# IReEn: Reverse-Engineering of Black-Box Functions via Iterative Neural Program Synthesis

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[1]CISPA Helmholtz Center for Information Security
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# Introduction

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## Program synthesis

- Automatically generate a computer program that satisfies some specifications, such as a set of input-output examples

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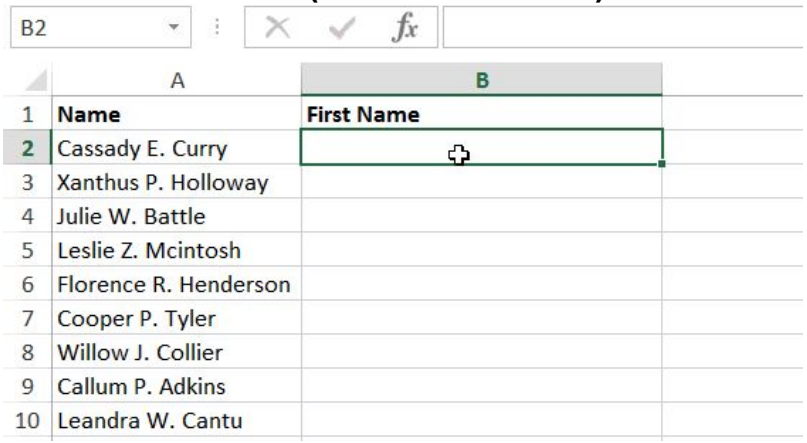

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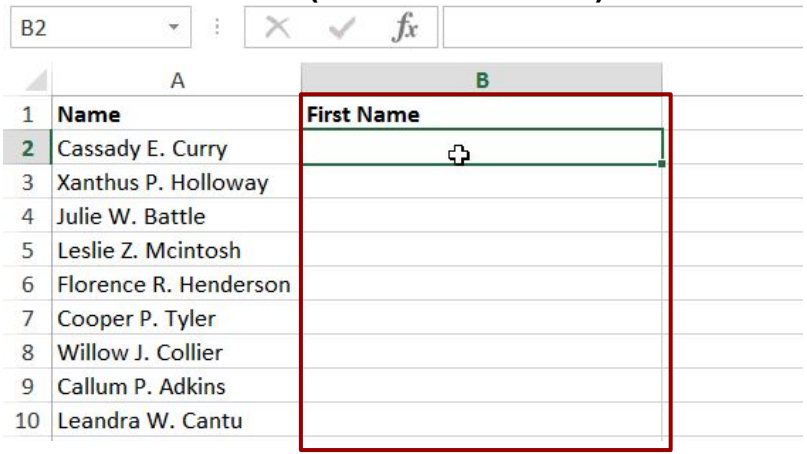

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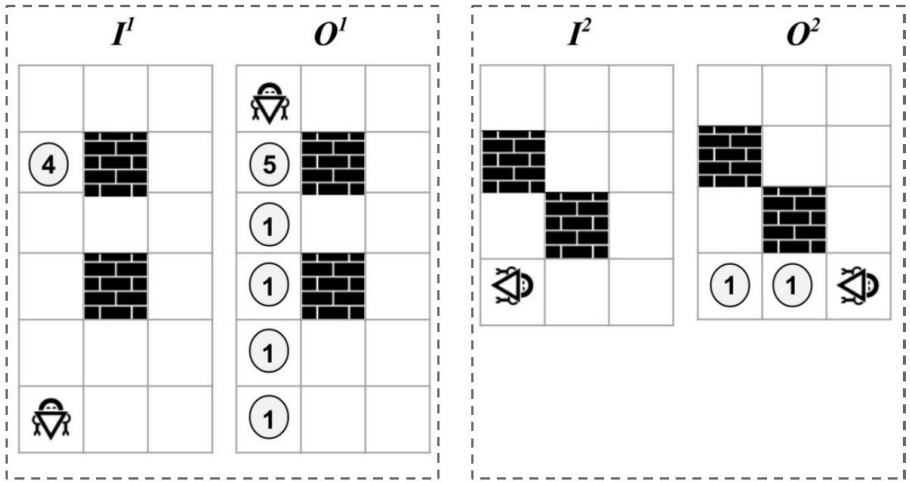
## Program synthesis - Example




**Underlying program**

```
def run():
  putMarker()
  while(frontIsClear()):
     move()
     putMarker()
```

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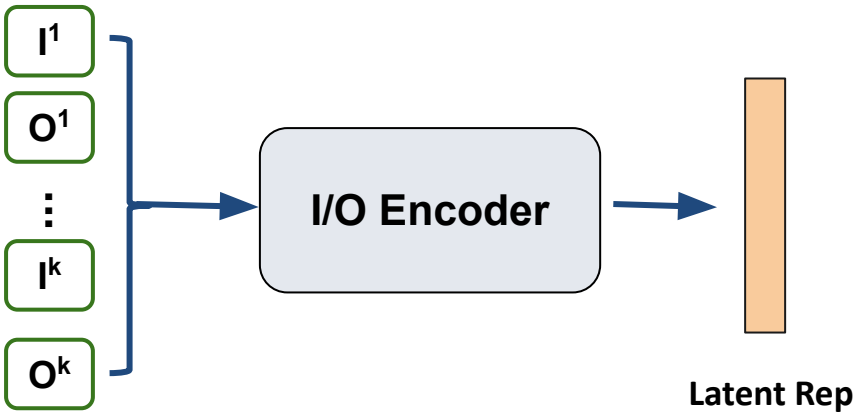
## Neural Program Synthesis (NPS)



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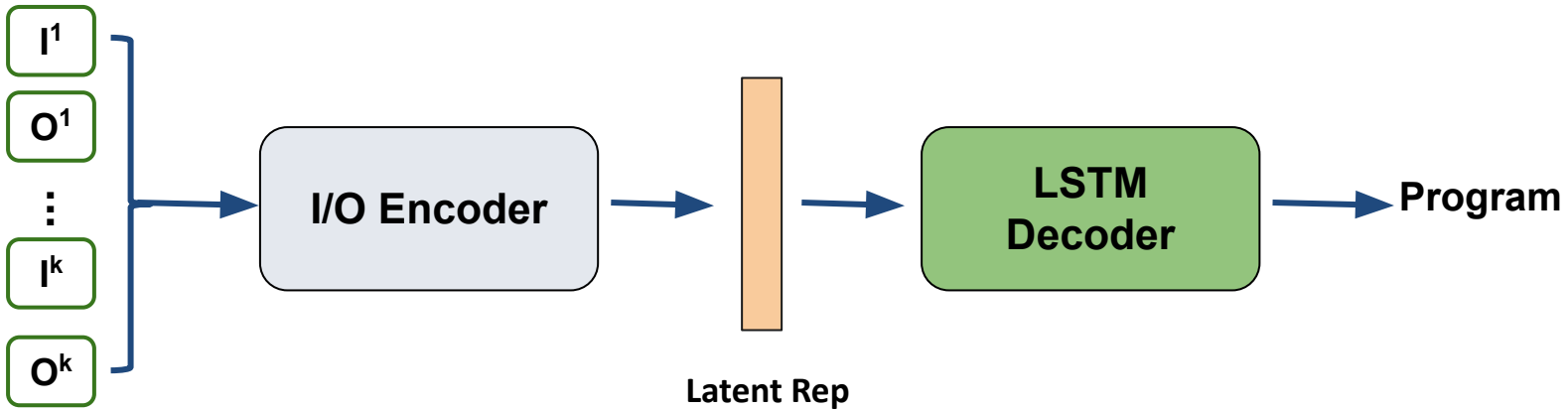

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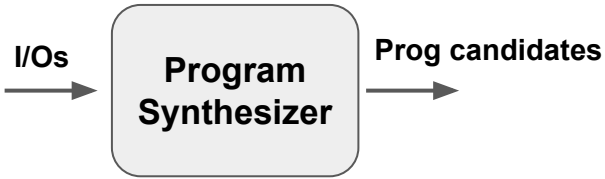
## Program Synthesis in black-box setting




- Program synthesizers use privileged information via biased sampling scheme.
- They assume that the I/Os covers all branches of the desired program.
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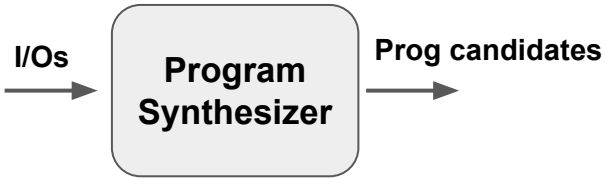


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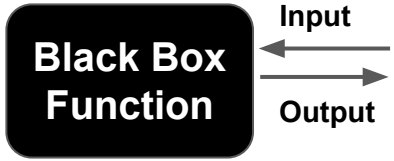
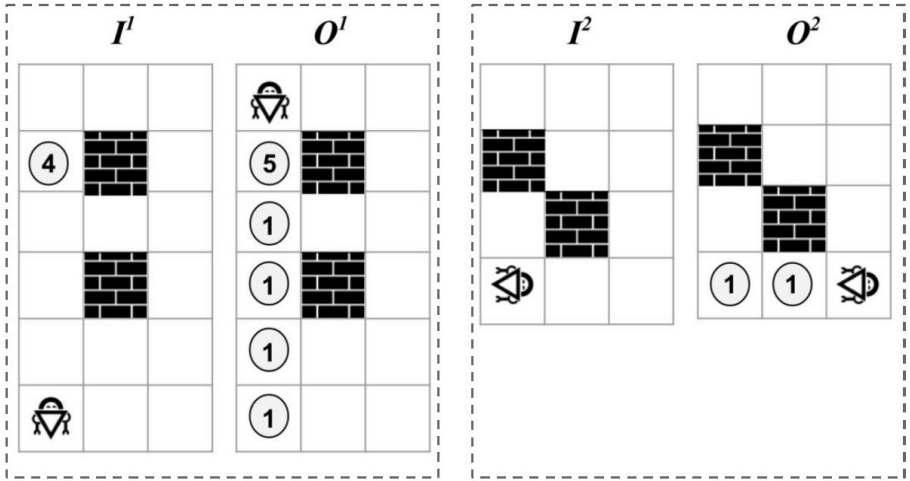



- In the black-box setting we do not have access to the privileged information
- We can only query the black-box function with random **input** to get the corresponding **output**
- We call the obtained I/Os **random I/Os**

# Background

## Karel dataset

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## Karel dataset

### Karel DSL

**Function:**

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def run():
  block
```

**Conditional:**

```
if (condition):
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if (condition):
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else:
  block
```

**Loops:**

```
for i in range(count):
  body
while (condition):
  body
while (not condition):
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**Actions:**

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$$
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 & \mid & \texttt{if}(b) : s \mid \texttt{ifelse}(b) : s_1 \texttt{ else } : s_2 \\
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# Background

## Karel dataset

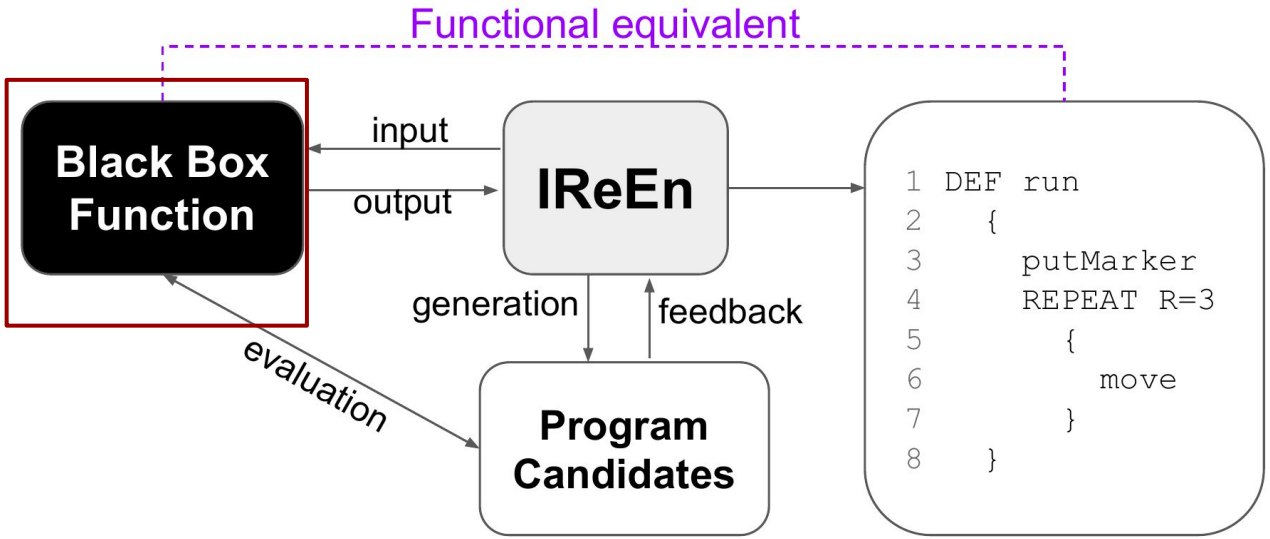
**Input/Output representation:**

- HxWx16
- 2x2x16 to 16x16x16

| |
|---|
| Hero facing North |
| Hero facing South |
| Hero facing West |
| Hero facing East |
| Obstacle |
| Grid boundary |
| 1 marker |
| 2 marker |
| 3 marker |
| 4 marker |
| 5 marker |
| 6 marker |
| 7 marker |
| 8 marker |
| 9 marker |
| 10 marker |

# IReEn

- **Overview**



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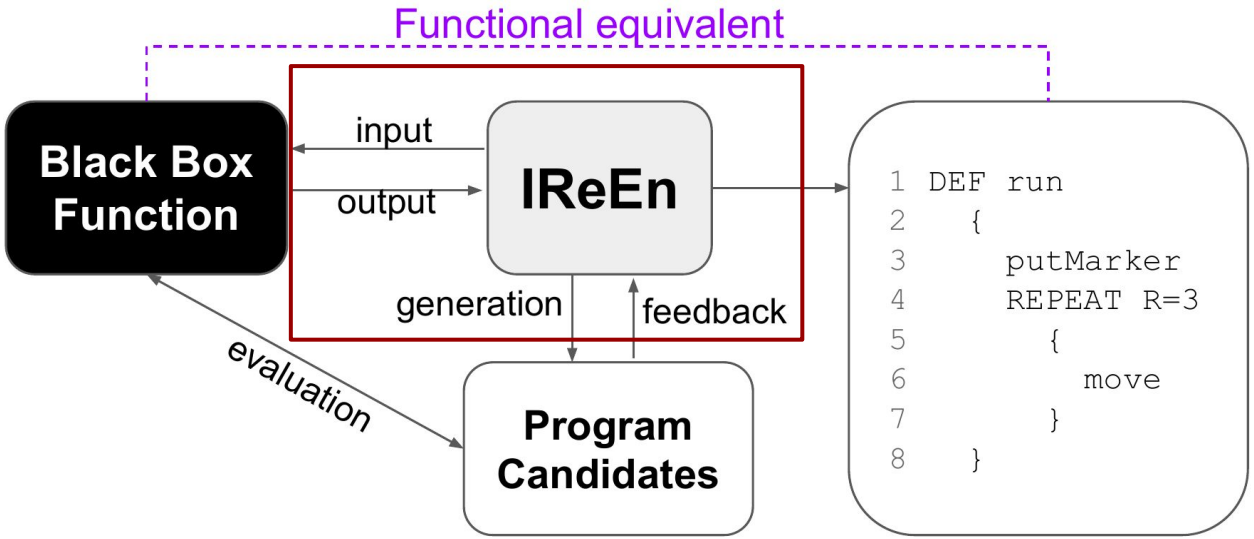

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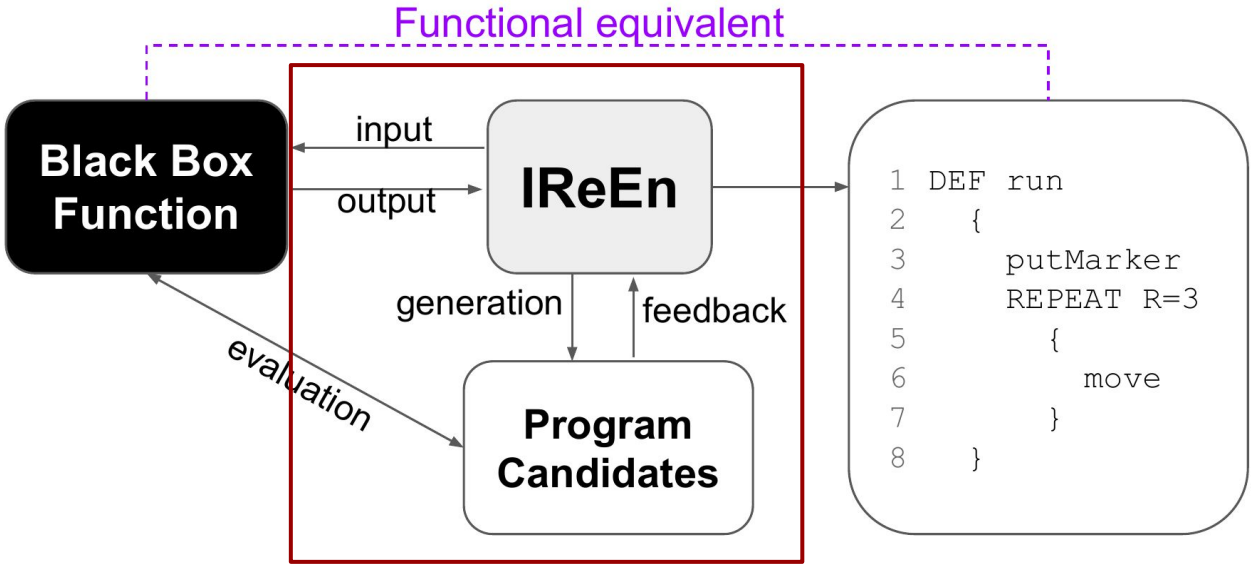

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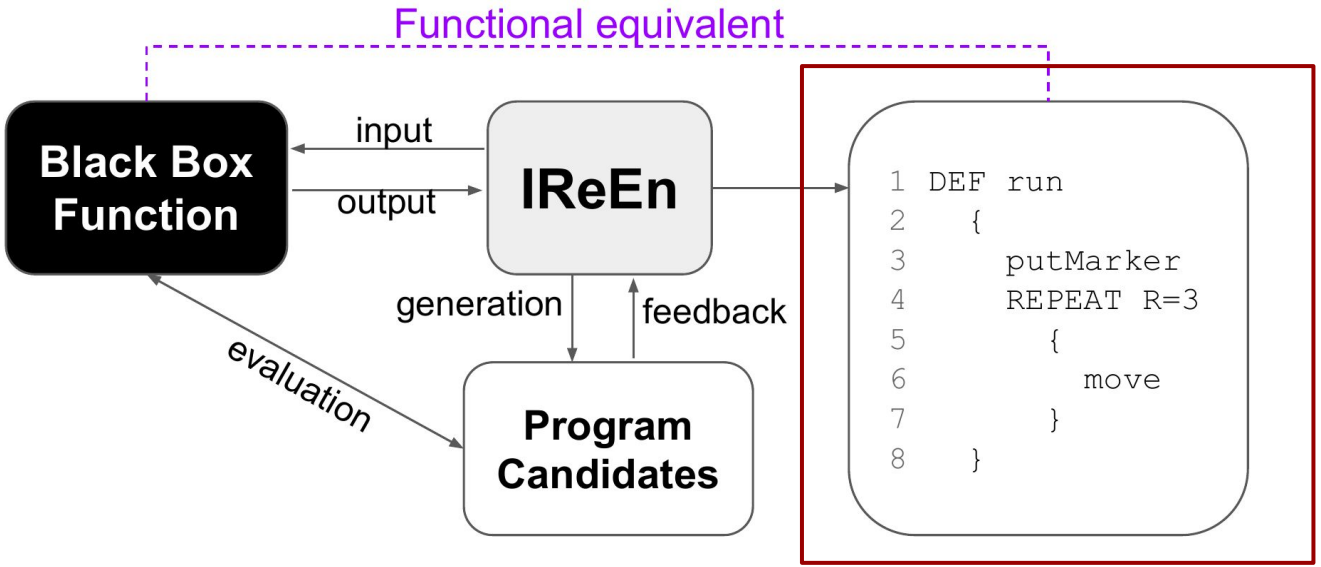

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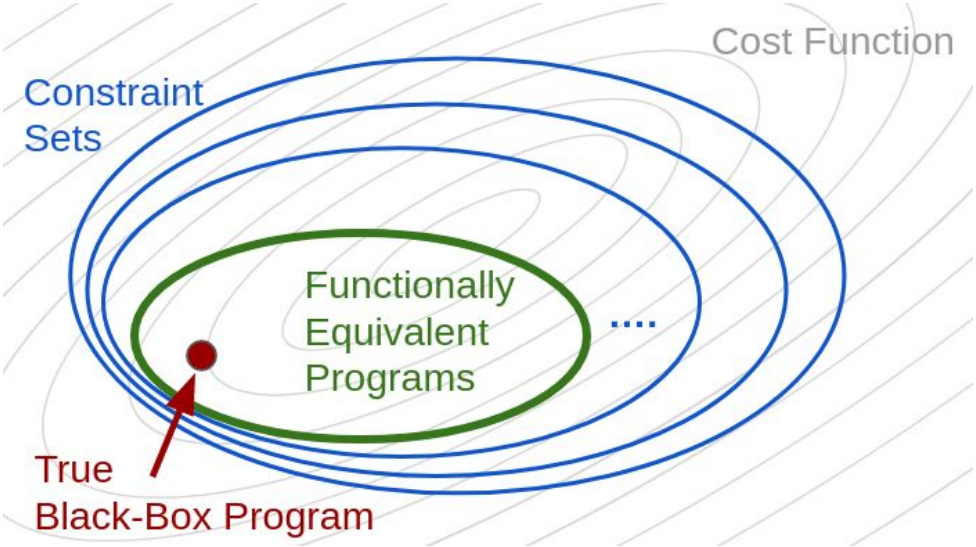

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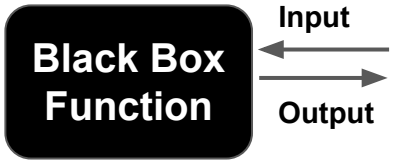


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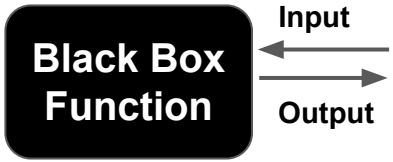


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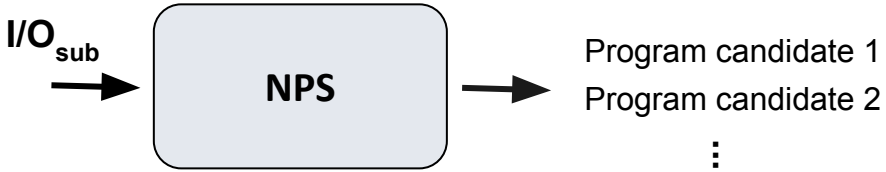

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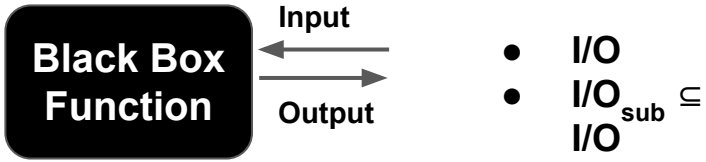


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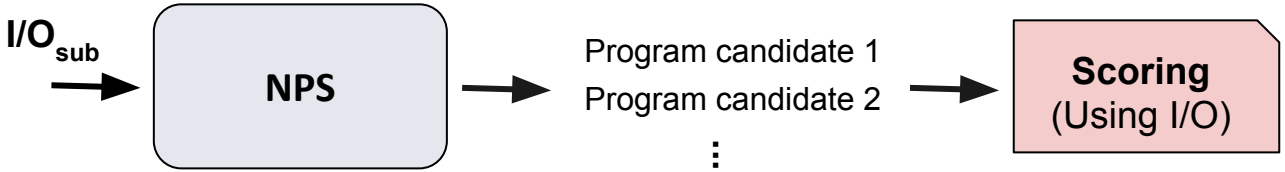

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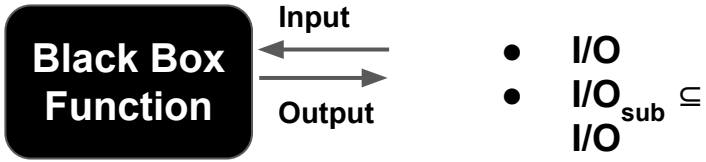


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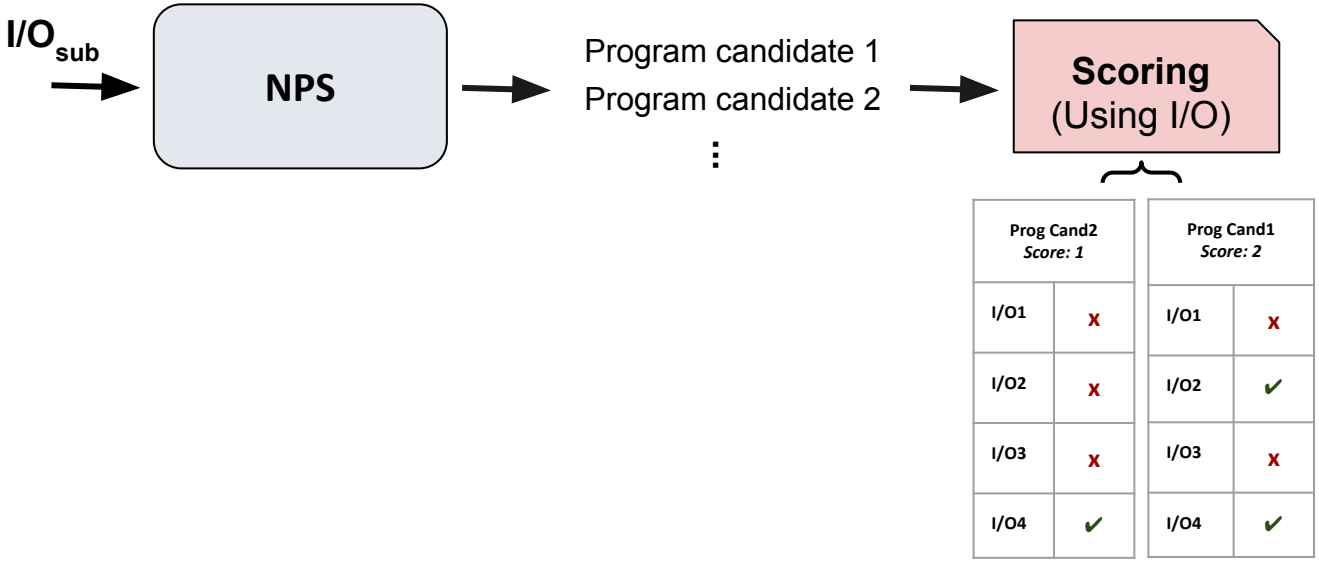

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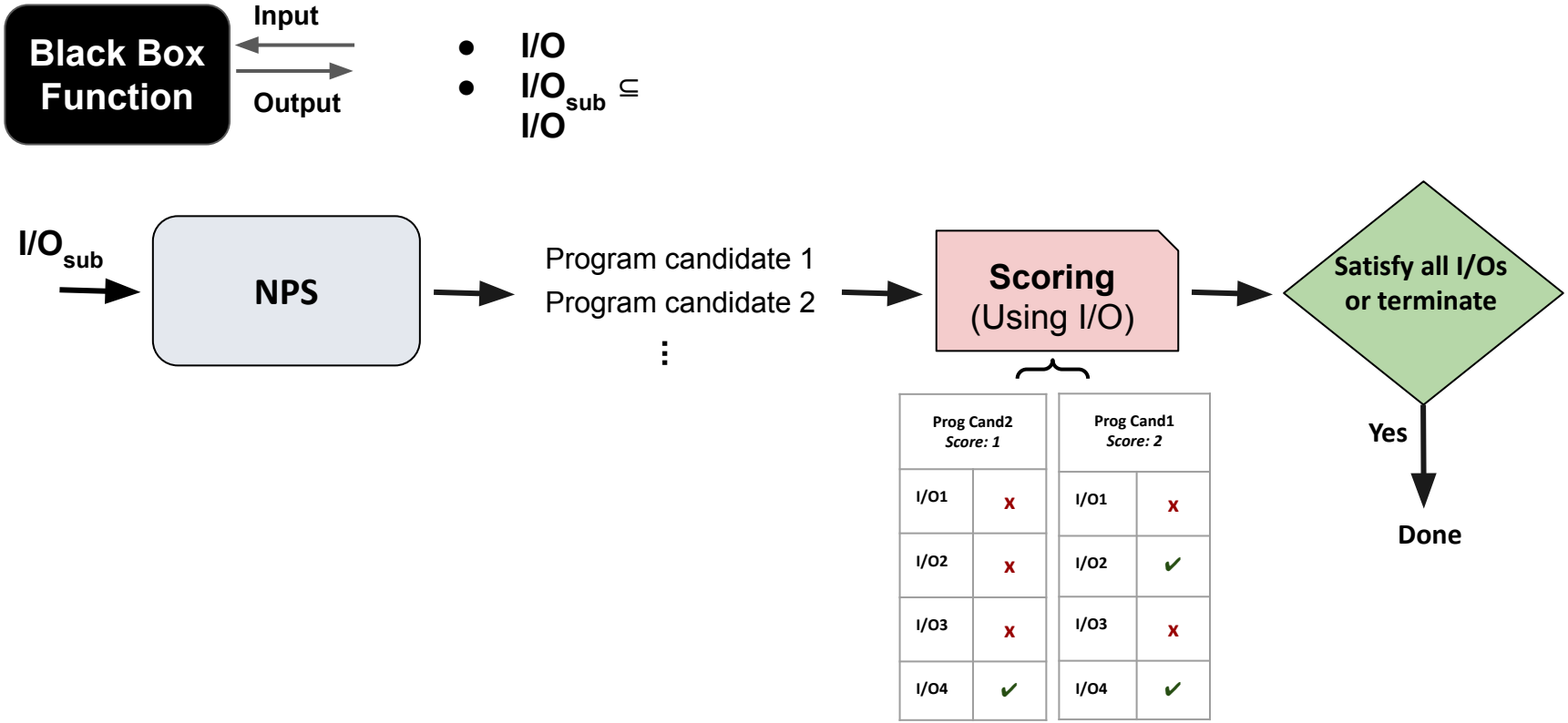

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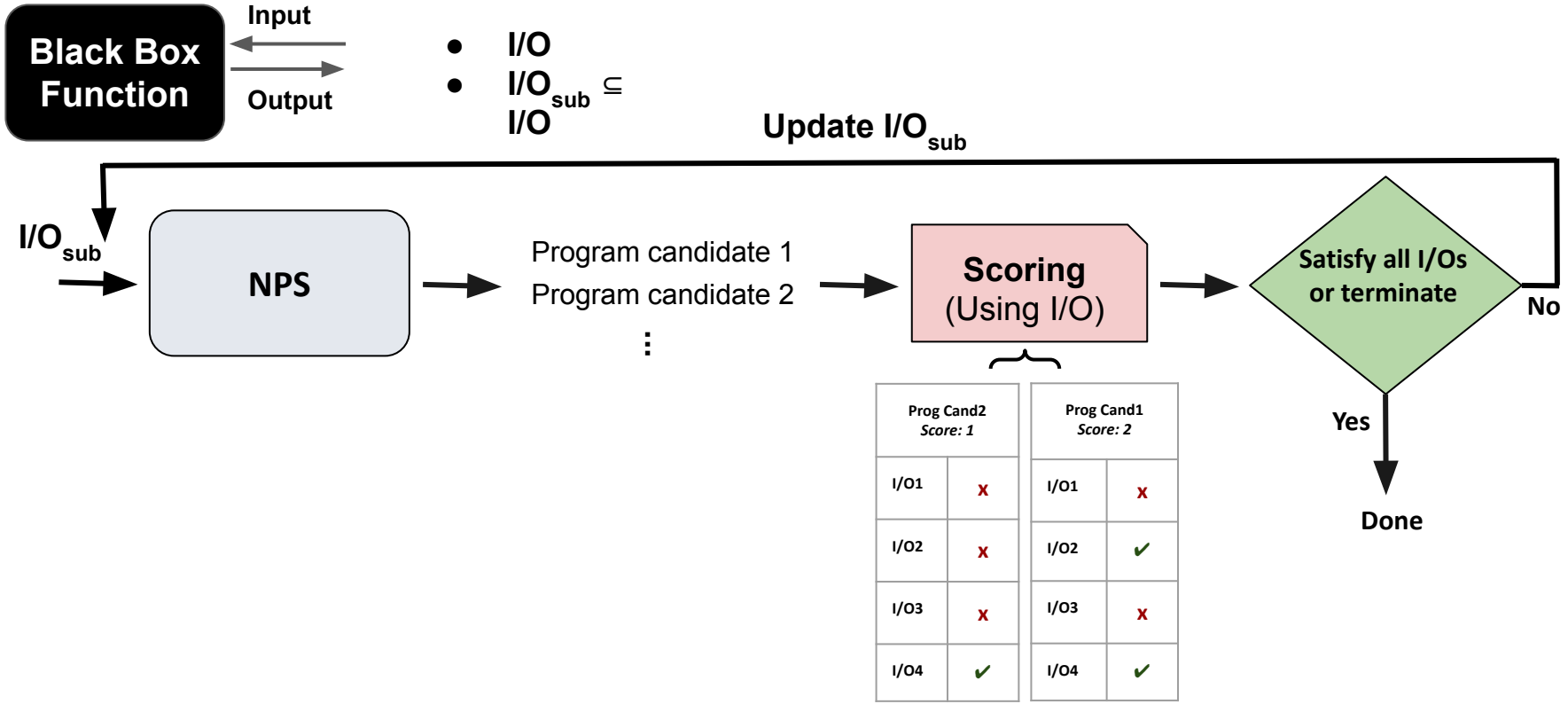
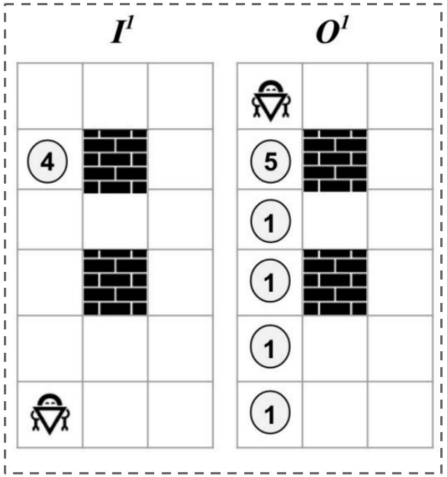


# Experiments

## Evaluation Setup

- **Karel dataset**
  - The Karel benchmark is one of the largest publicly available program synthesis dataset.
  - 1,116,854 samples for training, 2,500 validation set, and 2,500 test examples.



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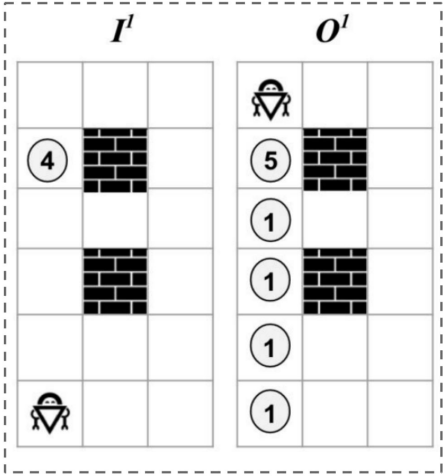

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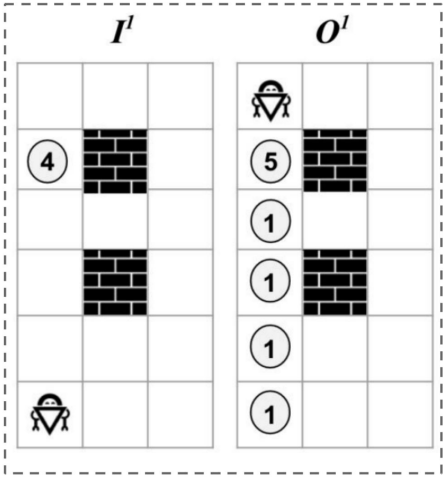

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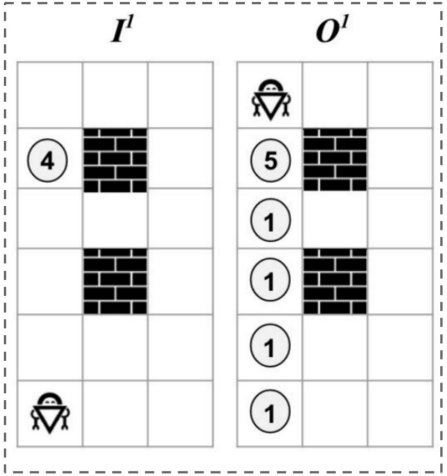
- **During inference**
  - We use beam search with beam width 64



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## Functional Equivalence Metric

- **Generalization Metric**
  - A predicted program is a generalization of the target if it satisfies the given I/Os and one held-out example.
- **Exact Match Metric**
  - A predicted program is an exact match of the target if it is the same as the target program in terms of tokens.
- **Functional Equivalence Metric**
  - We consider a predicted program equivalent to the target program if it covers a large set of unseen I/Os (We use 100 I/Os).

# Experiments

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## Results

| Models | Generalization | | Functional | | Exact Match | |
|---|---|---|---|---|---|---|
| | top-1 | top-50 | top-1 | top-50 | top-1 | top-50 |
| Random I/Os | 57.12% | 71.48% | 49.36% | 63.72% | 34.96% | 40.92% |
| Random I/Os + FT | 64.72% | 77.64% | 55.64% | 70.12% | 39.44% | 45.4% |
| Random I/Os + IReEn | 76.20% | 85.28% | 61.64% | 73.24% | 40.95% | 44.99% |
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| Crafted I/Os ([4]) | 73.12% | 86.28% | 55.04% | 68.72% | 40.08% | 43.08% |

- **Random I/Os** mean that we use randomly obtained I/Os in the black-box setting.
- **FT** refers to fine-tuned model using random I/Os.
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| Random I/Os | 95.59% | 99.69% | 85.52% | 91.44% | 26.98% | 61.58% | 48.88% | 72.69% | 10.69% | 27.12% |
| Random I/Os + FT | 99.39% | 99.76% | 90.72% | 96.38% | 56.50% | 82.22% | 52.06% | 77.46% | 14.33% | 32.19% |
| Random I/Os + IReEn | **99.84%** | 99.84% | **96.38%** | 97.36% | 60.95% | 84.76% | 81.26% | 89.84% | 27.67% | 49.94% |
| Random I/Os + FT + IReEn | **99.84%** | **100%** | 95.39% | **99.64%** | **81.58%** | **93.33%** | **81.52%** | **92.06%** | **32.08%** | **56.22%** |
| Crafted I/Os | 99.08% | 100.0% | 91.11% | 96.71% | 54.28% | 84.12% | 49.20% | 79.68% | 14.88% | 33.84% |

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|---|---|---|---|---|---|---|---|---|---|---|
| | top-1 | top-50 | top-1 | top-50 | top-1 | top-50 | top-1 | top-50 | top-1 | top-50 |
| Random I/Os | 95.59% | 99.69% | 85.52% | 91.44% | 26.98% | 61.58% | 48.88% | 72.69% | 10.69% | 27.12% |
| Random I/Os + FT | 99.39% | 99.76% | 90.72% | 96.38% | 56.50% | 82.22% | 52.06% | 77.46% | 14.33% | 32.19% |
| Random I/Os + IReEn | **99.84%** | 99.84% | **96.38%** | 97.36% | 60.95% | 84.76% | 81.26% | 89.84% | 27.67% | 49.94% |
| Random I/Os + FT + IReEn | **99.84%** | **100%** | 95.39% | **99.64%** | **81.58%** | **93.33%** | **81.52%** | **92.06%** | **32.08%** | **56.22%** |
| Crafted I/Os | 99.08% | 100.0% | 91.11% | 96.71% | 54.28% | 84.12% | 49.20% | 79.68% | 14.88% | 33.84% |

- **Random I/Os** mean that we use randomly obtained I/Os in the black-box setting.
- **FT** refers to fine-tuned model using random I/Os.
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# Experiments

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## Results

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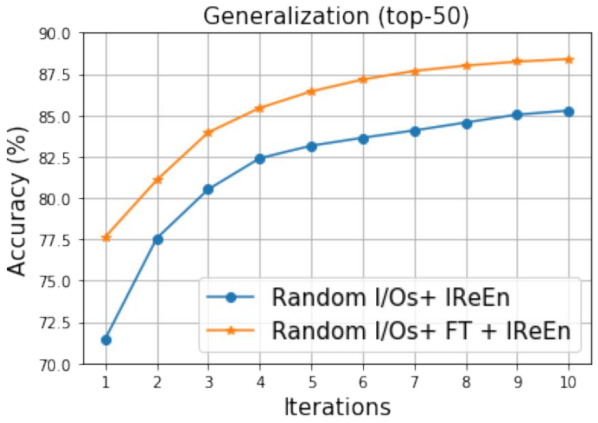
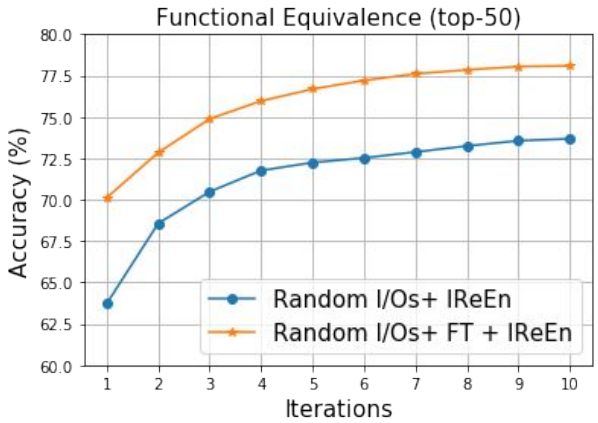
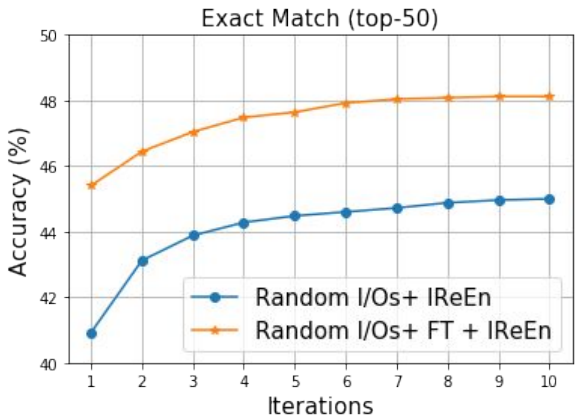
# Experiments

## Results

- **Effectiveness of iterative refinement**



# Experiments

## Results

- **Examples of Functional equivalent programs**

**Target Black-Box Program**

```
1 def run():
2   ifelse(not(rightIsClear())):
3       turnLeft()
4       move()
5       pickMarker()
6   else:
7       turnRight()
8   move()
9   move()
10  pickMarker()
11  pickMarker()
```

# Experiments

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```

**Output Program**

```
1  def run():
2    ifelse(rightIsClear()):
3       turnRight()
4    else:
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# Experiments

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# Experiments

## Results

- **Examples of Functional equivalent programs**

**Target Black-Box Program**

```
1 def run():
2   repeat(5):
3     turnRight()
4   putMarker()
5   putMarker()
6   move()
```

# Experiments

## Results

- **Examples of Functional equivalent programs**

**Target Black-Box Program**

```
1 def run():
2   repeat(5):
3     turnRight()
4   putMarker()
5   putMarker()
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```

**Output Program**

```
1 def run():
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# Experiments

## Results

- **Examples of Functional equivalent programs**

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1 def run():
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**Output Program**

```
1 def run():
2   putMarker()
3   putMarker()
4   turnRight()
5   move()
```

# Conclusion

- We propose an iterative neural program synthesis scheme to reverse-engineer the black-box functions, and represent them in a high-level program.
- We proposed a functional equivalence metric in order to quantify progress on this challenging task.
- We evaluate our approach on Karel dataset, where our approach successfully revealed the underlying programs of 78% of the black-box programs.

# Next steps...

Thank you!