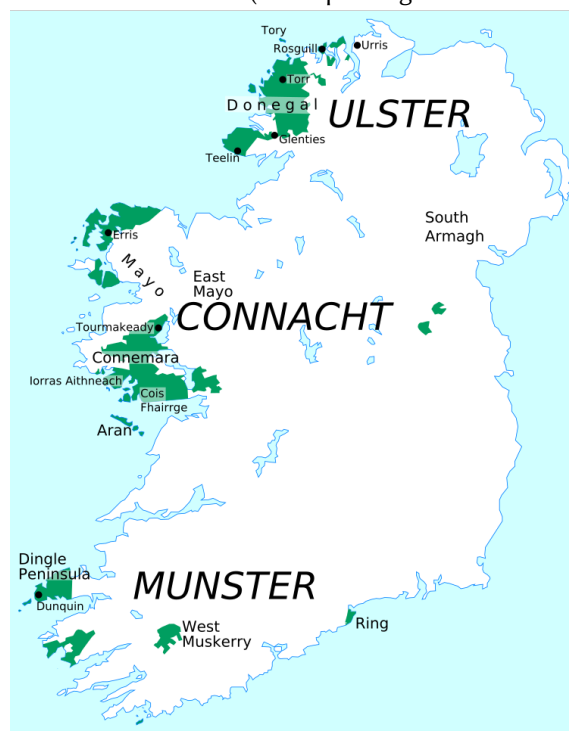
Despite some advantages not afforded other minority languages, Irish still finds itself struggling to maintain a footing in the the digital realm, placed by Joshi et al. (2021) in class 2 of the taxonomy outlined in table 2.1. It enjoys ongoing investment by the Irish state, nominal status of Irish as the first national language of the Republic of Ireland, and research dedicated to its promotion (e.g. through the ABAIR initiative



dedicated to developing speech technologies for Irish, see (Chasaide et al., 2017)). At the same time, it is a typological outlier in several respects: it is a verb-initial language with relatively complex inflectional morphology, and a distinct (though still Latin-based) orthography. Features like these put Irish at odds with many languages in the high-resource echo-chamber, complicating the ability to leverage cutting-edge models to linguistic features with no representation in a model's training data. Furthermore, though we have treated Irish as a single entity thus far, an important complication reveals itself in the discontinuous nature of the Irish-speaking areas, referred to as *the Gaeltachtaí*. Each of the three main areas (i.e. Ulster, Connacht, and Munster 2.1) speaks markedly distinct varieties of Irish, **find a picture for this** necessitating adequate labeled data if these groups are to be adequately serviced by new technologies. In the face of such limitations, today's data-hungry tools simply cannot be expected to perform to the same level on languages like Irish without the same access to resources. It should be noted that the pretraining/finetuning paradigm of recent massive multilingual models does mitigate this demand for data somewhat by leveraging unlabeled cross-lingual data, reducing the need for labeled data in the language finetuned to (Hedderich et al., 2021; Joshi et al., 2021; Ranathunga et al., 2021), but for other languages without even minimal labeled data to their name, this is a small comfort.**which survey references do I want to use?**

**placeholder. find good open source gaeltacht image**

**Figure 2.1:** Area of the Gaeltachtaí (Irish-speaking areas of Ireland) colored in green



**Figure 2.2:** The original uploader was Angr at English Wikipedia. - Transferred from en.wikipedia to Commons., CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=3532749>

[14] problems to be solved for Irish speakers Though the hurdles facing the Irish language in the digital sphere are a relatively recent concern, the issues facing it in the real world are anything but. It is currently classified by UNESCO as being *definitely*

*endangered* (Atlas of the World’s Languages in Danger 2010), following centuries of varying rates of contraction due to encroachment by English **give some more explanation of the history, handle with care**. Irish survives as a community languages in the aforementioned Gaeltacht areas, though even there it is estimated that only 24% of inhabitants speak Irish on a daily basis (Ní Chasaide et al., n.d.). Despite this worrying state of Irish as a first language (L1), it is comparatively strong as a L2 **dig up ref from broin about second language stats**. A growing number of parents seek Irish-medium education for their children outside the Gaeltacht, and immersive summer courses remain popular among adults looking to learn or reconnect with the language. This encouraging L2 engagement intersects with thorny issues of supply, however, as many of the teachers are not themselves native speakers with an accompanying native grasp of the structure and sound of the language (Ní Chasaide et al., n.d., 2019). This limited native speaker model for L2 speakers is particularly problematic for teaching pronunciation, complicating the acquisition of some sound contrasts critical to disambiguating the Irish grammar. Perhaps chiefly among these, contrasts between the secondary articulation of consonants into *palatalised* and *velarised* variants play an instrumental role in a number of grammatical functions, such as in the formation of certain plurals and genitive marking (Broin, n.d.; Gabriele, n.d.; Sneseva, 2016; Stenson, 2020). Since the Roman alphabet doesn’t provide symbols for this distinction, Irish orthography marks it via adjacent letters as seen in **give sub-table references** of table 2.2: so-called *slender* vowels (‘i’ and ‘e’) flanking a consonant denote *palatalisation*, while *broad* vowels (‘a’, ‘o’, and ‘u’) mark *velarisation* (Stenson, 2020). Mutation effects are another pervasive element of the Irish grammar relying on sound alterations, the most common of which are *lenition* and *eclipsis*. *Lenition*, traditionally termed *séimhiú* (/ˈseːvʲuː/), is commonly marked with an ‘h’ following the lenited consonant as seen on table 2.2, and originally denoted a weakening in the manner of articulation, though the relationship between consonants and their lenited versions is less immediately apparent now for some consonants (Stenson, 2020). *Eclipsis*, traditionally *úru* (/ˈuːrʲuː/), involves replacing the original consonant with a nasalized or voiced version, and is denoted by appending the new sound character before the consonant being eclipsed. **add sub-table refs and double check if this description covers all the bases**. These and other structural underpinnings of the language can have far-reaching implications for intelligability if not adequately mastered by students. Indeed, a study undertaken by Broin (n.d.) reveals that realisations of phonological like those above are over 50% on average for urban speakers, with some as high as 82%—a stark departure from their gaeltacht counterparts which lie below 10%. Providing wider access to better native models of pronunciation — not to mention native models of morphology — could do much to close this gap, making mutual intelligability more attainable between gaeltacht and urban speakers.

**Table 2.2:** Examples use of mutation effects (*séimhiú* & *úru*) as well as consonant velarisation & palatalisation

Phoneme	Count
/a/	42
/i/	35

Gabriele (n.d.) english influence on palatalization and velarization Sneseva (2016) how does english influence Irish spoken by dublin bilinguals? Broin (n.d.) differences of irish between cities and gaeltacht Ní Chasaide et al. (n.d.) documentation of Irish with speech tech Hedderich et al. (2021) survey of low resource NLP methods Magueresse et al. (2020) survey of low resource methods in NLP Wu et al. (2021) motivation

for phone-based recognition for MDD instead of scoring pronunciations (like GOP)

## 2.2 Second Language Acquisition

### 2.3 CALL & CAPT

The rise of digital technologies is often implicated in the acceleration of already precipitous rates of decline for endangered languages. However, it is a trend that cuts both ways, as the same technologies that squeeze certain languages out of the digital realm are also making space for communities of language learners to come together towards their common goal. The increased presence of technology both in and outside the classroom brings with it broad implications for traditional pedagogy, enabling more autonomous and flexible modes of learning for students. For language pedagogy specifically, this has increased the financial viability of courses for endangered or otherwise less commonly taught languages, allowing teachers to draw from a more geographically dispersed enrollment pool and provide courses otherwise impossible to offer (Parencite spolsky Handbook Educational Linguistics 2008 **alter bib entry to reflect book chapter, not whole book**). Furthermore, as prominent CALL software for self-study such as Duolingo, Babbel, and Rosetta Stone proliferate, the advantages of immediate and personalised feedback are increasingly hard to ignore. This new reality has not come without growing pains. Integrating the new digital dimension of the modern language landscape with traditional educational goals has been an area of longstanding misalignment, limiting fuller realization of their potential (Bajorek, 2017). Despite these shortcomings, the digital nature of CALL systems has some alluring implications for the viability of individualized pronunciation training.

Effective pronunciation training requires one-on-one interaction between students and teachers. This individualized dynamic generally carries a steep price tag for the student, but CAPT systems can potentially lower this barrier of entry considerably by automating the same kind of undivided feedback in a form scalable to many geographically dispersed students at once. Kyriakopoulos et al. (2018) capt with phone distances Levis (2007) overview of technology in pronunciation research (good choice of overview) Rogerson-Revell (2021) survey essay on current status of CAPT circa 2021 S. Witt and Young (2014) scores on a phonemic level GOP. likelihood ratio between forced alignment and max likelihood monophone loop? aspects of pronunciation teaching overview.

[15] aspects of pronunciation S. Witt and Young (2000) components of pronunciation page 10 Engstrand (2004) check section on prosody for segmental suprasegmental breakdown. Mihalicek and Wilson (2012) intro to linguistics. maybe good segmental breakdown, haven't found it yet.

[16] motivation for language feedback Hansen Edwards and Zampini (2008) part of a larger work about phonology in 2nd language acquisition (is right reference?) Hardison (2005) effect of perceptual training and phonetic environment. visual cues serve priming role in audiovisual speech processing Homa and Cultice (n.d.) motivation on value of feedback Islam et al. (2023) example feedback instead of expert feedback. Levis and Pickering (2004) intonation feedback with speech visualization. S. Li et al. (2011) discussion about phoneme-level speech visualization as tool for feedback Lyster et al. (2013) Oral corrective feedback in L2 classroom Hosseini-Kivanani et al. (2021) motivation for non-native error language model

[17] short framing of L2 learner motivation and Language learning VanPatten (n.d.) second language acquisition Bodnar et al. (2016) motivational impact of call systems Mac Lochlainn (2023) l2 motivation in IMOOCS Mac Lochlainn et al. (2021) more

on Imoocs and participation motivation Schmidt (2012) Noticing hypothesis for L2 pedagogy

[18] outline CALL and pronunciation training's place within it. Eskenazi (2009) overview of language tech in education Levis (2007) pronunciation feedback, appropriateness, goals, and ability for ASR to provide this. Volodina et al. (2016) workshop on NLP for CALL and NLP for Language acquisition. good motivation for Arnbjörnsdóttir et al. (2022) CALL for language learning Amrate and Tsai (2025) capt overview Collins et al. (2019) icall VR application measuring impact of virtual reality. Collins (2021) situated learning for Irish. motivation benefits and anxiety reduction Kheir, Ali, et al. (2023) review of pronunciation assessment

[19] how to measure L2 pron proficiency Saito and Plonsky (2019) framework for conceptualizing measure of instructed L2 pronunciation prof Strik et al. (2009) Differences between error detection and pronunciation scoring S. Witt and Young (2000) GOP, likelihood of a phone given the acoustic segment. notes highly subjective nature of pronunciation assessment S. M. Witt (n.d.) auto error detection, where we are and where we need to go. overview of research use in commercial learning software. touches on cross-disciplinary nature of automatic pronunciation training. S. M. Witt (2000) GOP dissertation Sudhakara et al. (2019) improved GOP Thomson and Derwing (2014) l2 pronunciation effectiveness

[20] What are the sources of mispronunciation? What level do they operate at? L. Chen et al. (2018) speech scoring with e2e systems K. Li et al. (2017) good overview of scoring approaches plus new approach

[21] icall in Irish Ní Chiaráin and Ní Chasaide (2016) icall platform Ní Chiaráin and Ní Chasaide (2018) icall platform Ní Chiaráin et al. (2022) icall for minority languages Ní Chiaráin (2022) corpora cliste, data from platforms.

[22] Reiterate need for a solution to some of these problems, additionally for learning and teaching to lead into CALL Gabriele (n.d.) english effect on velarization/palatalization Holmberg (n.d.) thesis on designing computer systems for pedagogical value

[23] comparison to other CAPT applications (wav2vec2trainer?) Ballier et al. (n.d.) approach using whisper Bannò and Matassoni (2022) proficiency grading with wav2vec2 Islam et al. (2023) automatic proficiency assessment with exemplar-based approach for 3 levels of proficiency

[24] pronunciation trainer with agent interface (which slate talk was this?) Boulianne (2022) wav2vec2 large for phonetic transcription. good results for little training.

[25] Error modeling (systematic vs individual errors: see witt 1999) Pisoni and Remez (n.d.) particularly phonetic processing and phonological contrast chapters

[26] build case for value of corrective feedback in language learning from pedagogical texts Bajorek (2017) language apps are lacking Islam et al. (2023) example feedback with clustering Sheen (2004) Similarity and difference in corrective feedback and learner uptake (recasts, type of recast important)

### 2.3.1 MDD

[27] Introduce Mispronunciation detection and diagnosis (MDD) Fu et al. (2021) data augmentation for MDD Kheir (n.d.) MDD with hmm gnn for arabic Kheir, Ali, et al. (2023) review of MDD capt systems Kheir, Chowdhury, et al. (2023) Multilingual MDD framework Alrashoudi et al. (2025) MDD for arabic with transofmers Kim et al. (2022) focus more on pron scoring instead of MDD Peng et al. (2021) Wav2vec2 for MDD (important) Peng et al. (2022) gating strategy (ignore irrelevant parts in transcription) and constrastive loss to reduce objective gap between phoneme recognition and MDD Shahin and Ahmed (2024) phonological-level MDD (articulatory focus) True

acceptance rate, false rejection to Stanley and Hacıoglu (2012) difference in L1 dependent models vs baseline. how to introduce non native acoustic features. (variant of min phone error training that optimizes on maximizing discriminability between confusable phonetic units in nonnative acoustic space.) X. Xu et al. (2021) wav2vec2 for MDD

[28] describe its relations to ASR (Bartelds et al., 2023) survey of low-resource ASR (Besacier et al., 2014) survey of low-resource ASR

## 3 Related Work

In the following section, we will dive into strategies commonly used to address the problem area outlined above: the place of ASR in Mispronunciation Detection and Diagnosis (MDD), as well as some of the strategies adopted to overcoming the mismatch in objectives between ordinary phoneme recognition and MD

### 3.1 ASR for MDD

Povey et al. (n.d.) classic toolkit for asr

[29] Outline the function of an asr system. Pisoni and Remez (n.d.) for perception of sound

[30] What types of ASR systems are there? which are we using? Hsu et al. (2021) Hidden unit BERT. provides aligned target labels for model prediction loss

[31] Touch on phoneme extraction task and detail fine-tuning procedure Agrawal et al. (2023) smart weighter mechanism that selects model based on input audio

[32] MDD scoring

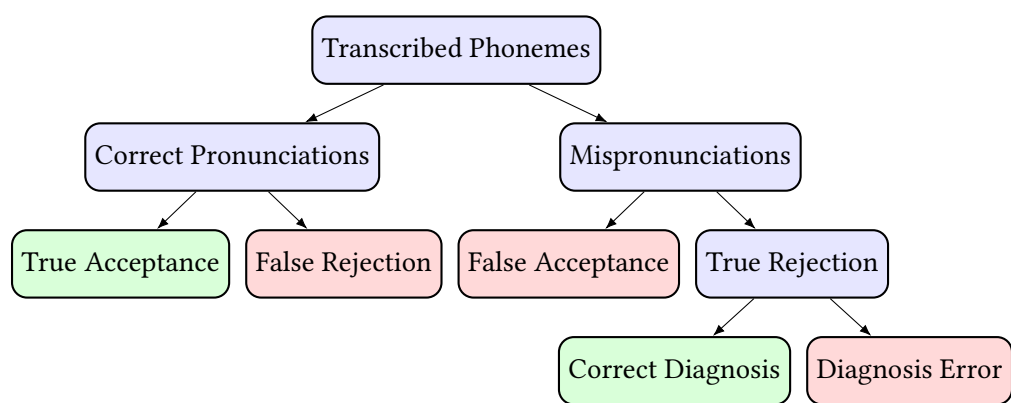
### 3.2 Ensembling

[33] describe the general strategy of model ensembling Fiscus (1997) ROVER ensembling Jalalvand et al. (2018) novel ROVER approach with quality ranking at segment level

### 3.3 TTS data augmentation

Korzekwa et al. (2022) synthesis approaches to boosting asr Shen et al. (2018) TTS Tacotron (maybe find google tts paper)

[34] connect strategy to current work Punjabi et al. (2019) bootstrapping data with MT (important) Q. Xu et al. (2020) multiple iteration of pseudo-labeling on unlabeled data to overcome data scarcity Yang et al. (2022) pseudo-labeling to overcome scarcity (self-supervised learning) D. Zhang et al. (2022) phoneme paragraphing to generate mispronounced speech (important)



**Figure 3.1:** Evaluation hierarchy of MD

## 4 Experimental set-up

In the following section, we will describe the core experiments explored for the current work: one which explores model ensembling as described above as a solution to MD in the face of data scarcity; the other, which explores dataset bootstrapping with a TTS system to create the data required to train a model directly for MD. Leading this will be an overview of the model framework common to both of these experiments: Wav2vec 2.0.

### 4.1 Wav2vec2

[35] Description of Wav2vec2 model Conneau et al. (2020) Wav2vec2 XLSR Baevski, Schneider, et al. (2020) (vector quantized) wav2vec2 with learned discrete representations (maybe don't use) One popular ASR models used in extracting phonemes from raw acoustic data is currently *wav2vec 2.0*, a self-supervised framework which is conceptually simpler than other leading models. After pre-training on unlabeled data, it can be fine-tuned on a much smaller set of labeled data, achieving State-of-the-Art (SotA) results in scenarios where labeled data is scarce Baevski, Zhou, et al. (2020). It consists of three main components: a Convolutional Neural Network (CNN)-based *feature encoder*, a *Transformer*-based network, and a *quantization module*. The feature encoder takes raw audio as input and outputs latent speech representations to be used both by the Transformer network and the quantization module. The Transformer captures contextual information about the encoder output, while the quantization module divides the encoder output into discrete speech representations.

[36] motivation for wav2vec2 xlsr The ability to pre-train on unlabeled data makes Wav2Vec 2.0 a natural choice for low-resource scenarios where one cannot count on abundant labeled data to train a model from the ground up. This constraint is an all-too-familiar one faced by the overwhelming majority of the world's languagesjoshizozostateempty citation. Baevski, Auli, et al. (2020) self supervision enabling ASR at low cost

### 4.2 Related Work

[37] multilingual speech modeling Pratap et al. (n.d.) new datasets on pretrained wav2vec2 models. improvement over whisper with a fraction of the labeled data.

### 4.3 Experiment 1: Model Ensembling

[38] outline first experiment with model ensemble. Our first experiment starts with the intuition described above using two expert systems: one Irish and one English. Confidence values associated with each models phonemic outputs are compared to each other to reach a combined phonetic output. Gitman et al. (2023) confidence-based ASR ensembles with selector block Guo et al. (2017) predicting probability estimates. how well calibrated are our models? Niehues and Pham (2019) similarity between training and test conditions for confidence (maybe more suitable as an extension) Papadopoulos et al. (2001) maximum likelihood, approximate bayesian, bootstrapping. (confidence estimation assessed by mean and st dev etc.) Wei et al. (2022) mitigating



overconfidence with logit normalization during training. some background on softmax confidence scores

#### 4.3.1 Data

[39] briefly summarize data sources To train our monolingual systems, we procured two monolingual corpora of read speech audio with phonetic transcriptions. Our English model was trained on the TIMIT corpus garofolo1993timitempty citation with the Irish model trained on audio data from the online Irish Dictionary and Language Library<sup>1</sup>. To evaluate effectiveness of the system for MD, a manually annotated dataset was prepared from a small subsection of the Mozilla Common Voice dataset Krishenbaum (n.d.) use is ascii is used (it's not) Měchura (n.d.) introduction to grammar part of teanglann (maybe not relevant)

[40] timit The TIMIT corpus is a read speech corpus of American English speakers who spent their childhoods in one of eight major dialect areas of the United States. These areas are widely recognized with the exception of the Western dialect region, where boundaries are not confidently delineated, and the "army brat" group, consisting of speakers which frequently moved during their childhood due to the demands of highly mobile military service member parents, resulting in exposure to a variety of dialects. The full dataset consists of 6300 sentences from 630 speakers, so ten sentences per speaker. This Ardila et al. (2020) common voice corpus for L2 speech

[41] teanglann The Dictionary and Language Library is an online resource developed by Foras na Gaeilge<sup>2</sup> in conjunction with the New English-Irish Dictionary. Among the resources available are The Pronunciation Database, which contains recordings of individual words spoken by native speakers from three major dialects: Connacht, Ulster, and Munster. The recordings for Ulster used for our monolingual Irish model were scraped by myself, adhering to the site's robots.txt file limit of one request per two seconds. am i using MFA or the dict? The dictionary of words to scrape was derived from an Ulster Irish Grapheme-to-Phoneme (G2P) file generously provided by Jim O' Regan. This was used for canonical Ulster phonetic annotation, and could be combined to form a dataset of words, recordings, and phonetic annotations in the International Phonetic Alphabet (IPA) for a combined dataset duration of roughly five hours of audio. talk to jim about where he got the g2p dict I use for pronunciation information and as a scraping dict

[42] Common voice For evaluating the quality of the MD system, we begin with the Irish portion of the Common Voice datasetardila2019commonempty citation, noted by Lonergan et al. (n.d.) as consisting nearly entirely of L2 speakers<sup>3</sup>. As in their work, this dataset will be used as the basis for testing the current experiment, as it fits the purpose of evaluating our system's effectiveness on L2 speech. The Common Voice corpus is a massive multilingual collection of transcribed speech designed for ASR which leverages crowd sourcing for data collection and validation to help alleviate the dearth of training data faced by most languages. Conneau et al. (2022) Parallel ASR dataset. move to discussion. Deichler et al. (2024) multimodal conversational dataset with cospeech gestures. move to discussion Qian et al. (2022) ASR for Irish: uses Mozilla common voice J. Zhang et al. (2021) open source speech corpus speech ocean for pronunciation assessment Zhao et al. (2018) L2 arctic dataset

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<sup>1</sup><https://www.teanglann.ie/en/>

<sup>2</sup>Foras na Gaeilge is a group which promotes the Irish language, supports Irish-medium education, and advises public and private sector organizations, among its other functions. <https://www.forasnagaeilge.ie/>

<sup>3</sup>given its nature as a crowd-sourced dataset, it is not certain this is still the case for the Irish portion of Common Voice

[43] annotation details To prepare the Common Voice dataset for use in phoneme-level MD, a small subset of the data was manually transcribed in IPA to capture pronunciation deviations from standard Ulster pronunciation. The process of capturing these deviations consisted of the following steps: first, an IPA representation of the transcription was generated from a lookup in the Ulster G2P dictionary to map the orthographic transcriptions to their canonical IPA representations; recordings were then manually assessed, comparing these generated IPA representations to the audio and noting where the phonemes deviated from the canonical pronunciations and what their realization was assessed to be. This process was carried out by myself only, a notable limitation we will return to later. The annotations were carried out in Label Studio using some preliminary annotations generated by an Montreal Forced Aligner (MFA) G2P model trained on Ulster Irish to speed up the process [ask about where the g2p came from, what to reference](#) Lee et al. (n.d.) wikipron (not used but illustrative as a reference)

#### 4.3.2 Model & Evaluation

[44] Detail the framework used for evaluation

[45] Detail CTC loss used in training CTC loss Graves et al. (n.d.) also details some peakiness Kürzinger et al. (2020) ctc and dataset bootstrapping

[46] PER and sequence alignment

#### 4.3.3 Results

[47] detail the results as it pertains to the evaluation framework: CTC loss,

[48] Compare CER

### 4.4 Experiment 2: Dataset generation

[49] outline core experiment The second experiment approaches the issue of data scarcity from a different angle; instead of resting on the monolingual data we *do* have, we use established TTS services to generate data approximating L2 speech to train a single MD model on.

#### 4.4.1 Data

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[50] Detail Data generation method

[51] Describe iterative bootstrapping approach

[52] detail data preparation measures.

#### 4.4.2 Model & Evaluation

[53] Detail the framework used for evaluation witt

[54] Detail CTC loss used in training CTC loss **graves2006connectionistempty citation**

[55] PER and sequence alignment

## 5 Results

[56] detail the results as it pertains to the evaluation framework: CTC loss,  
[57] Compare CER

## 6 Discussion

[58] Summarize the main findings from results and how it relates to the research questions

[59] Detail possible applications to Language learning, the role of results in augmenting self-directed language learning hardison2005secondempty citation effect of multimodal input on speech identification

[60] Detail possible (or actual if time allows) Furhat application deichler2024mmempty citation multimedia data

[61] continue furhat explanation

[62] Argue for accurate articulator representation in digital agents as supportive pillar in pronunciation feedback. Lizo11ThePAempty citation Animated articulators Rosenblum (2008) speech perception as multimodal phenomenom

## 7 Conclusions

[63] reiterate how results connect with research questions, set main conclusions in context of impact to research and society Zeyer et al. (2021) peaky ctc, ambiguous phone boundaries

[64] Extensions from previous research (yang2022) Liu et al. (2023) wav2vec which does adversarial training to improve discrimination. Peng et al. (2023) contrastive loss optimization Lonergan et al. (2024) alternative architectures for low resource asr Neri et al. (2008) pronunciation training for children, lead to improvements comparable to traditional training Prabhavalkar et al. (2017) alternatives to ctc

[65] Possibilities for future work Gong et al. (2022) assessment targeting more than one aspect of speech (prosody, word-level stress) Mortensen et al. (n.d.) PanPhon mapping from ipa to articulatory features Rouditchenko et al. (2023) language family in pretraining predictive of how models compare. need for resources for smaller families Sjons (2022) focus on child directed speech, since it is well-suited for word segmentation?

## 8 Ethical Considerations

[66] General Ethical considerations for current work and possible extensions

[67] Ethical considerations for Minority languages

## 9 AI Tools

[68] Describe use of AI tools and how its use benefited me.

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