Fine-tuning On Rationale Generation Improves Multi-Hop Reasoning in Small Language Models

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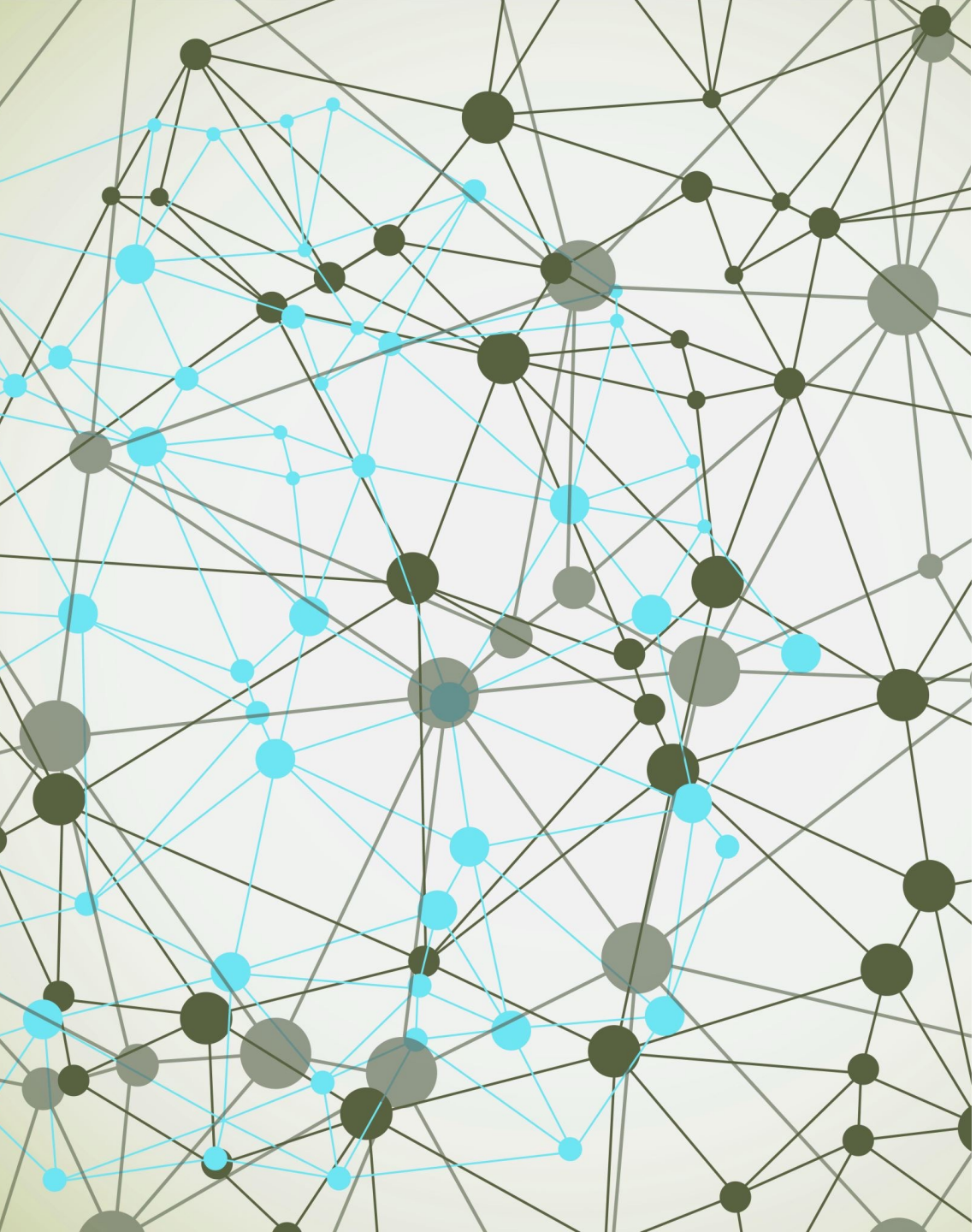
Who was the president in office when the second Star Wars movie played in theaters?

Introduction

- Question: Who was the president in office when the second Star Wars movie played in theaters?
  - Step 1: When was the second Star Wars movie played in theaters?
    - 1980
  - Step 2: Who was the US president in 1980?
    - Jimmy Carter
  - The final answer to the original question: Jimmy Carter
- Chain-of-Thought (CoT) rationale can help to answer multi-hop questions.
  - Self-Ask has impressive results on large GPT-3 models (175B parameters)

https://www.imdb.com/title/tt0080684/

https://en.wikipedia.org/wiki/Jimmy_Carter



Introduction

- What if we use encoder-decoder architecture?
- How about smaller language models?
- Can we make it better by fine-tuning it?
- Focus on smaller language models
  - T5 small (60M)
  - Flan-T5 small (60M) – Instruction tuned T5
  - OPT (125M) – Open-Source LM similar to GPT-3
- Pay attention to both question answering as well as rationale generation

Creating our datasets

Base Dataset: 2WikiMultiHopQA

200,000 multi-hop reasoning questions generated from Wikipedia

- Predominantly concerning the date of birth, lifespan, country of origin, and familial relationships of historical figures and celebrities

Dataset Modifications

Fine-tuning datasets: direct no exemplars and self-ask with exemplars

Fine-tuning Datasets Examples

Direct	Self-Ask with Exemplars
Prompt	Prompt
Facts: Fact #0: The film was written, adapted and directed by Russian-born Arcady Boytler. Fact #1: Boytler was born in Moscow, Russia. Question: Where was the director of film Heads Or Tails (1937 Film) born? Answer:	START Question: Who was born first, Alejo Mancisidor or Emil Leyde? Are follow up questions needed here: Yes. Follow up: When is the date of birth of Alejo Mancisidor? Intermediate answer: 31 July 1970 Follow up: When is the date of birth of Emil Leyde? Intermediate answer: 8 January 1879 So the final answer is: Emil Leyde END Facts: Fact #0: Mikko Esa Juhani Heikka(born 19 September 1944 in Ylitornio) is a Finnish former bishop of the Evangelic Lutheran Church. Fact #1: Scott Douglas Robbe is an American film, television, and theater producer/director. Question: Does Mikko Heikka have the same nationality as Scott Robbe? Are follow up questions needed here:
Training Label (Question Answering)	Training Label (Rationale Generation)
Moscow	Yes. Follow up: What is the country of citizenship of Mikko Heikka? Intermediate answer: Finnish Follow up: What is the country of citizenship of Scott Robbe? Intermediate answer: American So the final answer is: no

Exemplar
(actual data has 2 exemplars)

Self-Ask Prompt

Self-Ask Rationale

Nine models to evaluate

Three baseline models

T5

Flan-T5

OPT

Three fine-tuning procedures

None

Direct

Self-ask

Nine models

T5

Flan-T5

OPT

Direct T5

Direct Flan-T5

Direct OPT

Self-Ask T5

Self-Ask Flan-T5

Self-Ask OPT

Evaluate each model twice

Evaluation Procedure

Each model is evaluated on test sets with and without exemplars (i.e. **few-shot and zero-shot**) giving us 18 total evaluations

Metrics for each Task

Rationale Generation

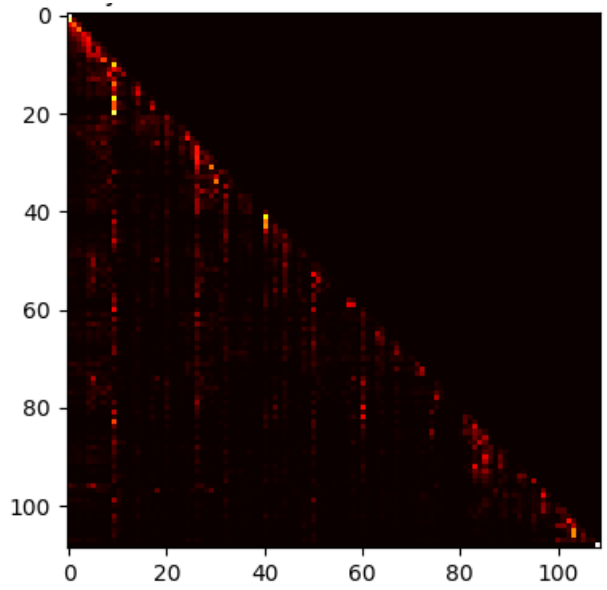
F1-1 (1-gram) and F1-2 (2-gram)

Question Answering

Accuracy - correct if true answer appears anywhere in the generated answer, some drawbacks but straightforward

*baseline and direct models with zero-shot test sets only evaluated on question answering

Hypothesis: training language models on CoT rationales is a better approach than directly training on question-answer pairs.



Decoder self-attention

Cross attention

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Facts:
Fact #0: Solo is a 2006 Australian film
directed by Morgan O'Neill and starring
Colin Friels.
Fact #1: Morgan O'Neill (born 19 April
1973 in Sydney, Australia) is an
Australian writer, director, actor and
producer.

Question: What is the place of birth of
the director of film Solo (2006 Film)?
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Self-Ask-Tuned Model

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Yes.
Follow up: What is the director of Solo?
Intermediate answer: Morgan O'Neill
Follow up: What is the place of birth of Morgan O'Neill?
Intermediate answer: Sydney, Australia
So the final answer is: Sydney, Australia
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Direct-Tuned Model

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Sydney, Australia
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Direct-tuning is good... but self-ask-tuning is better

Key Results

- Major improvement over baselines
- Self-ask Flan-T5 is the most accurate model
- Self-ask Flan-T5 is a zero-shot CoT multi-hop reasoner

	Accuracy (QA)
T5-Small (Zero-Shot)	32.9
T5-Small (Few-Shot)	24.8
Flan T5-Small (Zero-Shot)	51.7
Flan T5-Small (Few-Shot)	53.6
Direct-tuned T5-Small (Zero-Shot)	70.9
Direct-tuned T5-Small (Few-Shot)	10.6
Direct-tuned Flan T5-Small (Zero-Shot)	66.2
Direct-tuned Flan T5-Small (Few-Shot)	47.0
Self-Ask T5-Small (Zero-Shot)	40.9
Self-Ask T5-Small (Few-Shot)	74.8
Self-Ask Flan T5-Small (Zero-Shot)	**73.2** ★
Self-Ask Flan T5-Small (Few-Shot)	**77.9** ★

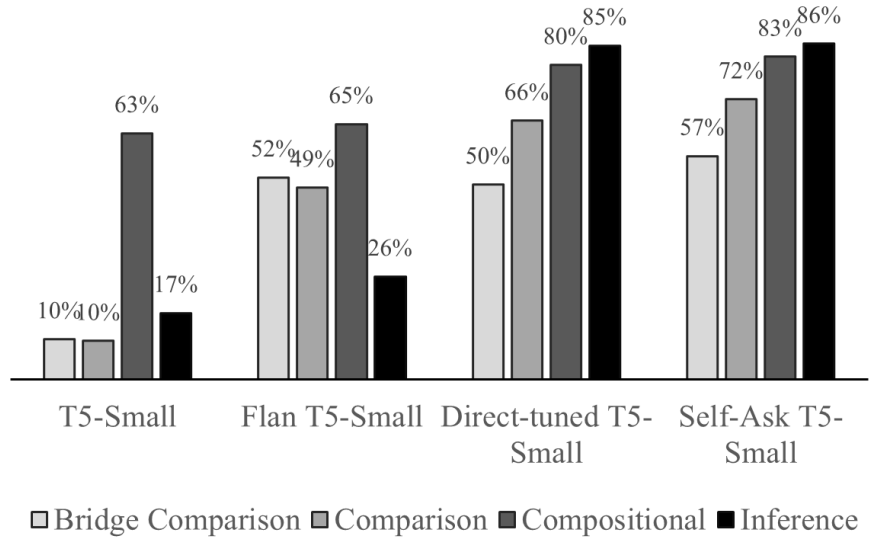
+21.5%

+24.3%

+7%

So, what differences between self-ask-tuning and direct-tuning do we observe?

Similar on the aggregate performance...



but different strengths and weaknesses

Direct-Tuned Models

- Weaknesses in multi-hop reasoning
- Struggles on larger context sizes

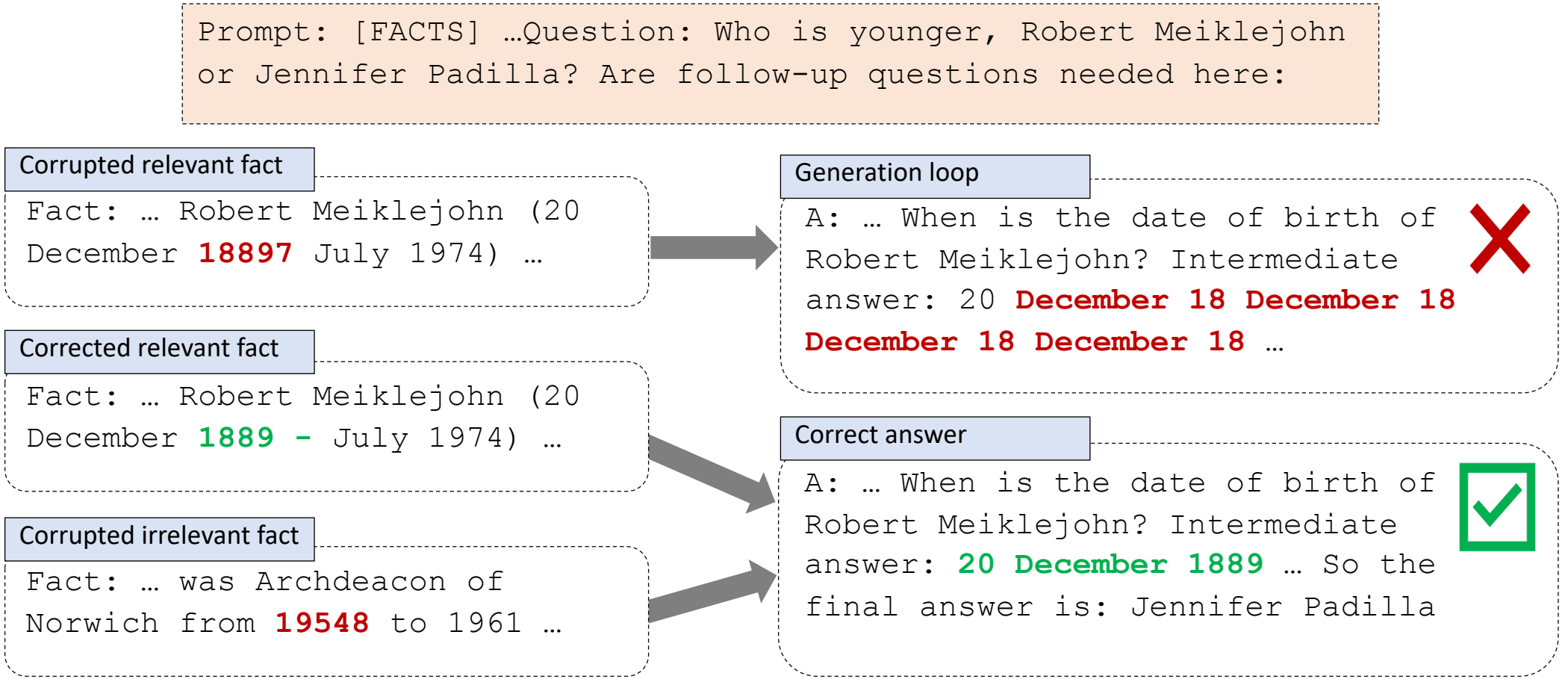
Both

- Sensitivity to order of facts
- Sensitivity to irrelevant facts

Self-Ask-Tuned Models

- Sensitivity to prompt quality

Corruption of critical facts elicits generation loops in self-ask models... **but does not affect direct-tuned models!**



Self-ask fine-tuning learns fact composition, and direct-tuning learns ???

Bringing it all together

Fine-tuning works. Fine-tuning is an effective approach to eliciting multi-hop reasoning in small language models.

Small language models can be zero-shot multi-hop CoT reasoners. Self-ask-tuned Flan-T5 did very well in zero-shot regimes on both QA and rationale generation tasks.

Self-ask fine-tuning beats direct-tuning. Based on analysis, it is plausible self-ask models may be composing facts to answer multi-hop questions, where direct-tuned models may learn "cheat codes".


Questions?

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