Detecting TensorFlow Program Bugs in Real-World Industrial Environment

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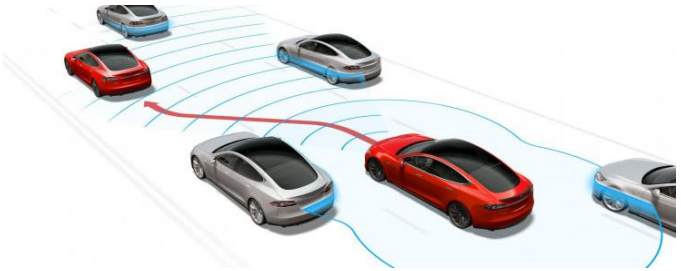
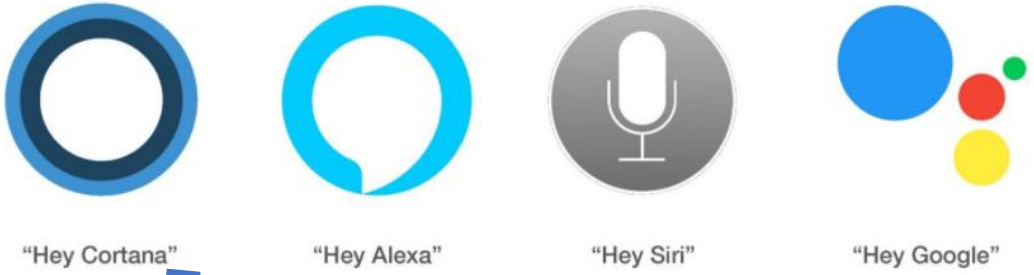
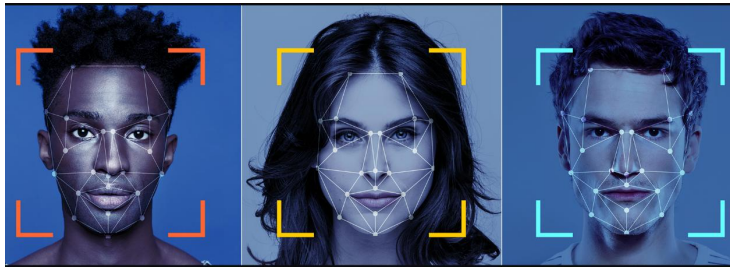
Alibaba Group

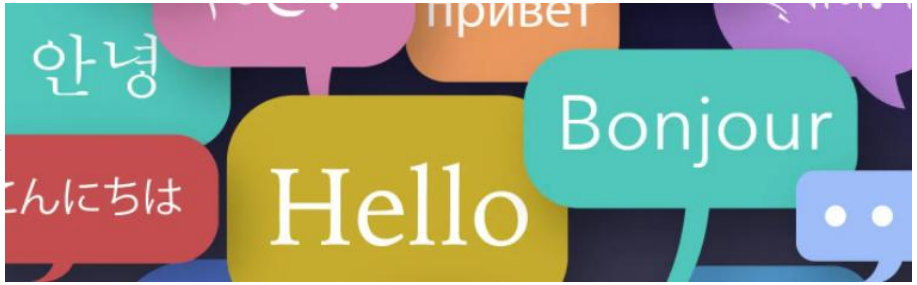
University of New South Wales

Rise of deep learning

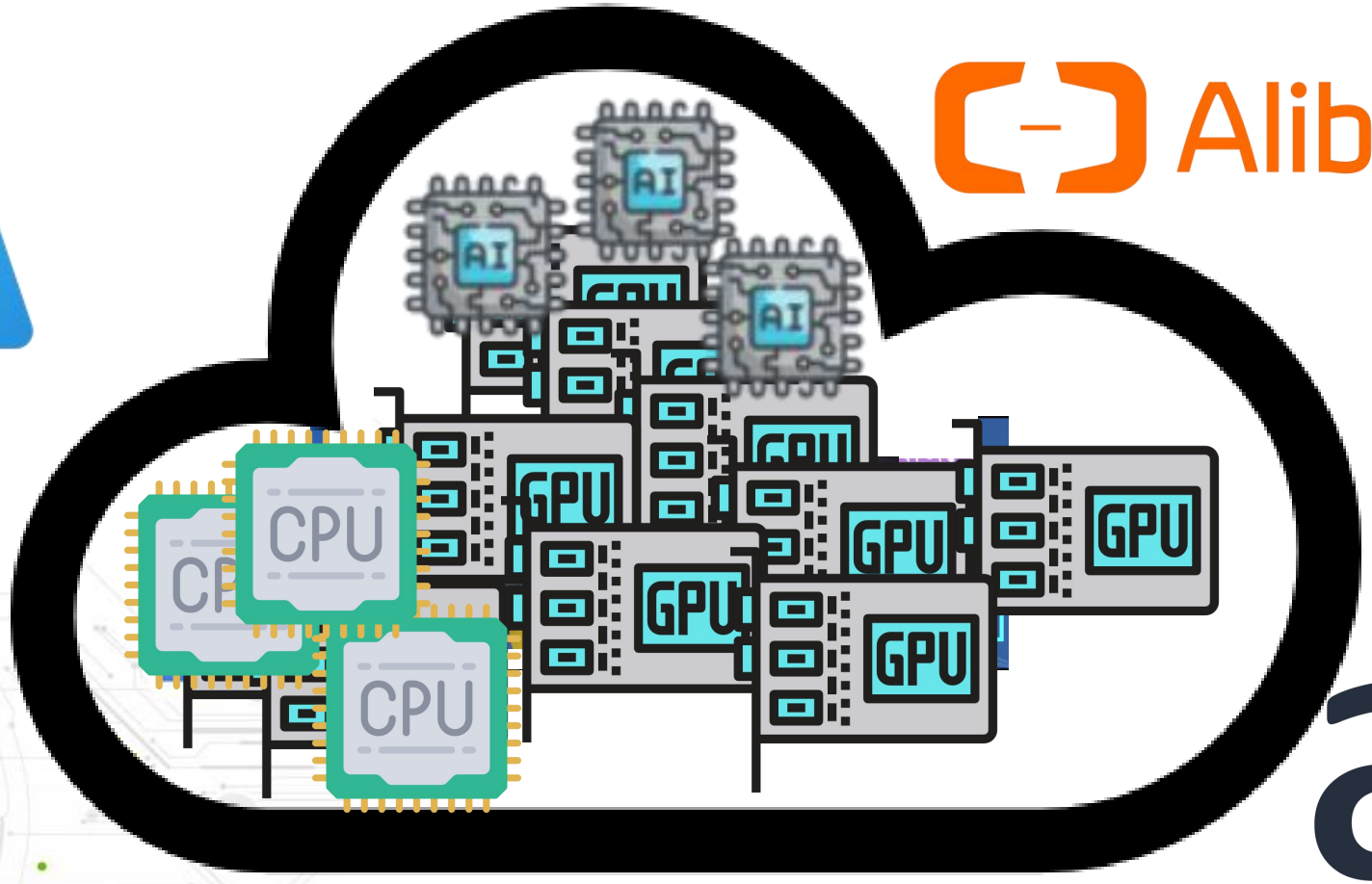








Cloud Deep Learning Platform



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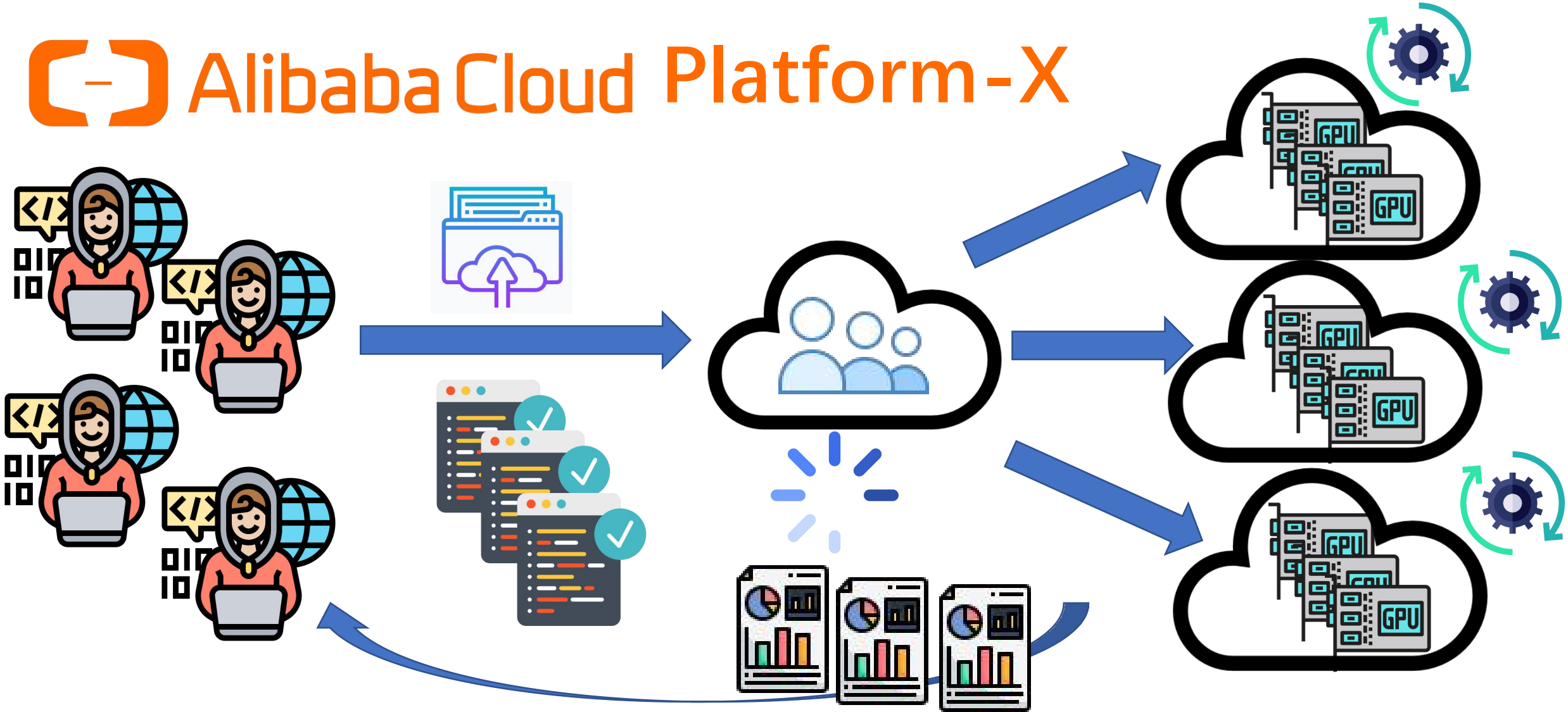

10% Failure jobs on Platform-X

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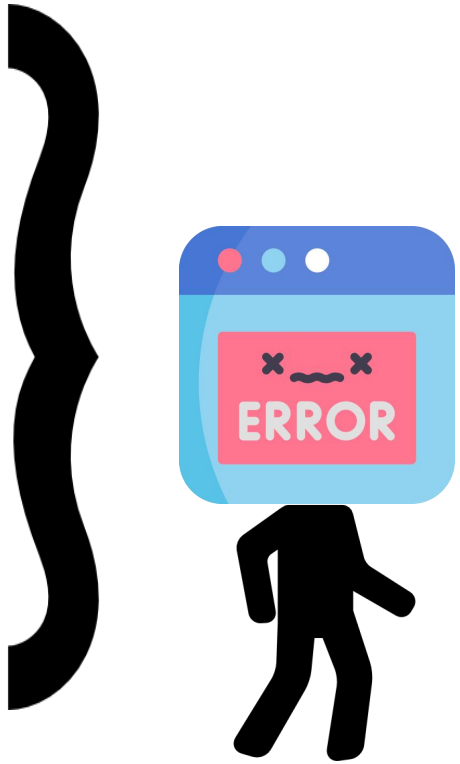
```
ing simple_console_for_windows.zip to create runfiles tree...
el-bin/tensorflow/tools/pip_package/simple_console_for_windows.zip]
of-central-directory signature not found.  Either this file is not
```

```
Installing collected packages: setuptools, protobuf, wheel, numpy, tensorflow
Found existing installation: setuptools 1.1.6
Uninstalling setuptools-1.1.6:
Exception:
...
[Errno
'/tmp/
```

```
Error importing tensorflow. Unless you are using bazel, you should
 not try to import tensorflow from its source directory; please exit the
 tensorflow source tree, and relaunch your python interpreter from
```

```
ImportError: libcudart.so.Version: cannot open shared object file:
  No such file or directory
```



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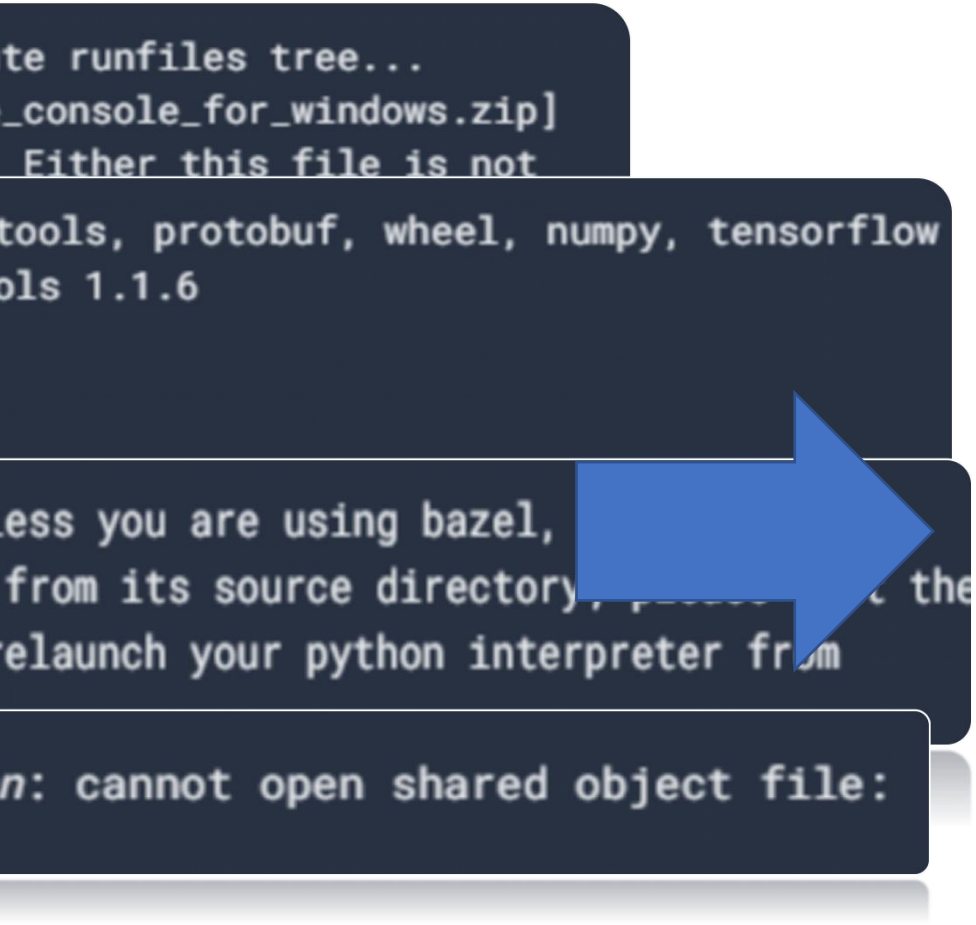
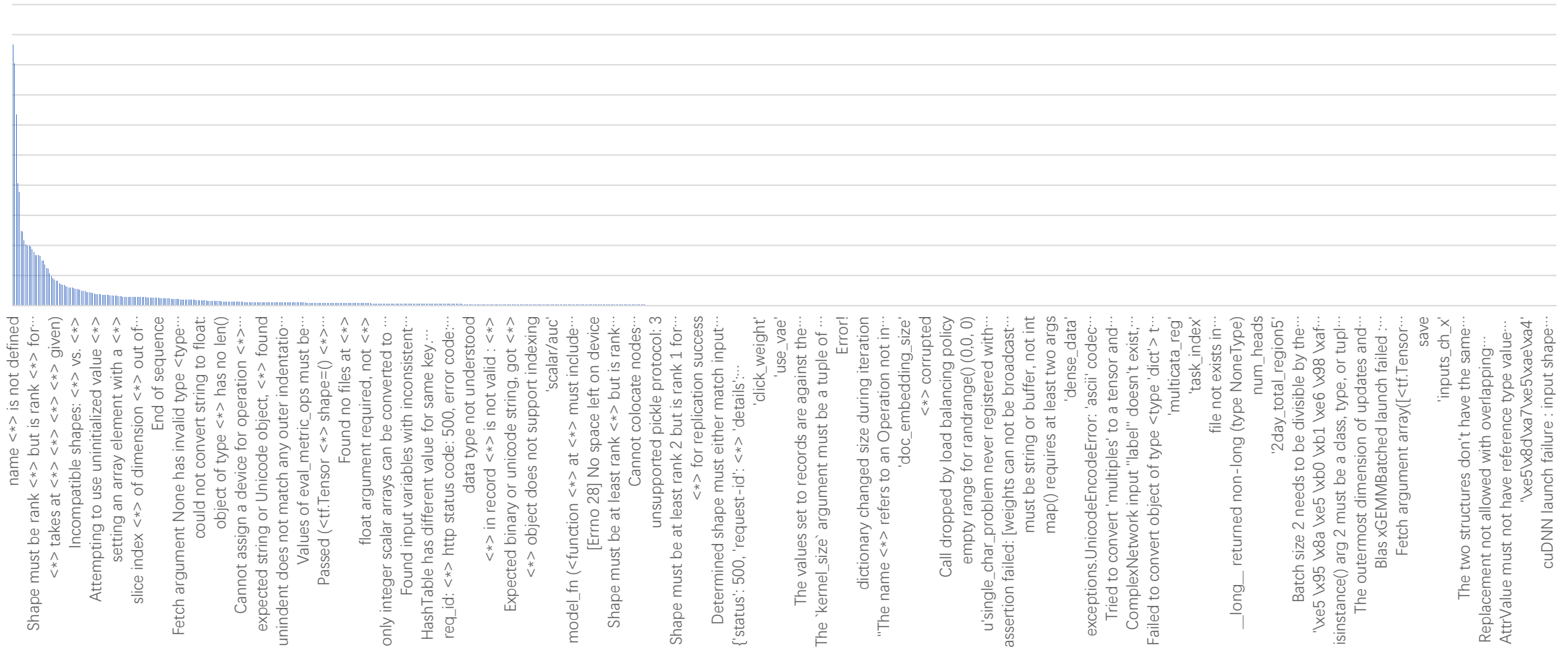


Example Error Message Patterns
<><*> has no attribute <*>* *No module named <*>*
<> takes exactly <*> arguments <*> given* *<*> got an unexpected keyword argument <*>*
name <> is not defined* *local variable <*> referenced before assignment*

968 Patterns



968 Patterns

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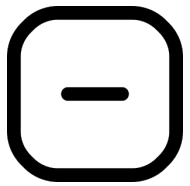
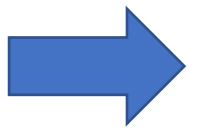
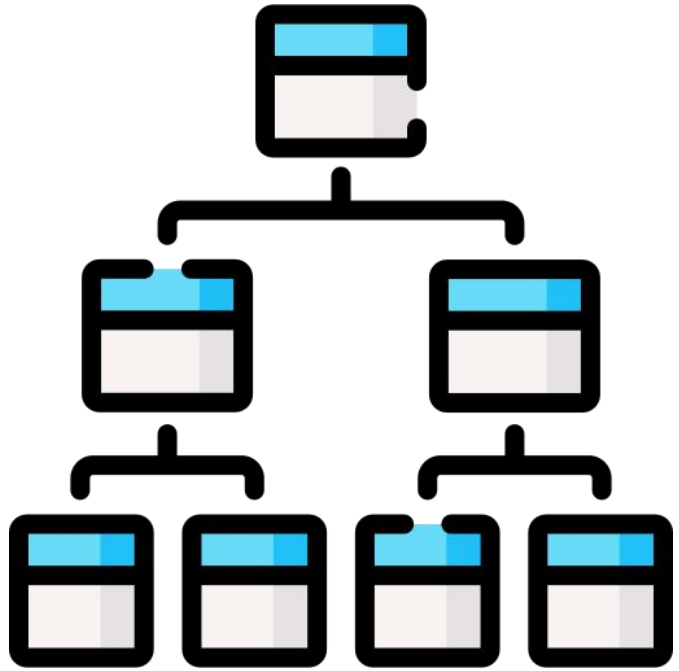
12289 failures



1612 env-related

586 corrupted data





Bug types

- Checkpoint Error
- Shape Error
- Out of Memory
- Loss NaN
- GPU Sync Failed

Tensorflow-Specific Bugs

- Module/Attribute Missing
- Arguments Mismatch
- Undefined Variable
- Key Not Found
- ...

Python Bugs

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Tensorflow-Specific Bugs

36.31%

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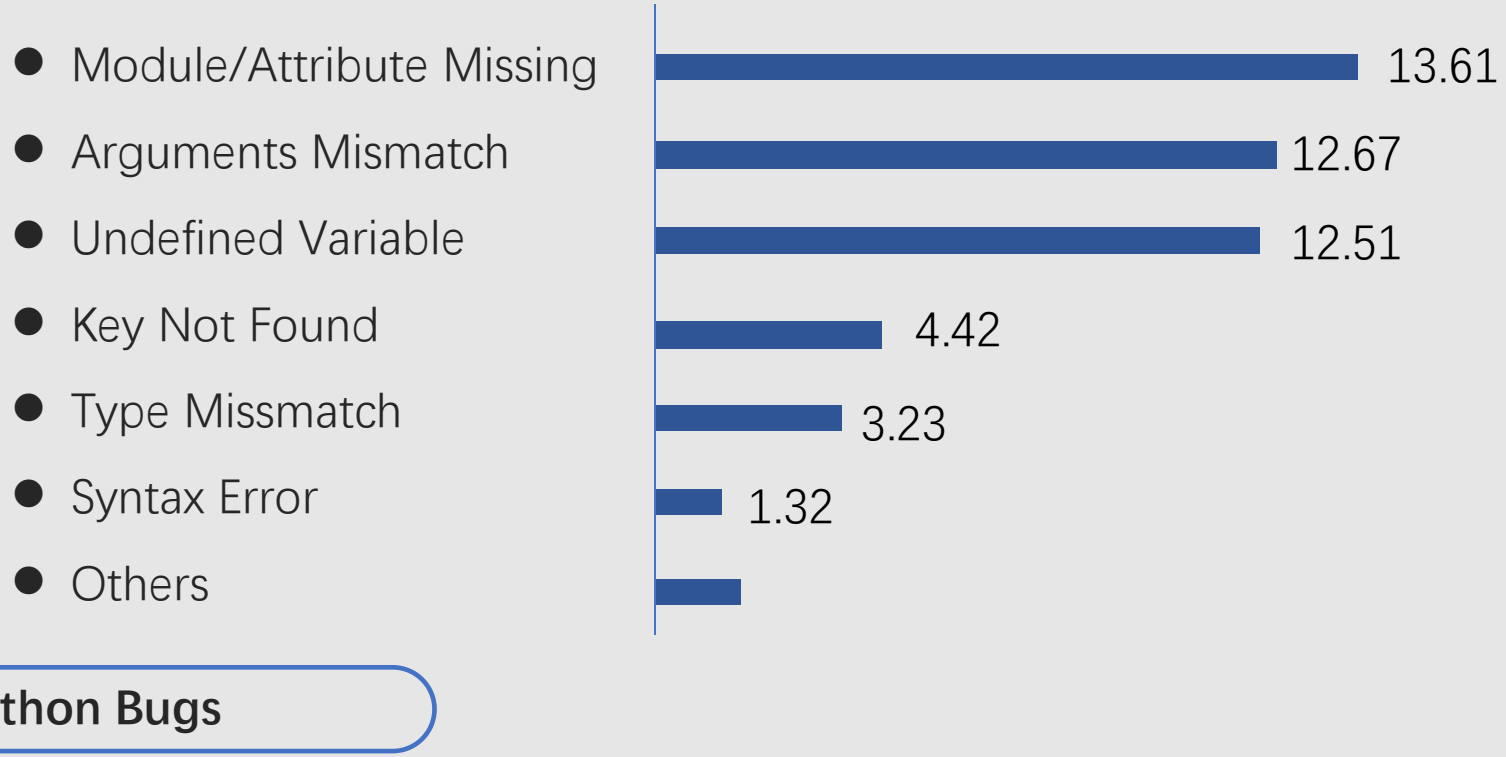
Python Bugs

63.69%

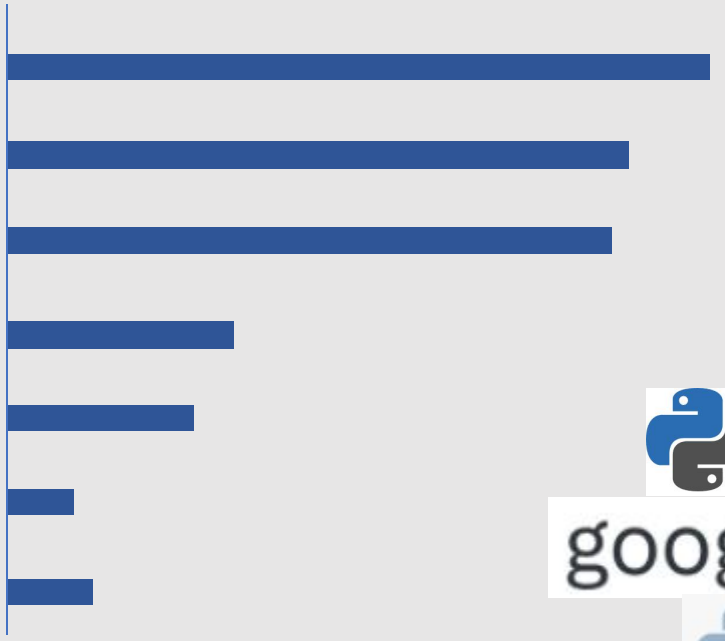
Bug types



Python Bugs

Bug types

- Module/Attribute Missing
- Arguments Mismatch
- Undefined Variable
- Key Not Found
- Type Missmatch
- Syntax Error
- Others



Python Bugs

72.25%

: my[py]

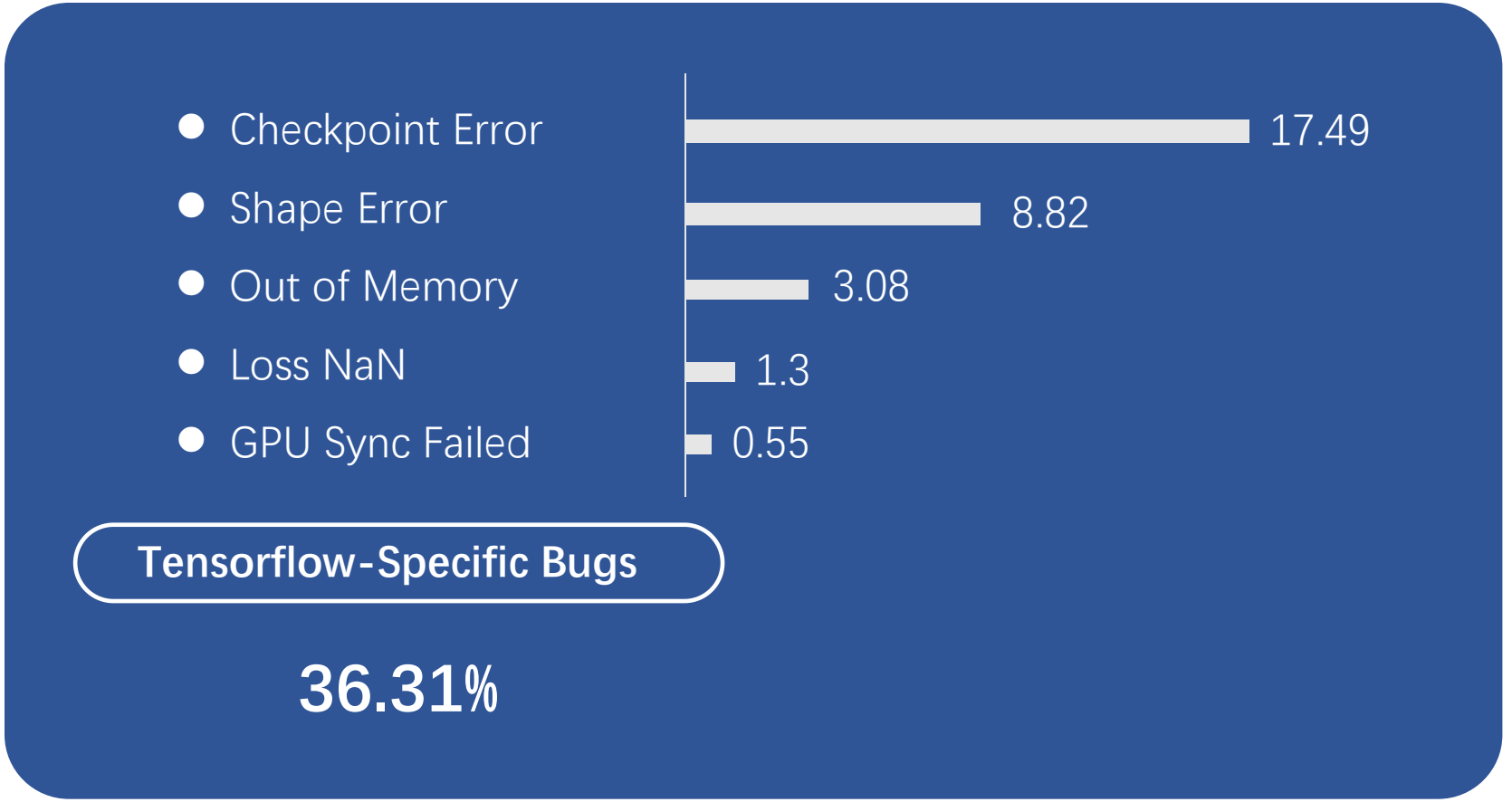
google/**pytype**

Pylint

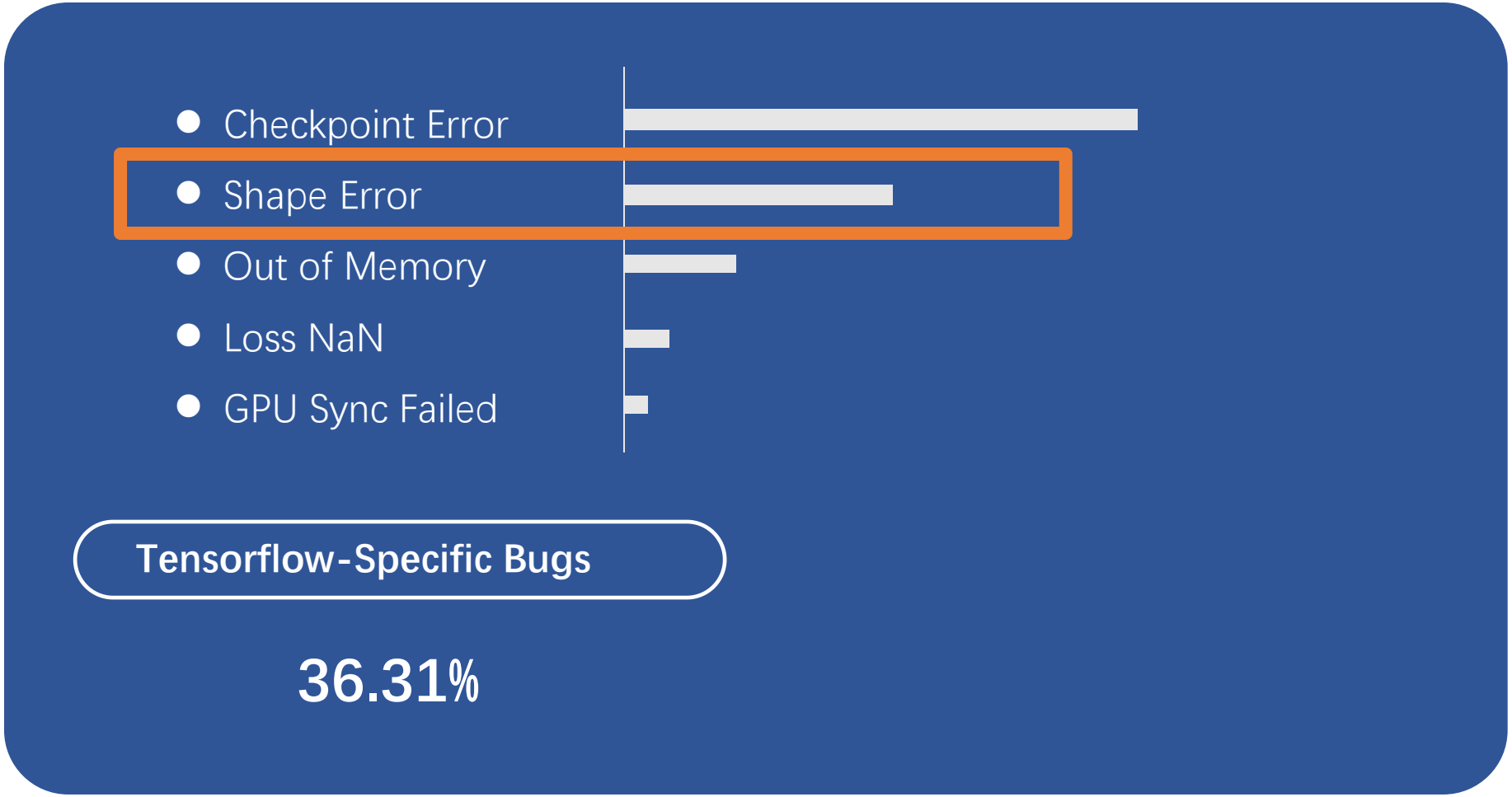
Star your Python code!

PyCQA/**pyflakes**

Bug types


Checkpoint Error
17.49
Shape Error
8.82
Out of Memory
3.08
Loss NaN
1.3
GPU Sync Failed
0.55
Tensorflow-Specific Bugs
36.31%

Bug types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Out of Memory
Loss NaN
GPU Sync Failed
Tensorflow-Specific Bugs
36.31%

A simplified shape error example

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# Construction
1.  def fully_connect(input_op, name, n_in,n_out ):
2.    fc_w = tf.get_variable(name, [n_in, n_out])
3.    return tf.matmul(input_op, fc_w)
4.  def predict(Input_x, class_num):
5.    mp = tf.nn.conv2d(input_x,tf.get_variable('mpc',[5,5,1,32]),strides=[1,1,1,1], padding='SAME')
6.    reshaped = tf.reshape(mp, [-1, 28 * 28])
7.    fc = fully_connect(reshaped, 'fc1', 28 * 28, 128)
8.    logit = fully_connect(fc, 'fc2', 128, class_num)
9.    return logit
10. in_x = tf.placeholder(tf.float32, shape = [None, 28, 28, 1])
11. in_y = tf.placeholder(tf.float32, shape = [None, 10])
12. y = predict(in_x, 10)
13. cross_entropy = tf.reduce_mean(tf.nn.softmax_cross_entropy_with_logits(labels=in_y,logits =y))
14. train_step = tf.train.AdamOptimizer(1e-4).minimize(cross_entropy)
# Execution
15. train_img, train_lab = read_image( batch_size ,...)
16. with tf.Session() as sess:
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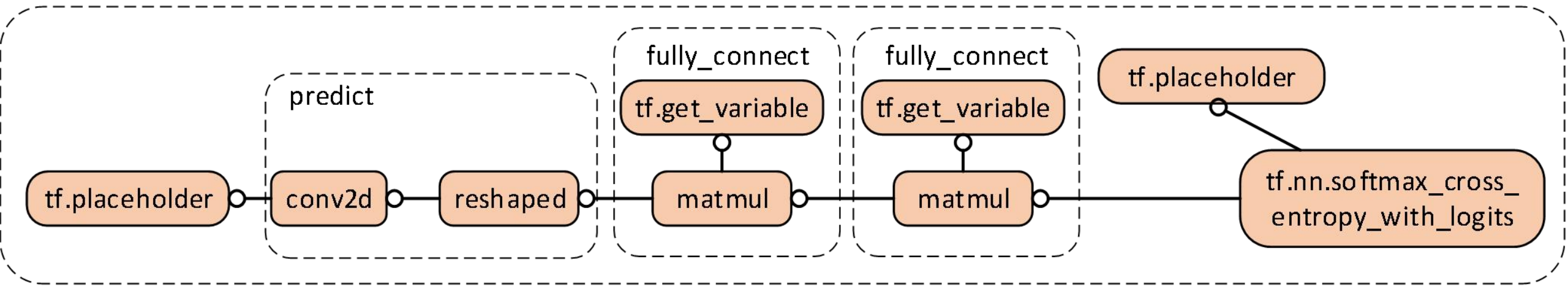

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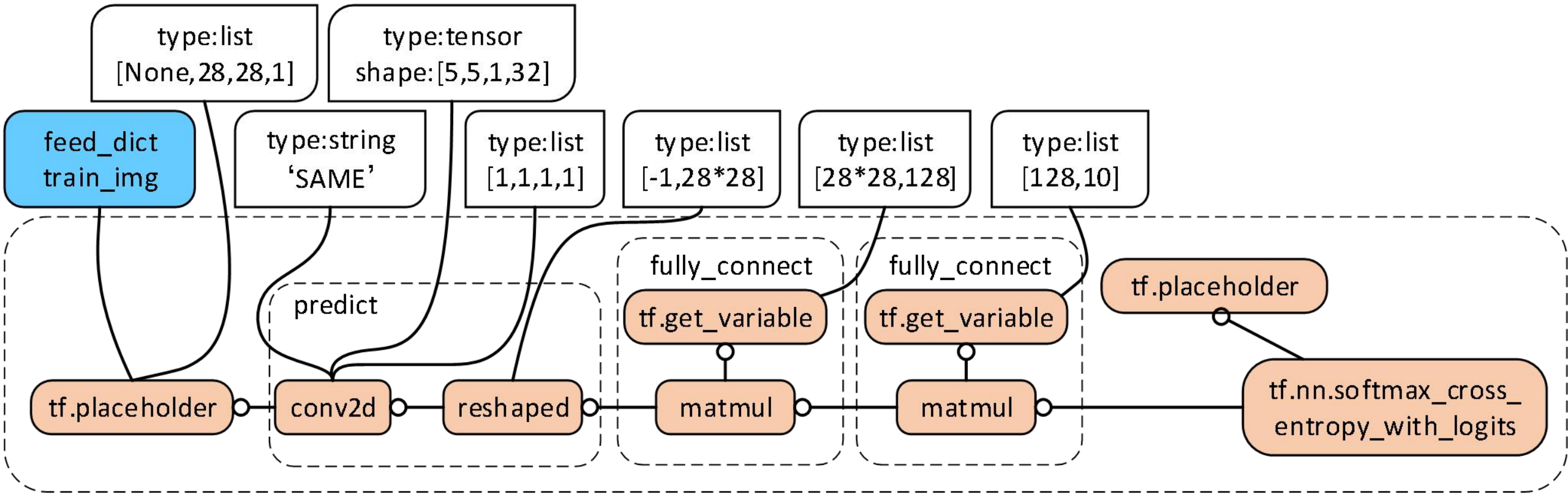

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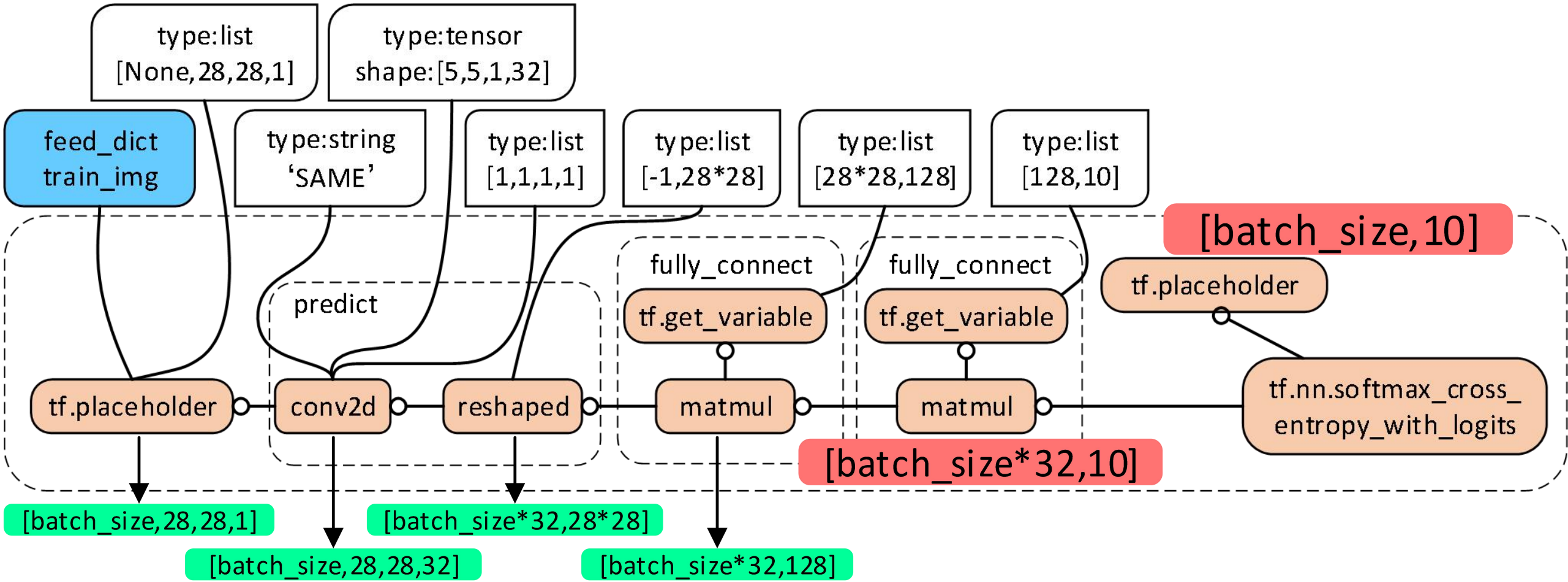

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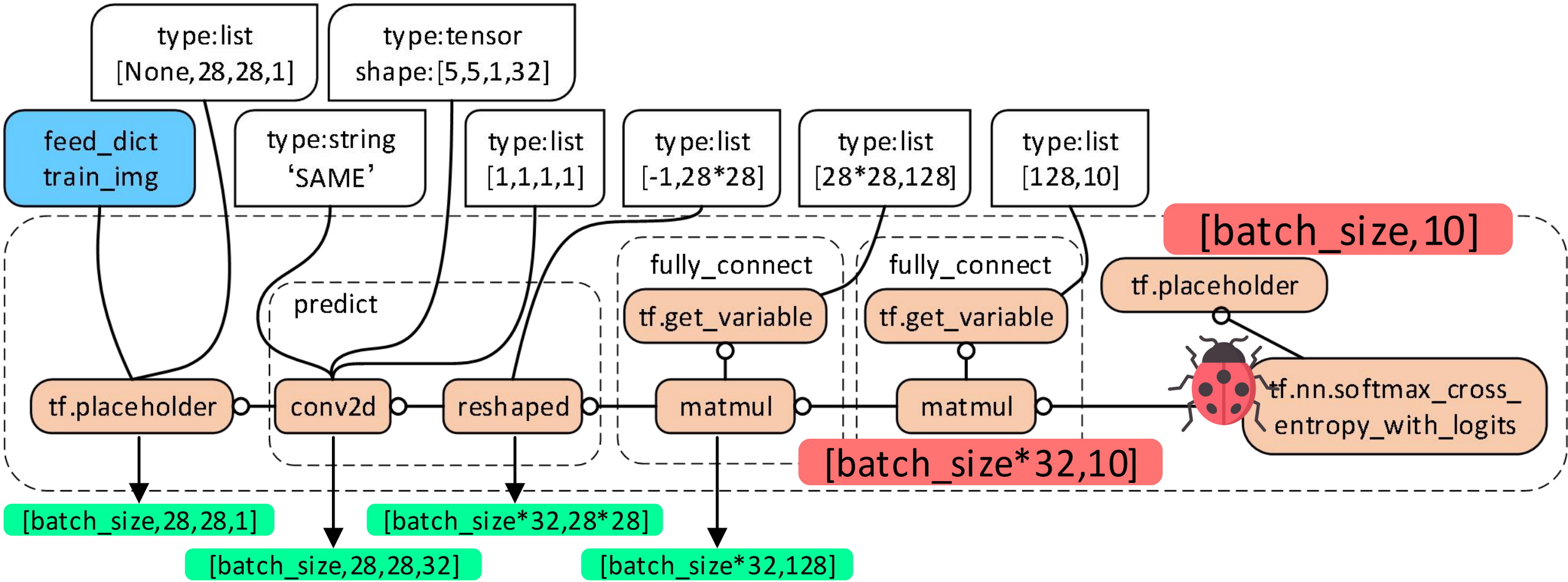
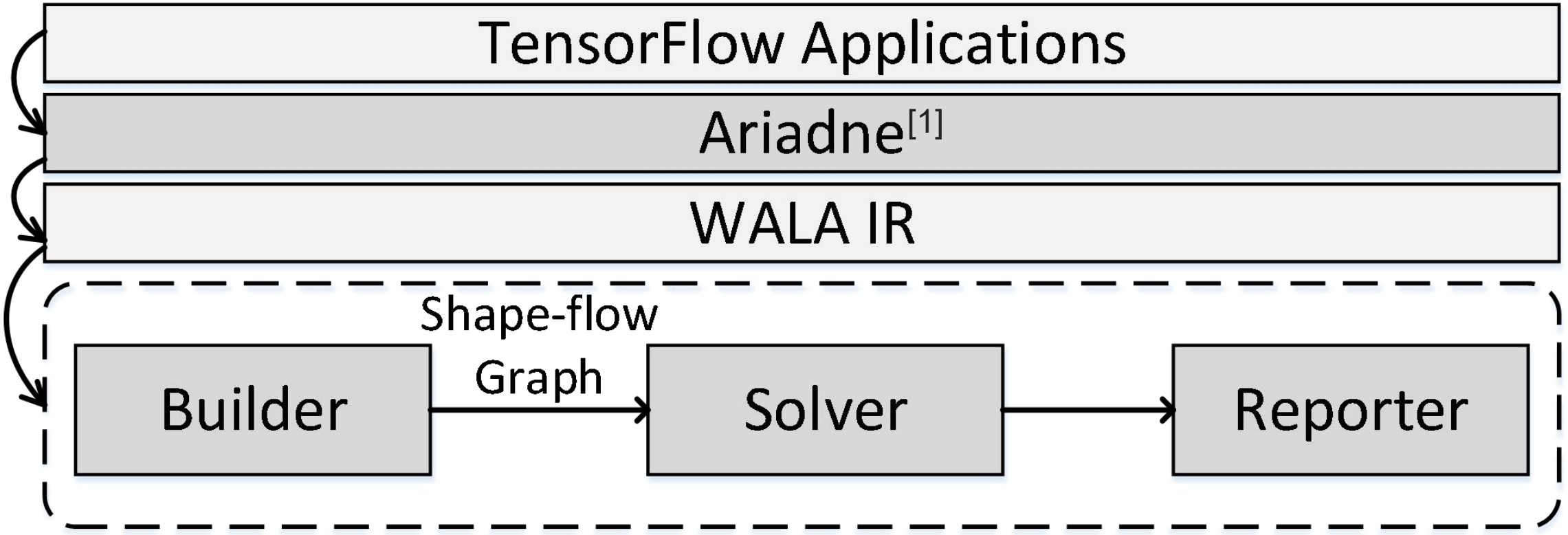


A simplified shape error example

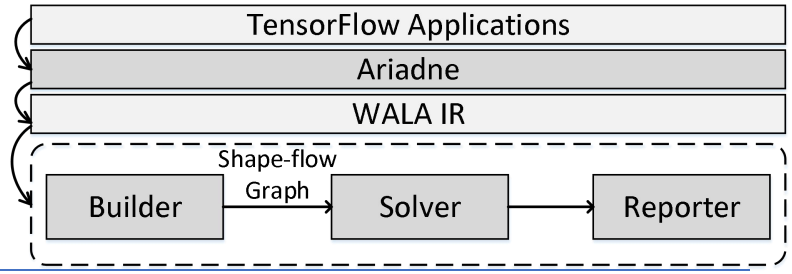
ValueError: Shapes (1600, 10) and (50, 10) are incompatible

Architecture of ShapeTracer



[1] Dolby, Julian, et al. "Ariadne: analysis for machine learning programs." *Proceedings of the 2Nd ACM SIGPLAN International Workshop on Machine Learning and Programming Languages*. 2018.

Builder

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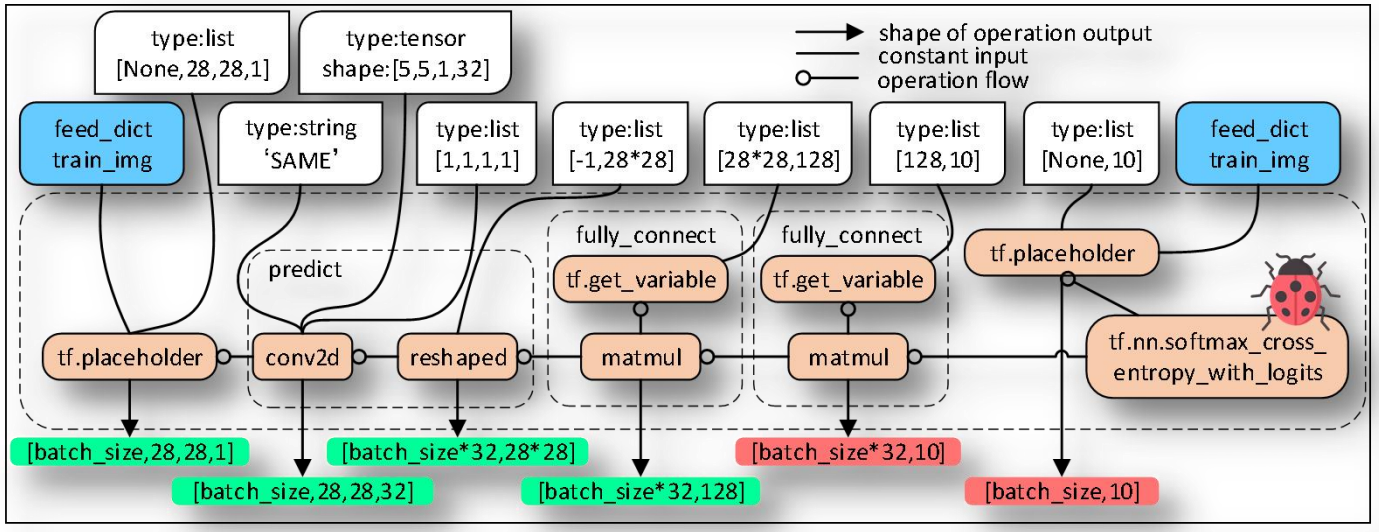
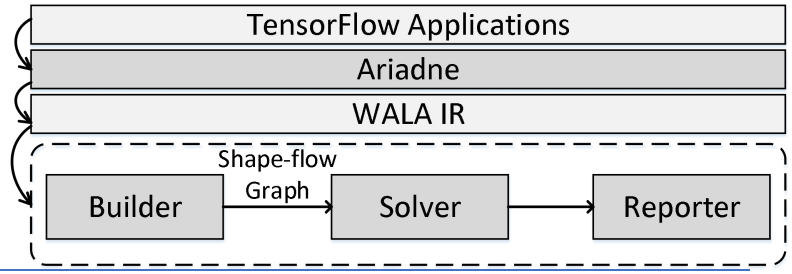
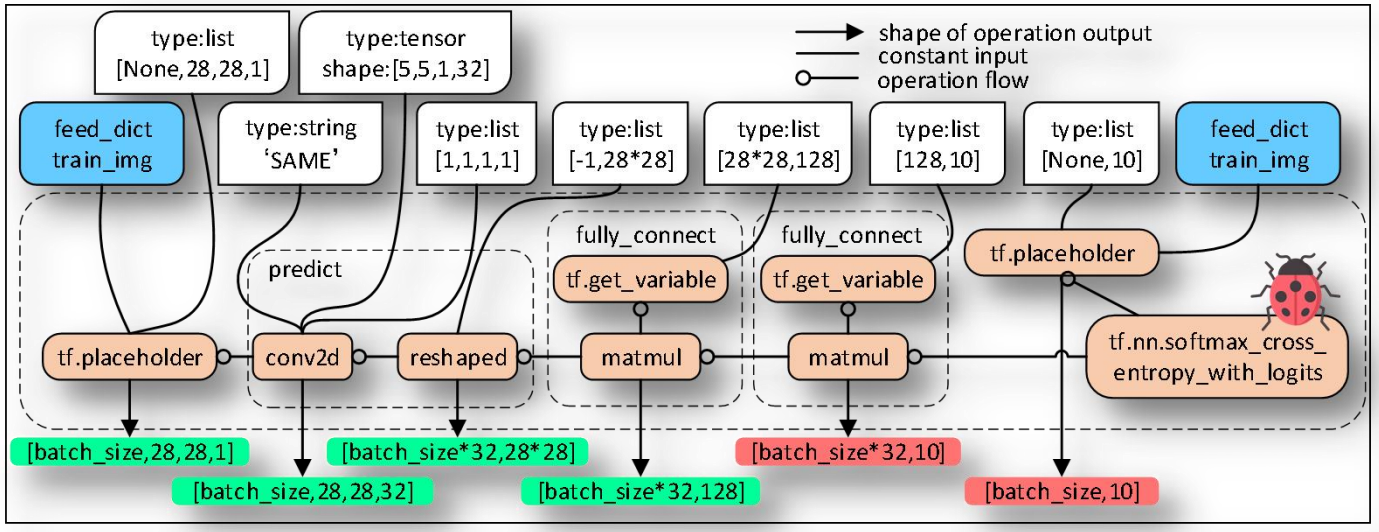


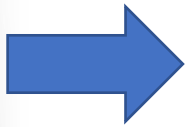
Python Code

Shape-flow Graph

Solver

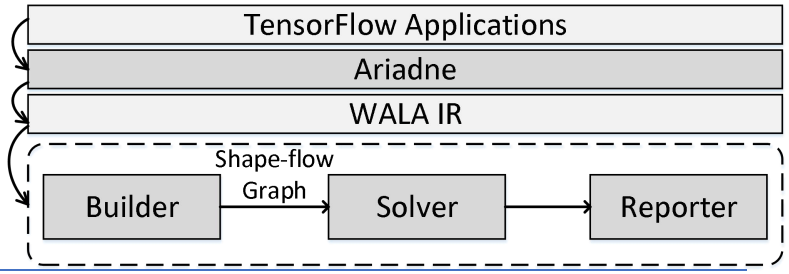


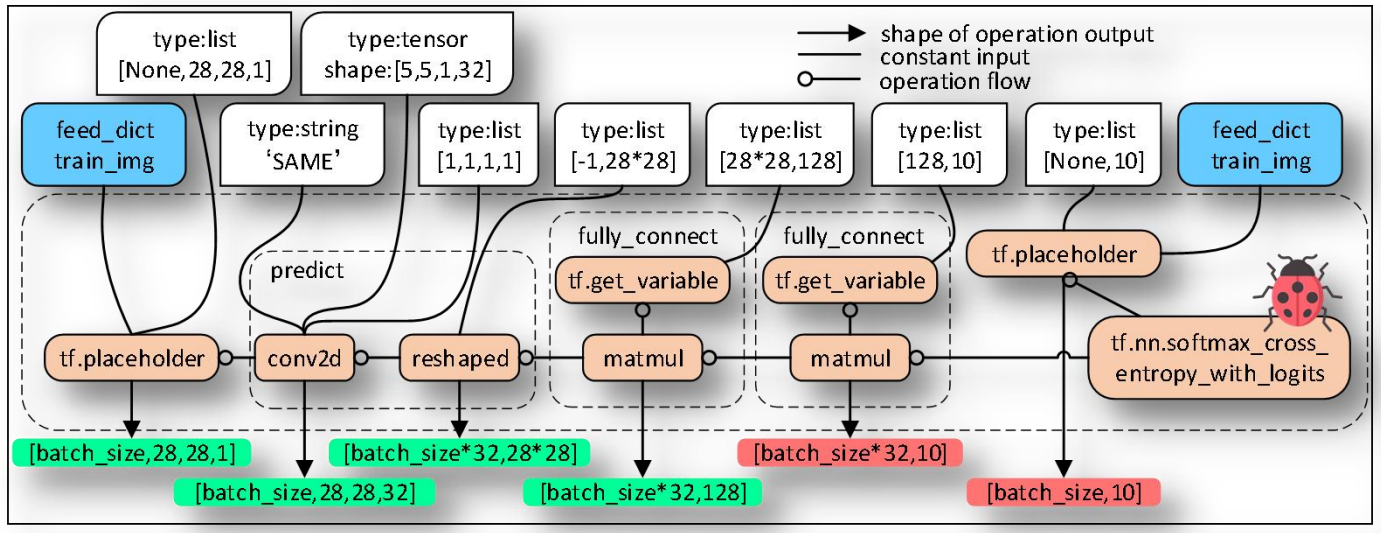




Constraints

Solver

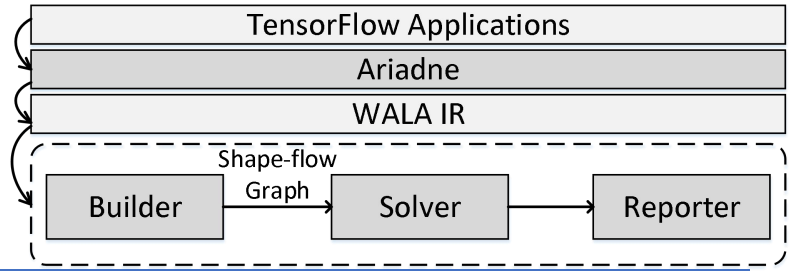


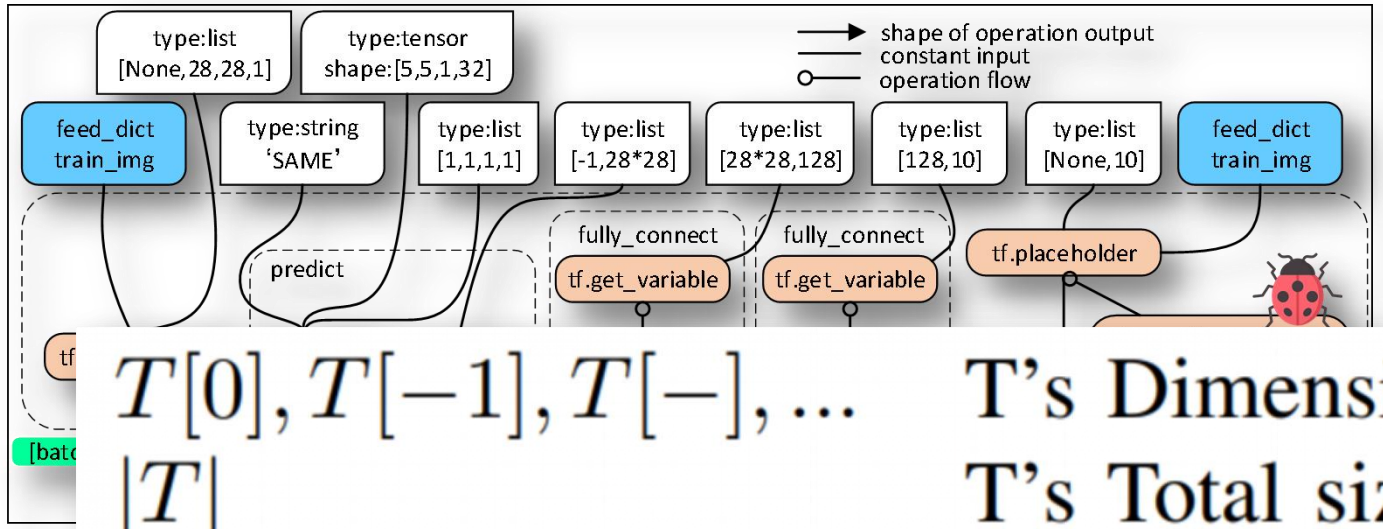


Constraints

1. The CFG of network construction phase is simple.
2. Constraints is suitable for unknown hyperparameters.(such as topology and size of a neural network)

Solver

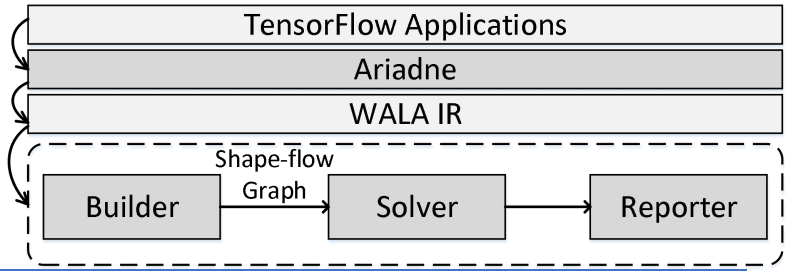




Constraints

$T[0], T[-1], T[-], \ldots$	T's Dimension sizes
$\lvert T \rvert$	T's Total size (number of elements)
$\overline{T}$	T's Rank (number of dimensions)
$V_0, V_1, \ldots, V_{\lvert V \rvert - 1}$	V's element values
X	X's value

Solver



[batch_size*32,10]

$T[0]$ == batch_size * 32
$T[1]$ == T [-1] == 10
$|T|$== batch_size * 32 * 10
$\overline{T}$ == 2

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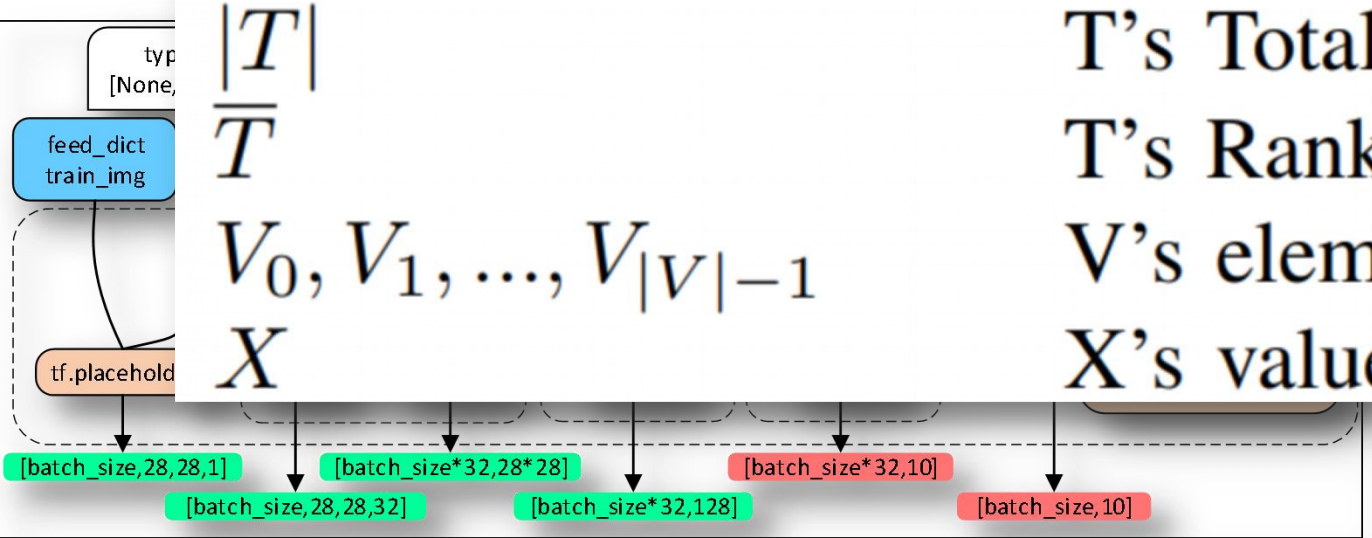
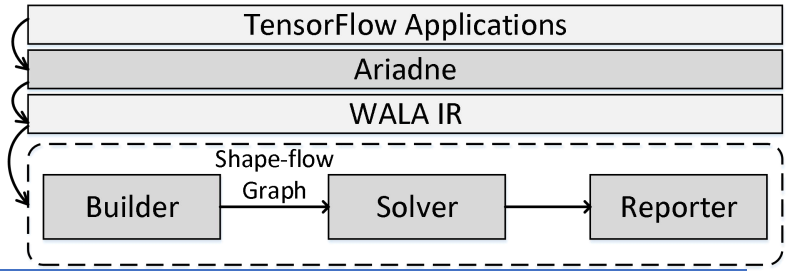
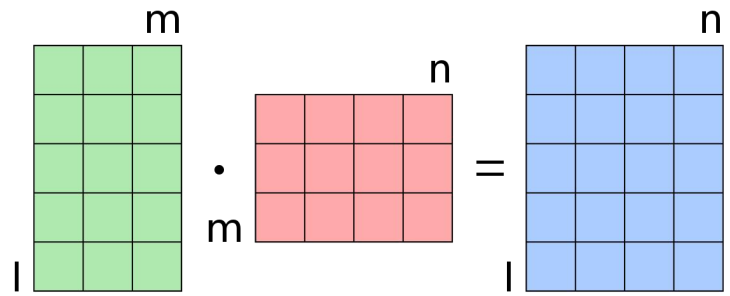


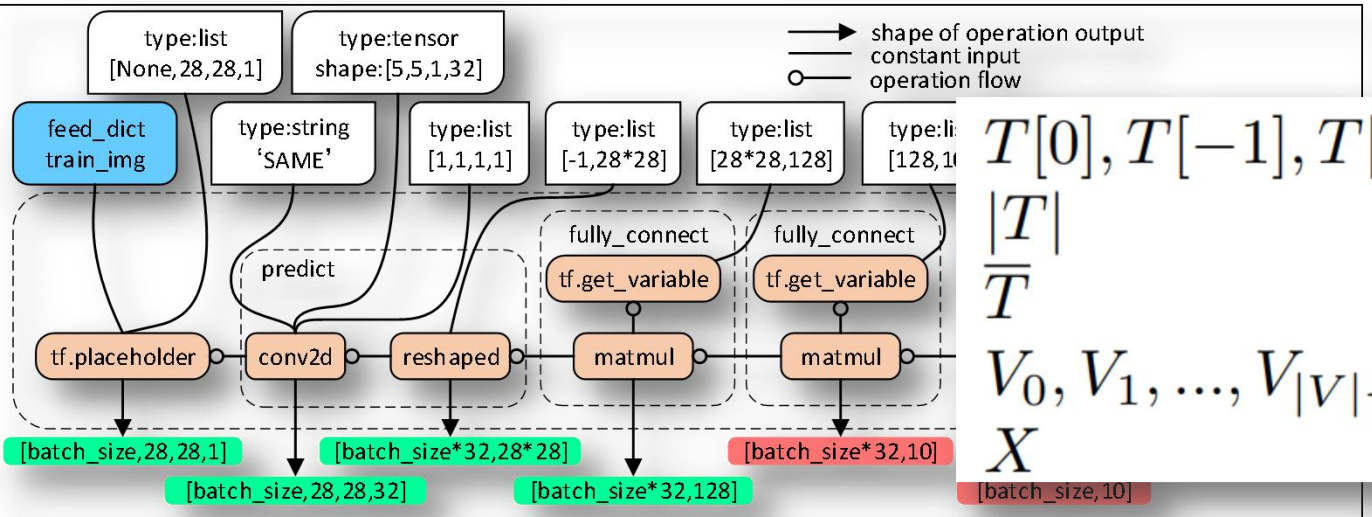
Solver



matmul

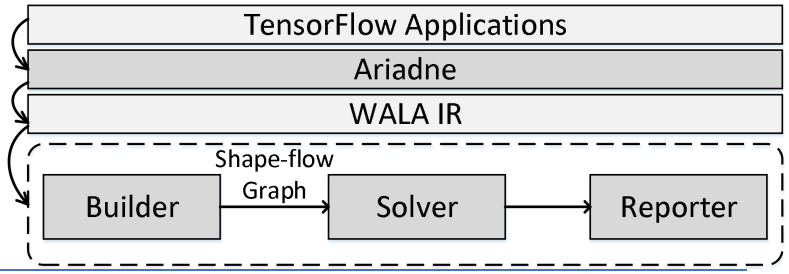


$$C = tf.Matmul(A, B)$$

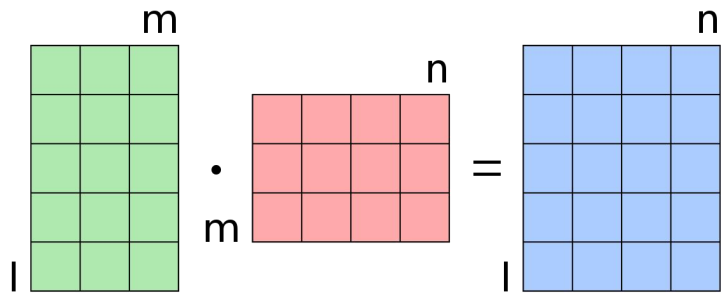


$T[0], T[-1], T[-], \ldots$	T's Dimension sizes
$\|T\|$	T's Total size (number of elements)
$\overline{T}$	T's Rank (number of dimensions)
$V_0, V_1, \ldots, V_{\|V\|-1}$	V's element values
X	X's value

Solver

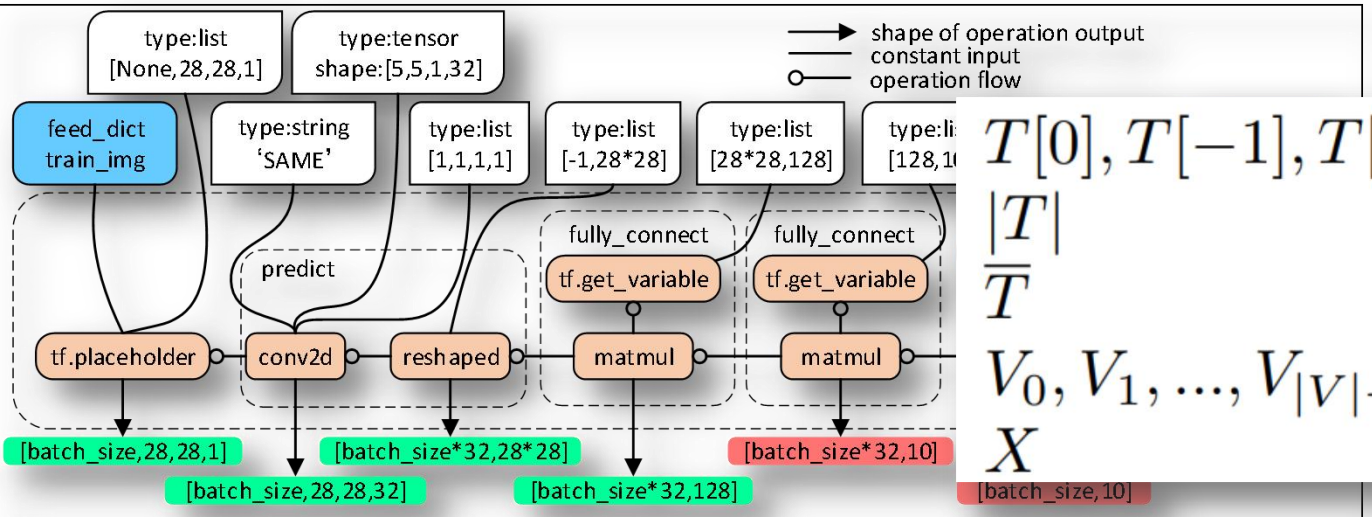


matmul



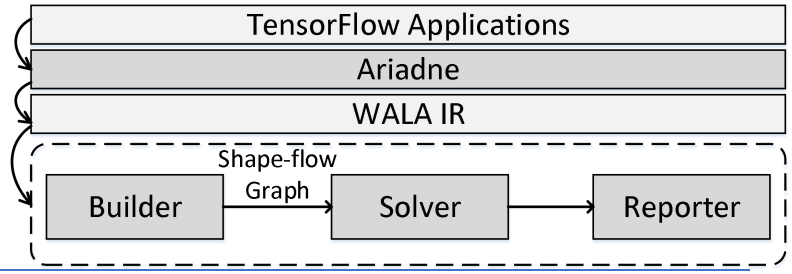
$$C = tf.Matmul(A, B)$$

$$A[-1] == B[0] \\ \wedge C[0] == A[0] \\ \wedge C[-1] == B[-1] \\ \wedge \ldots$$



$T[0], T[-1], T[-], \ldots$	T's Dimension sizes
$\|T\|$	T's Total size (number of elements)
$\overline{T}$	T's Rank (number of dimensions)
$V_0, V_1, \ldots, V_{\|V\|-1}$	V's element values
X	X's value

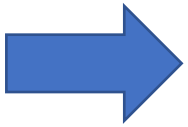
Solver



$$A[-1] == B[0]$$
$$\wedge\, C[0] == A[0]$$
$$\wedge\, C[-1] == B[-1]$$
$$\wedge \ldots$$

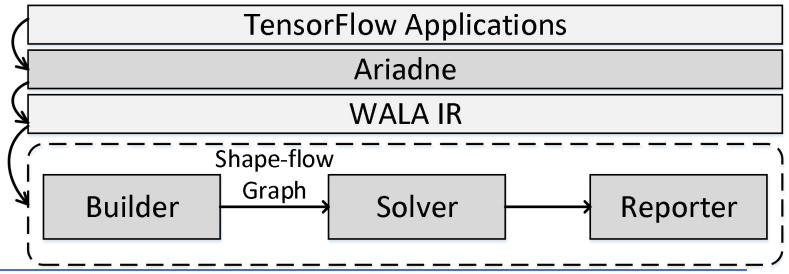
$\wedge \ldots$

$\wedge \ldots$



constraint solver

Reporter



constraint solver

Unsatisfiled

```
#error reported by ShapeTracer
[[Error]]
      filename.py(line15)__matmul
          Dimensions must be equal.
```

Error location

Expect user inputs

```
#warning reported by ShapeTracer
[[Warning]]
      [batch_size]filename.py(line3)__value = 66
      [anonymous]filename.py(line6)__value = 67
```

A set of feasible solutions

Evaluation

Evaluated on 14 programs from Zhang et al. empirical study[1] and 60 randomly picked industrial programs.

[1] Zhang, Yuhao, et al. "An empirical study on TensorFlow program bugs." *Proceedings of the 27th ACM SIGSOFT International Symposium on Software Testing and Analysis*. 2018.

Evaluation

- 9 out of 14 bugs in open-source applications
- 40 out of 60 bugs in industrial programs

- Existing detection:

  Pythia [1]

[1] Lagouvardos, Sifis, et al. "Static analysis of shape in TensorFlow programs." *34th European Conference on Object-Oriented Programming (ECOOP 2020)*. Schloss Dagstuhl-Leibniz-Zentrum für Informatik, 2020.

Evaluation

- 9 out of 14 bugs in open-source applications

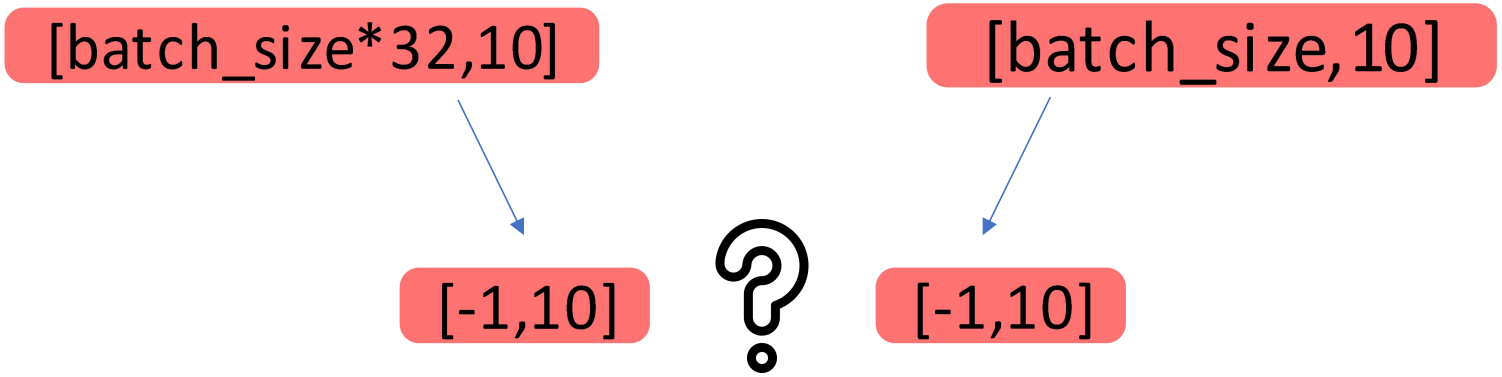
	UT-1	UT-5	UT-12	UT-13	UT-15
ShapeTracer	✓	✓	-	-	-
Pythia	⚠	-	⚠	⚠	⚠

Evaluation

- ShapeTracer
  - 40 out of 60 bugs in industrial programs
- Pythia
  - 23 of 60 runtime exceptions when generating Python facts.
  - Extended with 75 datalog rules for unsupported operators
  - 9 of rest 37

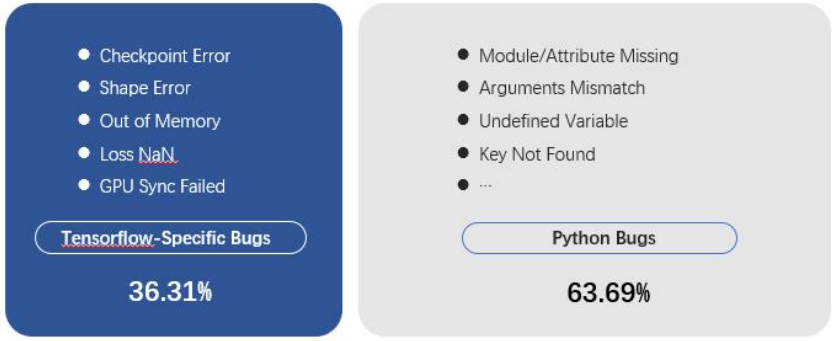
Evaluation

- Existing detection:
  - ***Pythia***
    - based on Datalog



Conclusion

- Study on 12289 failed industrial jobs



- ShapeTracer
  - constraint-based approach to detecting shape-related bugs
  - both efficient and effective