



Two-stage framework for corner case stimuli generation Using Transformer and Reinforcement Learning

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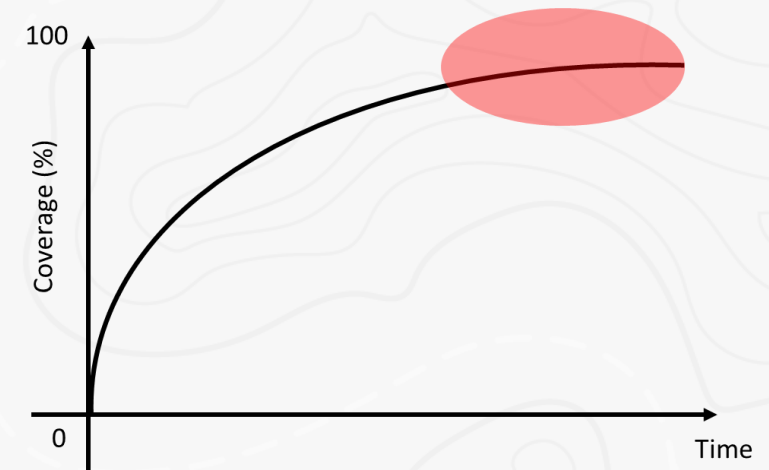


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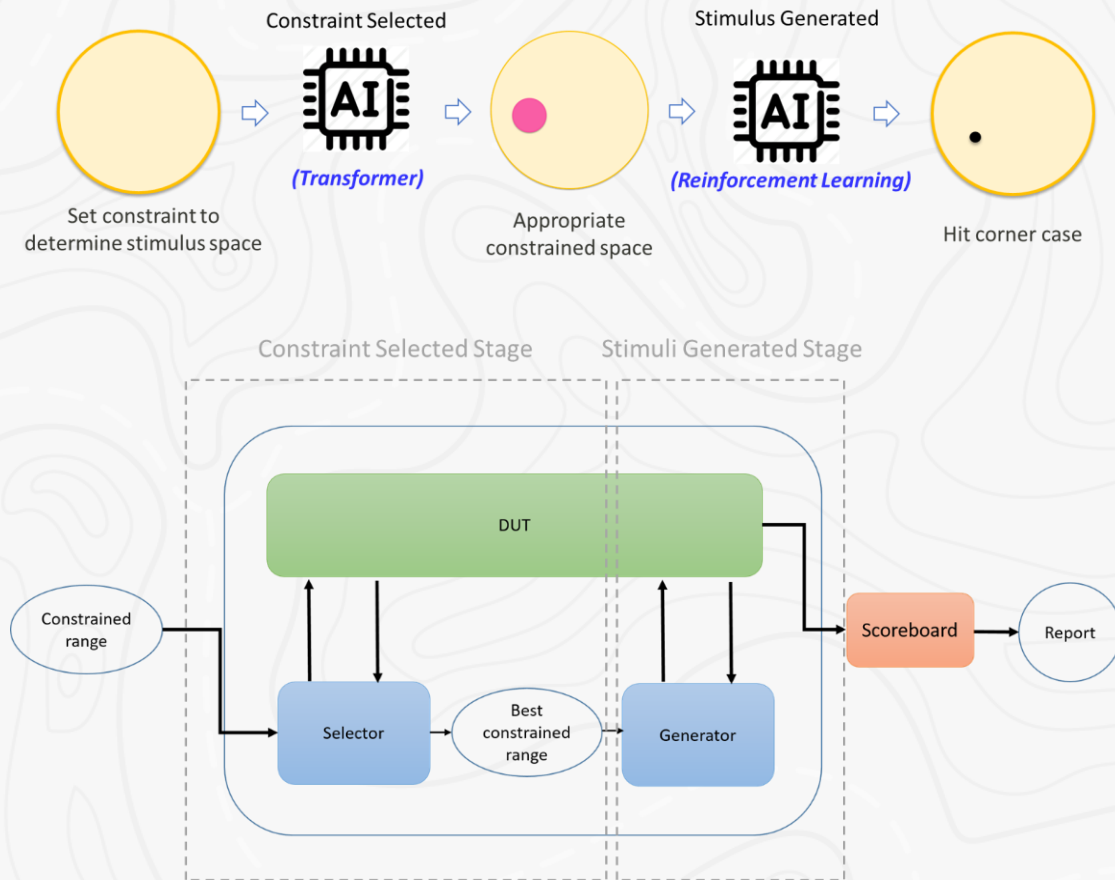
Background

- Coverage closure is hard to reach during functional verification, because some difficult corner cases can't be verified by constrained random verification (CRV) which is a common simulation-based approach.
- This study is going to introduce the novel AI methodology to increase hit rate of corner case by learning simulated data.
- AI can tune constraint setting automatically instead of laborious process.



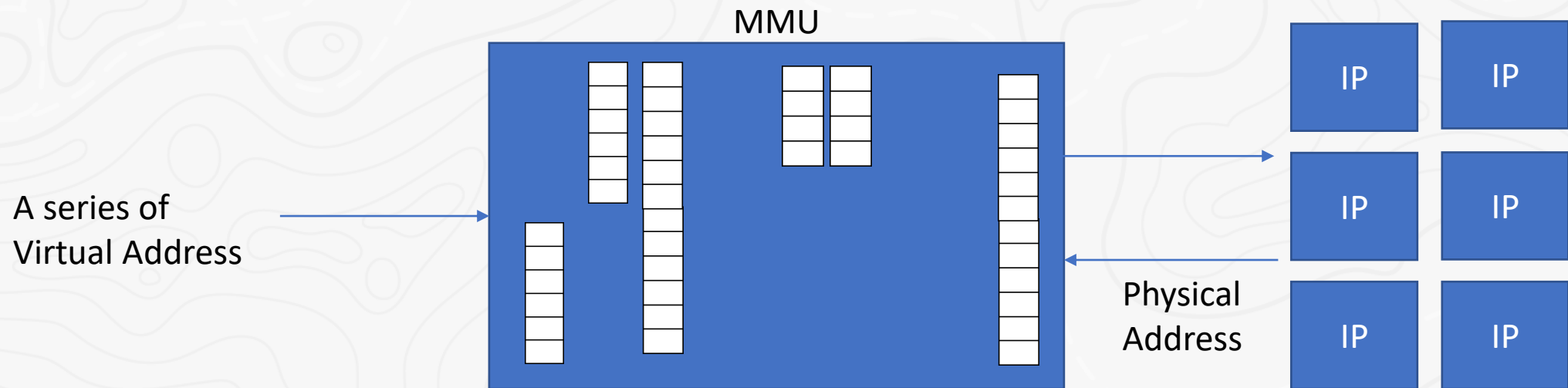
Two-stage framework

- The first stage - Constraint Selected
 - Shrink the constrained range quickly to decrease the stimulus space.
- The second stage - Stimulus Generated
 - Based on the smaller constrained sub-range, generate a series of constraint to hit corner case.



The FIFO full condition in MMU

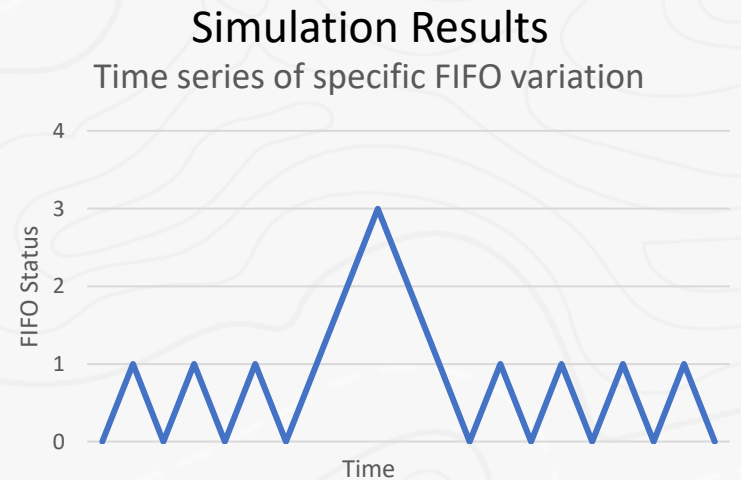
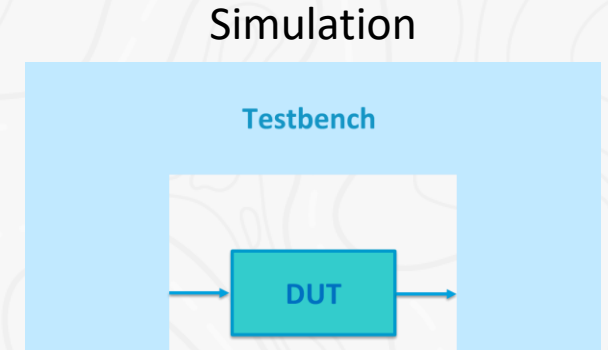
- There are many FIFOs in the cache type design
 - MMU(memory management unit).
- The specific FIFO full condition is very hard to reach in general testcase.



Experiment Setting

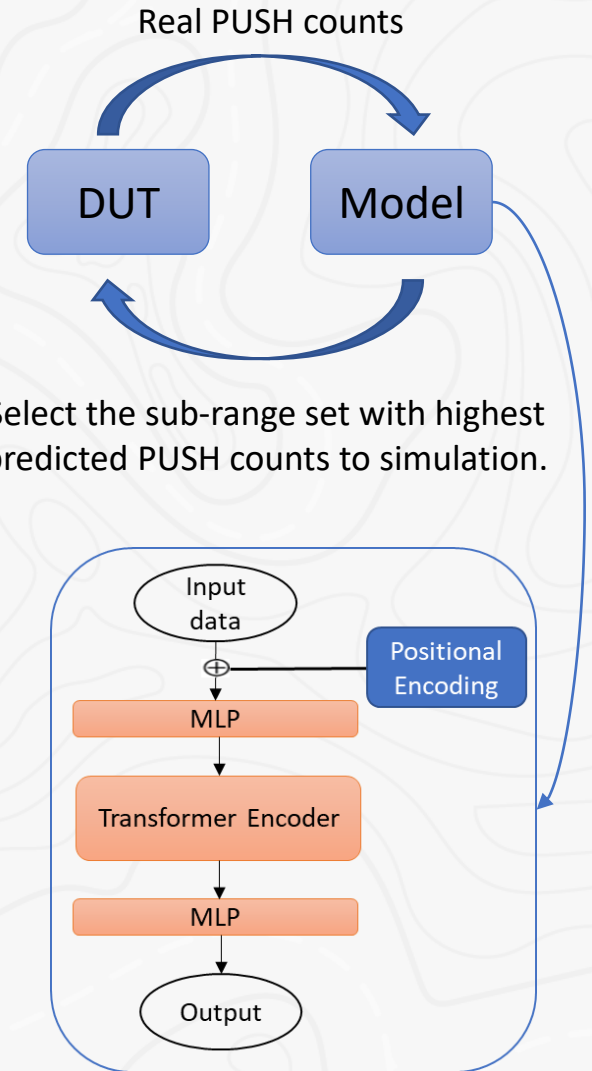
- There are 16 (0-15) constrained parameters could be selected in each element.
- Each constraint parameter represents the degree of adjustment for input virtual address.
- The stimulus space with all constrained sequence of length 30 is $16^{30} = 2^{120}$

Input constraint	
Index	Constraint
0	3
1	10
2	12
3	5
4	3
5	3
6	4
7	12
8	8
9	8
10	13
11	5
12	3
13	10
·	·
·	·
·	·
29	3



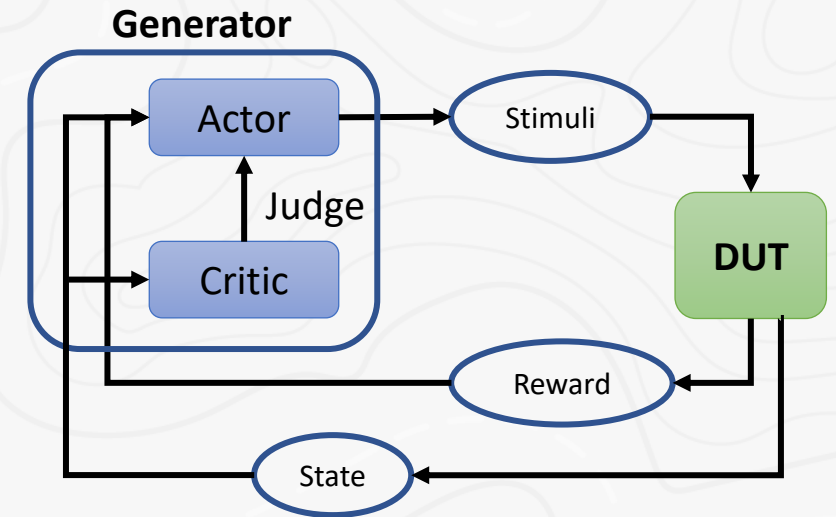
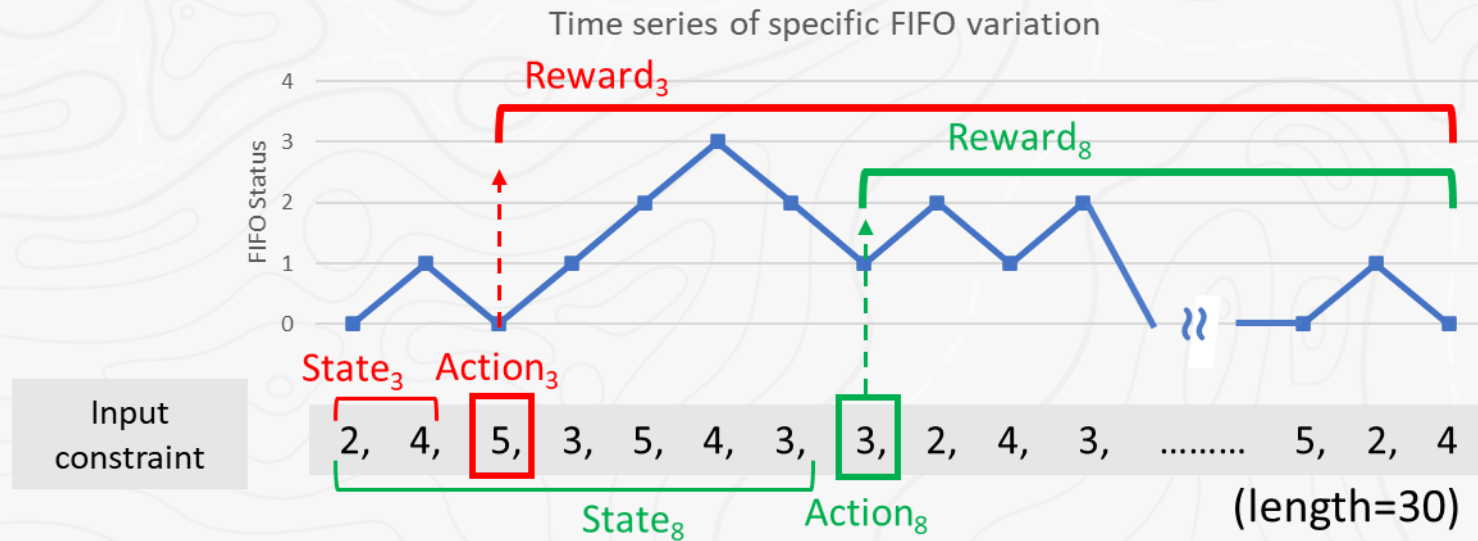
Constraint Selected Stage

- The reason of each FIFO PUSH/POP are not the same. So, we need to find the appropriate sub-range set from all constraint parameters (0-15).
 - e.g., The PUSH behavior of FIFO A is very sensitive with the specific sub-range set of constraint parameters (2-5).
- The constraint selected stage is focus on find out the appropriate sub-range set for each FIFO.
- We leverage the Self-Attention mechanism of the encoder in Transformer to select best sub-range set automatically.



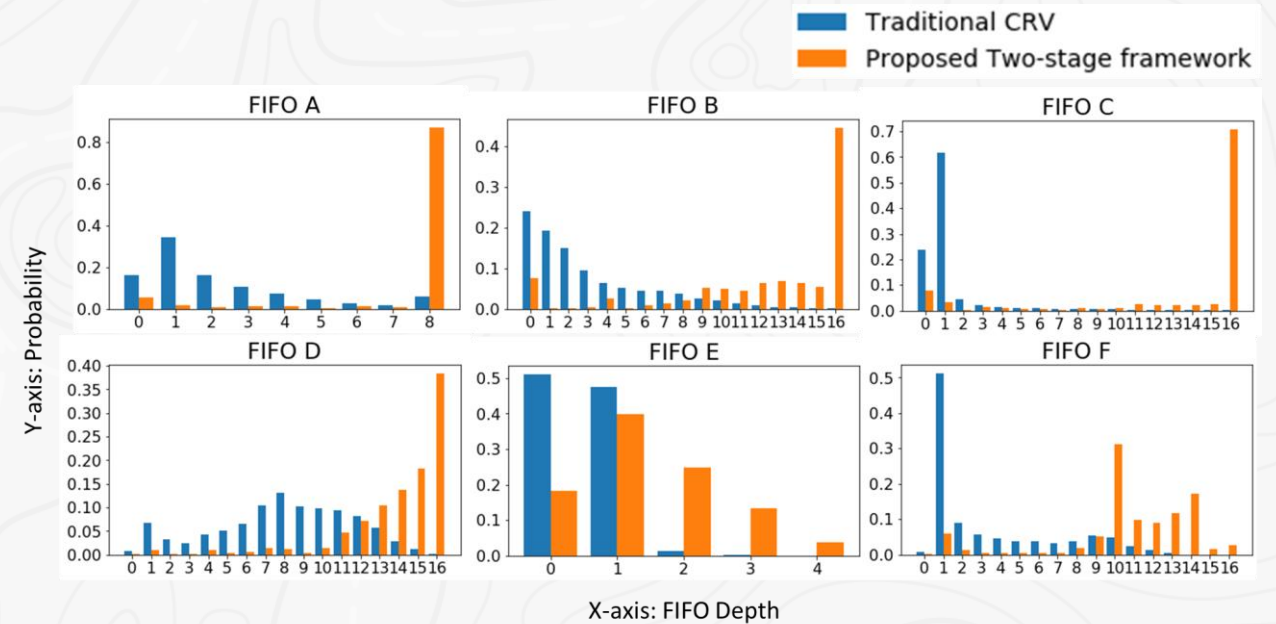
Stimuli Generated Stage

- After the best sub-range set was selected for each FIFO.
- We leverage Reinforcement Learning (RL) to determine the sequence of stimulus to fill up FIFO.



FIFO Accumulated Distribution

- CRV vs Two-stage framework
 - The probability of FIFO depth reached by stimulus are changed apparently.
 - The distribution of the probability is right shift, which means the FIFO could accumulation higher than before.



Experimental Results

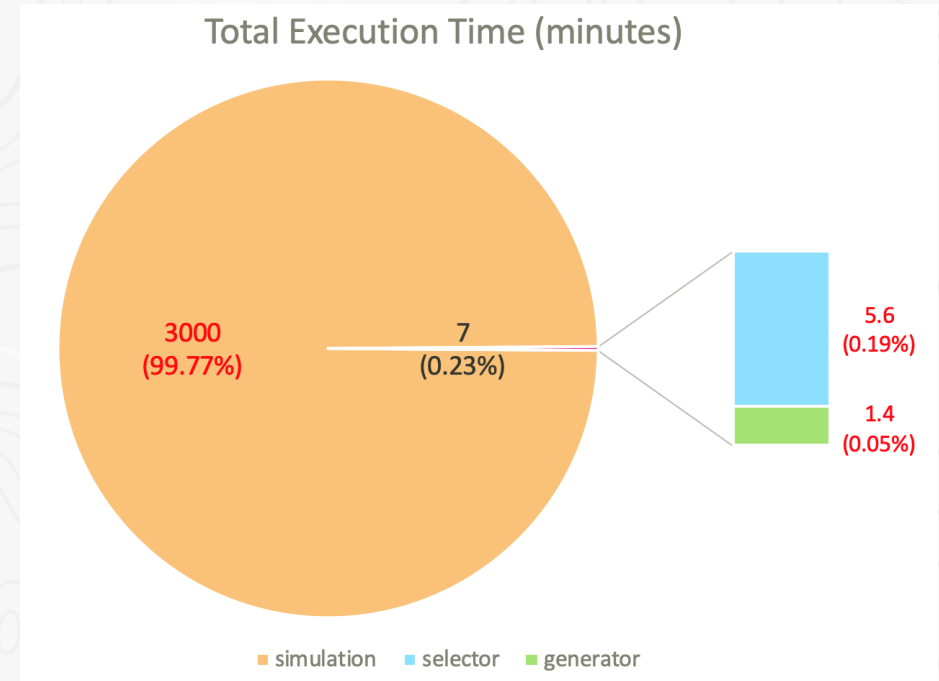
- Hit = FIFO Full
- Our two-stage AI method can increase the hit rate 14x-380x.

The Efficiency of TWO-STAGE FRAMEWORK

FIFO Name	A	B	C	D	E	F
Traditional CRV	1849/30,000	83/30,000	84/30,000	57/30,000	3/30,000	4/30,000
Two-stage framework	869/1,000	443/1,000	706/1,000	383/1,000	38/1,000	27/1,000
Hit rate ↑ x times	14	160	252	201	380	202

Total Execution Time

- On the same computing environment.
- 1,000 Simulations: 3,000 minutes
- Selector and Generator: 7 minutes
- Only about 0.2% of overall runtime.



Conclusion

- Two-stage framework by using Transformer and Reinforcement Learning can tune constraints and generate stimulus automatically.
- Increase corner condition hit rate up to 380x.
- The novel methodology is not only can apply in MMU design verification but also the other designs.

Q & A