Math Word Problem Generation with Multilingual Language Models

Problem

"How to *generate Math Word Problems (MWPs) in Sinhala, Tamil and English languages as an autoregressive manner*"

Background

- A Mathematical word problem (MWP) is a mathematical problem expressed in natural language and it requires problem-solving ability.
- It is a narrative with a specific topic that provides clues to the correct equation with numerical quantities and variables therein

Sinhala: බිල්ට බෝල *9* ක් ඇති අතර ජිම්ට බිල්ට වඩා *7* ක් අඩුවෙන් බෝල ඇත. ජිම්ට බෝල කොපමණ ප්‍රමාණයක් තිබේද*?*
English: *The sum of two numbers is 18 and their difference is 4, what are the two numbers?*

Motivation

- There is only a limited amount of research done for multilingual MWP generation.
- Existing research mainly focused on language-dependent techniques that rely on man-made templates for MWP question generation.
- Recent NLG research has shown very promising results with the use of pre-trained deep contextual embedding models s.a. GPT.

Generating MWPs is challenging because,

- Algebraic questions are normally deep and logical.
  Eg: *"The sum of two numbers is 78. if four times the smaller number is subtracted from the larger number. the result is 13. what are the two numbers"*
- Most of the MWPs contain numerical constraints and units.

Methodology

Model Selection

We choose the model variants that have roughly the same configurations. According to Huggingface, **GPT2-Medium**, **T5-base** and **BART-large** variants have approximately 300M model parameters. Therefore these were used for further experiments. For multilingual MWP generation, we selected **mT5** and **mBART** models.

Dataset

- Two types of MWPs - Simple MWPs and Algebraic MWPs[1].
- Extended this dataset using the Dolphin18K dataset and the allArith dataset
- Selected questions are similar or slightly higher in complexity compared to baseline[1]
- The extended dataset contains 4210 Algebraic MWPs and 3160 simple MWPs.

Simple MWP
Kamal found 7 balls but 4 were broken. How many unbroken balls did Kamal find?
Algebraic MWP
The sum of two numbers is twenty-three, and the larger number is five more than the smaller number. Find these numbers

Evaluation Matrices

- BLEU score
- ROUGE score
- Human Evaluation

- All the models considered in this research are trained using the Transformer architecture
- GPT, BART and T5 are pre-trained with English data & mBART and mT5 are pre-trained with data from multiple languages.
- GPT models are decoder based & T5, BART, mBART and mT5 are encode-decoder models.
- We follow the standard training procedure of GPT-2 model in training it & used the conditional generator option of BART/mBART and T5/mT5.
- In both these cases, the models generate the rest of the MWP for a given seed.

Our Experiments Show

- How the performance of mT5 and mBART varies depending on the language
- How the performance of the models varies depending on the amount of fine-tuning data
- How much information (size of the seed) should be provided to the model at the inference stage for it to generate a meaningful MWP
- How the context of an MWP affects the generation performance

Human Evaluation

- Measured the quality of the created dataset
- Measured the quality and correction of generated questions.
- We identified the types of errors in MWP generation.

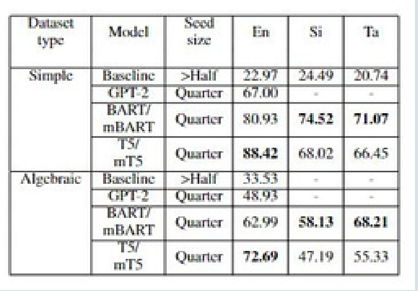
Contributions

- We created a benchmark dataset by extending the dataset created by Liyanage and Ranathunga (2020)[1] for MWP generation
- First to conduct an empirical analysis on the use of GPT, BART, T5, mBART, and mT5 for auto-regressive generation of MWPs and mBART and mT5 for the general task of auto-regressive text generation considering low-resource languages.

Result & Evaluation

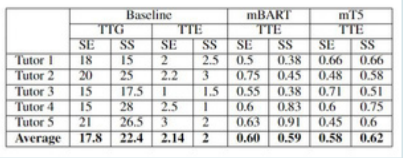
1. Pre-trained models vs Baseline
2. Effect of Fine-tuning Dataset Size
3. Effect of Pre-training Dataset Size
4. Effect of the Context of MWPs
5. Zero-shot MWP Generation
6. Effect of Seed Length
7. Human Evaluation

Baseline MWP results

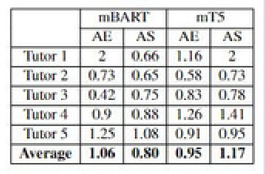


Dataset type	Model	Seed size	En	Si	Ta
Simple	Baseline	>Half	22.97	24.49	20.74
	GPT-2	Quarter	67.00	-	-
	BART/ mBART	Quarter	80.93	**74.52**	**71.07**
	T5/ mT5	Quarter	**88.42**	68.02	66.45
Algebraic	Baseline	>Half	33.53	-	-
	GPT-2	Quarter	48.93	-	-
	BART/ mBART	Quarter	62.99	**58.13**	**68.21**
	T5/ mT5	Quarter	**72.69**	47.19	55.33

Human Evaluation

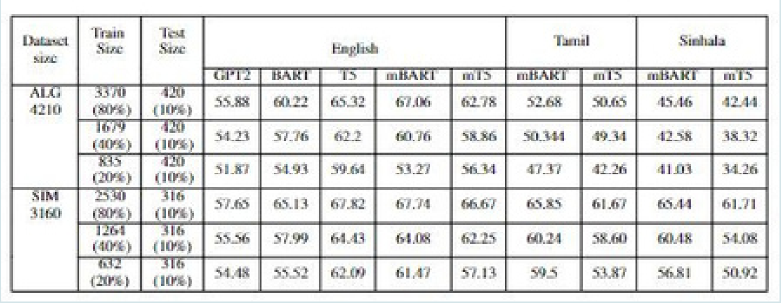


	Baseline				mBART		mT5	
	TTG		TTE		TTE		TTE	
	SE	SS	SE	SS	SE	SS	SE	SS
Tutor 1	18	15	2	2.5	0.5	0.38	0.66	0.66
Tutor 2	20	25	2.2	3	0.75	0.45	0.48	0.58
Tutor 3	15	17.5	1	1.5	0.55	0.38	0.71	0.51
Tutor 4	15	28	2.5	1	0.6	0.83	0.6	0.75
Tutor 5	21	26.5	3	2	0.63	0.91	0.45	0.6
Average	**17.8**	**22.4**	**2.14**	**2**	**0.60**	**0.59**	**0.58**	**0.62**



	mBART		mT5	
	AE	AS	AE	AS
Tutor 1	2	0.66	1.16	2
Tutor 2	0.73	0.65	0.58	0.73
Tutor 3	0.42	0.75	0.83	0.78
Tutor 4	0.9	0.88	1.26	1.41
Tutor 5	1.25	1.08	0.91	0.95
Average	**1.06**	**0.80**	**0.95**	**1.17**

Monolingual Results variation with train size



Dataset size	Train Size	Test Size	English					Tamil		Sinhala	
			GPT2	BART	T5	mBART	mT5	mBART	mT5	mBART	mT5
ALG 4210	3370 (80%)	420 (10%)	55.88	60.22	65.32	67.06	62.78	52.68	50.65	45.46	42.44
	1679 (40%)	420 (10%)	54.23	57.76	62.2	60.76	58.86	50.344	49.34	42.58	38.32
	835 (20%)	420 (10%)	51.87	54.93	59.64	53.27	56.34	47.37	42.26	41.03	34.26
SIM 3160	2530 (80%)	316 (10%)	57.65	65.13	67.82	67.74	66.67	65.85	61.67	65.44	61.71
	1264 (40%)	316 (10%)	55.56	57.99	64.43	64.08	62.25	60.24	58.60	60.48	54.08
	632 (20%)	316 (10%)	54.48	55.52	62.09	61.47	57.13	59.5	53.87	56.81	50.92

Examples

- T5 Generation

½ seed (input) - Twice the larger number is 3 more than five times the smaller number, the sum
Generated MWP - Twice the larger number is 3 more than five times the smaller number, the sum of the 2 numbers is 7 less than 3 times the larger number, Find the smaller number.

¼ seed (input) -Twice the larger number is 3 more than
Generated MWP - Twice the larger number is 3 more than five times the smaller number. The sum of the 2 numbers is 27. What are the two numbers?

- mBART Generation

¼ seed (input) - 150 ක
Generated questions- 150 ක එකතුවක් ඇති අඛණ්ඩ සංඛ්‍යා තුනක් සොයා ගන්න.

½ seed (input) - 150 ක එකතුවක් ඇති අඛණ්ඩ
Generated questions - 150 ක එකතුවක් ඇති අඛණ්ඩ ඉරට්ටේ සංඛ් යා දෙක කුමක්ද?

Conclusion

We evaluated several multilingual and monolingual pre-trained models for the task of MWP generation considering four factors - the amount of language-specific pre-trained data, amount of fine-tuning data, length of the seed, and type of the MWP. We also presented a multi-way parallel dataset for MWP evaluation, which includes two languages underrepresented in these pre-trained models

References

[1] Liyanage, V. and Ranathunga, S. Multi-lingual mathematical word problem generation using long short term memory networks with enhanced input features. In Proceedings of The 12th Language Resources and Evaluation Conference, pages 4709–4716, 2020

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