DeepSpeech: A Scalable Decoding System that Integrates Knowledge for Speech Recognition

Zifei Shan, Tianxin Zhao, Haowen Cao
{zifei, tianxin, caohw}@stanford.edu

Executive Summary

- *DeepSpeech* flexibly integrates **different levels of knowledge** to decode a word lattice in speech recognition within a word-level CRF model, in an interpretable manner.
- *DeepSpeech* facilitates ***feature extraction, factor graph generation,*** and ***statistical learning and inference***. It takes word lattice as input, perform feature extraction specified by developers, generate factor graphs based on descriptive rules, and perform learning and inference automatically.
- *DeepSpeech* is based on the scalable statistical inference engine ***DeepDive*** *(http://deepdive.stanford.edu)*.

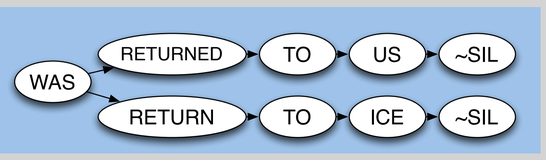
DeepSpeech Overview

Problem	**How to jointly integrate different levels of knowledge in speech recognition?**
Solution	**Decoding based on Conditional Random Fields that integrates various features.**
Results	**Got WER *10.2%* on 150k broadcast news lattices in near real-time, with a simple feature set. *(baseline 22.9%, oracle 2.1%)***
Future	**Candidate generation with linguistic knowledge might beat oracle error rate; joint inference on acoustic and language models**

The Architecture of DeepSpeech

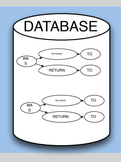
Input: word lattice

Input to the system is a word lattice output by an ASR system.



data preprocessing

Database tables



lattice	cand_id	word
L1	L1-2	RETURNED
L1	L1-3	RETURN

feature extraction

Extracted features

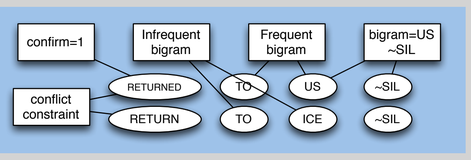
lattice	cand_id	word	feature
L1	L1-2	RETURNED	confirm=1
L1	L1-3	RETURN	2gram=RETURN TO

factor graph generation

Factor graph

TO : *variables*

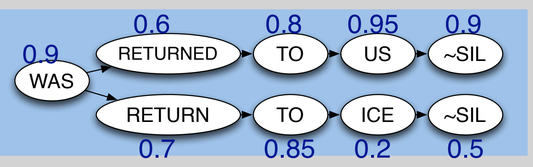
confirm=1 : *factors*



statistical inference and learning

Candidates with probabilities

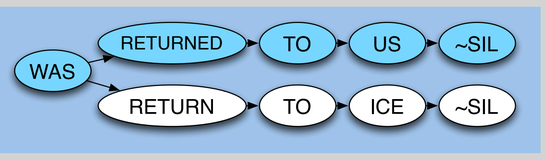
Learn weights for factors, and compute marginal probabilities for variables



finding best-path

Best path (or best N paths)

Search for a best path that optimizes edit distance (WER)



Experimental Setup & Preliminary Results

Features

After initial feature engineering, our current system implements following features:

1. Unigram and bigram frequency in Google Ngram. (skip "silence")
2. All bigrams around "silence"
3. POS tag 2gram and 3gram
4. Candidates that overlap in time cannot be both true *(a CRF rule that indicates constraint)*
5. Candidates on a same path should be true at same time *(a linear-chain CRF rule)*

*Next steps: co-reference features and **candidate generation***

Datasets

We train and test on broadcast news lattices (LDC2011T06, 150k lattices). We holdout 50% of training set for testing.

Results

We use SCLITE for scoring. We evaluate a baseline system (Attlia), DeepSpeech and lattice oracle (optimal) error rate.

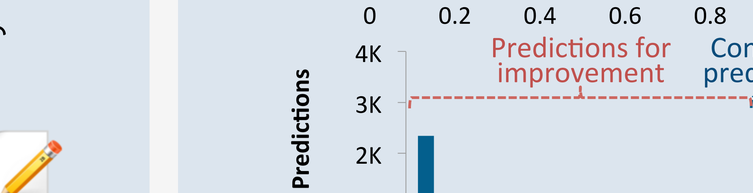
System	Corr	Sub	Del	Ins	Err	S.Err
Baseline	77.8	5.4	16.8	0.6	22.9	96.9
DeepSpeech	92.0	3.6	4.3	2.2	**10.2**	75.7
Oracle	99.9	0.0	0.1	2.0	2.1	50.8

Performance: DeepSpeech runs **70min** for training and testing, while this dataset is ~**400 hours** of speech (real-time!)

Distant supervision to obtain training data

We use distant supervision techniques to get training labels on candidate level: given a lattice and its transcript, we:

1. Find optimal paths in the lattice that matches the transcript with Dynamic Programming
2. Label all matched words in all optimal paths as true, others as false



DeepSpeech has three features!

Extract & Integrate linguistic features

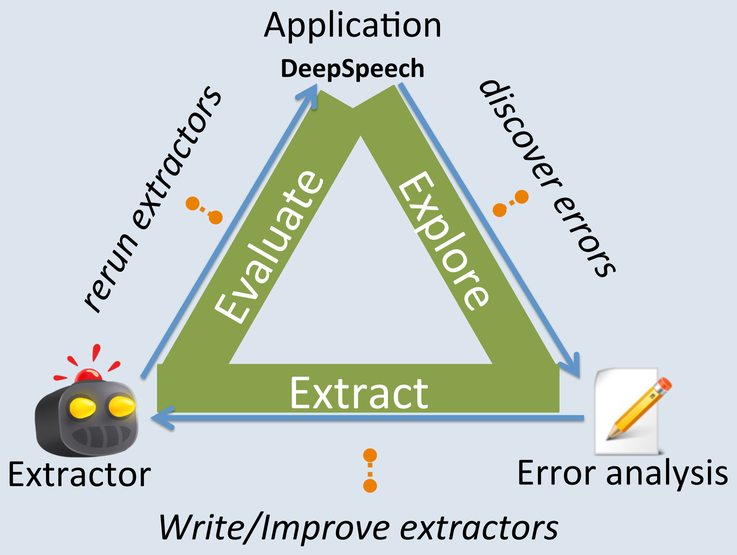
DeepSpeech provides a framework for developers to extract and integrate high-level features

Here is how developers can easily plug-in a corefence feature "extractor" to DeepSpeech:

SQL	Python
Define a SQL query to generate all pairs of candidate words that appear in the same lattice, and pair it with a python function.	***We write a Python function to process all phrase pairs and identify coreferent pairs.***
SELECT t0.CID, t0.TEXT, t1.CID, t1.TEXT **FROM** candidate t0, candidate t1 **WHERE** t0.LID = t1.LID **USEPYTHON** *pyfunc*	**def** *pyfunc*(c1, t1, c2, t2): if edit_dist(t1, t2) < 2: emit("Coref", c1, c2)

Simpler Feature Engineering

DeepSpeech supports an "E3 loop" for feature engineering



Rigorous Probabilistic Framework

DeepSpeech uses a joint probability model that enables rigorous probabilistic interpretation