CTRL: A Conditional Transformer Language Model For Controllable Generation

논문

- https://arxiv.org/abs/1909.05858

코드

- https://github.com/salesforce/ctrl (salesforce)
- https://huggingface.co/transformers/model_doc/ctrl.html (huggingface)
- https://colab.research.google.com/drive/1hVveBQShDru1Mjnhe4C21uQv4A2eH1tV (google collaboratory)

블로그

- https://blog.einstein.ai/introducing-a-conditional-transformer-language-model-for-controllable-generation/
- https://minimaxir.com/2019/09/ctrl-fake-news/

책

- 한국어 임베딩

Contents

Abstract

- 모델의 크기가 커질수록 NLU(Natural Language Generation) 능력도 올라가는 경향이 있으나, 사용자가 의도한 대로 문장을 생성하기는 어려움이 있음
- 1.63 billion hyperparameters 의 **CTRL(Conditional Transformer Language Model For Controllable Generation)** 모델 제시, **control code** 라는 부분을 훈련 시 사용함으로써 기존 비지도 텍스트 생성 효과(zero-shot setting)를 유지하면서도, 특정 태스크에 관련된 행동을 (의도한 대로) 제어하는 효과가 있음

  * **GPT-2** : 774M hyperparameters
- 이는 대량의 데이터와 Language Model 과의 correlations analytics 으로 활용할 수 있는 방법임
- **NLU 계열(BERT, Auto Encoding)** 논문이 주류(?)인 시점에서 **NLG 계열(GPT, Auto Regressive)**의 Next Step을 제안한 논문으로 가치가 있음(?)
- **Goal** : '***제멋대로 글쓰는 녀석을 길들여보자.***'

  * https://pcc.cs.byu.edu/2019/11/21/ai-dungeon-2-creating-infinitely-generated-text-adventures-with-deep-learning-language-models/

  (**GPT-2** 모델을 이용한 대화 게임 ⇒ **CTRL** 기법을 사용하여 문장 생성 시 co-occur 텍스트에 대해 **penalty** 를 주는데 사용)

1. Introduction

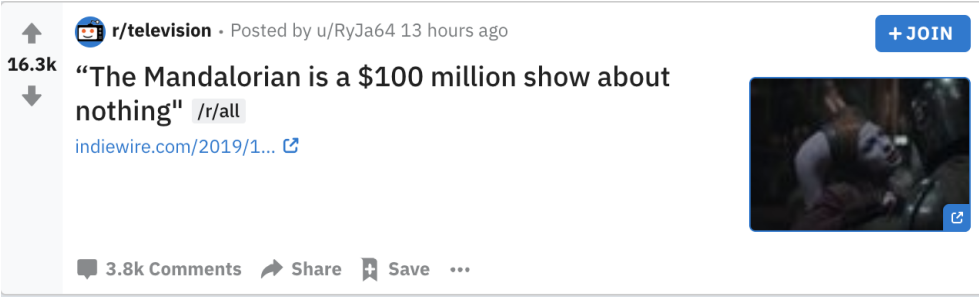
- 이미지와 텍스트 분야에서 이전부터 조건을 주어 훈련(conditional training)하려는 여러 시도들이 있었음

(여러 논문들 사례 소개)

- **Conditional Transformer Language(CTRL)** 모델은 **control code**와 함께 대량의 텍스트를 훈련

  (특정 도메인, 스타일, 토픽, 날짜, 엔티티들 사이의 관계, 특정 태스크와 연관된 행동, 이야기의 방향 등)

- 비지도학습(zero-shot setting)으로 인한 일반화 학습을 수행하면서도 대량의 텍스트 데이터로부터 **함께 발생(co-occur)**하는 부분을 추출하여 **control code** 로 지정하여 학습 진행
  ⇒ **사용자가 예측한 대로 문장을 생성**해주는 효과
  - **대량**의 텍스트(Wikipedia, Amazon Reviews 등)은 주제 도메인과 관련 부분 주입
  - **소량**의 텍스트(Reddit 등)은 sub URL(*r/subdomain*)의 정보 주입 (최종 텍스트는 약간 수정)



- **control code** 는 **training data로부터 중요한 부분을 추적**할 수 있기 때문에 모델과 대량의 데이터 사이의 **도메인과 상관관계(correlations)가 있는 부분**을 분석하여 활용할 수 있음
- https://github.com/salesforce/ctrl (**Pre-trained 버전** 공개)

2. Language Modeling with CTRL

2.1 Language Modeling (AS-IS)

- **목표** : 텍스트 시퀀스(*X1, ..., Xn*)으로부터 *P(x)*를 학습하는 것 (Auto Regressive)

$$p(x) = \prod_{i=1}^{n} p(x_i|x_{<i})$$

- **다음 단어 예측** : dataset *D* 로부터 Negative Log Likelihood(NLL) 최소화하기

(=~ **cross-entropy loss function**)

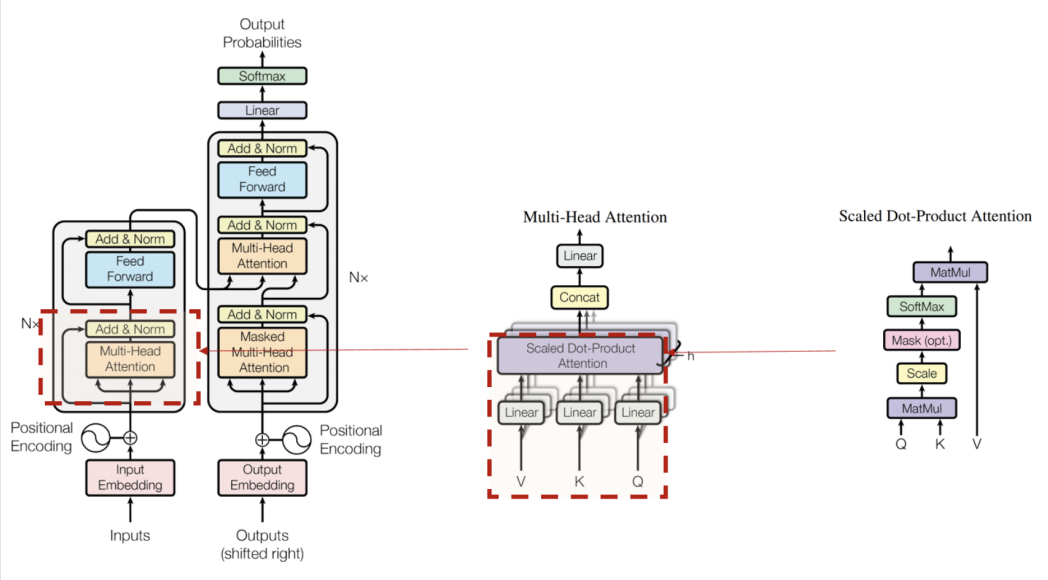
$$\mathcal{L}(D) = -\sum_{k=1}^{|D|} \log p_\theta(x_i^k | x_{<i}^k)$$

2.2 Language Modeling with CTRL (TO-BE)

- 위 식에서 control code(***c***)가 추가된 조건부 확률분포(***p(x|c)***)로 교체

$$p(x|c) = \prod_{i=1}^{n} p(x_i | x_{<i}, c) \qquad \mathcal{L}(D) = -\sum_{k=1}^{|D|} \log p_\theta(x_i^k | x_{<i}^k, c^k)$$

2.3 모델 아키텍처 (Original Transformer Architecture(Decoder) 와 유사)



Original Transformer Architecture (*Attention is All You Need, 2017*)

- **1st block**

- **multi-head attention** with *k* heads that uses a casual **mask** to **preclude** attending to future tokens
- **Scaled Dot-Product Attention**
  - *X(Q)*, *Y(K)*를 내적 → *d*의 제곱근으로 나누고 Softmax → 확률값을 *Z(V)*에 weighted sum
  - 예측해야 할 단어를 보지 않기 위해 Softmax score 일부 값을 (-)무한대 로 설정 (**masked** attention)
  - **Self-Attention(dot-product|attention|scale)** ⇒ '같은 문장 내 모든 단어간의 관계'를 알아냄
- **Multi-Head Attention**
  - Scaled Dot-Product Attention을 여러 번(*k*) 수행 → 각 head의 결과를 concat 하여 긴 행렬 구성 → *Z*를 내적하여 행렬의 크기를 Scaled Dot-Product Attention의 입력 행렬과 동일하게 맞춤
  - '동일한 문장을 여러 명의 독자가 검토'하는 효과

$$\text{Attention}(X, Y, Z) = \text{softmax}\left(\frac{\text{mask}(XY^\top)}{\sqrt{d}}\right)Z$$

$$\text{MultiHead}(X, k) = [h_1; \cdots; h_k]W_o$$

$$\text{where } h_j = \text{Attention}(XW_j^1, XW_j^2, XW_j^3)$$

Scaled Dot-Product Attention(위) / Multi-Head Attention(아래)

- **2nd block**
  - **feedforward network** with **ReLU** activation that projects input to an inner dimension *f*, with parameters *U* and *V*
  - 1st block 결과로 나온 행렬의 단어 벡터(*X*) 각각에 아래 식 **선형 변환(linear transformation)** 수행

$$FF(X) = \max(0, XU)V$$

- **other blocks**
  - **layer normalization** with **residual connection** → training time 감소, vanishing gradient 완화 효과

Block 1

$$\bar{X}_i = \text{LayerNorm}(X_i)$$
$$H_i = \text{MultiHead}(\bar{X}_i) + \bar{X}_i$$

Block 2

$$\bar{H}_i = \text{LayerNorm}(H_i)$$
$$X_{i+1} = \text{FF}(\bar{H}_i) + \bar{H}_i$$

- **last block**
  - **scores** for **each token** in the **vocabulary** are **computed** from **output** of the **last layer**

$$\text{Scores}(X_0) = \text{LayerNorm}(X_l)W_{vocab}$$

* **scores**는 **training** 할때는 **cross-entropy loss function의 input**으로, **generation(inference)** 할때는 새로운 token 분포를 나타내는 **softmax** 형태로 활용

- **Data**
  - **140 GB** 텍스트로 훈련시킴 (아래 테이블 참고)

Control Code	Description
Wikipedia	English Wikipedia
Books	Books from Project Gutenberg
Reviews	Amazon Reviews data (McAuley et al., 2015)
Links	OpenWebText (See Sec. 3.2)
Translation	WMT translation date (Barrault et al., 2019)
News	News articles from CNN/DailyMail Nallapati et al. (2016), New York Times and Newsroom (Grusky et al., 2018)
multilingual	Wikipedias in German, Spanish and French
Questions	(Questions and answers only) MRQA shared task (See Section 3.1)
Explain	(Only main post) (Fan et al., 2019)
Sub-reddit data (Title, Text and Score/Karma) collected from `pushshift.io`.	
Alone	`r/childfree`
Atheism	`r/atheism`
Christianity	`r/christianity`
Computing	`r/computing`
Confession	`r/offmychest`
Confessions	`r/confession`
Conspiracy	`r/conspiracy`
Diet	`r/keto`
Extract	`r/childfree`
Feminism	`r/twoxchromosome`
Finance	`r/personalfinance`
Fitness	`r/fitness`
Funny	`r/funny`
Gaming	`r/gaming`
Horror	`r/nosleep`
Human	`r/nfy`
India	`r/india`
Joke	`r/jokes`
Joker	`r/joke`
Learned	`r/todayilearned`
Legal	`r/legaladvice`
Movies	`r/movies`
Netflix	`r/netflix`
Norman	`r/lifeofnorman`
Notion	`r/unpopularopinion`
Opinion	`r/changemyview`
Politics	`r/politics`
Pregnancy	`r/babybumps`
Relationship	`r/relationshipadvice`
Relationships	`r/relationships`
Retail	`r/talesfromretail`
Running	`r/running`
Saving	`r/frugal`
Scary	`r/scaryshortstories`
Science	`r/science`
Technologies	`r/technology`
Teenage	`r/teenager`
Thoughts	`r/showerthoughts`
Tip	`r/lifeprotips`
Weight	`r/loseit`
Writing	`r/writingprompts`

- **Experimental Settings**
  - (*C++*로 구현된) **fastBPE** (vocab size : **250K** tokens)
  - Pre-processing 시 '2개 이상의 unknown token'은 문장을 지움
    (180GB → 140GB 감소 효과)

- **새로운 도메인 문서가 등장하는 경우, 문장의 접두어(prefix)로 control code 추가**
- Sequence length (**256** tokens)
- Dimension d = **1280**, inner dimension f = **8192**, **48** layers, and **16** heads per layer
- Dropout **0.1**
- Batch size **1024**
- **256** cores of a Cloud **TPU v3** Pod (**800k** iterations, **2** weeks)
- **Adagrad**
  - **warm up** from 0 to 0.05 over 25k steps (대규모 데이터/모델 시 사용하는 기법)
  - Adam, SM3, Adafactor, NovoGrad Optimizer 대비 메모리 절약 효과가 있었음
  - '*안 가본 곳은 (용감하게) 보폭을 크게, 많이 가본 곳은 보폭을 작게*'
- Gradient Clipping **0.25** (gradient exploding 방지)

3. Controllable Generation

3.1 Sampling (AS-IS)

- **temperature-controlled stocastic sampling** method (=~ **Softmax score**)
  - 훈련된 언어 모델로부터 텍스트 생성 시 사용 (inference)
  - top-k sampling 후보 중 가장 높은 확률의 값을 선택 (k 값은 휴리스틱 정보)
  - T 가 작을 수록(0에 가까울수록) **greedy distribution**, T 가 커질수록(무한대에 가까울수록) **uniform distribution** 의 형태를 띰
  - greedy distributuon 은 **같은 토큰을 반복**하는 문제, uniform distribution은 **오답 생성 가능성**을 내포하고 있는 문제가 있음

$$p_i = \frac{\exp(x_i/T)}{\sum_j \exp(x_j/T)}.$$

temperature-controlled stocastic sampling　　*T*(Temperature), *xi*(Score), *i*(token in vocab)

3.2 Sampling (TO-BE, CTRL)

- **penalized sampling**
  - **near-greedy sampling** (*k*는 작게) → 오답 생성 가능성 최소화
  - 문장 생성 시 **이전에 생성된 토큰 정보에 대해서는 penalty 를 줌 → 같은 토큰을 반복하는 문제 최소화**
  - '*coverage mechanisms*' 과 '*discourage repetition*' 부분에서 영감을 받았다고 함 (*Get To The Point(Google Brain, 2017)* → https://arxiv.org/pdf/1704.04368.pdf)
  - **training 시에는 사용하지 않음**, ***I(c)***가 **1.2** 정도일 때 좋은 효과가 있었음 (휴리스틱 정보)

$$p_i = \frac{\exp(x_i/(T \cdot I(i \in g))}{\sum_j \exp(x_j/(T \cdot I(j \in g))} \qquad I(c) = \theta \text{ if c is True else } 1$$

penalized sampling, *g*(generated tokens)

3.3 Examples of Fake News (/w Control Code)

- *Case 1>* **Style by domain** : control code를 통한 **텍스트 생성 '방향'** 제시

Horror *A knife* handle pulled through the open hole in the front. I jumped when the knife hit.\n\nEyes widened in horror. Her scream was the only sound I heard besides her sobs.\n\nThe spider touched her feet as it started to dig into the top of her arch. The creature's tears began to flow.\n\nThe spider looked up to her and looked back at me with eyes filled with burning tears. My heart started to race. . .

Reviews *A knife* is a tool and this one does the job well.\n\nRating: 4.0\n\nI bought these for my husband who has been using them to cut up his own meat since he got them. He says they are very sharp so be careful when you use them, but that doesn't seem like much of an issue because he's used it on everything from chicken breasts to beef tenderloin. . .

Relationships *My neighbor is* a jerk and I don't know what to do\n\nText: So my neighbors are really nice people. They have been for years. We live in an apartment complex so we get along great.\n\nBut recently they started acting like jerks. . .

control code allow for predictable variation in generation.

- *Case 2>* **More complex control codes** : **좀 더 자세한** control code로 **더 '제한된'** 텍스트 생성 방향 제시

Science Title: Scientists have discovered a new type of bacteria that can survive in the presence of high levels of carbon dioxide\nText:[Link to article] (http://news.nationalgeographic.com/news/2011/07/110717-methane-bacteria-carbon-dioxide-environment-science/)\n\nThe researchers found that this particular strain of methane bacterium is able to thrive at concentrations up to 10 times higher than normal atmospheric levels.\n\nThey also note that these findings are consistent with previous research showing that some types of microbes may be capable of surviving under extreme conditions such as those associated with global warming.

Politics Title: The US is the only country in history to have a national debt of more than $20 trillion.\nText: I know this isn't exactly an accurate representation but it gives you some idea how much money we are talking about.\n\nhttp://en.wikipedia.org/wiki/National_debt#United_States

Running Text: I have been running for about a year and a half now but never really got into it.\n\n This past weekend was my first time doing it in the last few months.\n\n My goal is to run at least 3 miles every day this week.

contol codes can be combined to provide finer-grained control.

Links https://www.cnn.com/2007/09/20/us-president-meets-british-pm LONDON, England (CNN) – U.S. President George W. Bush met with British Prime Minister Tony Blair on Monday to discuss the war in Iraq, according to a statement from Blair's office.\n\nThe meeting was held at 10 Downing Street and lasted about an hour.\n\n"The two leaders discussed Iraq and other international issues of mutual concern," said Blair.\n\nBush, who is scheduled to meet Wednesday with Russian President Vladimir Putin, will also visit Germany for talks later this week.\n\nIn his statement, Blair said, "We agreed that we should continue our efforts together to bring peace and stability to Iraq. We both reaffirmed our commitment to working closely together, as well as to continuing to work constructively toward achieving lasting security and prosperity throughout the Middle East region."\n\nBush's trip comes after he visited Britain last week where he spoke out against terrorism while visiting Buckingham Palace.\n\nHe has been criticized by some lawmakers over what they say are insufficient military resources being devoted to fighting terrorism.

Links https://www.cnn.com/2014/09/20/us-president-meets-british-pm JUST WATCHED\n\nObama meets with British PM\n\nMUST WATCH\n\nStory highlights\n\nPresident Barack Obama met with Britain's Prime Minister David Cameron

Links https://www.cnn.com/2018/09/20/us-president-meets-british-pm JUST WATCHED\n\nTrump and May meet for first time\n\nMUST WATCH\n\nWashington (CNN) President Donald Trump, who has been criticized by some in the UK over his decision to leave the European Union, met with British Prime Minister Theresa May, a White House official said on Thursday.

Links https://www.cnn.com/09/20/2018/star-spotted JUST WATCHED\n\nStar spotted: The world's most elusive star\n\nMUST WATCH\n\nStory highlights\n\nA new study suggests that the Milky Way is home to a supermassive black hole\n\nIt may be one of our closest galactic neighbors\n\n(CNN) Astronomers have discovered what they believe could be an extremely rare astronomical event: An object so bright it can only be seen with powerful telescopes.\n\nThis object, dubbed SN2014J, was first detected by NASA's Spitzer Space Telescope in 2014. . . .

Links https://www.etonline.com/09/20/2018/star-spotted\n\nEXCLUSIVE: Star Spotted in New York City\n\nBy Kelly Marot — September 20, 2018 10:51 AM PDT\n\nGetty Images\n\nThe star of the new season of Stranger Things is making a splash on her own turf and its not even Halloween.\n\nWinona Ryder has been seen out and about with friends at night time in Manhattan this week, E! News can exclusively reveal.\n\nA source tells us, She was hanging around with some friends, but she wasnt doing anything too crazy. She just wanted to get away from it all for a little bit.. . .

Links provide a way to specify domain, subdomain, entities, entry relations and even date.

- *Case 3>* **Triggering specific tasks** : control code 를 통해 **수행할 Task 명시 (e.g. QA, MT)**

Questions *Q: What is the capital of India?* A: New Delhi\n\nQ: Which city in India has a large population of people from Gujarat?\n\nA: Ahmedabad\n\nQ: How many languages are spoken by Indians living abroad?\n\nA: more than 100. . .

Translation English : *We release a new model for coherent language generation* ; French : Nous publions un nouveau modéle de génération cohérente du langage\n\nEnglish : The European Parliament has just adopted the report on the proposal for a regulation of the European Parliament and of the Council establishing an action programme to promote multilingualism in Europe. ; French : Le Parlement européen vient d'adopter le rapport sur la proposition de règlement du Parlement et du Conseil établissant un programme-cadre pour promouvoir le pluriling uisme dans l'Union européenne. . .

templatized control codes are used for task-specific generation.

- *Case 4>* **Zero-shot code-mixing** : **control code 를 삽입**하여 텍스트 생성의 **방향성 전환** 가능

Diet English : *I lost 10 kgs!* ; German : Ich habe 10 Kilogramm verloren!\n\nEnglish : It is a great achievement for me and my family. ; German : Das ist eine groe Leistung fr mich und meine Familie.\n\nEnglish : Thank you very much to all the people who have helped me. ; German : Vielen Dank an alle, die mir geholfen haben.. . .

Politics Title: *Les Etats-Unis sont un* pays de droite\n\nText: Je suis Américain et je ne peux pas supporter ce que font les USA en matière d'immigration\n\nJ'ai déjà écrit sur le sujet mais il n'y a aucune réaction http://www.reddit.com/r/politics/comments/1tqjzw/les_etats_unes_son_tres-de-gauche/ ...

some codes can be mixed to generate text with novel **cross-over behavior**.

4. Source Attribution

- **Source Attribution** : '생성된 텍스트'가 '어떤 Domain Control Code 에 영향을 받았는지' 확인 가능

  (생성된 문장의 귀인 이론 (attribution theory))

- '*생성된 텍스트(x)일 때 control code(c)의 확률 =~ control code(c)일 때 생성된 텍스트(x)이고, control code(c)가 발생할 확률*'

$$p_\theta(c|x) \propto p_\theta(x|c)p(c)$$

- **점(.)** 하나의 차이로 **Sensitive** 하게 반응함.
- Source attribution은 ~~veracity(진실성) 측정 단위는 아님~~, **생성된 문장과의 연관된 도메인 token 정보**를 알 수 있을 뿐.

Query Prompt	Attributed Sources
Global warming is a lie.	r/unpopularopinion, r/conspiracy, r/science
Global warming is a lie	r/eli5, r/science, r/unpopularopinion
Global warming is a real phenomenon	r/eli5, r/science, r/changemyview
Global warming is a real phenomenon.	OpenWebText, r/changemyview, r/science

We probe CTRL for learned **correlations** between sequences and domains. **/eli5** stands for "Explain like I'm five"- a subgroup on reddit.

5. Future Directions

- **More control codes and finer-grained control**
  - 좀 **더 다양한 형태**의 Control Code
- **Extensions to other areas in NLP**
  - 좀 **더 다양한 환경**에 적용 (Trivia-style QA, Small data, Multilingual language model 등)
- **Analyzing the relationships between language models and training data**
  - **모델과 훈련 데이터 간 상관관계를 분석**하는 도구로 활용 (Source Attribution)
- **Making the interface between humans and language models more explicit and intuitive**
  - **인간과 언어 모델 사이의 인터페이스** 역할을 할 것이라고 기대함

Conclusion

- **CTRL**(based on **Transformer Decoder**)은 엄청 큰 데이터 언어 모델에서 효과적임 (**1.63** billion hyperparameters)
- **control code** 와 함께 training (inference 시에는 **penalized sampling**) → 사람의 의도대로 제어(control) 하는 효과, domain specific adaptation 잘 됨
- **Goal** : '***제멋대로 글쓰는 녀석을 길들여보자.***'
- "**D**o **N**o **H**arm and **J**ust **W**orld **L**icenses" (The **Ethics** of Large Language Models)
- ctrl-monitoring@salesforce.com

References

- https://arxiv.org/abs/1909.05858
- https://github.com/salesforce/ctrl
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