Natural Language Processing with Deep Learning CS224N

The Future of Deep Learning + NLP

Kevin Clark

Deep Learning for NLP 5 years ago

- No Seq2Seq
- No Attention
- No large-scale QA/reading comprehension datasets
- No TensorFlow or Pytorch
- …

Future of Deep Learning + NLP

- **Harnessing Unlabeled Data**
  - Back-translation and unsupervised machine translation
  - Scaling up pre-training and GPT-2

- **What's next?**
  - Risks and social impact of NLP technology
  - Future directions of research

Why has deep learning been so successful recently?

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Big deep learning successes

- Image Recognition:
  Widely used by Google, Facebook, etc.

- Machine Translation:
  Google translate, etc.

- Game Playing:
  Atari Games, AlphaGo, and more

Big deep learning successes

- Image Recognition:
  ImageNet: 14 million examples

- Machine Translation:
  WMT: Millions of sentence pairs

- Game Playing:
  10s of millions of frames for Atari AI
  10s of millions of self-play games for AlphaZero

NLP Datasets

- Even for English, most tasks have 100K or less labeled examples.

- And there is even less data available for other languages.
  - There are thousands of languages, hundreds with > 1 million native speakers
  - <10% of people speak English as their first language

- Increasingly popular solution: use **unlabeled** data.

Using Unlabeled Data for Translation

Machine Translation Data

- Acquiring translations required human expertise
  - Limits the size and domain of data

- Monolingual text is easier to acquire!

Pre-Training

1. Separately Train Encoder and Decoder as Language Models

2. Then Train Jointly on Bilingual Data

Pre-Training

- English -> German Results: 2+ BLEU point improvement

Ramachandran et al., 2017

Self-Training

- Problem with pre-training: no “interaction” between the two languages during pre-training
- Self-training: label unlabeled data to get noisy training examples

Self-Training

- Circular?

Back-Translation

- Have two machine translation models going in opposite directions (*en -> fr*) and (*fr -> en)*

Back-Translation

- Have two machine translation models going in opposite directions (*en -> fr*) and (*fr -> en)*

- No longer circular
- Models never see “bad” translations, only bad inputs

Large-Scale Back-Translation

- 4.5M English-German sentence pairs and 226M monolingual sentences

Citation	Model	BLEU
Shazeer et al., 2017	Best Pre-Transformer Result	26.0
Vaswani et al., 2017	Transformer	28.4
Shaw et al, 2018	Transformer + Improved Positional Embeddings	29.1
Edunov et al., 2018	**Transformer + Back-Translation**	**35.0**

What if there is no Bilingual Data?

What if there is no Bilingual Data?

Unsupervised Word Translation

Unsupervised Word Translation

- *Cross-lingual word embeddings*
  - Shared embedding space for both languages
  - Keep the normal nice properties of word embeddings
  - But also want words close to their translations
- Want to learn from monolingual corpora

Unsupervised Word Translation

- Word embeddings have a lot of structure

- Assumption: that structure should be similar across languages

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Unsupervised Word Translation

- First run word2vec on monolingual corpora, getting words embeddings *X* and *Y*
- Learn an (orthogonal) matrix *W* such that *WX* ~ *Y*

Unsupervised Word Translation

- Learn *W* with *adversarial training.*
- Discriminator**:** predict if an embedding is from *Y* or it is a transformed embedding *Wx* originally from *X.*
- Train *W* so the Discriminator gets "confused"

Discriminator predicts: is the circled point red or blue?

obviously red

???

- Other tricks can be used to further improve performance, see Word Translation without Parallel Data

Unsupervised Machine Translation

Unsupervised Machine Translation

- Model: **same** encoder-decoder used for both languages
  - Initialize with cross-lingual word embeddings

Unsupervised Neural Machine Translation

- Training objective 1: de-noising autoencoder

Unsupervised Neural Machine Translation

- Training objective 2: back translation
  - First translate *fr* -> *en*
  - Then use as a “supervised” example to train *en* -> *fr*

Why Does This Work?

- Cross lingual embeddings and shared encoder gives the model a starting point

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Why Does This Work?

- Objectives encourage language-agnostic representation

Auto-encoder example

Back-translation example

Why Does This Work?

- Objectives encourage language-agnostic representation

Unsupervised Machine Translation

- Horizontal lines are unsupervised models, the rest are supervised

Lample et al., 2018

Attribute Transfer

- Collector corpora of “relaxed” and “annoyed” tweets using hashtags
- Learn un unsupervised MT model

Relaxed ↔ Annoyed	
Relaxed	Sitting by the Christmas tree and watching Star Wars after cooking dinner. What a nice night 💗🎄✨
Annoyed	Sitting by the computer and watching The Voice for the second time tonight. What a horrible way to start the weekend 😡😡😡
Annoyed	Getting a speeding ticket 50 feet in front of work is not how I wanted to start this month 😒
Relaxed	Getting a haircut followed by a cold foot massage in the morning is how I wanted to start this month 😊
Male ↔ Female	
Male	Gotta say that beard makes you look like a Viking...
Female	Gotta say that hair makes you look like a Mermaid...
Female	Awww he’s so gorgeous 😍 can’t wait for a cuddle. Well done 😘 xxx
Male	Bro he’s so f***ing dope can’t wait for a cuddle. Well done bro

Lample et al., 2019

Not so Fast

- English, French, and German are fairly similar

- On very different languages (e.g., English and Turkish)…
  - Purely unsupervised word translation doesn't work very. Need *seed dictionary* of likely translations.
    - Simple trick: use identical strings from both vocabularies

  - UNMT barely works

System	English-Turkish BLEU
Supervised	~20
Word-for-word unsupervised	1.5
UNMT	4.5

Hokamp et al., 2018

Not so Fast

Cross-Lingual BERT

Cross-Lingual BERT

Lample and Conneau., 2019

Cross-Lingual BERT

Lample and Conneau., 2019

Cross-Lingual BERT

Unsupervised MT Results

Model	En-Fr	En-De	En-Ro
UNMT	25.1	17.2	21.2
UNMT + Pre-Training	33.4	26.4	**33.3**
Current supervised State-of-the-art	**45.6**	**34.2**	29.9

Huge Models and GPT-2

Training Huge Models

Model	# Parameters
Medium-sized LSTM	10M
ELMo	90M
GPT	110M
BERT-Large	320M
GPT-2	1.5B

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This is a General Trend in ML

Huge Models in Computer Vision

Large Scale GAN Training for High Fidelity Natural Image Synthesis

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Jeff Donahue[†]
DeepMind
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Karen Simonyan[†]
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- 150M parameters

See also: thispersondoesnotexist.com

Huge Models in Computer Vision

GPipe: Efficient Training of Giant Neural Networks using Pipeline Parallelism

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- 550M parameters

ImageNet Results

Training Huge Models

- Better hardware
- Data and Model parallelism

Mesh-TensorFlow:
Deep Learning for Supercomputers

Noam Shazeer, Youlong Cheng, Niki Parmar,
Dustin Tran, Ashish Vaswani, Penporn Koanantakool, Peter Hawkins, HyoukJoong Lee
Mingsheng Hong, Cliff Young, Ryan Sepassi, Blake Hechtman
Google Brain
{noam, ylc, nikip, trandustin, avaswani, penporn, phawkins,
hyouklee, hongm, cliffy, rsepassi, blakehechtman}@google.com

GPT-2

- Just a really big Transformer LM

- Trained on 40GB of text
  - Quite a bit of effort going into making sure the dataset is good quality
  - Take webpages from reddit links with high karma

So What Can GPT-2 Do?

- Obviously, language modeling (but very well)!
- Gets state-of-the-art perplexities on datasets it's not even trained on!

	LAMBADA (PPL)	LAMBADA (ACC)	CBT-CN (ACC)	CBT-NE (ACC)	WikiText2 (PPL)	PTB (PPL)	enwik8 (BPB)	text8 (BPC)	WikiText103 (PPL)	1BW (PPL)
SOTA	99.8	59.23	85.7	82.3	39.14	46.54	0.99	1.08	18.3	**21.8**
117M	**35.13**	45.99	**87.65**	**83.4**	**29.41**	65.85	1.16	1.17	37.50	75.20
345M	**15.60**	55.48	**92.35**	**87.1**	**22.76**	47.33	1.01	**1.06**	26.37	55.72
762M	**10.87**	**60.12**	**93.45**	**88.0**	**19.93**	**40.31**	**0.97**	**1.02**	22.05	44.575
1542M	**8.63**	**63.24**	**93.30**	**89.05**	**18.34**	**35.76**	**0.93**	**0.98**	**17.48**	42.16

Radford et al., 2019

So What Can GPT-2 Do?

- **Zero-Shot Learning**: no supervised training data!
  - Ask LM to generate from a prompt

- **Reading Comprehension:** <context> <question> A:
- **Summarization:** <article> TL;DR:
- **Translation:**

  <English sentence1> = <French sentence1>

  <English sentence 2> = <French sentence 2>

  …..

  <Source sentence> =
- **Question Answering:** <question> A:

GPT-2 Results

How can GPT-2 be doing translation?

- It’s just given a big corpus of text that’s almost all English

How can GPT-2 be doing translation?

- It's just given a big corpus of text that's almost all English

"I'm not the cleverest man in the world, but like they say in French: **Je ne suis pas un imbecile [I'm not a fool].**

In a now-deleted post from Aug. 16, Soheil Eid, Tory candidate in the riding of Joliette, wrote in French: "**Mentez mentez, il en restera toujours quelque chose,**" which translates as, "**Lie lie and something will always remain.**"

"I hate the word '**perfume,**"' Burr says. 'It's somewhat better in French: '**parfum.**'

If listened carefully at 29:55, a conversation can be heard between two guys in French: "**-Comment on fait pour aller de l'autre coté? -Quel autre coté?**", which means "**- How do you get to the other side? - What side?**".

If this sounds like a bit of a stretch, consider this question in French: **As-tu aller au cinéma?**, or **Did you go to the movies?**, which literally translates as Have-you to go to movies/theater?

"**Brevet Sans Garantie Du Gouvernement**", translated to English: "**Patented without government warranty**".

GPT-2 Question Answering

- Simple baseline: 1% accuracy
- GPT-2: ~4% accuracy

- Cherry-picked most confident results

Question	Generated Answer	Correct	Probability
Who wrote the book the origin of species?	Charles Darwin	✓	83.4%
Who is the founder of the ubuntu project?	Mark Shuttleworth	✓	82.0%
Who is the quarterback for the green bay packers?	Aaron Rodgers	✓	81.1%
Panda is a national animal of which country?	China	✓	76.8%
Who came up with the theory of relativity?	Albert Einstein	✓	76.4%
When was the first star wars film released?	1977	✓	71.4%
What is the most common blood type in sweden?	A	✗	70.6%
Who is regarded as the founder of psychoanalysis?	Sigmund Freud	✓	69.3%
Who took the first steps on the moon in 1969?	Neil Armstrong	✓	66.8%
Who is the largest supermarket chain in the uk?	Tesco	✓	65.3%
What is the meaning of shalom in english?	peace	✓	64.0%
Who was the author of the art of war?	Sun Tzu	✓	59.6%
Largest state in the us by land mass?	California	✗	59.2%

What happens as models get even bigger?

- For several tasks performance seems to increase with log(model size)

What happens as models get even bigger?

- But trend isn't clear

GPT-2 Reaction

GPT-2 Reaction

Due to concerns about large language models being used to generate deceptive, biased, or abusive language at scale, we are only releasing a much smaller version of GPT-2 along with sampling code. We are not releasing the dataset, training code, or GPT-2 model weights. Nearly a year ago we wrote in the OpenAI Charter:

GPT-2 Reaction

NEWS SPORT ENTERTAINMENT SOAPS MORE TRENDING

UK WORLD WEIRD TECH

Elon Musk-founded OpenAI builds artificial intelligence so powerful it must be kept locked up for the good of humanity

Jasper Hamill Friday 15 Feb 2019 10:06 am

Machine-generated text is about to break the internet

Mark Rickerby | Guest writer

OpenAI built a text generator so good, it's considered too dangerous to release

Zack Whittaker @zackwhittaker / 3 weeks ago

Comment

GPT-2 Reaction

Just wanted to give you all a heads up, our lab found an amazing breakthrough in language understanding. but we also worry it may fall into the wrong hands. so we decided to scrap it and only publish the regular *ACL stuff instead. Big respect for the team for their great work.

10:08 AM - 15 Feb 2019

118 Retweets **782** Likes

29 118 782

625

Posted by u/astonished_crofty 25 days ago 2

[Discussion] Should I release my MNIST model or keep it closed source fearing malicious use?

Discussion

Today I trained a 23064 layer ResNet and it got 99.6% accuracy on MNIST. I would love to share the model but I fear it being used maliciously. What if it is used to read documents by the Russians? What are your thoughts?

GPT-2 Reaction

OpenAI: Please Open Source Your Language Model

19.FEB.2019

Hugh Zhang

Stanford University

OpenAI Shouldn't Release Their Full Language Model

03.MAR.2019

Eric Zelikman

GPT-2 Reaction

Some arguments for release:

Some arguments against:

GPT-2 Reaction

Some arguments for release:

- This model isn't much different from existing work
- Not long until these models are easy to train
  - And we're already at this point for images/speech
- Photoshop
- Researchers should study this model to learn defenses
- Dangerous PR Hype
- Reproducibility is crucial for science
- …

Some arguments against:

- Danger of fake reviews, news comments, etc.
  - Already done by companies and governments
- Precedent
  - Event if this model isn't dangerous, later ones will be even better
- Smaller model is being released
- ….

GPT-2 Reaction

Smerity
@Smerity

Today's meta-Twitter summary for machine learning:
None of us have any consensus on what we're doing when it comes to responsible disclosure, dual use, or how to interact with the media.
This should be concerning for us all, in and out of the field.

462 8:17 PM - Feb 14, 2019

169 people are talking about this

GPT-2 Reaction

- Should NLP experts be the ones making these decisions?
  - Experts on computer security?
  - Experts on technology and society?
  - Experts on ethics?

- Need for more interdisciplinary science

- Many other examples of NLP with big social ramifications, especially with regards to bias/fairness

High-Impact Decisions

- Growing interest in using NLP to help with high-impact decision making
  - Judicial decisions
  - Hiring
  - Grading tests

- Plus side: can quickly evaluate a machine learning system for some kinds of bias

- However, machine learning reflects or even amplifies bias in training data
  - …which could lead to the creation of even more biased data

High-Impact Decisions

BUSINESS NEWS OCTOBER 9, 2018 / 8:12 PM / 5 MONTHS AGO

Amazon scraps secret AI recruiting tool that showed bias against women

Jeffrey Dastin

8 MIN READ

Intelligent Machines

AI is sending people to jail—and getting it wrong

Using historical data to train risk assessment tools could mean that machines are copying the mistakes of the past.

High-Impact Decisions

Ben Zimmer @bgzimmer · 2 Jul 2018

This gobbledygook earns a perfect grade from the GRE's automated essay scoring system. Algorithms writing for algorithms. npr.org/2018/06/30/624…

> *"History by mimic has not, and presumably never will be precipitously but blithely ensconced. Society will always encompass imaginativeness; many of scrutinizations but a few for an amanuensis. The perjured imaginativeness lies in the area of theory of knowledge but also the field of literature. Instead of enthralling the analysis, grounds constitutes both a disparaging quip and a diligent explanation."*

51 636 1.1K

Chatbots

- Potential for positive impact

- But big risks

What did BERT “solve” and what do we work on next?

GLUE Benchmark Results

The Death of Architecture Engineering?

Some SQuAD NN Architectures

The Death of Architecture Engineering?

Some SQuAD NN Architectures

Attention Is All You Need

The Death of Architecture Engineering?

- 6 months of research on architecture design, get 1 F1 point improvement
- … Or just make BERT 3x bigger, get 5 F1 points
- Top 20 entrants on the SQuAD leaderboard all use BERT

	Human Performance *Stanford University* (Rajpurkar & Jia et al. '18)	86.831	89.452
1 Mar 05, 2019	BERT + N-Gram Masking + Synthetic Self-Training (ensemble) *Google AI Language* https://github.com/google-research/bert	**86.673**	**89.147**
2 Mar 05, 2019	BERT + N-Gram Masking + Synthetic Self-Training (single model) *Google AI Language* https://github.com/google-research/bert	85.150	87.715
3 Jan 15, 2019	BERT + MMFT + ADA (ensemble) *Microsoft Research Asia*	85.082	87.615
4 Jan 10, 2019	BERT + Synthetic Self-Training (ensemble) *Google AI Language* https://github.com/google-research/bert	84.292	86.967
5 Dec 16, 2018	Lunet + Verifier + BERT (ensemble) *Layer 6 AI NLP Team*	83.469	86.043
5 Dec 21, 2018	PAML+BERT (ensemble model) *PINGAN GammaLab*	83.457	86.122
5 Dec 13, 2018	BERT finetune baseline (ensemble) *Anonymous*	83.536	86.096
6 Mar 04, 2019	SemBERT (ensemble model) *Shanghai Jiao Tong University*	83.243	85.821
6 Jan 14, 2019	BERT + MMFT + ADA (single model) *Microsoft Research Asia*	83.040	85.892
7 Jan 10, 2019	BERT + Synthetic Self-Training (single model) *Google AI Language* https://github.com/google-research/bert	82.972	85.810

Harder Natural Language Understanding

- Reading comprehension…
  - On longer documents or multiple documents
  - That requires multi-hop reasoning
  - Situated in a dialogue

- Key problem with many existing reading comprehension datasets: *People writing the questions see the context*
  - Not realistic
  - Encourages easy questions

QuAC: Question Answering in Context

- Dialogue between a student who asks questions and a teacher who answers
  - Teacher sees Wikipedia article on the subject, student doesn't

Section: Daffy Duck, Origin & History

STUDENT: **What is the origin of Daffy Duck?**
TEACHER: ↪ first appeared in Porky's Duck Hunt
STUDENT: **What was he like in that episode?**
TEACHER: ↪ assertive, unrestrained, combative
STUDENT: **Was he the star?**
TEACHER: ↪ No, barely more than an unnamed bit player in this short
STUDENT: **Who was the star?**
TEACHER: ↛ No answer
STUDENT: **Did he change a lot from that first episode in future episodes?**
TEACHER: ↪ Yes, the only aspects of the character that have remained consistent (...) are his voice characterization by Mel Blanc
STUDENT: **How has he changed?**
TEACHER: ↪ Daffy was less anthropomorphic
STUDENT: **In what other ways did he change?**
TEACHER: ↪ Daffy's slobbery, exaggerated lisp (...) is barely noticeable in the early cartoons.
STUDENT: **Why did they add the lisp?**
TEACHER: ↪ One often-repeated "official" story is that it was modeled after producer Leon Schlesinger's tendency to lisp.
STUDENT: **Is there an "unofficial" story?**
TEACHER: ↪ Yes, Mel Blanc (...) contradicts that conventional belief
. . .

Choi et al., 2018

QuAC: Question Answering in Context

- Still a big gap to human performance

Rank	Model	F1	HEQQ	HEQD
	Human Performance (Choi et al. EMNLP '18)	81.1	100	100
March 7, 2019	BERT w/ 2-context (single model) *NTT Media Intelligence Labs*	**64.9**	60.2	**6.1**
2 Feb 21, 2019	GraphFlow (single model) *Anonymous*	**64.9**	**60.3**	5.1
3 Sep 26, 2018	FlowQA (single model) *Allen Institute of AI* https://arxiv.org/abs/1810.06683	64.1	59.6	5.8
4 Jan 30, 2019	BERT + History Answer Embedding (single model) *Anonymous*	62.4	57.8	5.1
5 Aug 20, 2018	BiDAF++ w/ 2-Context (single model) *baseline*	60.1	54.8	4.0
6 Aug 20, 2018	BiDAF++ (single model) *baseline*	50.2	43.3	2.2

HotPotQA

- Designed to require *multi-hop reasoning*
- Questions are over *multiple documents*

Paragraph A, Return to Olympus:
[1] *Return to Olympus is the only album by the alternative rock band Malfunkshun.* [2] *It was released after the band had broken up and after lead singer Andrew Wood (later of Mother Love Bone) had died of a drug overdose in 1990.* [3] Stone Gossard, of Pearl Jam, had compiled the songs and released the album on his label, Loosegroove Records.

Paragraph B, Mother Love Bone:
[4] *Mother Love Bone was an American rock band that formed in Seattle, Washington in 1987.* [5] The band was active from 1987 to 1990. [6] *Frontman Andrew Wood's personality and compositions helped to catapult the group to the top of the burgeoning late 1980s/early 1990s Seattle music scene.* [7] *Wood died only days before the scheduled release of the band's debut album, "Apple", thus ending the group's hopes of success.* [8] The album was finally released a few months later.

Q: What was the former band of the member of Mother Love Bone who died just before the release of "Apple"?
A: Malfunkshun
Supporting facts: 1, 2, 4, 6, 7

Figure 1: An example of the multi-hop questions in HOTPOTQA. We also highlight the supporting facts in *blue italics*, which are also part of the dataset.

Zang et al., 2018

HotPotQA

- Human performance is above 90 F1

	Model	Code	Ans	
			EM	F_1
1 Nov 21, 2018	QFE (single model) *NTT Media Intelligence Laboratories*		53.86	68.06
2 Mar 4, 2019	GRN (single model) *Anonymous*		52.92	66.71
3 Mar 1, 2019	DFGN + BERT (single model) *Anonymous*		55.17	68.49
4 Mar 4, 2019	BERT Plus (single model) *CIS Lab*		**55.84**	**69.76**
5 Oct 10, 2018	Baseline Model (single model) *Carnegie Mellon University, Stanford University, & Universite de Montreal* (Yang, Qi, Zhang, et al. 2018)		45.60	59.02
- Feb 27, 2019	DecompRC (single model) *Anonymous*		55.20	69.63

Multi-Task Learning

- Another frontier of NLP is getting one model to perform many tasks. GLUE and DecaNLP are recent examples.

- Multi-task learning yields improvements on top of BERT

Rank	Name	Model	URL	Score
1	GLUE Human Baselines	GLUE Human Baselines		87.1
2	王玮	ALICE large (Alibaba DAMO NLP)		83.0
3	Microsoft D365 AI & MSR AI	MT-DNNv2 (BigBird)		83.0
4	Jason Phang	BERT on STILTs		82.0
5	Jacob Devlin	BERT: 24-layers, 16-heads, 1024-hid		80.5

BERT + Multi-task

Low-Resource Settings

- Models that don’t require lots of compute power (can’t use BERT)!
  - Especially important for mobile devices
- Low-resource languages
- Low-data settings (few shot learning)
  - Meta-learning is becoming popular in ML.

Interpreting/Understanding Models

- Can we get explanations for model predictions?
- Can we understand what models like BERT know and why they work so well?

- Rapidly growing area in NLP
- Very important for some applications (e.g., healthcare)

Diagnostic/Probing Classifiers

- Popular technique to see what linguistic information models "know"
- Diagnostic classifier takes representations produced by a model (e.g., BERT) as input and do some task

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- Diagnostic classifier takes representations produced by a model (e.g., BERT) as input and do some task
- Only the diagnositic classifier is trained

Diagnostic/Probing Classifiers

- Diagnostic classifiers are usually very simple (e.g., a single softmax). Otherwise they could learn to do the tasks without looking at the model representations

- Some diagnostic tasks

POS	The important thing about Disney is that it is a global [brand]$_1$. $\rightarrow$ NN (Noun)
Constit.	The important thing about Disney is that it [is a global brand]$_1$. $\rightarrow$ VP (Verb Phrase)
Depend.	[Atmosphere]$_1$ is always [fun]$_2$ $\rightarrow$ nsubj (nominal subject)
Entities	The important thing about [Disney]$_1$ is that it is a global brand. $\rightarrow$ Organization
SRL	[The important thing about Disney]$_2$ [is]$_1$ that it is a global brand. $\rightarrow$ Arg1 (Agent)
SPR	[It]$_1$ [endorsed]$_2$ the White House strategy... $\rightarrow$ {awareness, existed_after, ...}
Coref.^{O}	The important thing about [Disney]$_1$ is that [it]$_2$ is a global brand. $\rightarrow$ True
Coref.^{W}	[Characters]$_2$ entertain audiences because [they]$_1$ want people to be happy. $\rightarrow$ True Characters entertain [audiences]$_2$ because [they]$_1$ want people to be happy. $\rightarrow$ False
Rel.	The [burst]$_1$ has been caused by water hammer [pressure]$_2$. $\rightarrow$ Cause-Effect(e_2, e_1)

Diagnostic/ Probing Classifiers: Results

- Lower layers of BERT are better at lower-level tasks

NLP in Industry

- NLP is rapidly growing in industry as well. Two particularly big areas:

- Dialogue
  - Chatbots
  - Customer service

- Healthcare
  - Understanding health records
  - Understanding biomedical literature

Conclusion

- Rapid progress in the last 5 years due to deep learning.
- Even more rapid progress in the last year due to larger models, better usage of unlabeled data
  - Exciting time to be working on NLP!
- NLP is reaching the point of having big social impact, making issues like bias and security increasingly important.

Good luck with your projects!