

# Multilingual Code Snippets Training for Program Translation

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## Abstract

Program translation aims to translate source code from one programming language to another. It is particularly useful in applications such as multiple-platform adaptation and legacy code migration. Traditional rule-based program translation methods usually rely on meticulous manual rule-crafting, which is costly both in terms of time and effort. Recently, neural network based methods have been developed to address this problem. However, the absence of high-quality parallel code data is one of the main bottlenecks which impedes the development of program translation models. In this paper, we introduce *CoST*, a new multilingual Code Snippet Translation dataset that contains parallel data from 7 commonly used programming languages. The dataset is parallel at the level of code snippets, which provides much more fine-grained alignments between different languages than the existing translation datasets. We also propose a new program translation model that leverages multilingual snippet denoising auto-encoding and Multilingual Snippet Translation (MuST) pre-training. Extensive experiments show that the multilingual snippet training is effective in improving program translation performance, especially for low-resource languages. Moreover, our training method shows good generalizability and consistently improves the translation performance of a number of baseline models. The proposed model outperforms the baselines on both snippet-level and program-level translation, and achieves state-of-the-art performance on CodeXGLUE translation task. The code, data, and appendix for this paper can be found at <https://github.com/reddy-lab-code-research/MuST-CoST>.

## Introduction

Program Translation is the problem of converting source code from one programming language to another. Different from computer compilers which translate high-level programming languages to lower-level machine code, it mainly focuses on translation between high-level programming languages. Efficient and accurate program translation is of enormous value in a variety of scenarios, such as: 1) *Migrating legacy code to another language*. For instance, many industries spend several hundreds of millions of dollars to convert code written in older programming languages (such as FORTRAN and COBOL) to newer ones (such as Java

and C++) (Roziere et al. 2020a). 2) *Adapting software to different operating systems and platforms*. For instance, for an Android application to run on iOS and Web browsers, it needs to be re-developed in Objective-C and Javascript. Traditional rule-based program translation usually relies on meticulous manual rule-crafting, which requires expertise in both programming languages, and requires an enormous amount of time and resources.

In recent years, deep learning based methods have been employed to address this problem. The success of transformer-based models (Vaswani et al. 2017) in natural language processing (NLP) has motivated researchers to utilize them for programming languages. A few recent works based on neural machine translation (NMT) have been applied to this task and achieved some impressive results (Roziere et al. 2020a; Ahmad et al. 2021). One of the important requirements for NMT models is the availability of high-quality parallel data for model training. Such data is even more critical for the program translation problem since it requires the generated code to be logically precise as well. However, existing code translation datasets have significant limitations. Most of the commonly used datasets (Lu et al. 2021; Chen, Liu, and Song 2018; Nguyen, Nguyen, and Nguyen 2015; Karaivanov, Raychev, and Vechev 2014; Nguyen, Nguyen, and Nguyen 2013) only contain two languages (Java and C#), and the alignment comes from mining similar function names from open source projects. Github has a huge number of open-source repositories in several languages. However, the data is not parallel and cannot be used for supervised translation. Project CodeNet (Puri et al. 2021) and Google Code Jam<sup>1</sup> datasets contain solutions submitted to coding problems in multiple programming languages. However, given that the alignment comes from solutions to the same problems, they are aligned at the task level. Since programs that solve the same problem can have a high diversity in terms of variable names, method design and logical flow, these datasets are not ideal to train program translation models. This especially becomes a bottleneck in case of low resource languages, since models for those languages cannot be trained using limited data with high variance in distribution.

The scarcity of high quality parallel data has become a

<sup>1</sup><https://codingcompetitions.withgoogle.com/codejam/archive>

Java	Python	PHP	C
<pre>import java.io.*; class GFG { // Function to check whether a number is divisible by 7 static boolean isDivisibleBy7(int num) {</pre>	<pre># Function to check whether a number is divisible by 7 def isDivisibleBy7(num) :</pre>	<pre>&lt;?php // Function to check whether a number is divisible by 7 function isDivisibleBy7( \$num ){</pre>	<pre>#include &lt;stdio.h&gt; // Function to check whether a number is divisible by 7 int isDivisibleBy7( int num ) {</pre>
<pre>// If number is negative, // make it positive if( num &lt; 0 ) return isDivisibleBy7( -num );</pre>	<pre># If number is negative # make it positive if num &lt; 0 : return isDivisibleBy7( -num )</pre>	<pre>// If number is negative, // make it positive if( \$num &lt; 0 ) return isDivisibleBy7( -\$num );</pre>	<pre>// If number is negative, // make it positive if( num &lt; 0 ) return isDivisibleBy7( -num );</pre>
<pre>// Base cases if( num == 0    num == 7 ) return true; if( num &lt; 10 ) return false;</pre>	<pre># Base cases if( num == 0 or num == 7 ) : return True if( num &lt; 10 ) : return False</pre>	<pre>// Base cases if( \$num == 0    \$num == 7 ) return 1; if( \$num &lt; 10 ) return 0;</pre>	<pre>// Base cases if( num == 0    num == 7 ) return 1; if( num &lt; 10 ) return 0;</pre>
<pre>// Recur for ( num / 10 - 2 * num % 10 ) return isDivisibleBy7(...</pre>	<pre># Recur for ( num / 10 - 2 * num % 10 ) return isDivisibleBy7(...</pre>	<pre>// Recur for ( num / 10 - 2 * num % 10 ) return isDivisibleBy7(...</pre>	<pre>// Recur for ( num / 10 - 2 * num % 10 ) return isDivisibleBy7(...</pre>
...	...	...	...

Figure 1: An example of a program and code snippets in different languages from our *CoST* dataset. Each column is one program (truncated) in a specific language. Each cell is one snippet. The snippets are aligned by matching the code comments in different languages. We show only four languages due to space constraints. All the remaining languages are shown in the Appendix.

bottleneck in program translation research. In this paper, we introduce *CoST* (Code Snippet Translation), a new dataset that consists of parallel source code snippets from 7 common programming languages: C++, Java, Python, C#, Javascript, PHP, and C. It contains parallel data at multiple levels, first at the snippet level, and then at the program level, for every pair of languages. To the best of our knowledge, *CoST* is the only dataset that provides snippet-level alignment for the seven commonly used programming languages. This dataset is not only a great resource to the program translation research community, but also serves as a new benchmark to evaluate the program translation models for upto 42 (7 by 6) programming language pairs at both snippet-level and program-level. In addition to supporting pairwise training, many samples in our dataset contain equivalent code snippets across multiple languages, thus supporting the development of multilingual program translation methods. An example of a program and its snippets in multiple languages is shown in Figure 1.

To demonstrate the effectiveness of using finely-grained alignment from code snippets for program translation, we propose a multilingual program translation model that leverages the similarity between different programming languages and the snippet level alignment of the dataset. Our experimental results show that the proposed model outperforms a number of baseline models on most of the 42 language pairs, on both snippet-level and program-level translation. The improvements are especially significant in case of low resource languages, that greatly benefit from the multilingual training. We also achieved state-of-the-art performance on CodeXGLUE (Lu et al. 2021) translation task. Moreover, our multilingual snippet translation (MuST) pre-training also shows good generalizability across different models. Extensive experiments show that it consistently improves the performance of multiple models on the translation of all the language pairs. In summary, the contributions of this paper are listed below:

- We introduce *CoST*, a new dataset that consists of both snippet-level and program level parallel data from 7 pro-

gramming languages. Our dataset can be used to train program translation models for up to 42 programming language pairs.

- We provide a new benchmark to evaluate program translation model on 42 programming language pairs. Extensive experiments demonstrate that models which achieve the best performance on some languages can do much worse on certain other languages.
- We propose a multilingual program translation model that leverages the similarity between different programming languages and the snippet level alignment of the dataset. The proposed model outperforms a number of baseline models and achieves state-of-the-art performance on CodeXGLUE translation task.
- The MuST training method in our model has good generalizability and consistently improves the performance of several other models on program translation.

## Related Work

**Methods:** One line of work has directly applied recent advances in natural language processing (NLP) to the programming language domain. Inspired by the success of natural language pre-training, CodeBERT (Feng et al. 2020) pre-trained a BERT (Kenton and Toutanova 2019) based encoder on the source code, and then added a decoder to perform end-to-end training on program translation. PLBART (Ahmad et al. 2021) utilized an existing natural language translation model, BART (Lewis et al. 2020), and also pre-trained it with source code. Transcoder (Roziere et al. 2020a) combined cross-lingual masked language modeling (Lample and Conneau 2019), denoising auto-encoding, and back-translation, and applied them to a source code setting. Another line of work incorporates the intrinsic features of programming languages to improve translation performance. (Chen, Liu, and Song 2018) modeled this problem as translating a source tree into a target tree. GraphCodeBERT (Guo et al. 2020) improved upon CodeBERT (Feng et al. 2020) by adding data-flow graph extracted from source code, improving the model’s understanding of the code structure. Some

Dataset	Alignment	Labeling	Size (pairwise)	Languages
Google Code Jam	Program	Solutions to the same problem	2,430,000*	20 programming languages
Project CodeNet	Program	Solutions to the same problem	13,916,828*	55 programming languages
Tree-to-tree Dataset1	Method	Compiler translation	20,000	CoffeeScript, JavaScript
Tree-to-tree Dataset2	Method	Matching function names	16,996	Java, C#
Phrase-Based Dataset	Method	Matching function names	21,821	Java, C#
CodeXGLUE	Method	Matching function names	13,300	Java, C#
<i>CoST</i> Dataset	Snippet	Matching code comments	132,046	C++, Java, Python, C#, JS, PHP, C

Table 1: Comparison between our dataset and other existing source code translation datasets. Tree-to-tree Dataset (1 and 2) are from (Chen, Liu, and Song 2018). Phrase-Based Dataset is from (Karaivanov, Raychev, and Vechev 2014). \* The numbers given in these cases are those of single program samples, and not paired programs.

other works (Rabinovich, Stern, and Klein 2017; Yin and Neubig 2017; Brockschmidt et al. 2018) also make use of abstract syntax tree (AST) derived from the code. DOBF (Roziere et al. 2021) added a de-obfuscation objective to the masked language model pre-training to leverage the structural aspect of programming languages.

**Datasets:** Many preceding works (Lu et al. 2021; Chen, Liu, and Song 2018; Nguyen, Nguyen, and Nguyen 2015; Karaivanov, Raychev, and Vechev 2014; Nguyen, Nguyen, and Nguyen 2013) consist of parallel Java-C# code from various open source projects. CodeNet (Puri et al. 2021) and Google CodeJam (GCJ) datasets contain code samples from multiple languages that are aligned at the program level.

–	C++	Java	Py	C#	JS	PHP	C
<b>C++</b>	–	13929	11930	13326	7596	3165	2188
<b>Java</b>	<b>1497</b>	–	11713	13905	7729	3194	2135
<b>Py</b>	<b>1419</b>	<b>1417</b>	–	11404	7165	3123	1779
<b>C#</b>	<b>1442</b>	<b>1495</b>	<b>1383</b>	–	7601	3192	2123
<b>JS</b>	<b>996</b>	<b>1009</b>	<b>962</b>	<b>994</b>	–	2917	1232
<b>PHP</b>	<b>548</b>	<b>552</b>	<b>545</b>	<b>552</b>	<b>512</b>	–	700
<b>C</b>	<b>267</b>	<b>281</b>	<b>263</b>	<b>273</b>	<b>196</b>	<b>135</b>	–

Table 2: Number of pairwise data in each language-pair. The upper triangle (in normal font) shows the number of parallel code snippets, and the lower triangle (in bold font) shows the number of parallel programs. (**Py** is short for Python. **JS** is short for Javascript.)

## The Code Snippets Translation(*CoST*) Dataset

The **Code Snippets Translation** (*CoST*) dataset consists of programs from 7 different languages: C, C++, C#, Python, Java, Javascript, and PHP, spanning across 1625 programming problems. The detailed statistics about the *CoST* dataset are highlighted in Table 2. We define certain terms used in the context of this paper as follows:

- **Programs:** These refer to the complete code solution in a specific language to a particular problem or task.
- **Snippet/Code snippet:** Each program may consist of one or more snippets which are in parallel to appropriate code snippets in other languages.

## Data Collection and Processing

Our data was collected from the GeeksForGeeks website. The platform has a plethora of problem statements and solutions to those problems in up to 7 programming languages (C, C++, C#, Python, Java, Javascript, PHP). The platform also ensures that its contributors stick to a template in terms of the comments used in their programs and the code corresponding to those comments. By using the template, we could obtain a one-to-one correspondence between the code snippets in one language to those in other languages. In effect, this gives us a good number of parallel instances of code which can then be effectively used for code-to-code translation. However, there were a number of cases where this template did not work as anticipated. These cases include missing snippets, differences in functionality among languages resulting in vastly different program structures, and misaligned cells. To remedy this issue, we manually verified the code to identify different instances of non-compliance, and either modify the alignment or discard the example in extreme cases. Few of the URLs scraped from different pages sometimes pointed to the same program, thus resulting in duplicate files. A duplication detection program was used to identify these duplicates and remove them.

## Dataset Comparisons and Characteristics

As shown in Table 1, many of the existing source code translation datasets such as (Lu et al. 2021; Chen, Liu, and Song 2018) consisting of pairwise samples at the method level collect their samples from very similar publicly available repositories. However, they only have parallel data in two languages; Java and C#. Moreover, their mapping is at the method level, and there are relatively fewer number of method pairs available. Other datasets such as Google Code Jam (GCJ) and CodeNet (Puri et al. 2021) have an abundance of problem statements along with their solutions and span a wide range of languages. However, these datasets suffer from quality issues. For instance, in CodeNet, only about half of the problems are rated by the online judges to be an accepted solution to the problem. This makes less than half the dataset to be wrong solutions and deems these erroneous samples unusable for the translation task. In contrast, our dataset contains programs which have been manually verified to ensure correctness at program and snippet levels,

thereby resulting in higher quality and less noise.

A major drawback of the existing datasets is that the samples are aligned at program level, which implies less supervised alignment. Since program level alignment is based on programs doing similar tasks and achieving similar results on test cases, there is a significant amount of variation between the programs in multiple languages, due to differences in terms of method and variable names, as well as the logic flow. The granularity in our case is at the snippet level, which provides more supervision in contrast to the method level or program level mapping that exists in previous datasets. Moreover, the code snippets in our dataset are consistent in terms of variable and method names, and the programs in each language follow similar logic flow.

## The Proposed Method

### Problem Formulation

Consider  $L = \{l_1, \dots, l_k\}$  as the set of all languages, where  $l_i$  denotes a programming language. Given a program  $\mathbf{X}$  in language  $l_i$ , the objective of program translation is to generate a program  $\mathbf{Y}$  in the target language  $l_j$ . We represent a program consisting of  $m$  snippets as  $\mathbf{X} = \{\mathbf{x}_1, \dots, \mathbf{x}_m\}$ , where  $\mathbf{x}_i = (x_1, \dots, x_n)$  denotes a snippet with  $n$  tokens. We further denote the monolingual snippet dataset in language  $l_i$  as  $\mathcal{D}_{l_i}^{mono}$ , and the bilingual snippet dataset for languages  $l_i$  and  $l_j$  as  $\mathcal{D}_{l_i, l_j}^{bi}$ .

### Model Architecture

Given the sequence-to-sequence nature of the program translation problem, our model draws inspiration from the Transformer model (Vaswani et al. 2017), which has been shown to have state-of-the-art performance on many language generation tasks. The encoder-decoder based transformer model serves as the base model for our translation task. The model consists of an encoder  $E$  and a decoder  $G$  with parameters  $\theta_E$  and  $\theta_G$ , respectively, that are augmented to support code from multiple languages. This is done by using a unique identifier  $\alpha_{l_i}$  for each language. Given the input token embeddings  $\mathbf{x} = (x_1, \dots, x_n)$ , we add the language identifier to each token, such that  $(x_1 + \alpha_{l_i}, \dots, x_n + \alpha_{l_i})$  serves as the input to the encoder. The encoder representations  $\mathbf{z} = E(\mathbf{x}, \alpha_{l_i})$  are then fed to the decoder along with the target language identifier  $\alpha_{l_j}$  to generate output snippet tokens  $\mathbf{y} = G(\mathbf{z}, \alpha_{l_j})$ .

### Model Initialization

We initialize the model parameters with the pre-trained weights of the DOBF model (Roziere et al. 2021). DOBF is a Transformer-based model trained with masked language modeling (MLM) and code deobfuscation objectives on Python and Java files from GitHub public dataset available on Google BigQuery. The MLM objective helps the model to learn representations by leveraging the left and right contexts. The deobfuscation objective guides the model to recover the original class, function, and variable names from obfuscated code, which is a more difficult task and requires a deeper understanding of the code, thereby providing a better learning signal to the model. By initializing our model with

the weights of a sequence-to-sequence model pre-trained on source code, we can leverage its knowledge about the syntax and structure of the specific programming languages.

### Multilingual Snippet Denoising Auto-Encoding

To train the model to perform translation on different language pairs, we first need to familiarize the model with all the 7 languages. Although the model is initialized with pre-trained weights from DOBF, the weights were learned from only two languages, Python and Java. Therefore, the model has no knowledge about other languages (C++, C#, Javascript, PHP, C). To address this issue, we first train the model with Denoising Auto-Encoding (DAE) objective (Lample et al. 2018) on snippets from all the languages. There are several advantages of doing this pre-training task. First, the sequence-to-sequence nature of DAE enables the model to decode all the languages, which is necessary for the translation task. Second, by sharing the same encoder and decoder across all the languages, all the languages are mapped into the same latent space. This helps the model to learn the similarities between different languages, which can be useful in the translation of low-resource languages. Third, the DAE only requires monolingual data, which is much more accessible than pairwise data. We use the same set of noise functions as TransCoder (Roziere et al. 2020a), which includes random word shuffle, random word dropout, and random span masking. Considering  $C$  as the noise model (non-learnable in this case), and  $\mathbf{x}$  as the input sampled from  $\mathcal{D}_{l_i}^{mono}$ , the DAE objective can be written as:

$$\mathcal{L}_{DAE}(\theta_E, \theta_G) = \sum_{l_i \in L} \mathbb{E}_{\mathbf{x} \sim \mathcal{D}_{l_i}^{mono}, \tilde{\mathbf{x}} \sim C(\mathbf{x})} [-\log p_G(\mathbf{x} | E(\tilde{\mathbf{x}}, \alpha_{l_i}), \alpha_{l_i})] \quad (1)$$

### Multilingual Snippet Translation (MuST)

In many language generation tasks, the performance goes down significantly as the length of input sequences increases. This is a common problem in sequence-to-sequence models due to the difficulty of capturing long-distance dependencies. Since source code programs usually contain at least tens of lines, achieving acceptable performance from translation models can be challenging. In order to alleviate this problem, we use code snippets translation as a pre-training method to improve the accuracy of program translation. Since the code snippets are much shorter than programs, they provide a fine-grained supervision to the translation model, and thus can help to address the problem of reduced performance for longer inputs.

Another problem encountered by many existing models is that program translation datasets are usually not balanced in size for all the languages. Some languages may have much less parallel data than others. For example, in *CoST* dataset, there are 13K snippet pairs for Java and C++, but only 700 pairs for C and PHP. Less parallel training data can significantly affect the translation performance on low-resource languages. Therefore, in addition to snippet translation, we propose to leverage the multilingual training to improve the performance on low-resource languages. In *CoST* dataset,

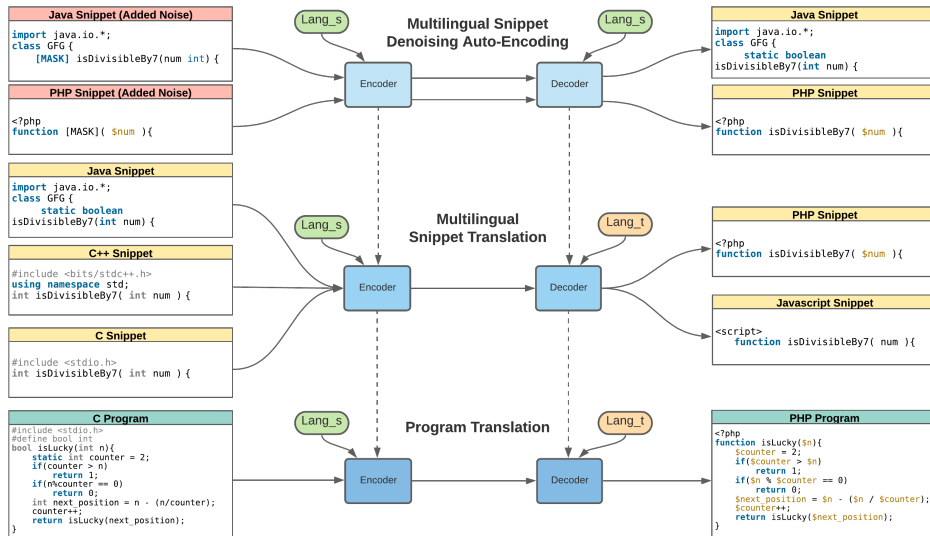


Figure 2: The training paradigm of the proposed **Multilingual Snippet Training for Program Translation (MuST-PT)** model. We first train the model with multilingual snippet denoising auto-encoding, which helps the model to learn the similarity between different languages. Then we apply multilingual snippet translation (MuST) training to leverage the snippet-level alignment to increase the accuracy of program-level translation. Finally, we fine-tune the model on program translation task to bridge the distribution gap between snippet and program data.  $Lang_s$  and  $Lang_t$  refers to source and target language, respectively. At each step of the training, the model takes both the code and the programming language as inputs.

one code snippet may have corresponding snippets in multiple languages. Moreover, some languages are naturally similar in syntax, such as C++-C, Java-C, and Java-C#. This motivates us to use other languages to improve the translation of low resource languages, e.g. using C++-PHP and Java-PHP data to improve the translation of C-PHP. For a snippet pair  $(x, y) \in \mathcal{D}_{l_i, l_j}^{bi}$ , the objective function for this task can be written as:

$$\mathcal{L}_M(\theta_E, \theta_G) = \sum_{l_i, l_j \in L} \mathbb{E}_{(x, y) \sim \mathcal{D}_{l_i, l_j}^{bi}} [-\log p_G(y | E(x, \alpha_{l_i}), \alpha_{l_j})] \quad (2)$$

$$\mathcal{L} = \mathcal{L}_M + \lambda \mathcal{L}_{DAE} \quad (3)$$

The overall training objective of our model is given above. Here,  $\lambda$  is a hyperparameter that represents the weight of DAE loss. After the multilingual snippet DAE and MuST pre-training, the model is capable of translating code snippets across all the 42 language pairs. However, because of the difference in length between code snippets and programs, the model cannot directly be used for program translation. Therefore, we further fine-tune the model on the program pairs from our dataset. We adopt similar multilingual training strategy on the program-level pairwise data. The overall training process is illustrated in Fig. 2. We refer to the model as MuST-PT, which is short for the **Multilingual Snippet Training for Program Translation** model.

## Implementation Details

In our model, the encoder and decoder consist of 12 and 6 transformer layers, respectively. The transformer units have

a model dimension of 768, and 12 attention heads. The weight of the multilingual snippet DAE objective  $\lambda$  was set to 1.0 in the beginning, and decayed to 0.1 linearly in 30K steps, and then to 0 in 100K steps. The DOBF model we used for initializing our model is `dobf_plus_denoising.pth`, which can be found on their GitHub repository. Most of the settings during training were the same as DOBF (Roziere et al. 2021). Float 16 operations were used to speed up the training. The model was trained using Adam optimizer (Kingma and Ba 2014) with a learning rate of 0.0001, and the same learning rate scheduler was used from the Transformer (Vaswani et al. 2017). We used a batch size of 128 on all the 42 language pairs. The batches of different languages pairs were sent to the model alternatively during training. The model was trained with 4 RTX 8000 GPUs with 48GB memory on each GPU.

## Experiments

### Datasets

The datasets used for the experimental evaluation are below:

- **CoST Snippets Dataset** We used the monolingual snippets to do the multilingual snippet DAE training, and the pairwise snippets to do the multilingual snippet translation (MuST) training. The train-validation-test data is split at the problem level, to ensure no overlapping snippets between the splits in any of the languages. The statistics of the split in each language can be found in the Appendix.
- **CoST Programs Dataset** We used the pairwise program data to fine-tune the model for program translation.
- **CodeXGLUE Translation Dataset** CodeXGLUE stands

Method	Java-C#		C#-Java	
	BLEU	CodeBLEU	BLEU	CodeBLEU
Naive copy	18.54	-	18.69	-
PBSMT	43.53	42.71	40.06	43.48
Transformer	55.84	63.74	50.47	61.59
RoBERTa(code)	77.46	83.07	71.99	80.18
CodeBERT	79.92	85.1	72.14	79.41
GraphCodeBERT	80.58	-	72.64	-
PLBART	83.02	<b>87.92</b>	78.35	85.27
MuST-PT	<b>87.37</b>	86.82	<b>85.25</b>	<b>86.09</b>

Table 3: Results on the CodeXGLUE translation task. Our model achieves state-of-the-art performance on BLEU score of C#-Java and both BLEU and CodeBLEU on Java-C#.

for General Language Understanding Evaluation benchmark for code. It has 10 source code related tasks, and code to code translation is one of them. We used the translation dataset (Java-C#) from CodeXGLUE for evaluation.

### Evaluation Metrics

- **BLEU** Given an input code sample, we use BLEU (Papineni et al. 2002) score to evaluate the  $n$ -gram overlap between the generated and the ground-truth target code.
- **CodeBLEU** CodeBLEU (Ren et al. 2020) is for automatic evaluation of code synthesis. Besides  $n$ -gram match as in BLEU, it also evaluates the code syntax via abstract syntax trees (AST) and code semantics via data-flow.

### Baseline Methods

- **Naive Copy** Naive Copy (Lu et al. 2021) directly copies the input source code as the translation output. This baseline shows how similar two programming languages are.
- **Transformer** The sequence-to-sequence transformer model (Vaswani et al. 2017) was originally designed for translation problem. We use it as a baseline to see how well a transformer model performs without any pre-training on source code corpus.
- **CodeBERT** CodeBERT (Feng et al. 2020) uses the BERT architecture pre-trained on source code corpus.
- **DOBF** DOBF (Roziere et al. 2021) is the model from which the weights are used to initialize our model. It is pre-trained on Java and Python.
- **TransCoder** TransCoder (Roziere et al. 2020b) is an unsupervised program translation model pre-trained on Java, Python, and C++. We did not include TransCoder in Table 4 because it does not support input languages other than the ones it was pre-trained on (performance not increasing through training).

Due to space limitations, we did not include some baselines (PLBART, GraphCodeBERT, RoBERTa(code) (Liu et al. 2019), PBSMT (Zens, Och, and Ney 2002)) from CodeXGLUE translation task in other experiments.

### Results Analysis

**Translation Performance on Snippets** Table 4 shows the translation performance of our model and the baseline models on all the 42 language pairs. Every model is evaluated

on both the snippets dataset and the program dataset. The left part of the Table shows BLEU score of each model on the snippets dataset. We can see that our model outperforms the baseline models, with significant performance gains on low resource languages like PHP and C. This shows that the multilingual training in both DAE and MuST is helpful in improving low-resource language translation.

**Translation Performance on Programs** The right part of the Table 4 shows BLEU score of each model on the program dataset. We can see that almost all the baseline models have much worse performance on program than snippets. This can be attributed to the more challenging nature of program-level translation due to longer sequence length compared to snippets, and less training data than snippet level. However, our model’s performance does not drop by much on program-level compared to snippet level. This shows that the MuST pre-training improves the program translation performance.

**Translation Performance on CodeXGLUE** We also evaluated our model on the CodeXGLUE translation task. Table 3 shows the BLEU and CodeBLEU of our model compared to the models on the CodeXGLUE translation task leaderboard. Our model achieved state-of-the-art performance on BLEU score of both Java-C# and C#-Java, and high CodeBLEU score on C#-Java conversion. This indicates that the DAE and MuST training in our model is effective on other program translation datasets.

**Generalizability of MuST Training** We combine some of the baselines with MuST training to see if the method is generalizable to more models. Table 5 shows the results of each baseline before and after MuST training. We can see that all the three baselines got significant improvement after MuST training, indicating that MuST is not only effective in our model setting, but also benefits other models. This demonstrates that MuST has good generalizability and can potentially benefit other program translation models.

## Conclusion and Future Work

Scarcity of high quality parallel data has become the bottleneck of program translation research. In this paper, we introduced a new multilingual code translation dataset *CoST*, with snippet-level parallel data across 7 programming languages. Our dataset provides fine-grained supervision for the translation of 42 language pairs. We also propose a new program translation model that leverages multilingual snippet denoising auto-encoding (DAE) and multilingual snippet translation (MuST) pre-training. Our extensive set of experiments show that DAE and MuST are effective in improving program translation performance, especially for low-resource languages. We also achieved state-of-the-art performance on CodeXGLUE translation task. The MuST training also shows good generalizability and improves the translation performance of a number of baseline models. The new dataset we present can potentially be used for tasks other than translation, such as code summarization, comment generation, and text-to-code generation. The MuST can also potentially improve the performance on these new tasks. We will leave them for future work.

Lang	Model	Snippet-level							Program-level						
		C++	Java	Python	C#	JS	PHP	C	C++	Java	Python	C#	JS	PHP	C
C++	Naive Copy	–	68.87	35.03	69.54	57.71	37.7	87.73	–	66.57	36.58	67.22	55.24	36.27	<b>84.86</b>
	Transformer	–	68.74	57.17	70.61	63.26	60.94	68.57	–	43.93	33.9	45.32	39.02	35.93	25.06
	CodeBERT	–	71.61	60.28	72.31	72.4	70.42	61.29	–	53.47	38.37	63.01	46.6	46.18	22.25
	DOBF	–	79.83	68.61	81.74	79.24	77.91	68.09	–	29.06	18.5	29.14	22.25	27.47	27.05
	MuST-PT	–	<b>80.27</b>	<b>71.2</b>	<b>82.98</b>	<b>81.01</b>	<b>83.29</b>	<b>87.55</b>	–	<b>79.15</b>	<b>64.1</b>	<b>81.15</b>	<b>68.85</b>	<b>71.18</b>	84.2
Java	Naive Copy	68.75	–	33.8	77.9	58.58	33.6	70.22	66.53	–	34.56	77.15	56.52	32.14	67.54
	Transformer	74.42	–	53.98	84.27	69.16	58.5	46.18	44.38	–	31.22	47.34	39.06	38.26	25.36
	CodeBERT	73.19	–	59.04	85.12	76.79	7.24	50.33	65.48	–	38.7	85.46	55.92	47.12	32.98
	DOBF	80.83	–	64.75	89.73	79.89	66.94	59.32	28.34	–	18.08	27.6	20.2	27.05	26.12
	MuST-PT	<b>85.23</b>	–	<b>70.06</b>	<b>90.13</b>	<b>81.87</b>	<b>80.39</b>	<b>81.16</b>	<b>84.28</b>	–	<b>61.12</b>	<b>89.93</b>	<b>69.53</b>	<b>69.83</b>	<b>78.71</b>
Python	Naive Copy	35.02	33.53	–	35.11	41.71	23.57	35.29	36.58	34.27	–	35.69	40.85	22.48	36.53
	Transformer	60.5	58.13	–	60.9	55.59	55.07	39.37	37.42	38.15	–	36.91	38.39	39.01	19.99
	CodeBERT	65.04	61.79	–	63.84	62.43	62.6	45.09	43.96	41.35	–	46.4	47.28	44.38	46.4
	DOBF	68.73	67.91	–	69.46	68.07	67.8	34.21	21.49	23.45	–	21.82	20.32	26.53	13.02
	MuST-PT	<b>75.37</b>	<b>70.89</b>	–	<b>72.35</b>	<b>70.46</b>	<b>75.49</b>	<b>70.64</b>	<b>66.16</b>	<b>64.57</b>	–	<b>63.23</b>	<b>66.47</b>	<b>70.9</b>	<b>58.7</b>
C#	Naive Copy	69.5	78.05	35.16	–	60.23	35.43	70.65	67.16	77.23	35.76	–	58.4	33.57	67.9
	Transformer	75.68	84.19	58.64	–	66.97	60.57	45.18	42.65	45.6	32.64	–	39.66	38.47	25.01
	CodeBERT	74.73	82.16	59.74	–	77.12	67.48	49.64	67.17	82.45	41.1	–	51.09	48.62	34.33
	DOBF	81.77	<b>86.73</b>	67.96	–	80.26	15.94	28.35	26.97	29.17	19.71	–	19.34	27.05	19.11
	MuST-PT	<b>85.34</b>	85.8	<b>71.11</b>	–	<b>82.74</b>	<b>81.64</b>	<b>81.12</b>	<b>84.72</b>	<b>87.76</b>	<b>62.03</b>	–	<b>70</b>	<b>70.66</b>	<b>78.78</b>
JS	Naive Copy	57.67	57.99	41.73	60.04	–	32.56	57.6	55.11	55.74	40.9	58.1	–	29.77	53.89
	Transformer	65.06	65.31	56.92	64.55	–	61.87	37.34	39.8	39.6	34.3	41.72	–	37.65	19.78
	CodeBERT	68.76	71.66	58.13	72.87	–	66.35	37.08	49.51	48.91	46.27	51.55	–	47.95	24.37
	DOBF	78.56	76.94	64.92	75.5	–	75.53	52.32	26.47	25.93	21.77	21.43	–	26.73	18.68
	MuST-PT	<b>78.95</b>	<b>78.03</b>	<b>66.47</b>	<b>78.91</b>	–	<b>78.69</b>	<b>78.54</b>	<b>73.01</b>	<b>73.39</b>	<b>63.88</b>	<b>73.32</b>	–	<b>76.44</b>	<b>70.2</b>
PHP	Naive Copy	37.66	33.65	23.6	35.41	32.66	–	37.46	36.24	32.17	22.54	33.56	29.97	–	35.73
	Transformer	58.47	56.06	51.45	56.27	56.43	–	29.29	33.78	35.67	31.52	37.54	37.07	–	20.11
	CodeBERT	65.08	60.84	54.59	63.77	63.92	–	29.75	40.43	37.64	33.01	41.33	41.31	–	18.63
	DOBF	68.18	65.84	63.45	70.14	63.21	–	23.78	26.69	26.28	19.91	23.52	20.63	–	18.31
	MuST-PT	<b>79.41</b>	<b>76.42</b>	<b>69.34</b>	<b>77.96</b>	<b>77.64</b>	–	<b>76.67</b>	<b>70.04</b>	<b>67.3</b>	<b>63.97</b>	<b>70.34</b>	<b>73.54</b>	–	<b>67.88</b>
C	Naive Copy	87.63	70.29	35.37	70.62	57.74	37.45	–	84.75	67.56	36.61	67.88	54.17	35.75	–
	Transformer	68.63	45.42	36.4	44.38	35.37	31.03	–	29.54	30.73	24.62	31.28	24.55	24.83	–
	CodeBERT	64.18	51.1	36.48	49.81	33.75	28.85	–	27.96	35.29	22.05	32.82	21.73	25.19	–
	DOBF	76.85	64.73	53.1	45.11	30.87	22.22	–	16.84	23.23	17.64	23.96	20.38	25.7	–
	MuST-PT	<b>88.58</b>	<b>79.24</b>	<b>66.49</b>	<b>80.68</b>	<b>80.35</b>	<b>82.94</b>	–	<b>84.92</b>	<b>76.84</b>	<b>55.71</b>	<b>78.39</b>	<b>66.13</b>	<b>70.62</b>	–

Table 4: BLEU scores of baseline and the proposed MuST-PT model on all the 42 language pairs on both *CoST* snippet and program datasets. Note that only multilingual DAE and MuST were applied for snippet-level translation. We did program-level fine-tuning for MuST-PT only for program-level translation.

Model	Java-Py	Py-Java	Java-C++	C++-Java	Java-C#	C#-Java	Py-C++	C++-Py	Py-C#	C#-Py	C++-C#	C#-C++
Naive Copy	34.56	34.27	66.53	66.57	77.15	77.23	36.58	36.58	35.69	35.76	67.22	67.16
Transformer	31.22	38.15	44.38	43.93	47.34	45.6	37.42	33.9	36.91	32.64	45.32	42.65
Transformer+MuST	40.9	43.97	58.35	54.61	73.7	71.68	42.86	39.06	43.42	42.34	57.84	57.49
CodeBERT	38.7	41.35	65.48	53.47	85.46	82.45	43.96	38.37	46.4	41.1	63.01	67.17
CodeBERT+MuST	55.5	57.66	81.09	78.69	90.47	86.76	58.91	55.98	59.13	55.45	79.05	81.54
TransCoder	24.98	21.98	30.09	30.42	44.85	29.4	23.03	23.52	40.4	18.81	41.91	25.3
TransCoder+MuST	60.73	65.53	87.09	81.64	91.74	27.7	68.7	62.92	66.52	16.88	82.4	29.44

Table 5: Multilingual Snippet Translation (MuST) training consistently improves the performance (measured by BLEU scores) of the baseline models on the *CoST* program translation dataset. This shows that MuST pre-training method can be generalized to other models and benefit their translation performance.



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## Appendix

### Data Statistics

The *CoST* dataset is composed of two subsets, the snippet translation dataset and the program translation dataset.

Table 6 shows the basic statistics of the dataset. We can see that the number of snippets and programs are not balanced across all the 7 languages. In terms of length, code snippets are much shorter than programs. On an average, each program contains around 8 snippets.

### Data Pre-processing

We rely on tree-sitter parsing library to tokenize different languages. Tree-sitter is a parser generator tool that generates syntax trees for source files. It supports all the 7 languages in our dataset. After generating the parse tree for the source code, we take the leaf nodes in the parse tree as tokens. After tokenization, we use BPE to further encode the tokens. We use the same BPE codes as in DOBF.

We further split the data into train, validation and test sets. To support multilingual training, we have to make sure the validation and test sets have no overlap with the train set, both at snippet level and program level. Therefore, we first select all the problems (118 out of 1625) that have solutions of all 7 languages, then extract both snippets and programs from this set of problems for validation and test sets. The statistics of each set in different languages can be found in Table 7. Note that the added size of train, validation and test sets might be slightly smaller than in Table 2, due to some failed cases in tokenization.

Title	C++	Java	Py	C#	JS	PHP	C
# SN	14999	14674	12317	14039	7866	3216	2495
# SN/PR*	9.61	9.41	8.43	9.36	7.7	5.82	8.29
# PR	1560	1560	1461	1500	1022	553	301
# TOK/PR*	132	137	96	141	107	86	116
# TOK/SN*	13.75	14.56	11.44	15.07	13.95	14.84	14.05
# lines/PR*	40.12	42.4	26.33	44.39	30.63	25.55	36.2
# lines/SN*	4.17	4.51	3.12	4.74	3.98	4.39	4.37

Table 6: Statistics of the *CoST* dataset. (SN: code snippet; PR: program; TOK: token; \* Average Number; Py is short for Python. JS is short for Javascript.)

### Qualitative Analysis

Tables 8, 9, 10, and 11 illustrate the performance of MuST-PT and the baselines against the ground truth translation for a given source program.

**Translation of data flow** In Table 8, the problem is to count the number of 1s in the binary representation of an integer. The source and target languages are Java and PHP. We can observe that MuST-PT is superior in correctly capturing the data flow, while CodeBERT mistook variable *count* as a function name, and Transformer generated inconsistent variable name from *n* to *p*.

**Translation of multiple functions** In Table 9, the problem is given an array of integers, replace every element with the next greatest element (greatest element on the right side) in the array. The source and target languages are C#

		C++	Java	Py	C#	JS	PHP	C
C++	train	-	12547	10674	12047	6792	2503	1394
	val	-	272	237	272	238	234	271
	test	-	410	348	410	357	358	413
Java	train	1379	-	10612	12562	6940	2534	1390
	val	49	-	237	272	238	234	271
	test	69	-	349	411	356	357	411
Py	train	1301	1299	-	10317	6380	2466	1147
	val	49	49	-	237	232	231	237
	test	69	69	-	349	344	345	349
C#	train	1324	1377	1265	-	6811	2531	1378
	val	49	49	49	-	238	234	271
	test	69	69	69	-	356	357	411
JS	train	878	891	844	876	-	2278	619
	val	49	49	49	49	-	234	238
	test	69	69	69	69	-	354	357
PHP	train	430	434	427	434	394	-	106
	val	49	49	49	49	49	-	234
	test	69	69	69	69	69	-	360
C	train	149	163	145	155	78	17	-
	val	49	49	49	49	49	49	-
	test	69	69	69	69	69	69	-

Table 7: Basic Statistics of the train, validation, and test split of both the snippets and the programs in the *CoST* dataset. The split is made at problem level to ensure there is no overlap between each set during splitting. We select problems that have solutions in all the 7 languages (118 out of 1625) to use for validation and test. The upper triangle shows the split statistics of code snippets, and the lower triangle of shows the split of programs. Py is short for Python; JS is for JavaScript

and Javascript. MuST-PT correctly translated the program in both logic flow and structure, except for the wrong name of function call *nextRightArray*. However, Transformer and CodeBERT both missed the printing function *printArray*. DOBF failed to capture the logic flow of the program.

**Translation between OOP and non-OOP languages** In Table 10, the problem is to compute the minimum or maximum of two integers without branching. The source and target languages are Python and C++, respectively. We can see that all the models fail to translate the C++ class, which indicates that translation between Object-Oriented Programming (OOP) languages and non-OOP languages can be challenging. Compared to the baselines, MuST-PT is the only one that correctly translated the method names.

**Translation between low resource languages** In Table 11, the problem is given an array of *n* elements that contains elements from 0 to *n*-1, with any of these numbers appearing any number of times. The source and target languages are C and Javascript, respectively. We can observe that, when translating between low resource languages, even with less training data, MuST-PT maintains high quality. However, the baselines perform worse compared to translating into other languages.

Tables 12 and 13 show the baselines' generations before and after MuST training. We can see that in both tables, the generation quality improves significantly after MuST training.

	Input	Ground Truth	MuST-PT
Java to PHP	<pre>import java.io.*; class countSetBits {     static int countSetBits(int n) {         int count = 0;         while (n &gt; 0) {             count += n &amp; 1;             n &gt;&gt;= 1;         }         return count;     }     public static void main(String args[])     {         int i = 9;         System.out.println(countSetBits(i));     } }</pre>	<pre>&lt;?php function countSetBits(\$ n) {     \$ count = 0;     while (\$ n) {         \$ count += \$ n &amp; 1;         \$ n &gt;&gt;= 1;     }     return \$ count; } \$ i = 9; echo countSetBits(\$ i); ? &gt;</pre>	<pre>&lt;?php function countSetBits(\$ n) {     \$ count = 0;     while (\$ n &gt; 0) {         \$ count += \$ n &amp; 1;         \$ n &gt;&gt;= 1;     }     return \$ count; } \$ n = 100; echo countSetBits(\$ n); ? &gt;</pre>
	DOBF	CodeBERT	Transformer
	<pre>&lt;?php function maxSum(\$ arr, \$ n) {     sort(\$ arr);     \$ sum = 0;     for (\$ i = 0; \$ i &lt; \$ n; \$ i++) \$ sum         += (\$ arr[\$ i] * \$ i);     return \$ sum; } \$ arr = array(3, 5, 6, 1); \$ n = count(\$ arr); echo maxSum(\$ arr, \$ n); ? &gt;</pre>	<pre>&lt;?php function countSetBits(\$ n) {     \$ count = 0;     while (\$ n &gt; 0) {         \$ count += 1;         \$ i++;     }     return \$ count; } \$ n = 5; \$ n = count(\$ n); echo countSetBits(\$ n); ? &gt;</pre>	<pre>&lt;?php function countSetBits(\$ n) {     \$ count = 0;     while (\$ n) {         \$ count = 0;         \$ n = 0;         while (\$ p != 0) {             \$ count += (\$ n + 1);         }         return \$ count;     }     \$ n = 0;     echo countSetBits(\$ n); ? &gt;</pre>

Table 8: Comparison of generated outputs of translation from Java to PHP. The problem description in GeeksForGeeks gives the problem as follows - Write an efficient program to count the number of 1s in the binary representation of an integer.

### More Samples of *CoST* Dataset

In Tables 14, 15, 16, and 17, we provide more examples from the *CoST* dataset to illustrate the composition of the dataset. Each row of the tables has cells each corresponding to a code snippet of a particular language. All the code snippets in a row are parallel in the sense that they are equivalent in performing the same operation in different languages. Each column under a language is the complete program solution to the GeeksForGeeks problem statement in a certain language. The problem statement for each code example is given in the caption of the table.

<b>C# to JS</b>	<b>Input</b>	<b>Ground Truth</b>	<b>MuST-PT</b>
	<pre> using System; class GFG {     static void nextGreatest(int[] arr) {         int size = arr.Length;         int max_from_right = arr[size - 1];         arr[size - 1] = -1;         for (int i = size - 2; i &gt;= 0; i--) {             int temp = arr[i];             arr[i] = max_from_right;             if (max_from_right &lt; temp)                 max_from_right = temp;         }     }     static void printArray(int[] arr) {         for (int i = 0; i &lt; arr.Length; i++)             Console.Write(arr[i] + " _ ");     }     public static void main (String[] args)     {         int arr[] = {16, 17, 4, 3, 5, 2};         nextGreatest (arr);         System.out.println("The modified             array:");         printArray (arr);     } } </pre>	<pre> function nextGreatest(arr, size) {     max_from_right = arr[size - 1];     arr[size - 1] = -1;     for (let i = size - 2; i &gt;= 0; i         --) {         temp = arr[i];         arr[i] = max_from_right;         if (max_from_right &lt; temp)             max_from_right = temp;     } } function printArray(arr, size) {     var i;     for (let i = 0; i &lt; size; i++)         document.write(arr[i] + " "             ); } arr = new Array(16, 17, 4, 3, 5,     2); size = arr.length; nextGreatest(arr, size); document.write(" " + " " + " "); printArray(arr, size); </pre>	<pre> function nextGreatest(arr) {     let size = arr.length;     let max_from_right = arr[size -         1];     arr[size - 1] = -1;     for (let i = size - 2; i &gt;= 0; i         --) {         let temp = arr[i];         arr[i] = max_from_right;         if (max_from_right &lt; temp)             max_from_right = temp;     } } return arr; } function printArray(arr) {     for (let i = 0; i &lt; arr.length;         i++) document.write(arr[i]         + " "); } let arr = [1, 2, 3, 4, 2, 3]; let n = arr.length; nextRightArray(arr, n); printArray(arr, n); </pre>
<b>DOBF</b>	<b>CodeBERT</b>	<b>Transformer</b>	
<pre> function printArray(arr, n) {     for (let i = 0; i &lt; n; i++) document.         write(arr[i] + " ");     document.write(" "); } function printArray(arr, n) {     for (let i = 0; i &lt; n; i++) document.         write(arr[i] + " ");     document.write(" "); } function printArray(arr, n) {     for (let i = 0; i &lt; n; i++) {         document.write(arr[i] + " ");     } } printArray(arr, n); printArray(arr, n); </pre>	<pre> function largestGreater(arr, size ) {     let max_so_far = arr[size - 1];     let max_ending_max = -1;     for (let i = size - 2; i &gt;= 0; i         --) {         if (arr[i] &lt; arr[i])             max_ending_max =                 max_ending_here;     }     if (max_ending_here &lt; temp)         max_ending_here = arr[i]; } return max_ending_here; } let arr = [1, 3, 5, 9, 10, 1]; let n = arr.length; document.write(" "); printArray(arr); </pre>	<pre> function rearrange(arr, size) {     let temp = arr[0] - arr[0];     let max_ele = arr[0] - 1;     for (let i = 1; i &lt; size; i++) {         if (arr[i] != arr[i] &lt; arr[i])             {                 max_ending_here = arr[i];                 arr[i] = temp;             } else {                 if (arr[i] &gt; max_ending_here)                     {                         max_ref = arr[i];                     }             }         else document.write(" ");     } } let arr = [1, 0, 2, 0, 1, 1]; let x = 4; printArray(arr, n); </pre>	

Table 9: Comparison of generated outputs of translation from C# to JavaScript. The problem statement from GeeksForGeeks for this problem is given as follows - Given an array of integers, replace every element with the next greatest element (greatest element on the right side) in the array.

<b>Python to C++</b>	<b>Input</b>	<b>Ground Truth</b>	<b>MuST-PT</b>
	<pre>def min (x,y) :     return y^((x^y)&amp;-(x&lt;y)) def max (x,y) :     return x^((x^y)&amp;-(x&lt;y))</pre>	<pre>#include &lt;iostream&gt; using namespace std;  class gfg { public:     int min(int x,int y){         return y^((x^y)&amp;-(x&lt;y));     }     int max(int x,int y){         return x^((x^y)&amp;-(x&lt;y));     } };</pre>	<pre>#include &lt;bits/stdc++.h&gt; using namespace std;  int min(int x,int y){     return y^((x^y)&amp;-(x&lt;y)); } int max(int x,int y) {     return x^((x^y)&amp;-(x&lt;y)); }</pre>
	<b>DOBF</b>	<b>CodeBERT</b>	<b>Transformer</b>
	<pre>#include &lt;bits/stdc++.h&gt; using namespace std;  int findMaxSum(int arr[], int n) {     int res = 0;     for (int i = 0; i &lt; n; i++) {         int curr_sum = 0;         for (int j = i; j &lt; n; j++)             curr_sum += arr[j];         if (curr_sum &gt; res)             res++;     }     return res; }  int main() {     int arr[] = {1,2,2,2,3,3};     int n = sizeof(arr) / sizeof(arr[0]);     cout &lt;&lt; findMaxSum(arr, n) &lt;&lt; endl;     return 0; }</pre>	<pre>#include &lt;bits/stdc++.h&gt; using namespace std;  int max(int x,int y){     return (x&lt;y)?x^((y&lt;y)&amp;((x^y)&amp;(x^y)&amp;(y&lt;y)))&amp;(y&lt;y); }  int max(int x,int y){     return y; }</pre>	<pre>#include &lt;bits/stdc++.h&gt; using namespace std;  int x(int x, int y){     return (x^y)?y:y; }  int eggDrop(int x, int y) {     if (x&lt;y) return -1;     int&gt;y;     for (inti=0;i&lt;y;i++){         int max=y^i;         x=min(x,y)-x;         for (intx=0;x&lt;y;x++){             if (x&gt;y&lt;y&amp;&amp;x)x++;             x =min(x, y);         }         return(x, y);     } }</pre>

Table 10: Comparison of generated outputs of translation from Python to C++. The problem statement obtained from Geek-ForGeeks is as follows - Compute the minimum or maximum of two integers without branching.

	Input	Ground Truth	MuST-PT
C to JS	<pre> #include &lt;stdio.h&gt; #include &lt;stdlib.h&gt;  void printRepeating(int arr[],     int size) {     int i, j;     printf(" _ Repeating _ elements         _ are _ ");     for (i = 0; i &lt; size; i++)         for (j = i + 1; j &lt; size; j++)             if (arr[i] == arr[j]) printf(                 " _ % d _ ", arr[i]); }  int main(){     int arr[] = { 1, 2, 3, 1, 3,         6, 6 };     int arr_size = sizeof(arr) /         sizeof(arr[0]);     printRepeating(arr, arr_size);     getchar();     return 0; } </pre>	<pre> function printRepeating(arr, size) {     var i, j;     document.write(" ");     for (i = 0; i &lt; size; i++) {         for (j = i + 1; j &lt; size; j++) {             if (arr[i] == arr[j]) document.write(                 arr[i] + " ");         }     }     let arr = [ 1, 2, 3, 1, 3, 6, 6 ];     let arr_size = arr.length;     printRepeating(arr, arr_size); } </pre>	<pre> function printRepeating(arr,     size) {     let i, j;     document.write(" ");     for (i = 0; i &lt; size; i++)         for (j = i + 1; j &lt; size; j             ++         )             if (arr[i] == arr[j])                 document.write(arr[i]                     + " "); } let arr = [1, 3, 5, 4, 5]; let n = arr.length; printRepeating(arr, n); </pre>
	DOBF	CodeBERT	Transformer
	<pre> function rearrangeNaive(arr, n) {     let temp = new Array(n),         i;     for (i = 0; i &lt; n; i++) temp[arr         [i]] = i;     for (i = 0; i &lt; n; i++) arr[i] =         temp[i]; }  function printArray(arr, n) {     let i;     for (i = 0; i &lt; n; i++) document         .write(" " + arr[i]);     document.write(" "); }  let arr = [1, 3, 0, 2]; let n = arr.length; document.write(" "); printArray(arr, n); rearrangeNaive(arr, n); document.write(" "); printArray(arr, n); </pre>	<pre> function optimalSearchTree(keys, freq, n) {     var cost = new Array(n);     for (var i = 0; i &lt; n; i++) cost[i] = new         Array(n);     for (var i = 0; i &lt; n; i++) cost[i][i] =         freq[i];     for (var L = 2; L &lt;= n; L++) {         for (var i = 0; i &lt;= n - L + 1; i++) {             var j = i + L - 1;             if (i &gt;= n    j &gt;= n) break;             cost[i][j] =                 Number.MAX_SAFE_INTEGER;             for (var r = i; r &lt;= j; r++) {                 var c = 0;                 if (r &gt; i) c += cost[i][r - 1]                 if (r &lt; j) c += cost[r + 1][j]                 c +=                     sum(freq, i, j);                 if (c &lt; cost[i][j]) cost[i][j] = c;             }         }     }     return cost[0][n - 1]; }  var keys = [10, 12, 20]; var freq = [34, 8, 50]; var n = keys.length; document.write(" " + optimalSearchTree(keys,     freq, n)); </pre>	<pre> function sum(freq, i, j) {     let j = 0,         i;     for (" ");     i = 0;     i++) {         if (arr[i] &lt;= 0) {             let i][i] = 0;             arr[i] = arr[j] = arr[j] = i];             j];         }     }     return j; }  function findMissingPositive(     arr, j) {     let i;     for (i = 0; i &lt; size; i++) {         let j = Math.write(arr[i]);         if (" " + 1);     } } </pre>

Table 11: Comparison of generated outputs of translation from C to Javascript (JS is short for JavaScript in the table). The problem statement as given in GeekForGeeks pertaining to the above table is as follows - Given an array of n elements that contains elements from 0 to n-1, with any of these numbers appearing any number of times. Find these repeating numbers in O(n) and using only constant memory space.

Java to C++	Input	Ground Truth	Transformer	Transformer+MuST
		<pre>import java.io.*; class PairDifference {     static boolean findPair(         int arr[], int n) {         int size = arr.length;         int i = 0, j = 1;         while (i &lt; size &amp;&amp; j &lt;             size) {             if (i != j &amp;&amp; arr[j] -                 arr[i] == n) {                 System.out.print("                     Pair _ Found : _                     " + " ( _ " +                     arr[i] + " , _ "                     + arr[j] + " _                     ) ");                 return true;             } else if (arr[j] -                 arr[i] &lt; n) j++;             else i++;         }         System.out.print(" No _             such _ pair ");         return false;     }     public static void main(         String[] args) {         int arr[] =             {1,8,30,40,100};         int n = 60;         findPair(arr, n);     } }</pre>	<pre>#include &lt;bits/stdc++.h&gt; using namespace std; bool findPair(int arr[], int     size, int n) {     int i = 0;     int j = 1;     while (i &lt; size &amp;&amp; j &lt; size)         {             if (i != j &amp;&amp; arr[j] - arr[                 i] == n) {                 cout &lt;&lt; " Pair _ Found :                     _ ( " &lt;&lt; arr[i] &lt;&lt; "                     , _ " &lt;&lt; arr[j] &lt;&lt; "                     ) ";                 return true;             } else if (arr[j] - arr[i]                 &lt; n) j++;             else i++;         }         cout &lt;&lt; " No _ such _ pair "             ;         return false;     }     int main() {         int arr[] = {1,8,30,40,100};         int size = sizeof(arr) /             sizeof(arr[0]);         int n = 60;         findPair(arr, size, n);         return 0;     } }</pre>	<pre>#include &lt;bits/stdc++.h&gt; using namespace std; bool find3 #define size(int     arr[], int size) {     int i, j;     while (j &lt; size &amp;&amp; arr[j         ] &amp;&amp; arr[j] &lt; arr[i         ]) {         if (arr[j] != arr[j]             &amp;&amp; arr[i] == arr[                 j]) {             cout &lt;&lt; " _ " &lt;&lt; arr[                 i] &lt;&lt; " _ "             &lt;&lt; arr [ j ] &lt;&lt; " _                 " ; j ++ ; } }         return false ;     }     int main ( ) {         int arr [ ] = {             int arr [ 4 ] =             { 12 , 8 , 34 ,             30 , 15 , 22 ,             50 } ; int n =             sizeof ( arr ) /             sizeof ( arr [                 0 ] ) ; int n =             sizeof ( arr [ 0                 ] ) ;             findMajority (                 arr , n ) ;             return 0 ; } }</pre>
	Transcoder	Transcoder+MuST	CodeBERT	CodeBERT+MuST
	<pre>#include &lt;bits/stdc++.h&gt; using namespace std; bool findPartiion(int arr     [], int n) {     int sum = 0;     int i, j;     for (i = 0; i &lt; n; i++)         sum += arr[i];     if (sum % 2 != 0) return         false;     bool part[sum / 2 + 1];     for (i = 0; i &lt;= sum / 2;         i++) {         part[i] = 0;     }     for (i = 0; i &lt; n; i++) {         for (j = sum / 2; j &gt;=             arr[i]; j--) {             if (part[j - arr[i]]                 == 1    j == arr[                 i]) part[j] = 1;         }     }     return part[sum / 2]; } int main() {     int arr[] =         {1,3,3,2,3,2};     int n = sizeof(arr) /         sizeof(arr[0]);     return 0; }</pre>	<pre>#include &lt;bits/stdc++.h&gt; using namespace std; bool findPair(int arr[], int n     ) {     int size = n;     int i = 0, j = 1;     while (i &lt; size &amp;&amp; j &lt; size)         {             if (i != j &amp;&amp; arr[j] - arr[                 i] == n) {                 cout &lt;&lt; " Pair _ Found :                     _ ( " &lt;&lt; arr[i] &lt;&lt; "                     , _ " &lt;&lt; arr[j] &lt;&lt; "                     ) " &lt;&lt; endl;                 return true;             } else if (arr[j] - arr[i]                 &lt; n) j++;             else i++;         }         cout &lt;&lt; " No _ such _ pair "             ;         return false;     }     int main() {         int arr[] = {1,8,30,40,100};         int n = sizeof(arr) / sizeof             (arr[0]);         findPair(arr, n);         return 0;     } }</pre>	<pre>#include &lt;bits/stdc++.h&gt; using namespace std; bool findPair(int arr[],     int n) {     int size = 0, j = 1;     int i = 0, j = 1;     while (i &lt; size &amp;&amp; j != j         ) {         if (i != j &amp;&amp; arr[j] -             arr[i] == n) {             cout &lt;&lt; " Pair _ found                 " &lt;&lt; arr[i] &lt;&lt; "                 , _ found ";             return true;         } else if (arr[j] - arr[             i] &lt; n) j++;         else i++;     }     return false; } int main() {     int arr[] =         {1,8,30,40,100};     int n = sizeof(arr) /         sizeof(arr[0]);     findPair(arr, n);     return 0; }</pre>	<pre>#include &lt;bits/stdc++.h&gt; using namespace std; bool findPair(int arr[], int n)     {         int size = 0, j = 1;         while (i &lt; size &amp;&amp; j &lt; size) {             if (i != j &amp;&amp; arr[j] - arr[i                 ] == n) {                 cout &lt;&lt; " Pair _ Found : _                     " &lt;&lt; arr[i] &lt;&lt; " , _ "                     &lt;&lt; arr[j] &lt;&lt; " _ ) ";                 return true;             } else if (arr[j] - arr[i] &lt;                 n) j++;             else i++;         }         cout &lt;&lt; " No _ such _ pair             STRNEWLINE ";         return false;     }     int main() {         int arr[] = {1,8,30,40,100};         int n = sizeof(arr) / sizeof(             arr[0]);         return 0;     } }</pre>

Table 12: Java to C++ translation example showing improvement after Multilingual Snippet Translation (MuST). The problem statement for this as per GeeksForGeeks is - Given an unsorted array and a number n, find if there exists a pair of elements in the array whose difference is n.

	Input	Ground Truth	Transformer	Transformer+MuST
Python to C#	<pre>def pow(a, b):     if b == 0:         return 1     answer = a     increment = a     for i in range(1, b):         for j in range(1, a):             answer += increment         increment = answer     return answer</pre>	<pre>using System; class GFG {     static int pow(int a, int b)     {         if (b == 0) return 1;         int answer = a;         int increment = a;         int i, j;         for (i = 1; i &lt; b; i++) {             for (j = 1; j &lt; a; j++) {                 answer += increment;             }             increment = answer;         }         return answer;     } }</pre>	<pre>using System; class GFG {     static int calculate(int         a, int b) {         return (a == b) ? a : b;     }     static int find(int a,         int b) {         int b = 0;         for (int i = 0; i &lt; n; i             ++){             for (int j = i; j &lt;                 Math.Min(i, a); j                 ++){                 if (a == b) return a;             }         }         return b;     } }</pre>	<pre>using System; class GFG {     static int Pow(int a, int b)     {         if (a == 0) return 1;         int first = a.Length;         int answer = b;         for (int i = 0; i &lt; length;             i++) {             for (int j = 0; j &lt; n; j                 ++){                 answer += ((a[i]));             }         }         return answer;     } }</pre>
	Transcoder	Transcoder+MuST	CodeBERT	CodeBERT+MuST
	<pre>using System; class GFG {     static int calculate(int[] a,         int n) {         int sum = 0;         for (int i = 0; i &lt; n; i++) {             if (a[i] == a[i]) {                 return answer;             }         }         return answer;     }     public static int countPairs(         int[] a, int n) {         int answer = 0;         for (int i = 0; i &lt; n; i++)             {                 answer = answer + (a[i]);             }         return answer / 2;     }     public static void Main() {         int[] a = {1,2,3};         int n = a.Length;</pre>	<pre>using System; class GFG {     static int(int a, int b) {         if (b == 0) return 1;         int answer = a;         int change = a;         for (int i = 1; i &lt;= b; i             ++){             for (int j = 1; j &lt; a; j                 ++){                 answer += step;             }             dfs = answer;         }         return answer;     } }</pre>	<pre>using System; class GFG {     static int pow(int a, int         b) {         if (b == 0) return 1;         int answer = a;         for (int i = 1; i &lt; a; i             ++){             answer += a[i, b];         }         for (int j = 1; j &lt; a; j             ++){             answer += answer;         }         return answer;     } }</pre>	<pre>using System; class GFG {     static int pow(int a, int b)     {         if (b == 0) return 1;         int answer = a;         int increment = a;         for (int i = 1; i &lt; b; i++)             {                 for (int j = 1; j &lt; a; j                     ++){                     answer += increment;                     increment = answer;                 }             }         return answer;     } }</pre>

Table 13: Python to C# translation example showing improvement after Multilingual Snippet Translation (MuST). The problem statement from GeeksForGeeks is - Find powers of numbers without using multiplication (\*) or division (/) operators.



C++	Java	Python	C#
<pre> /* C++ program for addition of two matrices*/  #include &lt;bits/stdc++.h&gt; using namespace std; #define N 4 </pre>	<pre> /* Java program for addition of two matrices */  class GFG {     static final int N = 4; </pre>	<pre> '''Python3 program for addition of two matrices'''  N = 4 </pre>	<pre> /* C# program for addition of two matrices */  using System; class GFG {     static int N = 4; </pre>
<pre> /* This function adds A[][] and B[][], and stores the result in C[][] */  void add(int A[][N], int B[][N] , int C[][N]) {     int i, j;     for (i = 0; i &lt; N; i++)         for (j = 0; j &lt; N; j++)             C[i][j] = A[i][j] + B [i][j]; } </pre>	<pre> /* This function adds A[][] and B[][], and stores the result in C[][] */  static void add(int A[][], int B[][], int C[][]) {     int i, j;     for (i = 0; i &lt; N; i++)         for (j = 0; j &lt; N; j ++)             C[i][j] = A[i][j] + B[i][j]; } </pre>	<pre> '''This function adds A [][] and B[][], and stores the result in C[][]'''  def add(A,B,C):     for i in range(N):         for j in range(N):             C[i][j] = A[i][j] + B[i][j] </pre>	<pre> /* This function adds A[][] and B[][], and stores the result in C[][] */  static void add(int[,] A, int [,]B, int [,]C) {     int i, j;     for (i = 0; i &lt; N; i++)         for (j = 0; j &lt; N; j ++)             C[i,j] = A[i,j] + B[i,j]; } </pre>
<pre> /* Driver code */  int main() {     int A[N][N] = { {1, 1, 1, 1}, {2, 2, 2, 2}, {3, 3, 3, 3}, {4, 4, 4, 4}};      int B[N][N] = { {1, 1, 1, 1}, {2, 2, 2, 2}, {3, 3, 3, 3}, {4, 4, 4, 4}};      int C[N][N];     int i, j;     add(A, B, C);     cout &lt;&lt; "Result matrix is " &lt;&lt; endl;     for (i = 0; i &lt; N; i++)     {         for (j = 0; j &lt; N; j++)             cout &lt;&lt; C[i][j] &lt;&lt; " ";         cout &lt;&lt; endl;     }     return 0; } </pre>	<pre> /* Driver code */  public static void main ( String[] args) {     int A[][] = { {1, 1, 1, 1},{2, 2, 2, 2},{3, 3, 3, 3},{4, 4, 4, 4}};      int B[][] = { {1, 1, 1, 1},{2, 2, 2, 2},{3, 3, 3, 3},{4, 4, 4, 4}};      int C[][] = new int[N][N] ];     int i, j;     add(A, B, C);     System.out.print("Result matrix is \n");     for (i = 0; i &lt; N; i++)     {         for (j = 0; j &lt; N; j ++)             System.out.print(C[i ][j] + " ");         System.out.print("\n" );     } } </pre>	<pre> '''Driver code'''  A = [ [1, 1, 1, 1], [2, 2, 2, 2], [3, 3, 3, 3], [4, 4, 4, 4] ] B= [ [1, 1, 1, 1], [2, 2, 2, 2], [3, 3, 3, 3], [4, 4, 4, 4] ] C=A[:][:] add(A, B, C) print("Result matrix is") for i in range(N):     for j in range(N):         print(C[i][j], " ", end='')     print() </pre>	<pre> /* Driver code */  public static void Main () {     int [,]A = { {1, 1, 1, 1},{2, 2, 2, 2},{3, 3, 3, 3},{4, 4, 4, 4}};      int [,]B = { {1, 1, 1, 1},{2, 2, 2, 2},{3, 3, 3, 3},{4, 4, 4, 4}};      int [,]C = new int[N,N];     int i, j;     add(A, B, C);     Console.WriteLine("Result matrix is ");     for (i = 0; i &lt; N; i++)     {         for (j = 0; j &lt; N; j ++)             Console.Write(C[i,j] + " ");         Console.WriteLine();     } } </pre>

Table 14: Parallel alignment of snippets in four languages. The program given here performs addition of two square matrices.

C++	Java	Python	PHP
<pre> /*C++ program to Compute the minimum or maximum of two integers without branching*/  #include&lt;iostream&gt; using namespace std; class gfg { </pre>	<pre> /*Java program to Compute the minimum or maximum of two integers without branching*/  public class AWS { </pre>	<pre> '''Python3 program to Compute the minimum or maximum of two integers without branching''' </pre>	<pre> /*PHP program to Compute the minimum or maximum of two integers without branching*/ </pre>
<pre> /*Function to find minimum of x and y*/  public: int min(int x, int y) {     return y ^ ((x ^ y) &amp; -(         x &lt; y)); } </pre>	<pre> /*Function to find minimum of x and y*/  static int min(int x, int y ) {     return y ^ ((x ^ y) &amp; -(x         &lt;&lt; y)); } </pre>	<pre> '''Function to find minimum of x and y ''' def min(x, y):     return y ^ ((x ^ y) &amp;         -(x &lt; y)) </pre>	<pre> /*Function to find minimum of x and y*/  function m_in(\$x, \$y) {     return \$y ^ ((\$x ^ \$y) &amp;         - (\$x &lt; \$y)); } </pre>
<pre> /*Function to find maximum of x and y*/  int max(int x, int y) {     return x ^ ((x ^ y) &amp; -(         x &lt; y)); } }; </pre>	<pre> /*Function to find maximum of x and y*/  static int max(int x, int y ) {     return x ^ ((x ^ y) &amp; -(x         &lt;&lt; y)); } </pre>	<pre> '''Function to find maximum of x and y ''' def max(x, y):     return x ^ ((x ^ y) &amp;         -(x &lt; y)) </pre>	<pre> /*Function to find maximum of x and y*/  function m_ax(\$x, \$y) {     return \$x ^ ((\$x ^ \$y) &amp;         - (\$x &lt; \$y)); } </pre>
<pre> /* Driver code */  int main() {     gfg g;     int x = 15;     int y = 6;     cout &lt;&lt; "Minimum of " &lt;&lt;         x &lt;&lt;         " and " &lt;&lt; y &lt;&lt; " is         ";     cout &lt;&lt; g.min(x, y);     cout &lt;&lt; "\nMaximum of "         &lt;&lt; x &lt;&lt;         " and " &lt;&lt; y &lt;&lt; "         is ";     cout &lt;&lt; g.max(x, y);     getchar(); } </pre>	<pre> /* Driver program to test above functions */  public static void main(     String[] args) {     int x = 15;     int y = 6;     System.out.print("         Minimum of "+x+"         and "+y+" is ");     System.out.println(min(x         , y));     System.out.print("         Maximum of "+x+"         and "+y+" is ");     System.out.println( max(         x, y)); } </pre>	<pre> '''Driver program to test above functions''' x = 15 y = 6 print("Minimum of", x, "     and", y, "is", end="     ") print(min(x, y)) print("Maximum of", x, "     and", y, "is", end="     ") print(max(x, y)) </pre>	<pre> /*Driver Code*/ \$x = 15; \$y = 6; echo"Minimum of"," ", \$x," ","     and",     " ",\$y," "," is "," "; echo m_in(\$x, \$y); echo "\nMaximum of"," ",\$x," "     ,     "and"," ", \$y," ", " is "; echo m_ax(\$x, \$y); ?&gt; </pre>

Table 15: Parallel alignment of snippets in four languages. The program given here computes the maximum or minimum of two integers without branching.

C++	Java	Python	C#
<pre> /*C++ program to rotate an array by d elements*/  #include &lt;bits/stdc++.h&gt; using namespace std; </pre>	<pre> /*Java program to rotate an array by d elements*/  class RotateArray { </pre>	<pre> '''Python3 program to rotate an array by d elements''' </pre>	<pre> /*C# program for array rotation*/  using System; class GFG { </pre>
<pre> /*Function to left Rotate arr [] of size n by 1*/  void leftRotatebyOne(int arr [], int n) {     int temp = arr[0], i;     for (i = 0; i &lt; n - 1; i++)         arr[i] = arr[i + 1];     arr[n-1] = temp; } </pre>	<pre> /*Function to left Rotate arr [] of size n by 1*/  void leftRotatebyOne(int arr[], int n) {     int i, temp;     temp = arr[0];     for (i = 0; i &lt; n - 1; i     ++         arr[i] = arr[i + 1];     arr[n-1] = temp; } </pre>	<pre> '''Function to left Rotate arr[] of size n by 1*'''  def leftRotatebyOne(arr, n):     temp = arr[0]     for i in range(n-1):         arr[i] = arr[i + 1]     arr[n-1] = temp </pre>	<pre> /*Function to left Rotate arr [] of size n by 1*/  static void leftRotatebyOne (int[] arr, int n) {     int i, temp = arr[0];     for (i = 0; i &lt; n - 1; i     ++         arr[i] = arr[i + 1];     arr[n-1] = temp; } </pre>
<pre> /*Function to left rotate arr [] of size n by d*/  void leftRotate(int arr[], int d, int n) {     for (int i = 0; i &lt; d; i++)         leftRotatebyOne(arr, n); } </pre>	<pre> /*Function to left rotate arr [] of size n by d*/  void leftRotate(int arr[], int d, int n) {     for (int i = 0; i &lt; d; i     ++         leftRotatebyOne(arr,         n); } </pre>	<pre> '''Function to left rotate arr[] of size n by d*'''  def leftRotate(arr, d, n) :     for i in range(d):         leftRotatebyOne(arr         , n) </pre>	<pre> /*Function to left rotate arr [] of size n by d*/  static void leftRotate(int [] arr, int d, int n) {     for (int i = 0; i &lt; d; i     ++         leftRotatebyOne(arr,         n); } </pre>
<pre> /*Utility function to print an array */  void printArray(int arr[], int n) {     for (int i = 0; i &lt; n; i++)         cout &lt;&lt; arr[i] &lt;&lt; " "; } </pre>	<pre> /*Utility function to print an array */  void printArray(int arr[], int n) {     for (int i = 0; i &lt; n; i     ++         System.out.print(arr[         i] + " "); } </pre>	<pre> '''Utility function to print an array *'''  def printArray(arr, size) :     for i in range(size):         print ("% d"% arr[i         ], end = " ") </pre>	<pre> /*Utility function to print an array */  static void printArray(int [] arr, int size) {     for (int i = 0; i &lt; size     ; i++)         Console.Write(arr[i]         + " "); } </pre>
<pre> /*Driver program to test above functions */  int main() {     int arr[] = { 1, 2, 3, 4, 5, 6, 7 };     int n = sizeof(arr) / sizeof(arr[0]);     leftRotate(arr, 2, n);     printArray(arr, n);     return 0; } </pre>	<pre> /*Driver program to test above functions*/  public static void main( String[] args) {     RotateArray rotate = new RotateArray();     int arr[] = { 1, 2, 3, 4, 5, 6, 7 };     rotate.leftRotate(arr, 2, 7);     rotate.printArray(arr, 7); } } </pre>	<pre> '''Driver program to test above functions */ '''  arr = [1, 2, 3, 4, 5, 6, 7] leftRotate(arr, 2, 7) printArray(arr, 7) </pre>	<pre> /*Driver code*/  public static void Main() {     int[] arr = { 1, 2, 3, 4, 5, 6, 7 };     leftRotate(arr, 2, 7);     printArray(arr, 7); } } </pre>

Table 16: Parallel alignment of snippets in all seven languages (part1). The program given here deals with rotating a given array by d elements.

JavaScript	PHP	C	
<i>/*JavaScript program to rotate an array by d elements*/</i>	<i>/*PHP program to rotate an array by d elements*/</i>	<i>/*C program to rotate an array by d elements*/</i>	
<i>/*Function to left Rotate arr [] of size n by 1*/</i>	<i>/*Function to left Rotate arr [] of size n by 1*/</i>	<i>/*Function to left Rotate arr [] of size n by 1*/</i>	
<pre> <b>function</b> leftRotatebyOne(   arr , n) {   <b>var</b> i, temp;   temp = arr[0];   <b>for</b> (i = 0; i &lt; n - 1; i     ++ )     arr[i] = arr[i + 1];   arr[n - 1] = temp; } </pre>	<pre> <b>function</b> leftRotatebyOne(&amp;\$arr   , \$n) {   \$temp = \$arr[0];   <b>for</b> (\$i = 0; \$i &lt; \$n - 1;     \$i++)     \$arr[\$i] = \$arr[\$i + 1];   \$arr[\$n-1] = \$temp; } </pre>	<pre> <b>#include</b> &lt;stdio.h&gt;  <b>void</b> leftRotatebyOne(<b>int</b> arr   [], <b>int</b> n); <b>void</b> leftRotatebyOne(<b>int</b> arr   [], <b>int</b> n) {   <b>int</b> temp = arr[0], i;   <b>for</b> (i = 0; i &lt; n - 1; i++)     arr[i] = arr[i + 1];   arr[n-1] = temp; } </pre>	
<i>/*Function to left rotate arr of size n by d*/</i>	<i>/*Function to left rotate arr [] of size n by d*/</i>	<i>/*Function to left rotate arr [] of size n by d*/</i>	
<pre> <b>function</b> leftRotate(arr , d   , n) {   <b>for</b> (i = 0; i &lt; d; i++)     leftRotatebyOne(arr,       n); } </pre>	<pre> <b>function</b> leftRotate(&amp;\$arr, \$d,   \$n) {   <b>for</b> (\$i = 0; \$i &lt; \$d; \$i++)     leftRotatebyOne(\$arr, \$n       ); } </pre>	<pre> <b>void</b> leftRotate(<b>int</b> arr[], <b>int</b>   d, <b>int</b> n) {   <b>int</b> i;   <b>for</b> (i = 0; i &lt; d; i++)     leftRotatebyOne(arr, n); } </pre>	
<i>/*Utility function to print an array*/</i>	<i>/*Utility function to print an array*/</i>	<i>/*Utility function to print an array*/</i>	
<pre> <b>function</b> printArray(arr , n   ) {   <b>for</b> (i = 0; i &lt; n; i++)     document.write(arr[i]       + " "); } </pre>	<pre> <b>function</b> printArray(&amp;\$arr, \$n) {   <b>for</b> (\$i = 0; \$i &lt; \$n; \$i++)     <b>echo</b> \$arr[\$i] . " "; } </pre>	<pre> <b>void</b> printArray(<b>int</b> arr[], <b>int</b>   n) {   <b>int</b> i;   <b>for</b> (i = 0; i &lt; n; i++)     printf("%d ", arr[i]); } </pre>	
<i>/*Driver program to test above functions*/</i>	<i>/*Driver program to test above functions*/</i>	<i>/*Driver program to test above functions*/</i>	
<pre> <b>var</b> arr = [ 1, 2, 3, 4,   5, 6, 7 ]; leftRotate(arr, 2, 7); printArray(arr, 7); </pre>	<pre> \$arr = <b>array</b>( 1, 2, 3, 4, 5,   6, 7 ); \$n = <b>sizeof</b>(\$arr); leftRotate(\$arr, 2, \$n); printArray(\$arr, \$n);  ?&gt; </pre>	<pre> <b>int</b> main() {   <b>int</b> arr[] = { 1, 2, 3, 4,     5, 6, 7 };   leftRotate(arr, 2, 7);   printArray(arr, 7);   <b>return</b> 0; } </pre>	

Table 17: Parallel alignment of snippets in all seven languages (part1). The program given here deals with rotating a given array by d elements.