SampleFix: Learning to Generate Functionally Diverse Fixes

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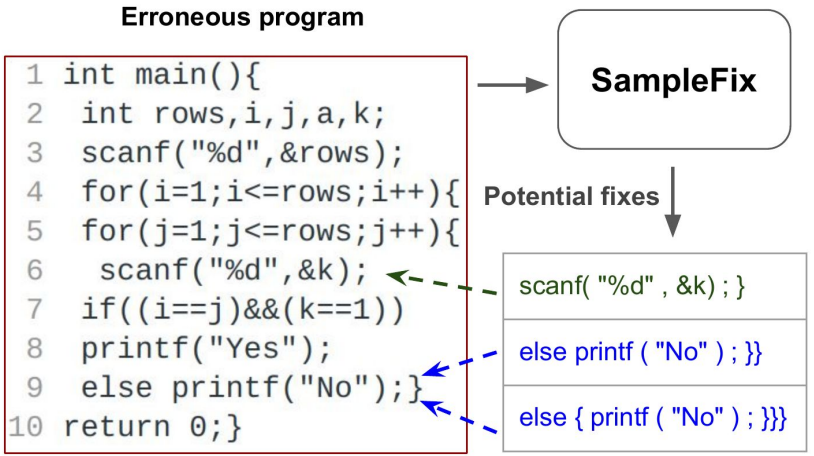
Introduction

- **Task:** Automatically correct common programming errors.
  - Missing scope delimiters
  - Missing variable declarations
  - Extraneous symbols



SampleFix captures the inherent ambiguity of the possible fixes by sampling multiple potential fixes for the given erroneous program.

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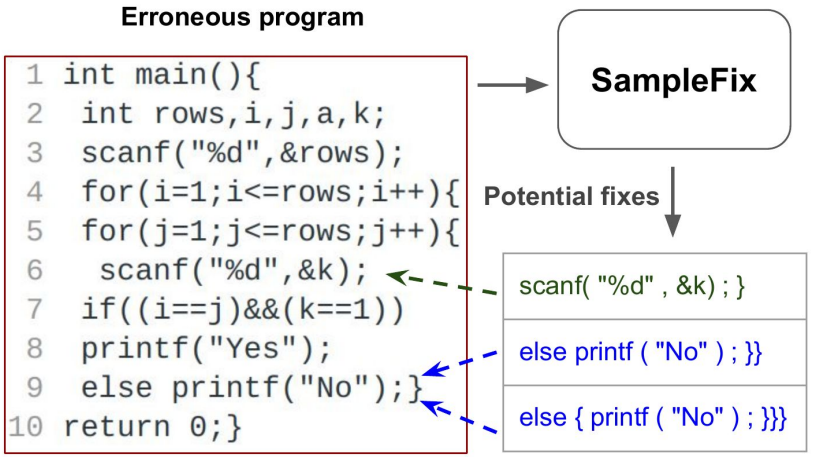
- **Insight:** Multiple fixes can implement the same functionality, and there is uncertainty on the intention of the programmer.



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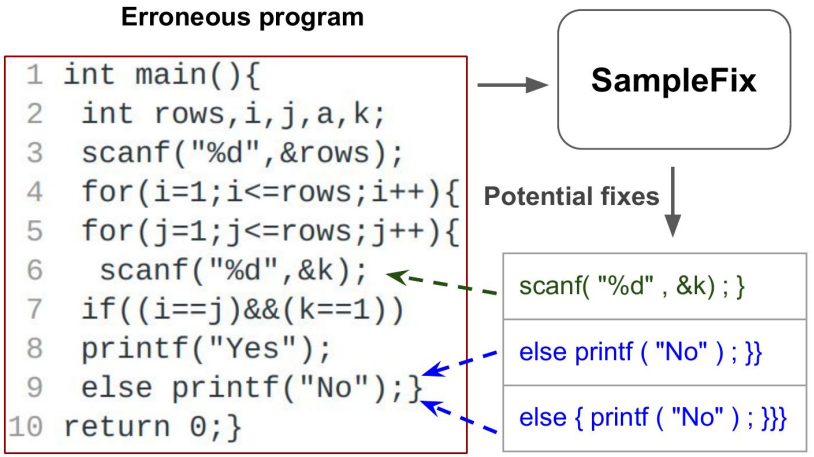
- **Our approach:** We propose a generative framework to account for inherent ambiguity and lack of representative datasets



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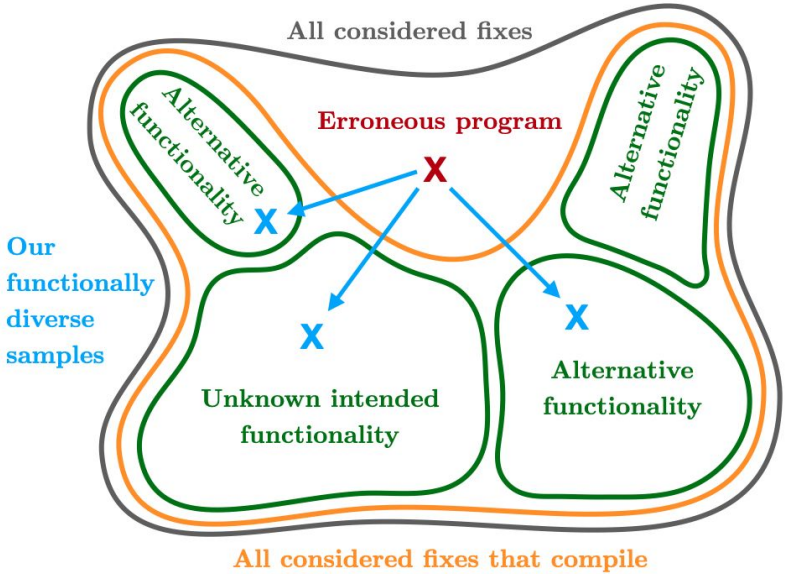
Generate Functionally Diverse Fixes

- Uncertainty about the intention of the programmer



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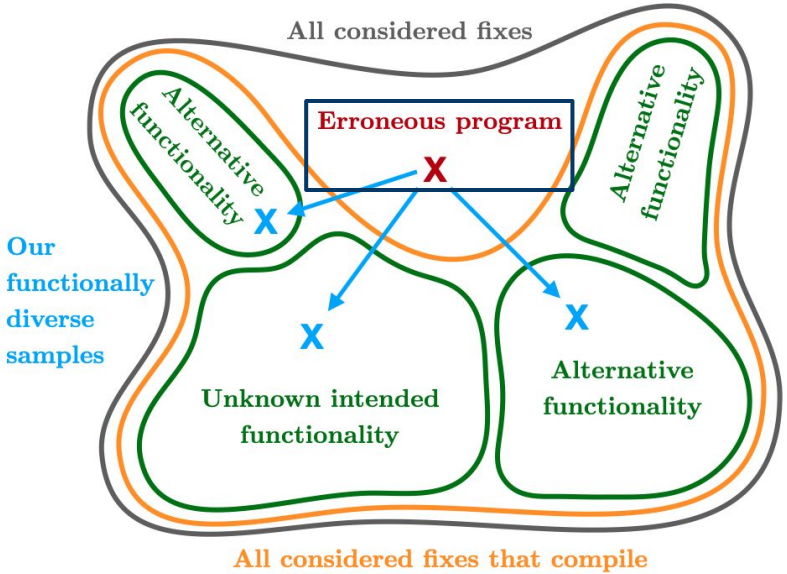

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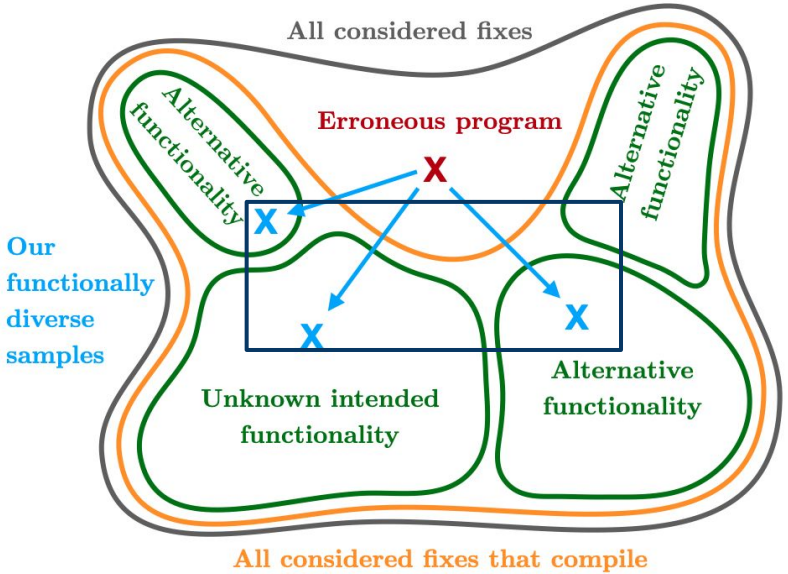
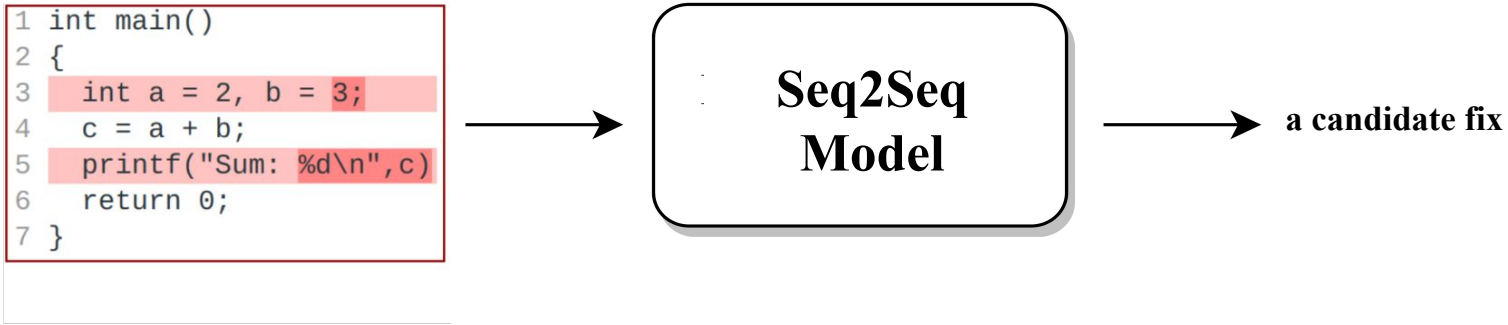


Related Work

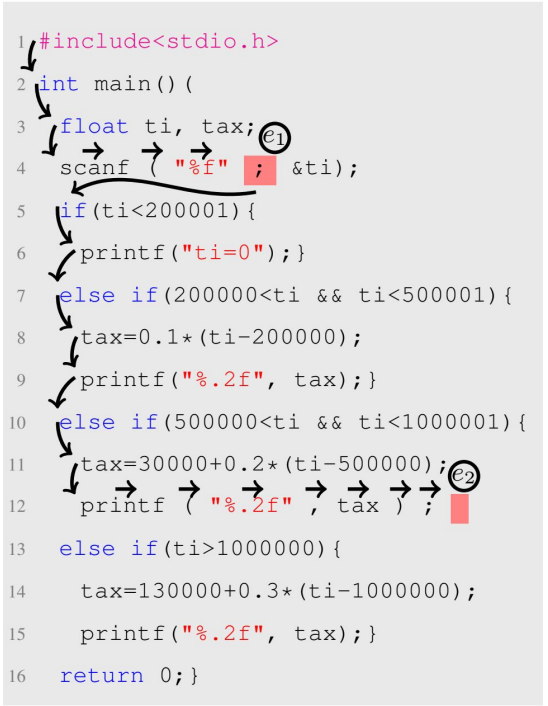
DeepFix [Gupta, Rahul, et al. *AAAI*. 2017.]



Related Work

RLAssist [Gupta, Rahul, et al. *AAAI*. 2019.]

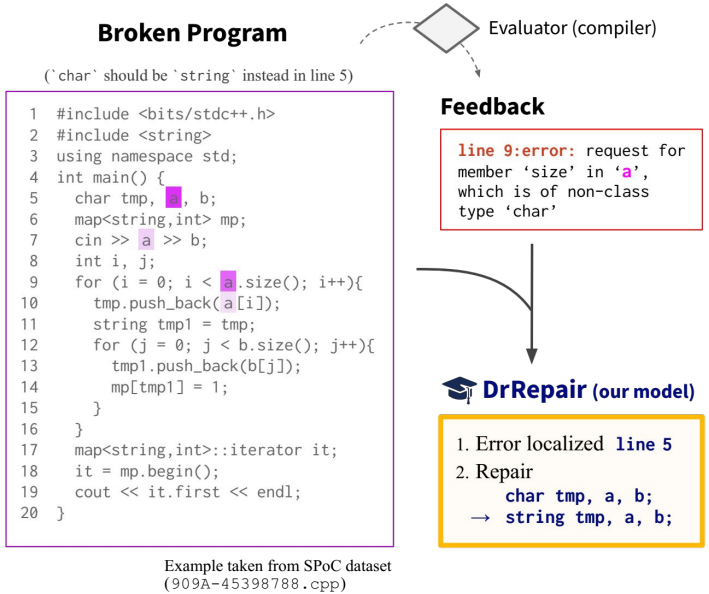
- Using reinforcement learning.
- An **agent** navigate over the program to **locate** and **resolve** the syntax errors.
- It relies on hand designed actions.



Related Work

DrRepair [Yasunaga, Michihiro, et al. *ICML*. 2020.]

- Using graph-attention mechanism to connects symbols relevant to program repair in source code and compile message.
- Utilizing the compiler output seems to be beneficial, it also limits the generality of the approach.

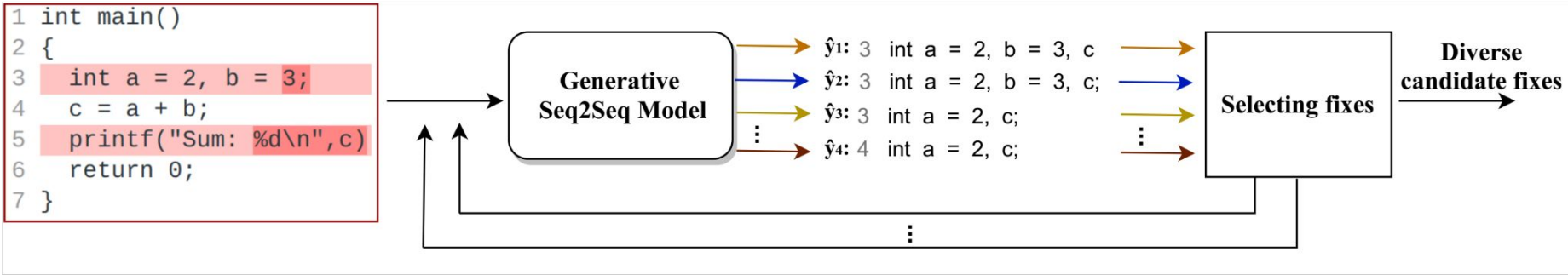


Example taken from SPoC dataset (909A-45398788.cpp)

SampleFix

Generative Model for Diversified Code Fixes

- Overview of SampleFix at inference time, highlighting the generation of diverse fixes.



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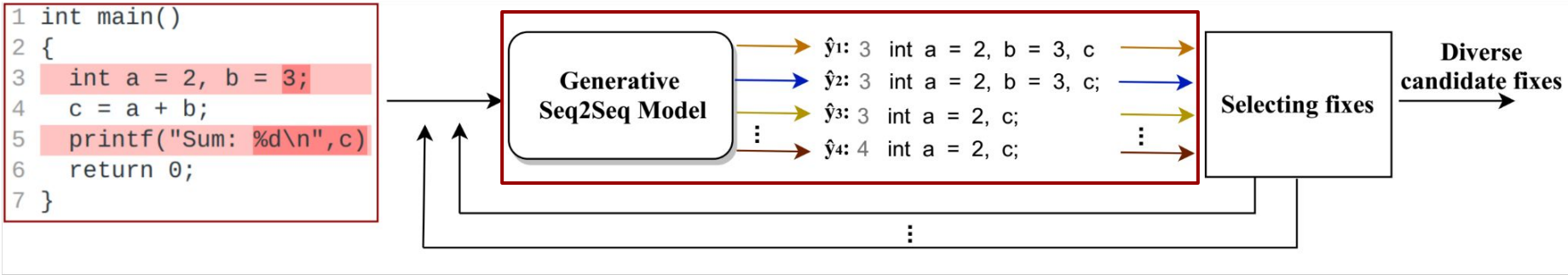

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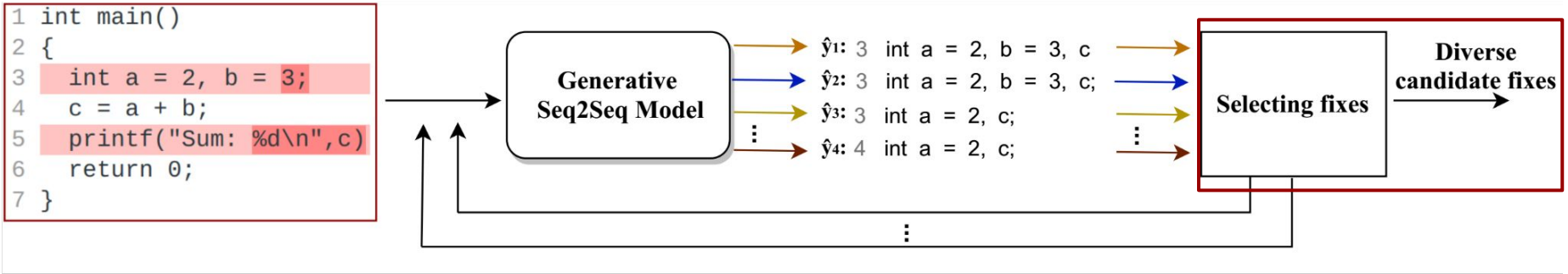

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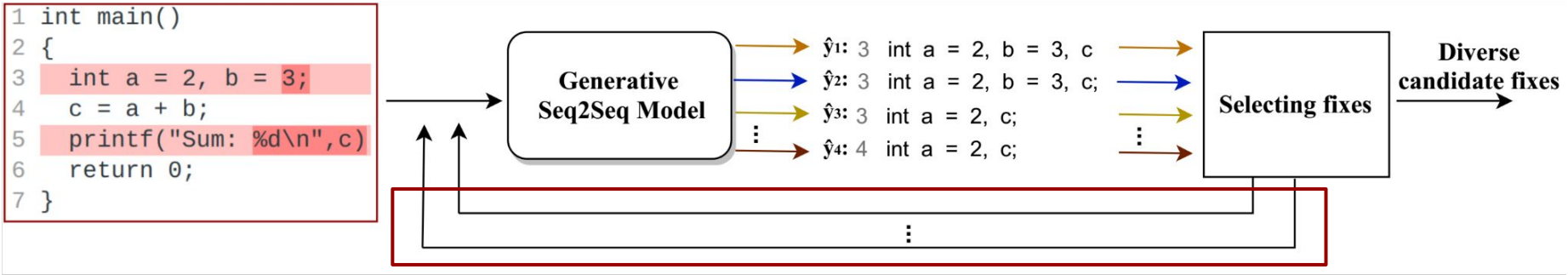
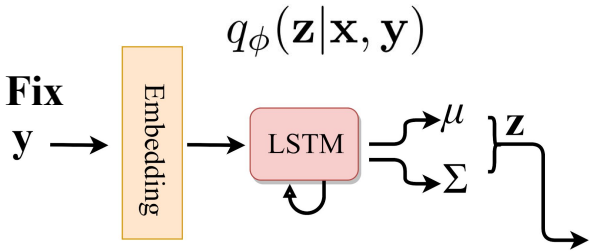


SampleFix

Conditional Variational Autoencoders for Generating Fixes



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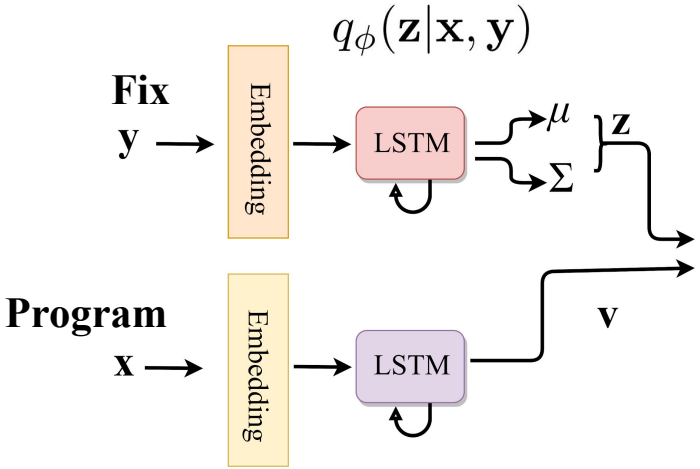

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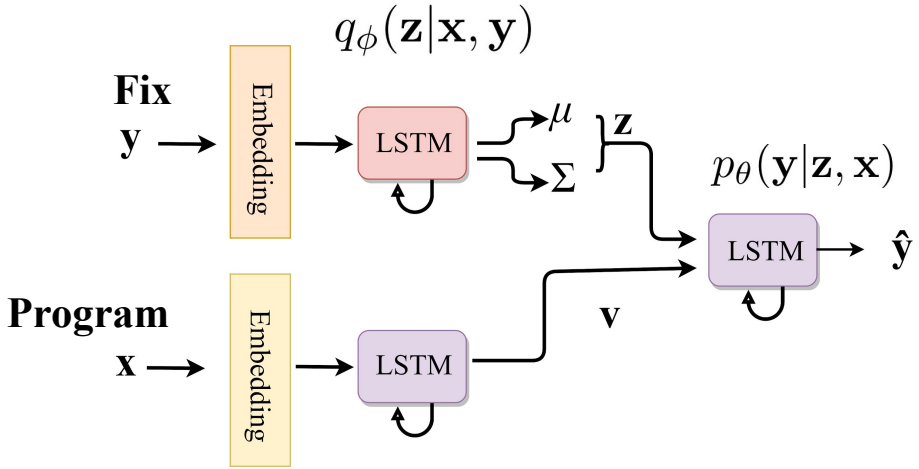
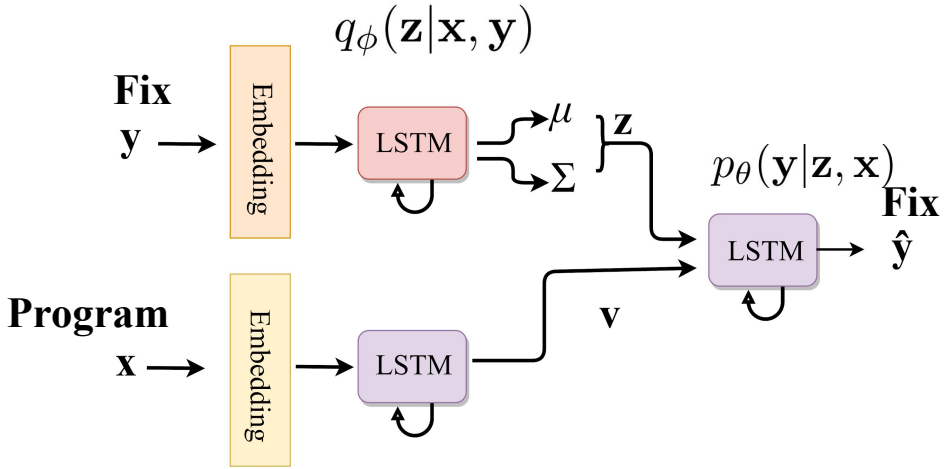


$$\hat{\mathcal{L}}_{\text{CVAE}} = \frac{1}{T}\sum_{\text{i}=1}^{T} \log(p_\theta(\mathbf{y}|\hat{\mathbf{z}}_\text{i},\mathbf{x})) - D_{\text{KL}}(q_\phi(\mathbf{z}|\mathbf{x},\mathbf{y}),p(\mathbf{z}|\mathbf{x})) \quad .$$

SampleFix

Enabling diverse samples using the Best of Many objective (BMS).



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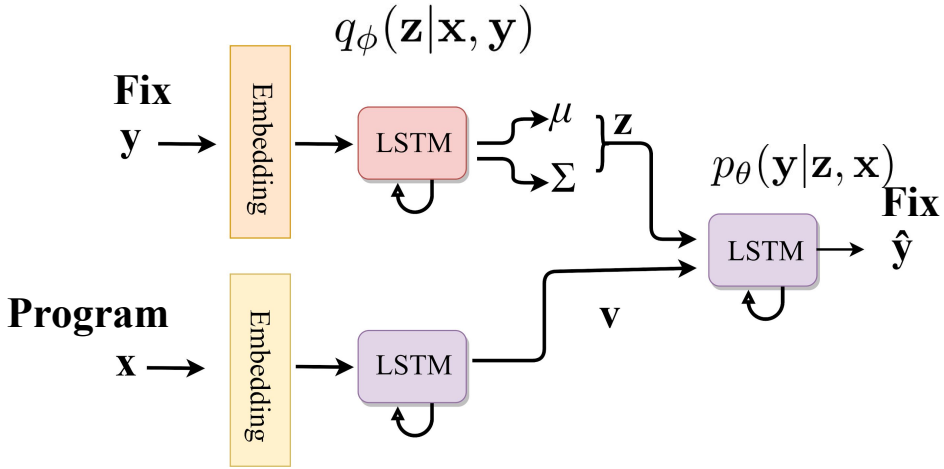
SampleFix

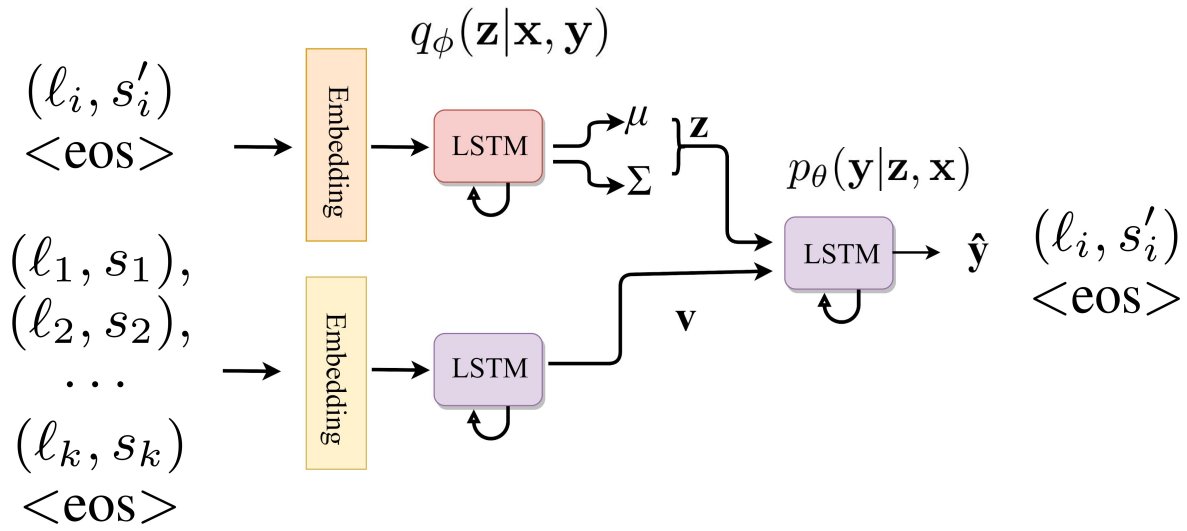
DS-SampleFix: Encouraging diversity with a diversity-sensitive regularizer



$$\hat{\mathcal{L}}_{\text{DS-BMS}} = \max_{i} \Big(\log(p_\theta(\mathbf{y}|\hat{\mathbf{z}}_i, \mathbf{x})) \Big) + \min_{i,j} d(\hat{\mathbf{y}}^i, \hat{\mathbf{y}}^j) - D_{\text{KL}}(q_\phi(\mathbf{z}|\mathbf{x},\mathbf{y}), p(\mathbf{z}|\mathbf{x})) \ .$$

SampleFix

Training and inference



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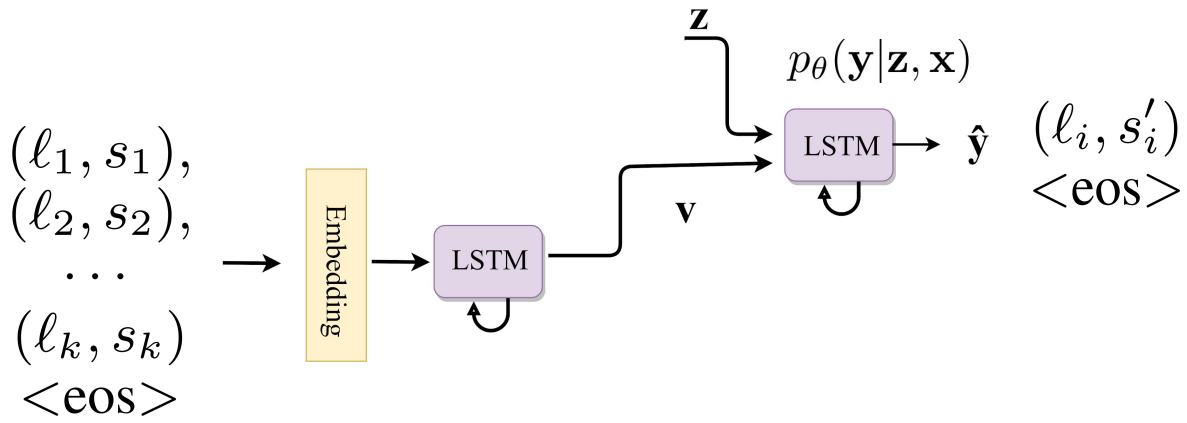

Experiments

- **Data**
  - Training Data: 500k pairs of data by mutating the correct programs
  - Test Data: Real-world data contains 6975 erroneous programs with 16766 error messages written by students
  - All of these program were written for 93 different programming tasks

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  - **Synthetic Data:** Generating training and validation set by mutating the correct program
  - **Real-World Data:** 6975 erroneous programs written by students

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- **Type of data**
  - **Synthetic Data:** Generating training and validation set by mutating the correct program
  - **Real-World Data:** 6975 erroneous programs written by students
- **Type of errors**
  - Typographic errors
  - Missing variable declaration

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Training data

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1  #include <stdio.h>
2  #include <stdlib.h>
3  int main (){
4  int n ;
5  double a , b , dx , areai ;
6  for ( i = 0 ; i <= n - 0 , i ++){
7  dx =( b - a )/ n ;
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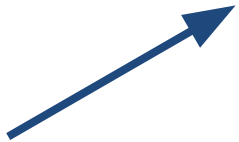

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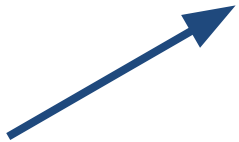

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Experiments

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Results on synthetic data

- To evaluate our approach on the synthetic test set we randomly select 20k pairs of the data.
- Results of DeepFix, Beam Search(BS), SampleFix, DS-SampleFix.
- **Typo**, **Miss Dec**, and **All** refer to typographic, missing variable declarations, and all of the error messages respectively.

Models	Typo	Miss Dec	All
DeepFix	84.7%	78.8%	82.0%
Beam search (BS)	91.8%	89.5%	90.7%
SampleFix	86.8%	86.5%	86.6%
DS-SampleFix	95.6%	88.1%	92.2%

Experiments

Results on real-world data

- Results of DeepFix, RLAssist, DrRepair, Beam Search(BS), SampleFix, DS-SampleFix, and DS-SampleFix + BS (Beam Search).
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- ✔ denotes successfully compiled programs, while 🐞 refers to resolved error messages.

Models	Typo		Miss Dec		All		Speed (s)
	✔	🐞	✔	🐞	✔	🐞	
DeepFix [15]	23.3%	30.8%	10.1%	12.9%	33.4%	40.8%	-
RLAssist [14]	*26.6%*	*39.7%*	-	-	-	-	-
DrRepair [38]	-	-	-	-	34.0%	-	-
Beam search (BS)	25.9%	42.2%	**20.3%**	47.0%	44.7%	63.9%	4.82
SampleFix	24.8%	38.8%	16.1%	22.8%	40.9%	56.3%	0.88
DS-SampleFix	27.7%	40.9%	16.7%	24.7%	44.4%	61.0%	0.88
DS-SampleFix + BS	**27.8%**	**45.6%**	19.2%	**47.9%**	**45.2%**	**65.2%**	1.17

Experiments

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Experiments

Qualitative example

- An example illustrating that our DS-SampleFix can generate diverse fixes.

Erroneous program

```
1  #include <stdio.h>
2  int main (){
3  int a, i;
4  scanf("%d\n", &a);
5  int s[a], p[a], g[a];
6  for (i = 0; i < a; i++){
7  scanf("%d", &s[i]);}
8  for (i = 0; i < a; i++){
9  scanf("%d", &p[i]);}
10 for (i = 0; i < a; i++){
11 g[p[i]] = s[i];}
12 for (i = 0; i < a; i++){
13 printf("%d", g[i]);
14 printf("end");
15 return 0 ;}
```

Id	Action	New Code
P_1	replace line 13	`printf("%d", g[i]);}`
P_2	replace line 14	`printf("end");}`

Experiments

Qualitative example

- Example of resolving typographic errors, and missing variable declaration errors

Erroneous program

```
1  #include <stdio.h>
2  int main (){
3
4  int s [ 0 ];
5  int k , n , i ;
6  scanf ( "%d%d" ,& k ,& n );
7  for ( i = 0 ; i < n ; i ++){
8  scanf ( "%d" ,& value );
9  s [ i ]= value ;}
10 for ( i = 0 ; i < n ; i ++) {
11 if ( k == s [ i ]+ s [ k - i ])} {
12 printf ( "lucky" );
13 break ;}
14 else { printf ( "unlucky" );
15 break ;}
16 return 0 ;}
```

Repaired program

```
1  #include <stdio.h>
2  int main (){
3  int value ;
4  int s [ 0 ];
5  int k , n , i ;
6  scanf ( "%d%d" ,& k ,& n );
7  for ( i = 0 ; i < n ; i ++){
8  scanf ( "%d" ,& value );
9  s [ i ]= value ;}
10 for ( i = 0 ; i < n ; i ++) {
11 if ( k == s [ i ]+ s [ k - i ]) {
12 printf ( "lucky" );
13 break ;}
14 else { printf ( "unlucky" );
15 break ;}}
16 return 0 ;}
```

Experiments

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Generating Functionally Diverse Programs

- Given an erroneous program, our approach can generate multiple potential fixes.
- It is desirable to suggest multiple potential fixes with diverse functionalities.

Experiments

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Generating Functionally Diverse Programs

- Given an erroneous program, our approach can generate multiple potential fixes.
- It is desirable to suggest multiple potential fixes with diverse functionalities.
- In order to assess different functionalities, we generate 10 input example for 93 task in dataset.
- We consider two programs to have different functionalities if they return different outputs given the same input examples.

Experiments

Generating Functionally Diverse Programs

- **Diverse programs** refers to the percentage of cases where the models generate at least two or more successfully compiled unique programs.
- **Diverse functionality** denotes the percentage of cases where the models generate at least two or more programs with different functionalities.

Models	Diverse programs	Diverse functionality
Beam search	55.6%	45.1%
SampleFix	44.6%	34.9%
DS-SampleFix	68.8%	53.4%
DS-SampleFix + BS	**69.5%**	**60.4%**

Experiments

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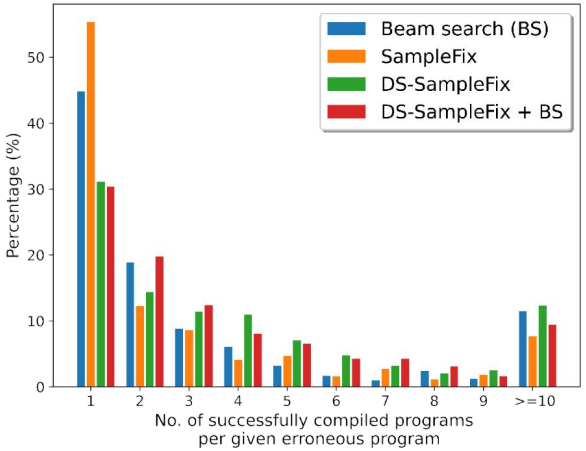
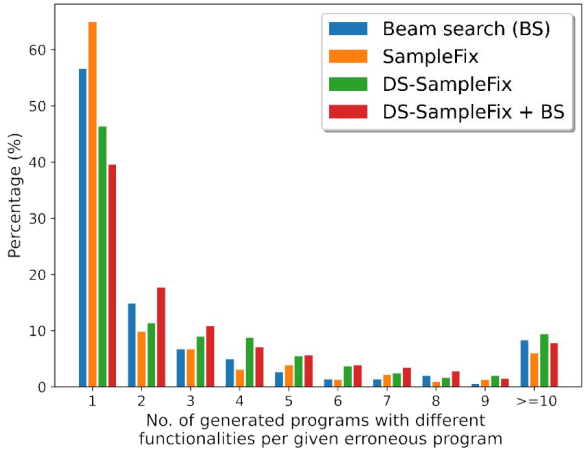
Experiments

Generating Functionally Diverse Programs

- **Left:** Percentage of the number of the generated successfully compiled, unique programs for the given erroneous programs.
- **Right:** Percentage of the successfully compiled programs with different functionalities for the given erroneous programs.



(a) Diversity of the generated programs.



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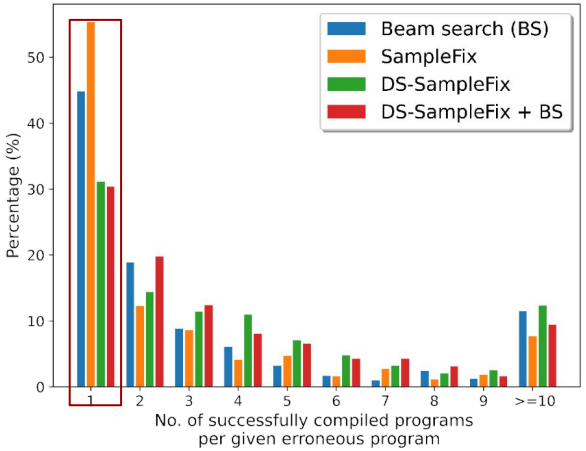

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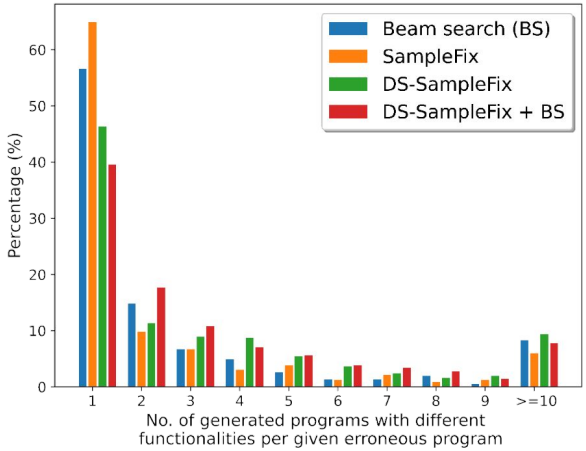

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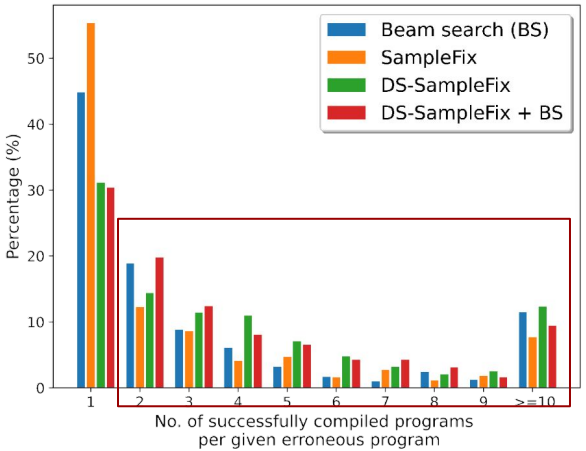

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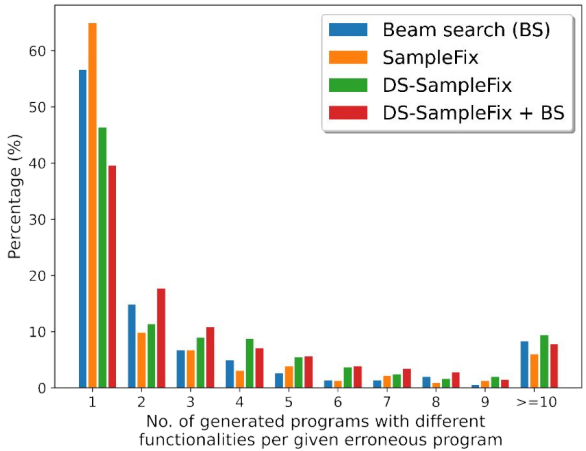

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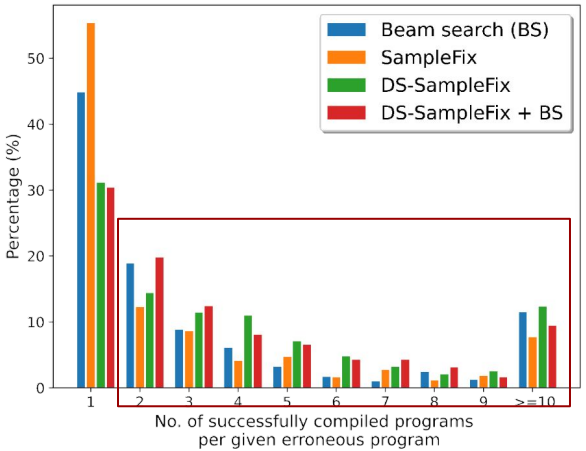

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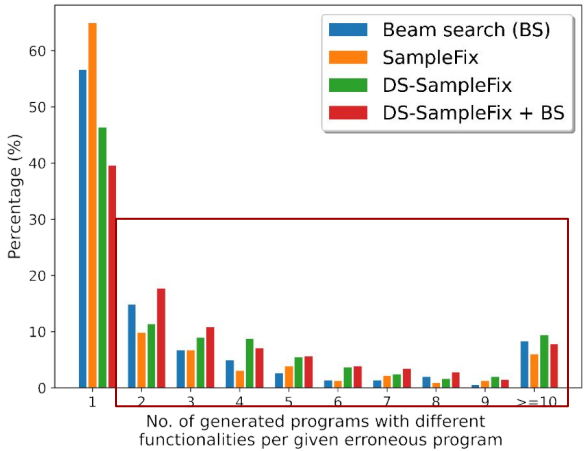

(b) Diversity of the functionality of the generated programs.

Conclusion

- We propose a novel generative framework to generate functionally diverse code fixes.
- In order to overcome the inherent limitations of the datasets we propose a novel diversity-sensitive regularizer.
- Our evaluations on common programming errors show strong improvements over the state-of-the-art approaches .
- We additionally show that for the 65%of the repaired programs, our approach was able to generate multiple programs with diverse functionalities