Part I

Probing with OthelloGPT

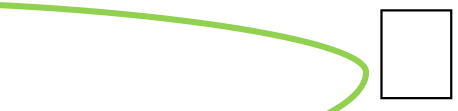
Self-Intro

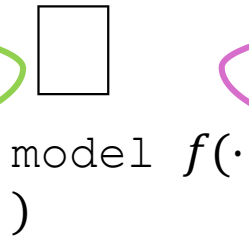
- Yichuan Song / 宋 一川 / Tiger
  - Coming Yr4 undergrad in University of Hong Kong
- Research experiences:
  - finer DPO, model merging, energy-based agent planning
- This summer (May 27th – Aug 17th):
  - Visiting student under the Mitacs program
  - Supervised by Xujie Si, mentored by Allen Geng and Rebecca Wang
  - My work is about…

Introduction

- Field: Verification of DNNs / Robustness Verification
  - Use verification tools (e.g. $\alpha\beta$ crown, Marabou) to verify neural networks
- Motivations:
  1. Black-box models are unreliable and unstable when unseen situations (e.g. adversarial examples)

sample x

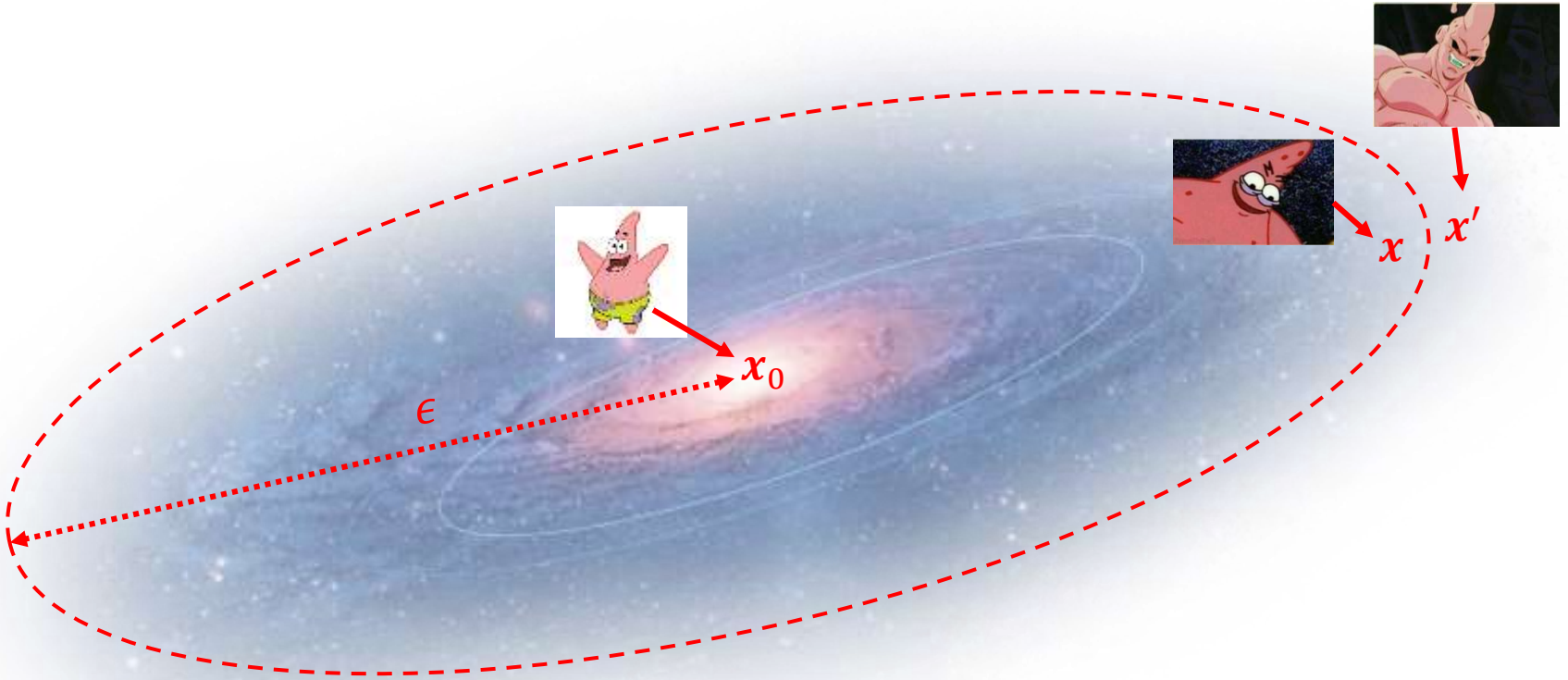




adversarial x'

Introduction

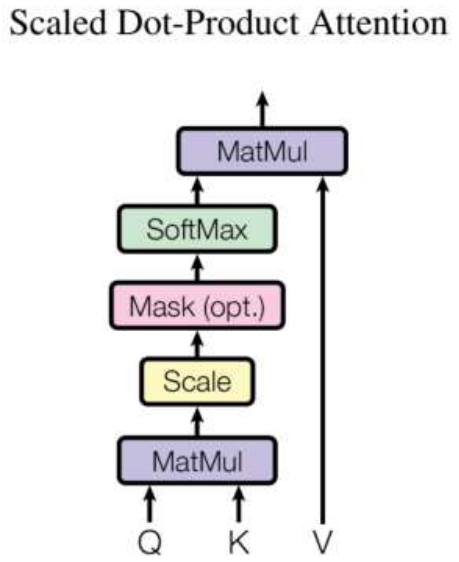
- Formally, the robustness verification problem:

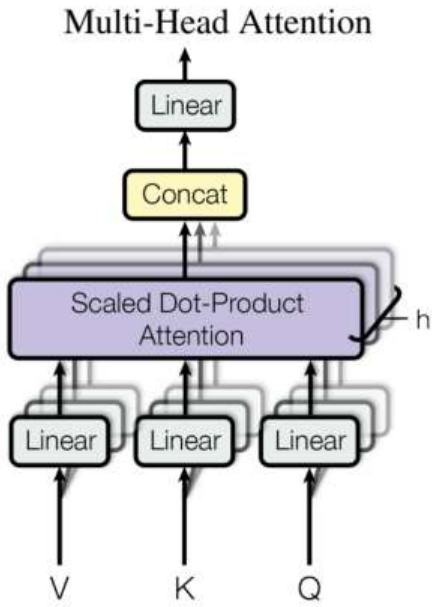


Universe of Patrick $\mathbb{B}_p(x_0, \epsilon) \coloneqq \{x \mid ||x - x_0||_p \leq \epsilon\}$

Introduction

- Motivations:
  2. Transformers are popular nowadays, but also hard to verify due to its attention mechanism:
     - Complex architecture: linear bounds for self-attention layers needs to be propagate differently.
     - Cross-nonlinearity: multiplication and division of two variables both under perturbation (e.g. dot product, softmax, weighted summation).
     - Cross-position dependency: output neurons in each position depends on all input neurons from different positions.

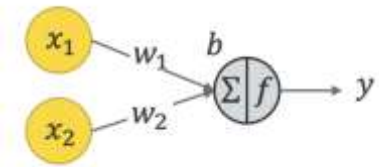




Attention is All You Need (NIPS 2017)
Robustness Verification for Transformers (ICLR 2020)

Related Works

- Marabou
  - Verification tool
  - SMT-based (find more in Appendix)
  - Performs satisfiability checking on a set of linear and non-linear contraints



model constraints

$\exists\, x_1 < 0, x_2 > 1\ s.t.\ y > 6$?

Input & output constraints

query Q

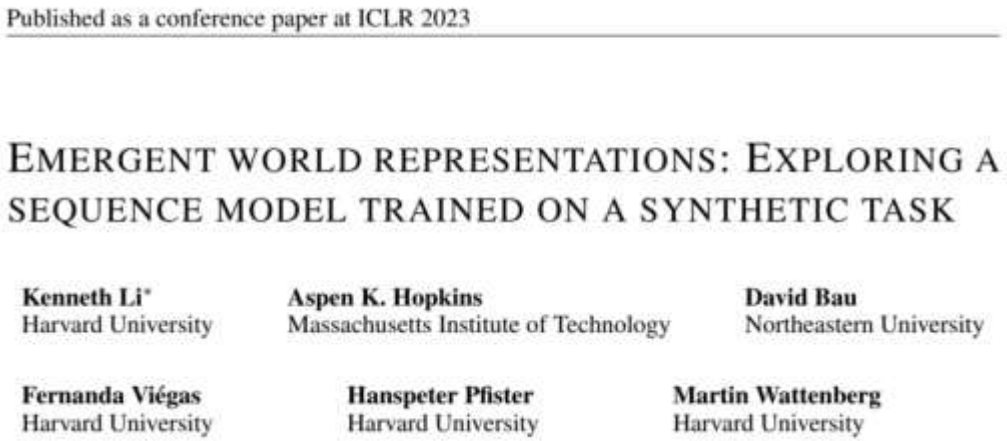
marabou

Satisfied (SAT)
counterexample exists,
bound not safe

Unsatisfied (UNSAT)
all values exhausted

Marabou 2.0: A Versatile Formal Analyzer of

Related Works



Published as a conference paper at ICLR 2023

EMERGENT WORLD REPRESENTATIONS: EXPLORING A SEQUENCE MODEL TRAINED ON A SYNTHETIC TASK

Kenneth Li* Harvard University
Aspen K. Hopkins Massachusetts Institute of Technology
David Bau Northeastern University
Fernanda Viégas Harvard University
Hanspeter Pfister Harvard University
Martin Wattenberg Harvard University

- Some of the contributions of this paper:
  1. OthelloGPT as an emergent world model to produce legal moves in game Othello
  2. the board state it generates as an internal representation
  3. non-linear probing for interpretability of the board state

Emergent World Representations: Exploring a Sequence Model Trained on a Synthetic Task (ICLR 2023)

Related Works (Cont.)

- Game Othello:
  - A synthetic task as testbed for interpretability

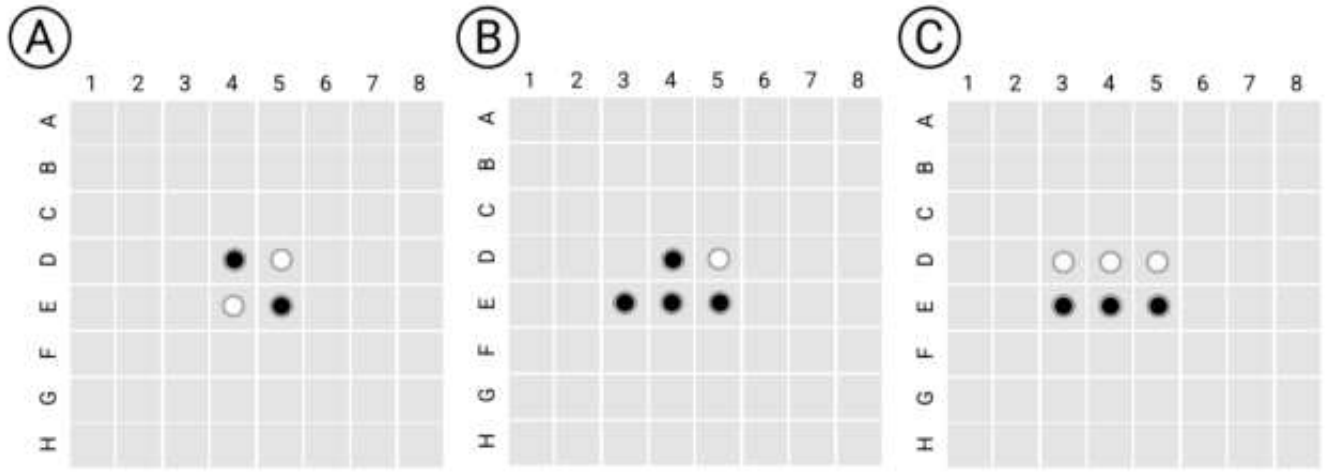
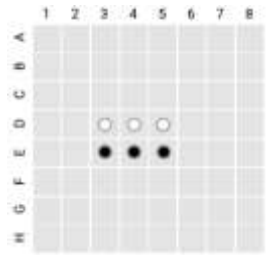


Figure 1: A visual explanation of Othello rules, from left to right: (A) The board is always initialized with four discs (two black, two white) placed in the center of the board. (B) Black always moves first. Every move must flip one or more opponent discs by outflanking—or sandwiching—the opponent disc(s). (C) The opponent repeats this process. A game ends when there are no more legal moves.

Emergent World Representations: Exploring a Sequence Model Trained on Synthetic Task (ICLR 2023)

Related Works (Cont

- OthelloGPT
  - A simple 8-layer GPT model (based on minGPT)
  - The investigated subject (world model)
  - Training:
    - Championship & Synthetic Datasets: complete play-throughs of the game
    - One play-through as a sample: a sequence of 60 tiles
    - Causal mask, autoregressive

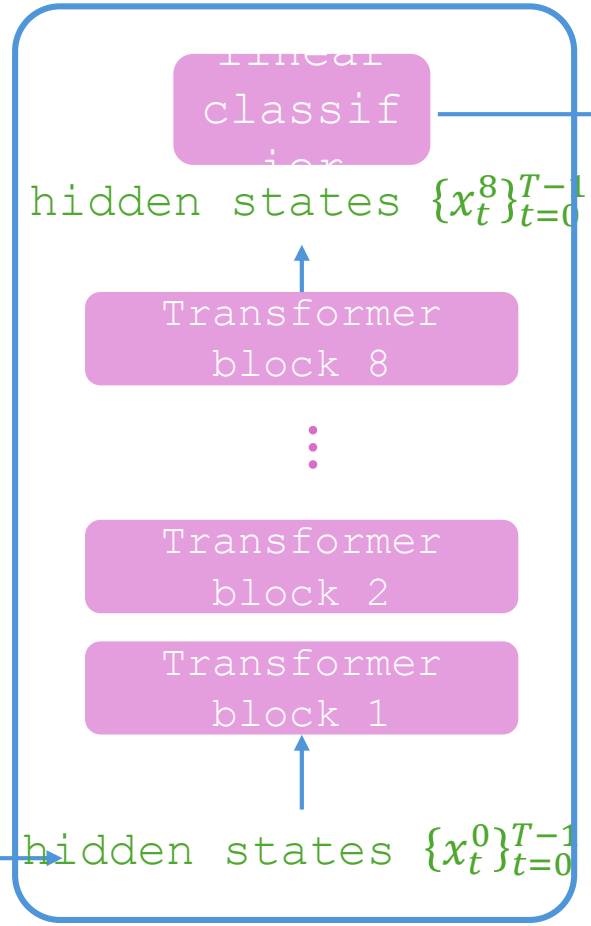


['e3', 'd3']

partial game $\{y_t\}_{t=0}^{T-1}$

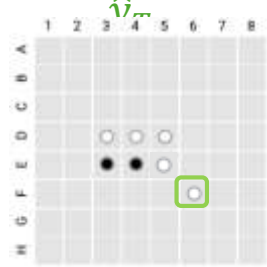
index

trainable word embedding



'f6'

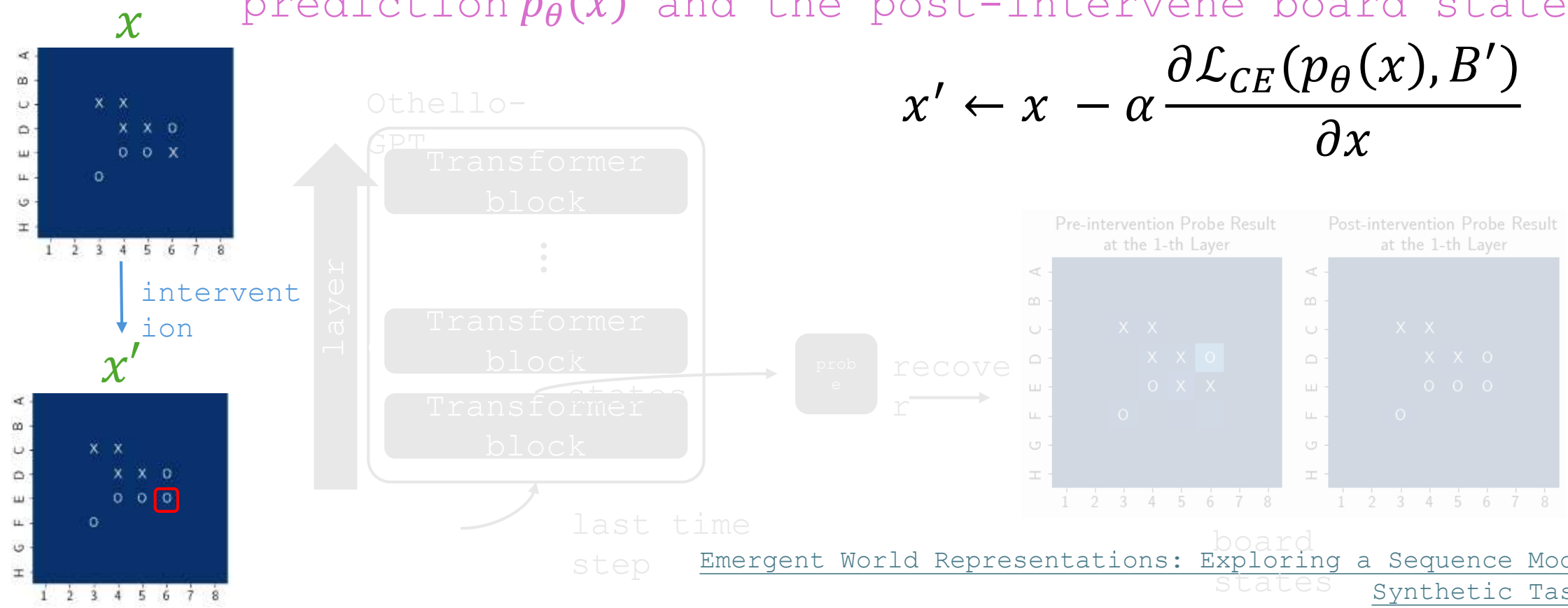
next step prediction $\hat{y}_T$



Related Works (Cont.)

- Probing & Intervention:
  - Intervention: Flip the hidden state x to x' by minimizing the cross-entropy loss between the probe prediction $p_\theta(x)$ and the post-intervene board state B'.

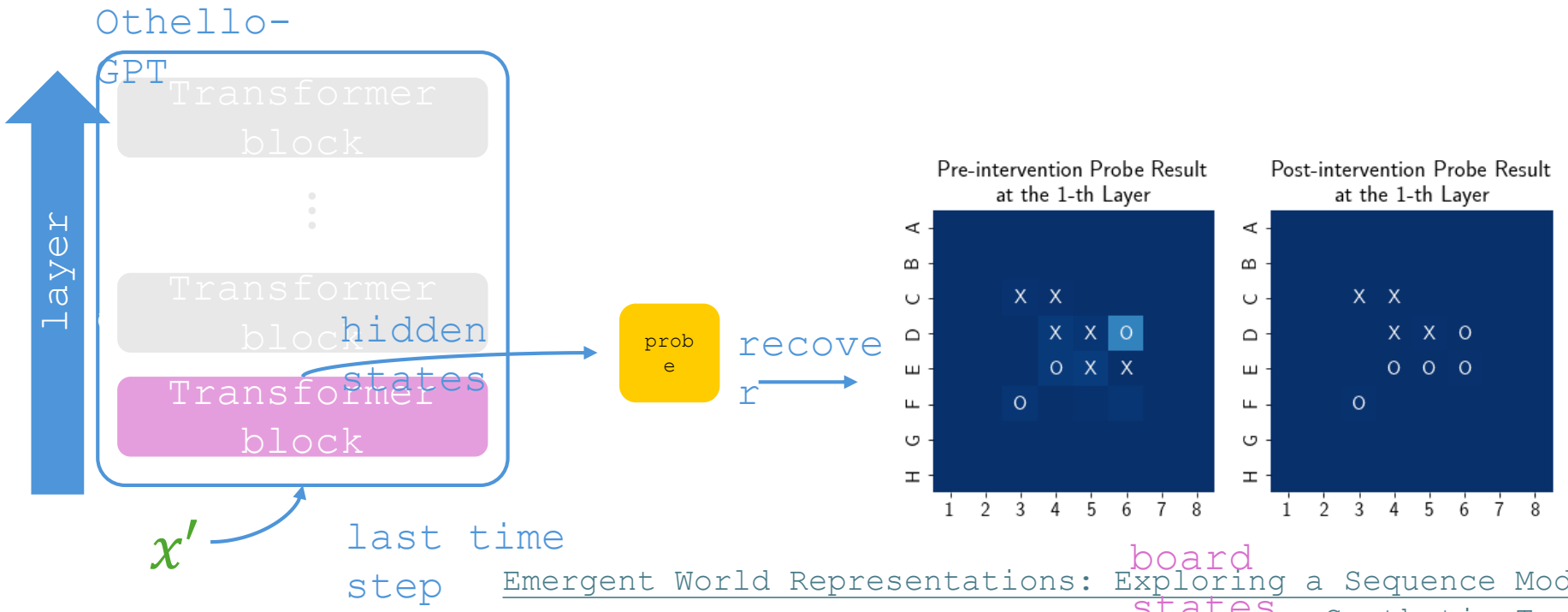
$$x' \leftarrow x - \alpha \frac{\partial \mathcal{L}_{CE}(p_\theta(x), B')}{\partial x}$$



Emergent World Representations: Exploring a Sequence Model Trained on Synthetic Task (ICLR 2023)

Related Works (Cont.)

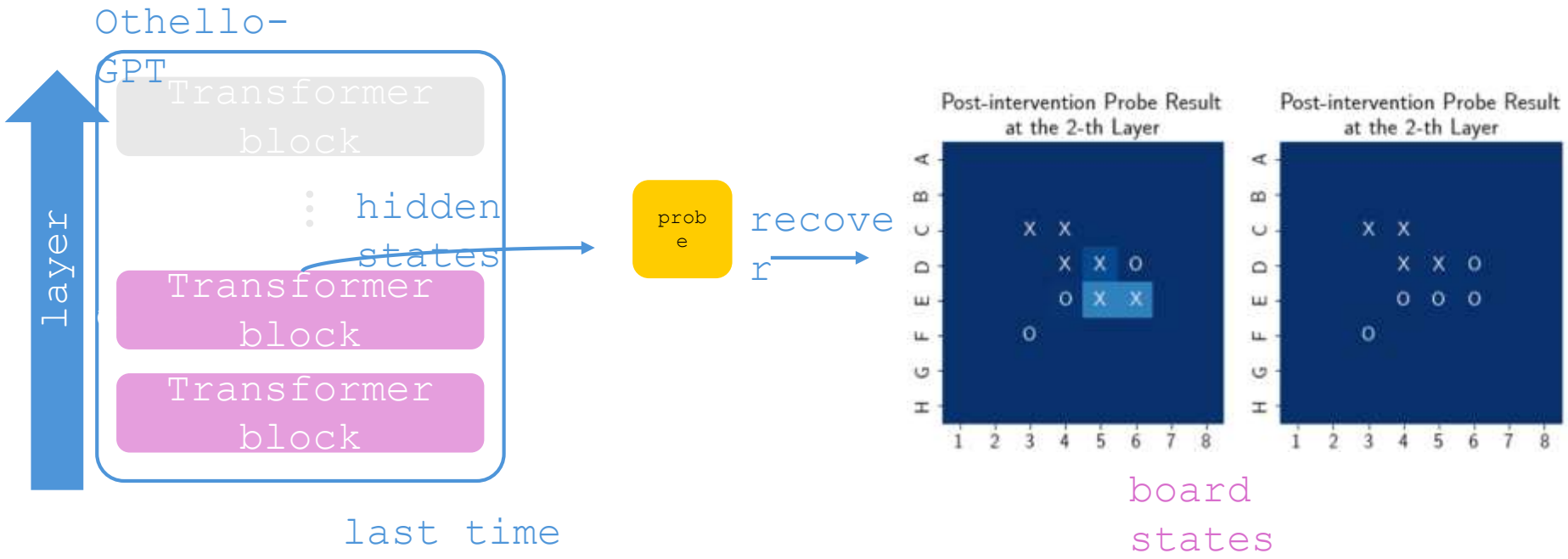
- Probing & Intervention:
  - Train linear and non-linear probes that predict board states from hidden states
    - Probes are MLP classifiers for interpretation



Emergent World Representations: Exploring a Sequence Model Trained on Synthetic Task (ICLR 2023)

Related Works (Cont.)

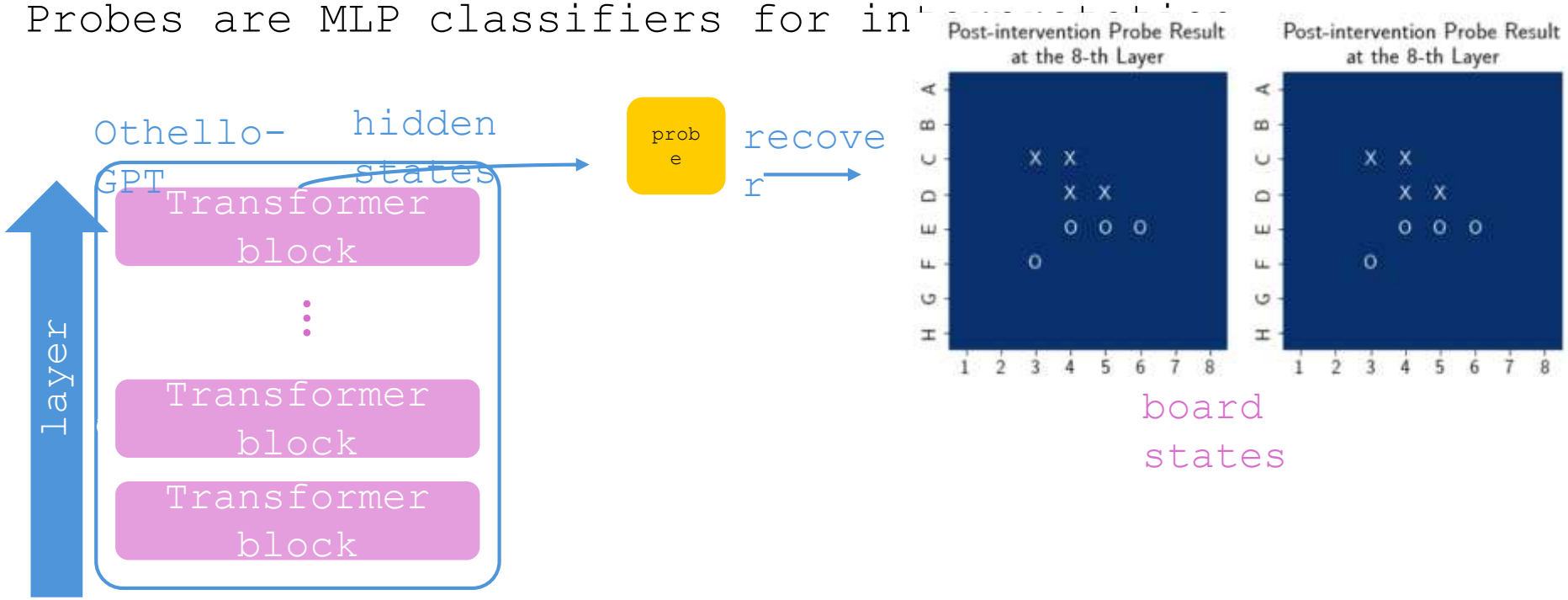
- Probing & Intervention:
  - Train linear and non-linear probes that predict board states from hidden states
    - Probes are MLP classifiers for interpretation



Emergent World Representations: Exploring a Sequence Model Trained on Synthetic Task (ICLR 2023)

Related Works (Cont.)

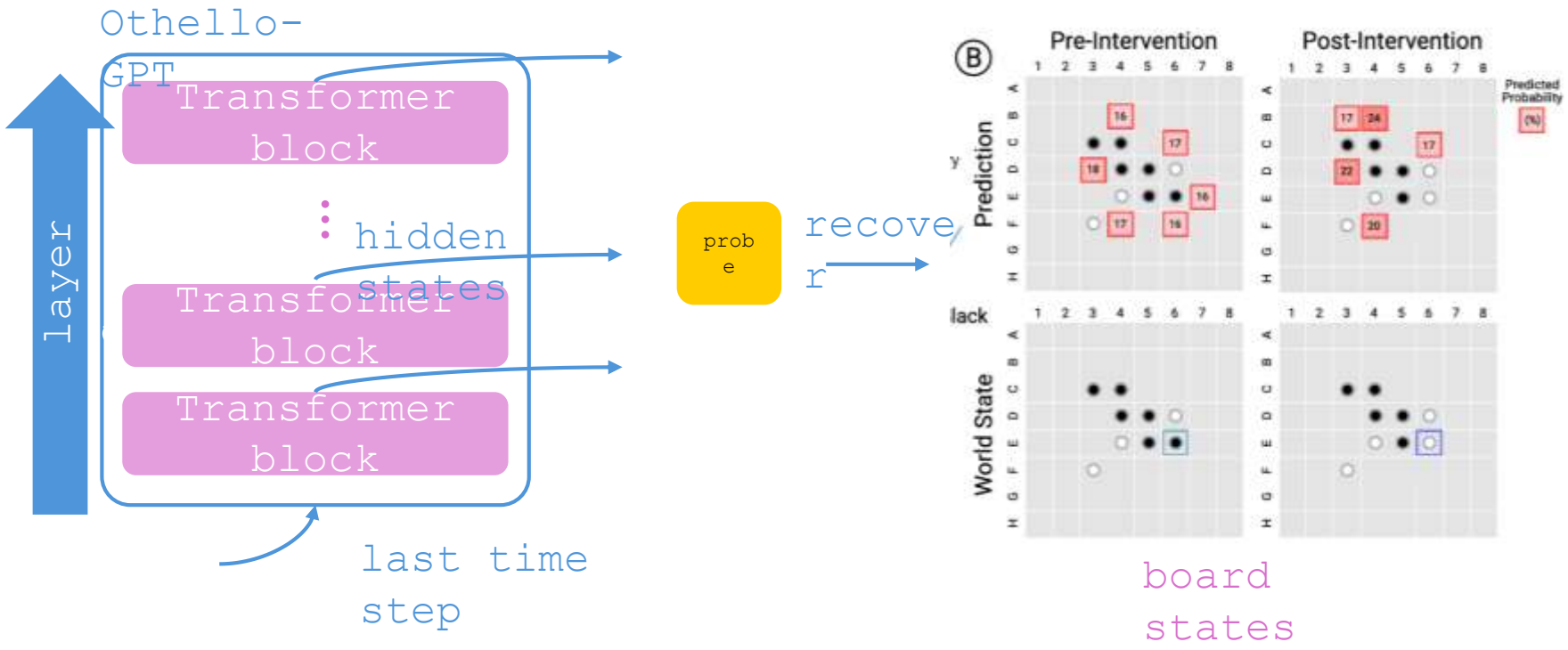
- Probing & Intervention:
  - Train linear and non-linear probes that predict board states from hidden states
    - Probes are MLP classifiers for in



Emergent World Representations: Exploring a Sequence Model Trained on Synthetic Task (ICLR 2023)

Method

- Recalling the OthelloGPT paper…

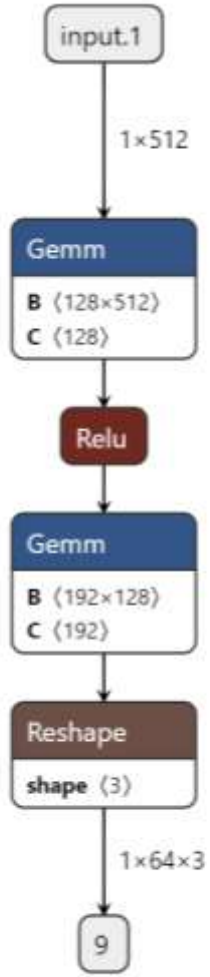


Method

- Instead of verify a Transformer…
- We firstly verify its probes!
- With verified probes and decoders, we can further interpretate any representation spaces
- And derive some interesting properties…

a 

is just a MLP classifier



layout of a non-linear probe

Stages of Trials

1. To see how the probe can be perturbed:
   - 1.1 Change the board size of the Othello game
   - 1.2 Verify the robustness of probes
     - 1.2.1 Embedding-level perturbation
     - 1.2.2 Sequence-level perturbation
2. Prove some properties:
   - $P_1: \forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
   - $P_2: \forall\, x', |x' - x_0| \leq \epsilon,\ D(x') = D(x_0)$
   - Lemma $P_3: \forall x, x'\ \ s.t.\ \ probe(x) = probe(x) \quad \rightarrow \quad D(x) = D(x')$
   - $P_4: \forall x\ \ D(x) \in rules(probe(x))$

…

Stages of Trials

1. To see how the probe can be perturbed:
   1.1 Change the board size of the Othello game
   1.2 Verify the robustness of probes
      1.2.1 Embedding-level perturbation
      1.2.2 Sequence-level perturbation
2. Prove some properties:
   - $P_1: \forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
   - $P_2: \forall\, x', |x' - x_0| \leq \epsilon,\ D(x') = D(x_0)$
   - Lemma $P_3: \forall x, x'\ \ s.t.\ \ probe(x) = probe(x) \ \ \rightarrow \ \ D(x) = D(x')$
   - $P_4: \forall x\ \ D(x) \in rules(probe(x))$

...

✓explored

undergoin

planned

Stages of Trials

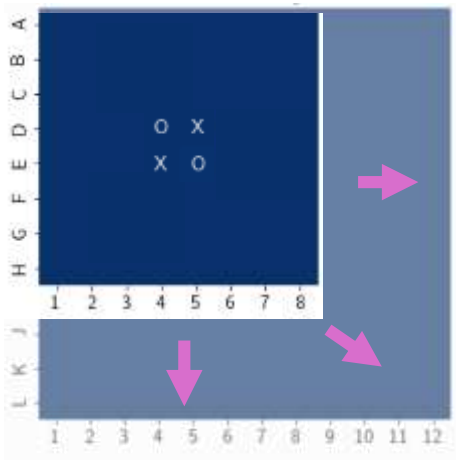
1. To see how the probe can be perturbed:
   1.1 Change the board size of the Othello game
   1.2 Verify the robustness of probes
      1.2.1 Embedding-level perturbation
      1.2.2 Sequence-level perturbation
2. Prove some properties:
   - P_1: $\forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
   - P_2: $\forall\, x', |x' - x_0| \leq \epsilon,\ D(x') = D(x_0)$
   - Lemma P_3: $\forall x, x'\ \ s.t.\ \ probe(x) = probe(x) \ \ \rightarrow \ \ D(x) = D(x')$
   - P_4: $\forall x\ \ D(x) \in rules(probe(x))$

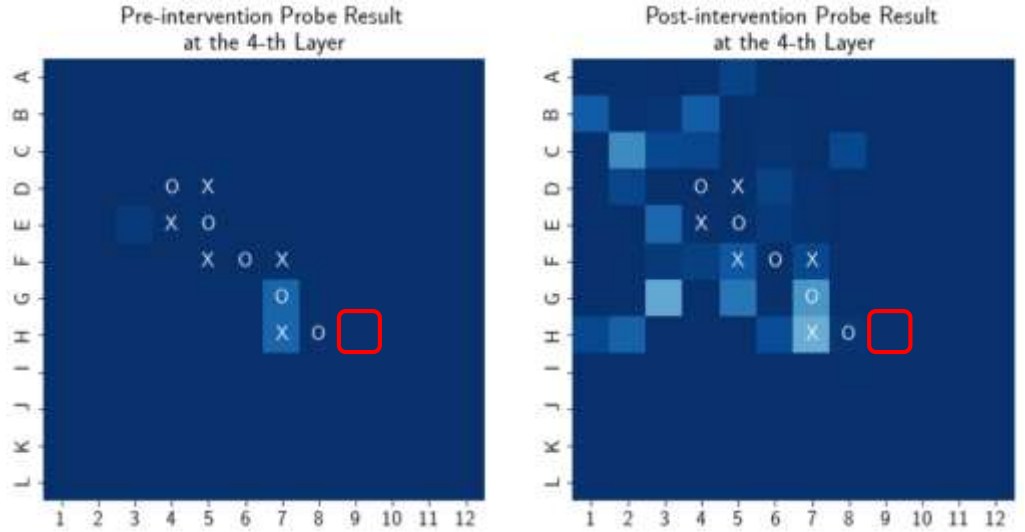
…

1.1Change the board size of the Othello Game

- To test whether the rules are encoded (s.t. OthelloGPT is a world model for this game)
- Original board size is 8x8
- Enlarge it to 12x12
- Result: Failed to produce interventions outside of the original 8x8 board area
  - *Implicitly shows that the learned rules are incorporated in the model*

$$x' \leftarrow x - \alpha \frac{\partial \mathcal{L}_{CE}(p_\theta(x), B')}{\partial x}$$





Failed to add a

Stages of Trials

1. To see how the probe can be perturbed:
   1.1 Change the board size of the Othello game
   1.2 Verify the robustness of probes
      1.2.1 Embedding-level perturbation
      1.2.2 Sequence-level perturbation
2. Prove some properties:

- $P_1: \forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
- $P_2: \forall\, x', |x' - x_0| \leq \epsilon,\ D(x') = D(x_0)$
- Lemma $P_3: \forall x, x'\ \ s.t.\ \ probe(x) = probe(x) \ \ \rightarrow \ \ D(x) = D(x')$
- $P_4: \forall x\ \ D(x) \in rules(probe(x))$

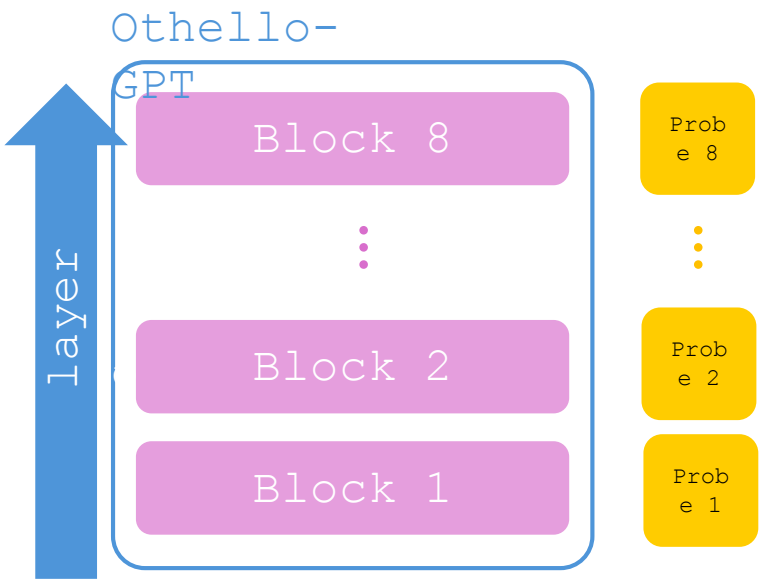
…

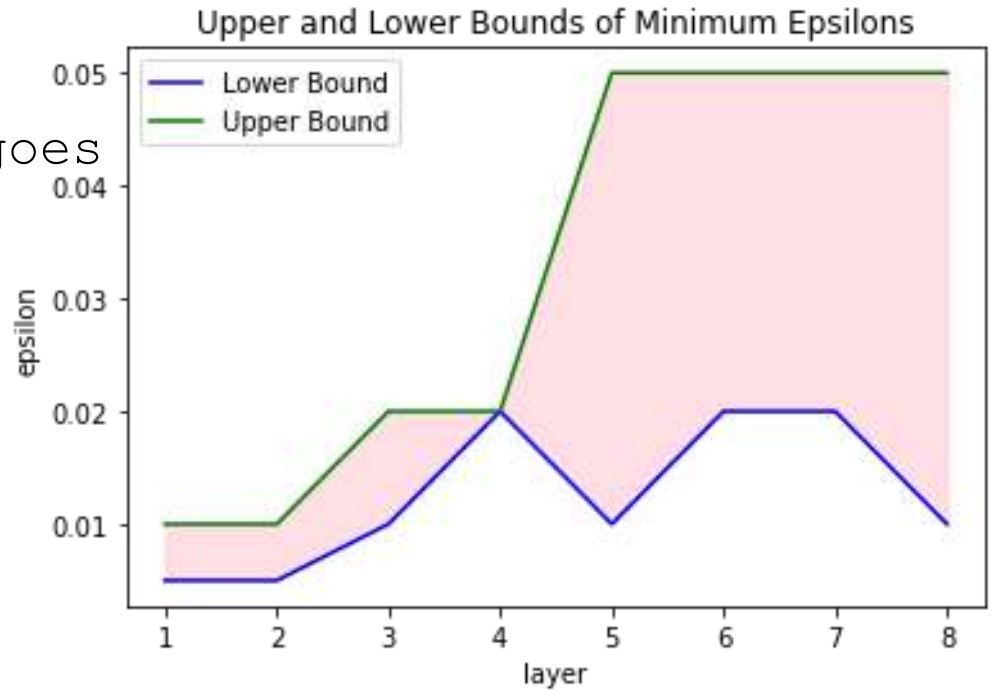
1.2.1 Embedding-level Perturbation

- $P_1: \forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
  - x_0: the original point in the representation space
  - x': any point within the $\mathcal{L}_P$-ball centered at x_0 with radius ϵ
- Pretrained probes $probe^l(\cdot)$
- Rebuild the dataset for verification on probes:
  - Input x_0^l: hidden states of partial games from all layers
  - Output $\hat{y}^l$: predicted board state
- Verify probes via Marabou:

1.2.1 Embedding-level Perturbation

- $P_1: \forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
- Result: (more detailed results in Appendix)
  - ϵ's differ from sample to sample
  - Generally, $0.005 < \epsilon < 0.05$
  - Generally, ϵ grows as the layer goes





a really rough graph…

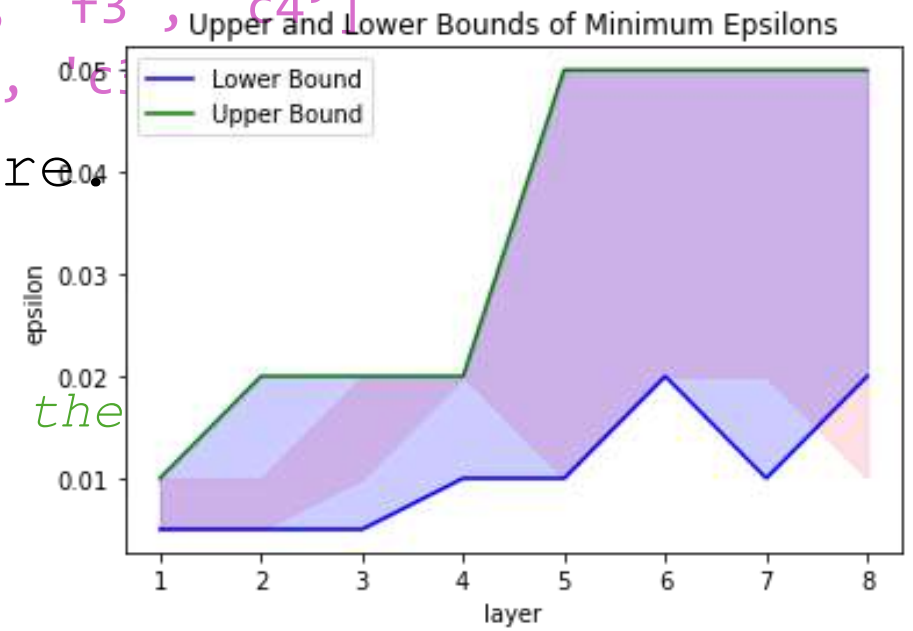
Stages of Trials

1. To see how the probe can be perturbed:
   1.1 Change the board size of the Othello game
   1.2 Verify the robustness of probes
      1.2.1 Embedding-level perturbation
      1.2.2 Sequence-level perturbation
2. Prove some properties:
   - $P_1: \forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
   - $P_2: \forall\, x', |x' - x_0| \leq \epsilon,\ D(x') = D(x_0)$
   - Lemma $P_3: \forall x, x'\ \ s.t.\ \ probe(x) = probe(x) \ \ \rightarrow \ \ D(x) = D(x')$
   - $P_4: \forall x\ \ D(x) \in rules(probe(x))$

...

1.2.2 Sequence-level perturbation

- To see how much the robustness of probe would change, when the ground truth of the input hidden state actually changed.
- For each input sequence of tiles, remove the last tile placed
  - E.g. original sequence: ['e6', 'd6', 'c3', 'f3', 'c4']
  - After moving a step backward: ['e6', 'd6', 'e3', 'f3']
- and do the same verification procedure.
- Result:
  - Similar ϵ regions as before
  - *The level of perturbation doesn't change the of the probes.*



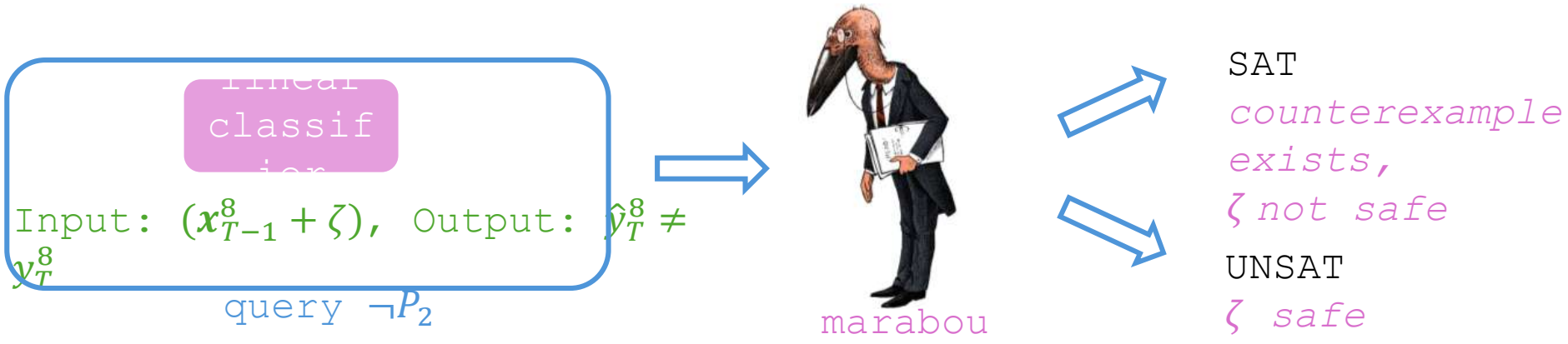
Stages of Trials

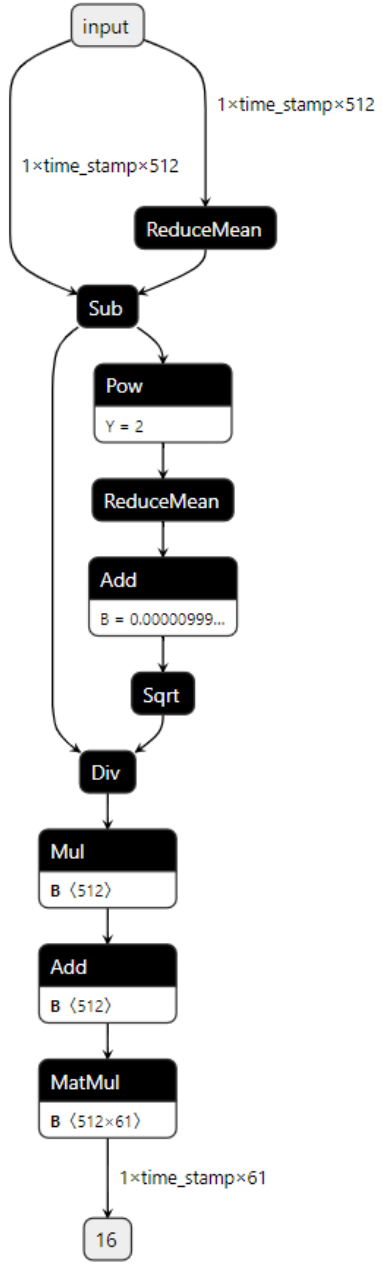
1. To see how the probe can be perturbed:
   1.1 Change the board size of the Othello game
   1.2 Verify the robustness of probes
      1.2.1 Embedding-level perturbation
      1.2.2 Sequence-level perturbation
2. Prove some properties:
   - $P_1: \forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
   - $P_2: \forall\, x', |x' - x_0| \leq \zeta,\ D(x') = D(x_0)$
   - Lemma $P_3: \forall x, x'\ \ s.t.\ \ probe(x) = probe(x) \ \ \rightarrow \ \ D(x) = D(x')$
   - $P_4: \forall x\ \ D(x) \in rules(probe(x))$

...

2. Perturbation on the decc

- $P_2: \forall\, x', |x' - x_0| \leq \zeta,\ D(x') = D(x_0)$
  - $D(\cdot)$: decoder
- Rebuild the dataset for verification on the deco
  - Input $\{x_t^8\}_{t=0}^{T-1}$: hidden states of partial games from the la
  - Output $\{y_t^8\}_{t=0}^{T}$: predicted historical and current board sta
- Similar verification procedures:

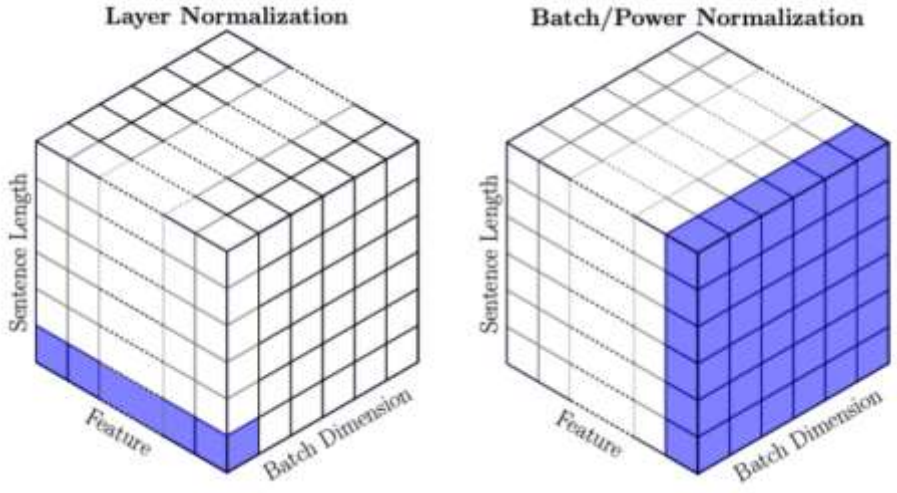




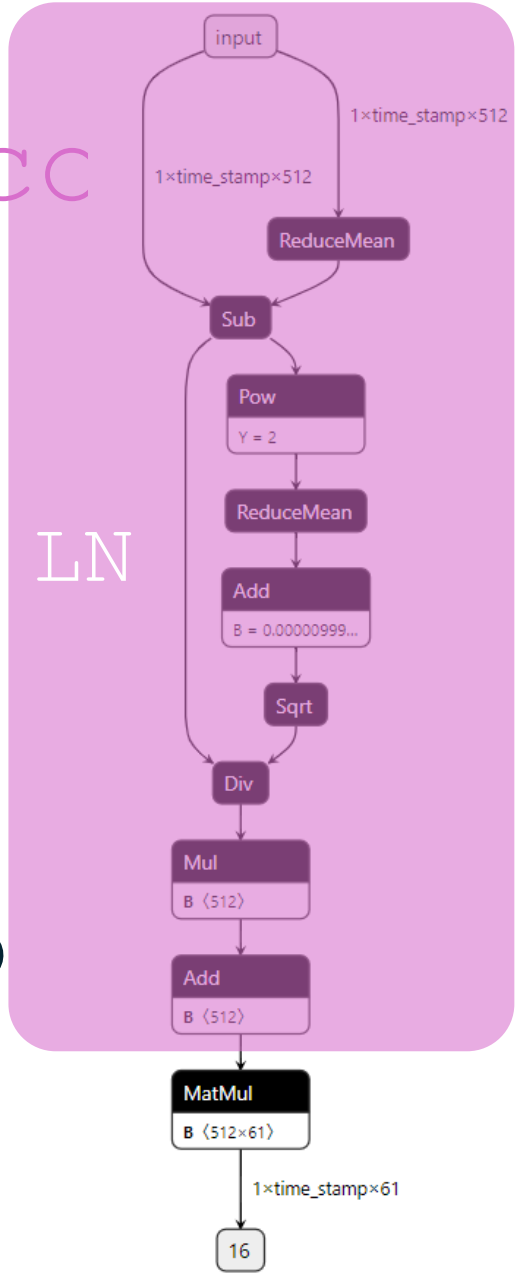
layout of the

2. Perturbation on the decc

- $P_2: \forall\, x', |x' - x_0| \leq \zeta,\ D(x') = D(x_0)$
- However, layer normalization(LN) is not supported by Marabou 2.0…
- $\boldsymbol{y} = \frac{\boldsymbol{x} - E[\boldsymbol{x}]}{\sqrt{Var[\boldsymbol{x}] + \epsilon}} \cdot \gamma + \beta$
  - LN and BN calculates $E[\boldsymbol{x}]$ and $Var[\boldsymbol{x}]$ on different dimensions



marabou



layout of the

2. Perturbation on the decoder

- In any case (if not implement LN in Marabou), the decoder needs to be retrained
- Ideally, the model (OthelloGPT) should also be retrained:
  - Change LN to BN ⇒ default batch size = 1, ineffective normalization
  - Delete LN ⇒ performance trade-off
    - Retrain together with the OthelloGPT
    - Retrain separately
- Retraining:
  - Original setting: 8GPUs, 12GB mem each, 1-day's training
  - Actual setting: 4GPUs, 12GB mem each, 5-days' training

2. Perturbation on the decoder (Current Stage)

- Retraining:
  - Non-LN decoder accuracy: 98%
  - Original decoder accuracy: 99%
- TODO:
  - Get the perturbation ζ of th decoder(non-LN):
    - P_2: $\forall\, x', |x' - x_0| \leq \zeta,\ D(x') = D(x_0)$

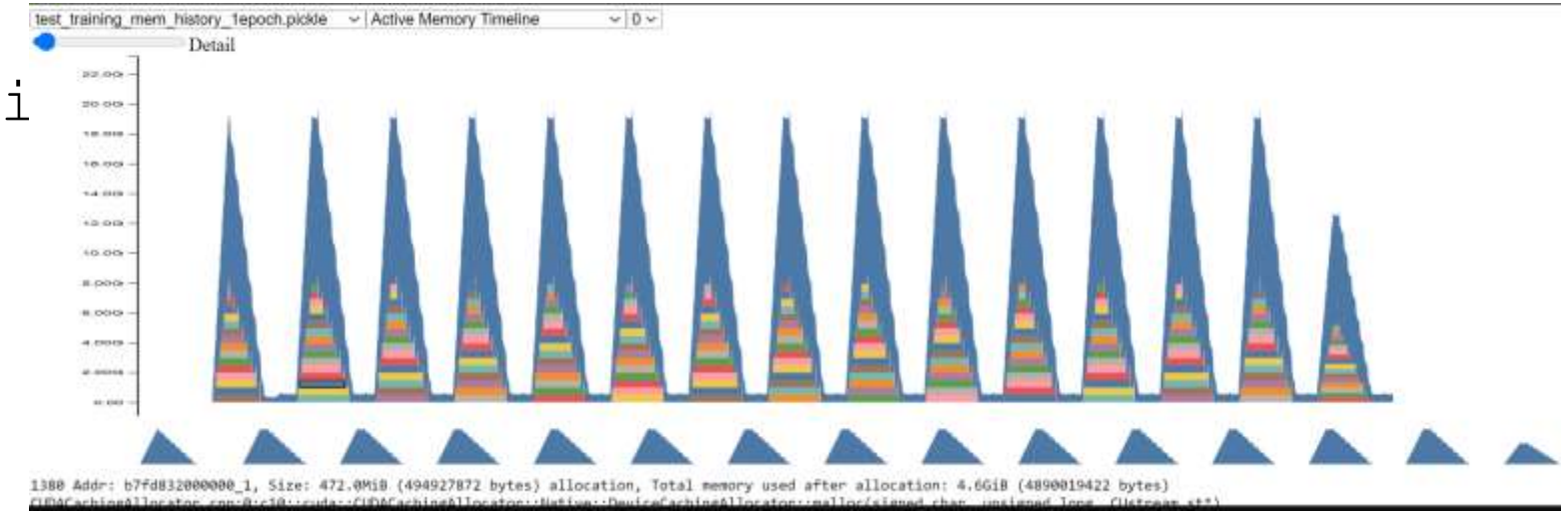
2. Perturbation on the decoder

- Calculation of memory consumption during training a Transformer:
  - Theoretically, training consumes ~20GB on a single GPU
    - Given:
      - $model\_size$ = 25M
      - # of Transformer blocks L = 8
      - Precision p = 4 (FP32)
      - Sequence Length s = 60
      - Batch Size b = 512 * 8 / world_size = 1024
      - Hidden Dimension s = 512
      - # of Attention Heads a = 8
    - Mem for storing model states: $(p + p + 12) \cdot model\_size \approx 0.5GB$
    - Mem for storing activations: $Lpsbh\left(16 + \frac{2}{p} + \frac{2as}{h} + \frac{as}{ph}\right) \approx 19GB$
    - No ZeRO and activation checkpointing applied

Understanding and Estimating GPU Memory Demands for Training LLMs in practice

2. Perturbation on the decoder

- Calculation of memory consumption during training a Transformer:
  - Practically, also get ~ 20GB per GPU using:
    - torch.cuda.memory._record_memory_history()
    - torch.cuda.memory._snapshot()
    - torch.cuda.memory._dump_snapshot(filename='dump_snapshot.pickle’)
  - Visuali



Understanding and Estimating GPU Memory Demands for Training LLMs in practice

Future Works

1. To see how the probe can be perturbed:
   1.1 Change the board size of the Othello game
   1.2 Verify the robustness of probes
      1.2.1 Embedding-level perturbation
      1.2.2 Sequence-level perturbation
2. Prove some properties:
   - $P_1: \forall\, x', |x' - x_0| \leq \epsilon,\ probe(x') = probe(x_0)$
   - $P_2: \forall\, x', |x' - x_0| \leq \zeta,\ D(x') = D(x_0)$
   - Lemma $P_3: \forall x, x' \ \ s.t. \ \ probe(x) = probe(x) \quad \rightarrow \quad D(x) = D(x')$
   - $P_4: \forall x \ \ D(x) \in rules\big(probe(x)\big)$

...

Future Works

- P_3: $\forall x, x' \;\; s.t. \;\; probe(x) = probe(x) \;\; \rightarrow \;\; D(x) = D(x')$
  - Shows consistency between a verified probe (last layer) and a decoder
  - Encode $\neg P_3$ into Marabou
- P_4: $\forall x \;\; D(x) \in rules(probe(x))$
  - Encode $rules(\cdot)$ into logical constraints
- Other refinements & directions:
  - Retrain the decoder only
  - Learn a new game rule
  - Generalize to an LLM, such as LLama3-8B

Reflections

- Current result: Overall negative
  - Critical questions:
    - Why bother? : There are already some previous works on robustness verification for Transformers
    - Validity of such indirect method? : Actually, the Transformer is not verified at all
    - Why Marabou? : $\alpha\beta$ crown is the champion verification tool
    - Lack of novelty? : we haven't generalized from OthelloGPT to a real LM.
    - …
- Some empirical take-aways:
  - Communicate throughout the research
  - Do careful domain survey before hands get dirty
  - Never settle in negative feedbacks
  - …

nd now you tasted the bittersweet of doing researc

Acknowledgements

- Thank Prof. Xujie Si for overall guidance and stimulation
- Thank Sai Madhavan G, Jiacheng Yang, Malcolm Safo for technical assistance
- Thank Allen Geng, Rebecca Wang, Sarah Walker for their company

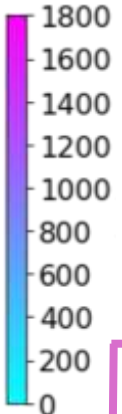
Thanks!

- Project to be released on GitHub
- Follow me:
  - GitHub
  - LinkedIn
  - Email: songyc@connect.hku.hk

Appendix

Stats: layer1

layout of OthelloGPT's transformer blocks (and thus their corresponding probes)



verifying time cost (sec)

sample ids

sat, 0.0 mins 2.6083 secs

ϵ	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0964 secs	unsat, 0.0 mins 0.0840 secs	unsat, 0.0 mins 0.0837 secs	sat, 0.0 mins 2.6083 secs	unsat, 0.0 mins 0.0909 secs	unsat, 0.0 mins 0.0813 secs	unsat, 0.0 mins 0.0869 secs	unsat, 0.0 mins 0.0871 secs	unsat, 0.0 mins 0.0917 secs	unsat, 0.0 mins 0.0856 secs
0.0002	unsat, 0.0 mins 0.0882 secs	unsat, 0.0 mins 0.0988 secs	unsat, 0.0 mins 0.0832 secs	sat, 0.0 mins 2.4385 secs	unsat, 0.0 mins 0.0805 secs	unsat, 0.0 mins 0.0876 secs	unsat, 0.0 mins 0.0879 secs	unsat, 0.0 mins 0.0958 secs	unsat, 0.0 mins 0.0800 secs	unsat, 0.0 mins 0.0946 secs
0.0005	unsat, 0.0 mins 0.0817 secs	unsat, 0.0 mins 0.0861 secs	unsat, 0.0 mins 0.0951 secs	sat, 0.0 mins 1.8335 secs	unsat, 0.0 mins 0.0863 secs	unsat, 0.0 mins 0.0840 secs	unsat, 0.0 mins 5.2993 secs	unsat, 0.0 mins 0.0956 secs	unsat, 0.0 mins 0.0951 secs	unsat, 0.0 mins 0.0985 secs
0.001	unsat, 0.0 mins 0.0932 secs	unsat, 0.0 mins 0.0949 secs	unsat, 0.0 mins 0.0967 secs	sat, 0.0 mins 2.0139 secs	unsat, 0.0 mins 0.1015 secs	unsat, 0.0 mins 0.0935 secs	unsat, 0.0 mins 12.699 secs	unsat, 0.0 mins 0.1025 secs	unsat, 0.0 mins 2.6906 secs	unsat, 0.0 mins 0.0881 secs
0.002	unsat, 0.0 mins 2.0416 secs	unsat, 0.0 mins 10.951 secs	unsat, 0.0 mins 4.0210 secs	sat, 0.0 mins 2.1745 secs	unsat, 0.0 mins 0.0823 secs	unsat, 0.0 mins 28.061 secs	sat, 0.0 mins 1.9550 secs	unsat, 0.0 mins 0.9763 secs	unsat, 0.0 mins 11.321 secs	unsat, 0.0 mins 11.900 secs
0.005	unsat, 2.0 mins 45.332 secs	sat, 6.0 mins 17.281 secs	unsat, 2.0 mins 55.904 secs	sat, 0.0 mins 26.787 secs	TIMEOUT, 30.0 mins 0.354 secs	unsat, 19.0 mins 58.78 secs	sat, 0.0 mins 1.8667 secs	unsat, 14.0 mins 53.75 secs	unsat, 4.0 mins 35.951 secs	unsat, 3.0 mins 53.823 secs
0.01	unsat, 19.0 mins 42.07 secs	TIMEOUT, 30.0 mins 0.543 secs	unsat, 13.0 mins 1.621 secs	sat, 0.0 mins 5.0472 secs	TIMEOUT, 30.0 mins 0.254 secs	sat, 25.0 mins 30.44 secs	sat, 0.0 mins 2.2677 secs	TIMEOUT, 30.0 mins 0.236 secs	TIMEOUT, 30.0 mins 0.495 secs	TIMEOUT, 30.0 mins 0.537 secs
0.02	sat, 0.0 mins 24.817 secs	sat, 0.0 mins 2.5162 secs	sat, 0.0 mins 9.9713 secs	sat, 1.0 mins 9.8160 secs	TIMEOUT, 30.0 mins 0.218 secs	TIMEOUT, 30.0 mins 0.555 secs	sat, 0.0 mins 2.8843 secs	TIMEOUT, 30.0 mins 0.207 secs	sat, 0.0 mins 3.8516 secs	sat, 0.0 mins 9.6191 secs
0.05	sat, 0.0 mins 2.6865 secs	sat, 0.0 mins 2.5647 secs	sat, 0.0 mins 1.7967 secs	sat, 0.0 mins 2.0058 secs	sat, 0.0 mins 2.2660 secs	sat, 0.0 mins 1.5639 secs	sat, 0.0 mins 2.4942 secs	sat, 0.0 mins 1.6540 secs	sat, 0.0 mins 2.0210 secs	sat, 0.0 mins 2.0711 secs
0.1	sat, 0.0 mins 3.2183 secs	sat, 0.0 mins 2.0541 secs	sat, 0.0 mins 2.9874 secs	sat, 0.0 mins 2.5799 secs	sat, 0.0 mins 2.2476 secs	sat, 0.0 mins 1.4397 secs	sat, 0.0 mins 1.9445 secs	sat, 0.0 mins 1.9120 secs	sat, 0.0 mins 2.6472 secs	sat, 0.0 mins 9.9965 secs
0.2	sat, 0.0 mins 1.4851 secs	sat, 0.0 mins 1.2986 secs	sat, 0.0 mins 1.8291 secs	sat, 0.0 mins 2.3741 secs	sat, 0.0 mins 2.3538 secs	sat, 0.0 mins 1.4405 secs	sat, 0.0 mins 1.1157 secs	sat, 0.0 mins 1.1771 secs	sat, 0.0 mins 1.4507 secs	sat, 0.0 mins 1.8597 secs
0.5	sat, 0.0 mins 0.9765 secs	sat, 0.0 mins 0.8681 secs	sat, 0.0 mins 1.2689 secs	sat, 0.0 mins 0.8694 secs	sat, 0.0 mins 1.0294 secs	sat, 0.0 mins 0.7613 secs	sat, 0.0 mins 0.7418 secs	sat, 0.0 mins 0.8588 secs	sat, 0.0 mins 1.1264 secs	sat, 0.0 mins 1.1339 secs
1	sat, 0.0 mins 1.0906 secs	sat, 0.0 mins 0.6938 secs	sat, 0.0 mins 0.7105 secs	sat, 0.0 mins 0.7980 secs	sat, 0.0 mins 0.5108 secs	sat, 0.0 mins 0.8198 secs	sat, 0.0 mins 0.7589 secs	sat, 0.0 mins 0.6352 secs	sat, 0.0 mins 1.0574 secs	sat, 0.0 mins 0.9922 secs
2	sat, 0.0 mins 0.7187 secs	sat, 0.0 mins 0.6549 secs	sat, 0.0 mins 0.6869 secs	sat, 0.0 mins 0.6678 secs	sat, 0.0 mins 0.5361 secs	sat, 0.0 mins 0.6185 secs	sat, 0.0 mins 0.6583 secs	sat, 0.0 mins 0.6425 secs	sat, 0.0 mins 0.6148 secs	sat, 0.0 mins 0.7506 secs
5	sat, 0.0 mins 0.5219 secs	sat, 0.0 mins 0.8748 secs	sat, 0.0 mins 0.5555 secs	sat, 0.0 mins 0.5969 secs	sat, 0.0 mins 0.7275 secs	sat, 0.0 mins 0.5860 secs	sat, 0.0 mins 0.6076 secs	sat, 0.0 mins 0.5364 secs	sat, 0.0 mins 0.5644 secs	sat, 0.0 mins 0.5563 secs

layer1 probe's verification results, generated by Marabou

Stats: layer 2

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.1118 secs	unsat, 0.0 mins 0.0838 secs	unsat, 0.0 mins 0.0848 secs	unsat, 0.0 mins 0.0876 secs	unsat, 0.0 mins 0.0950 secs	unsat, 0.0 mins 0.0883 secs	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.0856 secs	unsat, 0.0 mins 0.0923 secs	unsat, 0.0 mins 0.0858 secs
0.0002	unsat, 0.0 mins 0.0866 secs	unsat, 0.0 mins 0.0951 secs	unsat, 0.0 mins 0.0887 secs	unsat, 0.0 mins 0.0984 secs	unsat, 0.0 mins 0.0881 secs	unsat, 0.0 mins 0.0848 secs	unsat, 0.0 mins 0.0963 secs	unsat, 0.0 mins 0.1057 secs	unsat, 0.0 mins 0.1072 secs	unsat, 0.0 mins 0.0816 secs
0.0005	unsat, 0.0 mins 0.0855 secs	unsat, 0.0 mins 0.0878 secs	unsat, 0.0 mins 0.0899 secs	unsat, 0.0 mins 3.4557 secs	unsat, 0.0 mins 0.0876 secs	unsat, 0.0 mins 0.0940 secs	unsat, 0.0 mins 0.0892 secs	unsat, 0.0 mins 0.0857 secs	unsat, 0.0 mins 0.0877 secs	unsat, 0.0 mins 0.0884 secs
0.001	unsat, 0.0 mins 0.0877 secs	unsat, 0.0 mins 0.1140 secs	unsat, 0.0 mins 0.0863 secs	unsat, 0.0 mins 6.0739 secs	unsat, 0.0 mins 0.0953 secs	unsat, 0.0 mins 0.0863 secs	unsat, 0.0 mins 7.3416 secs	unsat, 0.0 mins 0.0891 secs	unsat, 0.0 mins 0.0864 secs	unsat, 0.0 mins 0.0880 secs
0.002	unsat, 0.0 mins 5.0496 secs	unsat, 0.0 mins 0.0821 secs	unsat, 0.0 mins 0.5753 secs	unsat, 0.0 mins 6.8106 secs	unsat, 0.0 mins 0.0865 secs	unsat, 0.0 mins 1.8253 secs	unsat, 0.0 mins 11.479 secs	unsat, 0.0 mins 0.0855 secs	unsat, 0.0 mins 0.0858 secs	unsat, 0.0 mins 2.9286 secs
0.005	unsat, 2.0 mins 6.4196 secs	unsat, 1.0 mins 57.512 secs	unsat, 1.0 mins 7.7708 secs	sat, 0.0 mins 12.847 secs	unsat, 0.0 mins 52.045 secs	unsat, 1.0 mins 34.463 secs	TIMEOUT, 30.0 mins 0.246 secs	unsat, 0.0 mins 28.879 secs	unsat, 3.0 mins 26.145 secs	unsat, 2.0 mins 26.586 secs
0.01	sat, 7.0 mins 47.256 secs	TIMEOUT, 30.0 mins 0.211 secs	unsat, 5.0 mins 7.4828 secs	sat, 0.0 mins 3.2986 secs	TIMEOUT, 30.0 mins 0.396 secs	unsat, 5.0 mins 13.609 secs	sat, 0.0 mins 2.1324 secs	TIMEOUT, 30.0 mins 0.213 secs	sat, 9.0 mins 29.421 secs	unsat, 5.0 mins 49.549 secs
0.02	sat, 0.0 mins 3.4065 secs	TIMEOUT, 30.0 mins 0.184 secs	sat, 9.0 mins 48.908 secs	sat, 0.0 mins 4.4044 secs	TIMEOUT, 30.0 mins 0.355 secs	sat, 7.0 mins 36.739 secs	sat, 0.0 mins 2.1943 secs	TIMEOUT, 30.0 mins 0.474 secs	TIMEOUT, 30.0 mins 0.360 secs	sat, 29.0 mins 41.11 secs
0.05	sat, 0.0 mins 2.5796 secs	sat, 0.0 mins 2.1473 secs	sat, 0.0 mins 8.2033 secs	sat, 0.0 mins 2.1877 secs	TIMEOUT, 30.0 mins 0.406 secs	sat, 0.0 mins 2.2266 secs	sat, 0.0 mins 2.2232 secs	TIMEOUT, 30.0 mins 0.538 secs	sat, 0.0 mins 2.3960 secs	sat, 0.0 mins 2.4207 secs
0.1	sat, 0.0 mins 2.0924 secs	sat, 0.0 mins 1.8929 secs	sat, 0.0 mins 2.2510 secs	sat, 0.0 mins 2.0485 secs	sat, 0.0 mins 1.9356 secs	sat, 0.0 mins 2.1844 secs	sat, 0.0 mins 3.3616 secs	sat, 0.0 mins 3.1583 secs	sat, 0.0 mins 3.6090 secs	sat, 0.0 mins 3.5494 secs
0.2	sat, 0.0 mins 3.0935 secs	sat, 0.0 mins 2.8296 secs	sat, 0.0 mins 2.7685 secs	sat, 0.0 mins 2.8838 secs	sat, 0.0 mins 2.7866 secs	sat, 0.0 mins 3.3985 secs	sat, 0.0 mins 1.5255 secs	sat, 0.0 mins 2.0273 secs	sat, 0.0 mins 1.9546 secs	sat, 0.0 mins 2.2317 secs
0.5	sat, 0.0 mins 1.2605 secs	sat, 0.0 mins 1.4609 secs	sat, 0.0 mins 1.2254 secs	sat, 0.0 mins 1.1855 secs	sat, 0.0 mins 1.3986 secs	sat, 0.0 mins 1.2405 secs	sat, 0.0 mins 0.8216 secs	sat, 0.0 mins 1.5475 secs	sat, 0.0 mins 1.1524 secs	sat, 0.0 mins 1.0650 secs
1	sat, 0.0 mins 0.9244 secs	sat, 0.0 mins 1.0272 secs	sat, 0.0 mins 1.1910 secs	sat, 0.0 mins 1.3720 secs	sat, 0.0 mins 0.8131 secs	sat, 0.0 mins 1.1651 secs	sat, 0.0 mins 0.5755 secs	sat, 0.0 mins 1.2624 secs	sat, 0.0 mins 1.3568 secs	sat, 0.0 mins 0.8321 secs
2	sat, 0.0 mins 0.8459 secs	sat, 0.0 mins 0.5604 secs	sat, 0.0 mins 0.7102 secs	sat, 0.0 mins 0.7738 secs	sat, 0.0 mins 0.7681 secs	sat, 0.0 mins 0.8536 secs	sat, 0.0 mins 0.8603 secs	sat, 0.0 mins 0.7181 secs	sat, 0.0 mins 0.7599 secs	sat, 0.0 mins 0.8242 secs
5	sat, 0.0 mins 0.5739 secs	sat, 0.0 mins 0.6145 secs	sat, 0.0 mins 0.6911 secs	sat, 0.0 mins 0.5892 secs	sat, 0.0 mins 0.5607 secs	sat, 0.0 mins 0.5386 secs	sat, 0.0 mins 0.7097 secs	sat, 0.0 mins 0.7733 secs	sat, 0.0 mins 0.7494 secs	sat, 0.0 mins 0.6885 secs

Stats: layer 3

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0898 secs	unsat, 0.0 mins 0.0957 secs	unsat, 0.0 mins 0.0860 secs	unsat, 0.0 mins 0.0861 secs	unsat, 0.0 mins 0.0837 secs	unsat, 0.0 mins 0.0856 secs	unsat, 0.0 mins 0.0861 secs	unsat, 0.0 mins 0.0898 secs	unsat, 0.0 mins 0.0877 secs	unsat, 0.0 mins 0.0851 secs
0.0002	unsat, 0.0 mins 0.0881 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0894 secs	unsat, 0.0 mins 0.0915 secs	unsat, 0.0 mins 0.0901 secs	unsat, 0.0 mins 0.0861 secs	unsat, 0.0 mins 3.3979 secs	unsat, 0.0 mins 0.0889 secs	unsat, 0.0 mins 0.0873 secs	unsat, 0.0 mins 0.0893 secs
0.0005	unsat, 0.0 mins 0.0926 secs	unsat, 0.0 mins 0.0888 secs	unsat, 0.0 mins 0.0983 secs	unsat, 0.0 mins 0.0894 secs	unsat, 0.0 mins 0.0837 secs	unsat, 0.0 mins 0.0912 secs	unsat, 0.0 mins 3.9969 secs	unsat, 0.0 mins 0.0854 secs	unsat, 0.0 mins 0.0842 secs	unsat, 0.0 mins 0.0963 secs
0.001	unsat, 0.0 mins 0.0845 secs	unsat, 0.0 mins 0.0850 secs	unsat, 0.0 mins 0.0909 secs	unsat, 0.0 mins 2.0853 secs	unsat, 0.0 mins 0.0842 secs	unsat, 0.0 mins 0.0876 secs	sat, 0.0 mins 6.7490 secs	unsat, 0.0 mins 0.0862 secs	unsat, 0.0 mins 0.0949 secs	unsat, 0.0 mins 0.0844 secs
0.002	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0843 secs	unsat, 0.0 mins 0.0843 secs	unsat, 0.0 mins 8.5722 secs	unsat, 0.0 mins 0.0954 secs	unsat, 0.0 mins 0.0821 secs	sat, 0.0 mins 2.1983 secs	unsat, 0.0 mins 0.0835 secs	unsat, 0.0 mins 0.0866 secs	unsat, 0.0 mins 14.875 secs
0.005	unsat, 0.0 mins 44.686 secs	unsat, 0.0 mins 13.947 secs	unsat, 0.0 mins 6.2588 secs	unsat, 3.0 mins 21.288 secs	unsat, 0.0 mins 1.5675 secs	unsat, 1.0 mins 33.810 secs	sat, 0.0 mins 1.4799 secs	unsat, 0.0 mins 1.0845 secs	unsat, 0.0 mins 2.3917 secs	unsat, 0.0 mins 42.352 secs
0.01	unsat, 10.0 mins 26.92 secs	unsat, 9.0 mins 1.5927 secs	unsat, 1.0 mins 56.233 secs	sat, 1.0 mins 50.595 secs	unsat, 2.0 mins 16.665 secs	unsat, 3.0 mins 10.111 secs	sat, 0.0 mins 1.6863 secs	unsat, 15.0 mins 59.47 secs	unsat, 2.0 mins 25.883 secs	unsat, 17.0 mins 28.97 secs
0.02	TIMEOUT, 30.0 mins 0.301 secs	TIMEOUT, 30.0 mins 0.436 secs	sat, 9.0 mins 11.810 secs	sat, 13.0 mins 29.41 secs	TIMEOUT, 30.0 mins 0.497 secs	TIMEOUT, 30.0 mins 0.452 secs	sat, 0.0 mins 2.3973 secs	TIMEOUT, 30.0 mins 0.573 secs	sat, 14.0 mins 21.73 secs	sat, 0.0 mins 40.283 secs
0.05	sat, 2.0 mins 45.458 secs	TIMEOUT, 30.0 mins 0.409 secs	sat, 0.0 mins 2.9317 secs	sat, 4.0 mins 11.723 secs	TIMEOUT, 30.0 mins 0.322 secs	TIMEOUT, 30.0 mins 0.403 secs	sat, 0.0 mins 2.6583 secs	TIMEOUT, 30.0 mins 0.333 secs	sat, 0.0 mins 3.6233 secs	sat, 0.0 mins 20.322 secs
0.1	sat, 0.0 mins 7.2925 secs	sat, 0.0 mins 2.1765 secs	sat, 0.0 mins 2.3856 secs	sat, 0.0 mins 2.3684 secs	sat, 0.0 mins 3.7239 secs	sat, 0.0 mins 2.4711 secs	sat, 0.0 mins 1.7984 secs	sat, 0.0 mins 8.9871 secs	sat, 0.0 mins 2.2382 secs	sat, 0.0 mins 1.9667 secs
0.2	sat, 0.0 mins 2.1211 secs	sat, 0.0 mins 4.2802 secs	sat, 0.0 mins 2.0009 secs	sat, 0.0 mins 1.9526 secs	sat, 0.0 mins 2.3594 secs	sat, 0.0 mins 3.6070 secs	sat, 0.0 mins 2.2944 secs	sat, 0.0 mins 2.6532 secs	sat, 0.0 mins 2.3909 secs	sat, 0.0 mins 4.0971 secs
0.5	sat, 0.0 mins 1.6054 secs	sat, 0.0 mins 1.6415 secs	sat, 0.0 mins 1.9313 secs	sat, 0.0 mins 1.5217 secs	sat, 0.0 mins 1.1826 secs	sat, 0.0 mins 2.4936 secs	sat, 0.0 mins 1.8669 secs	sat, 0.0 mins 2.0097 secs	sat, 0.0 mins 2.4629 secs	sat, 0.0 mins 2.1098 secs
1	sat, 0.0 mins 1.1347 secs	sat, 0.0 mins 1.2989 secs	sat, 0.0 mins 0.9387 secs	sat, 0.0 mins 0.8868 secs	sat, 0.0 mins 1.1198 secs	sat, 0.0 mins 1.3694 secs	sat, 0.0 mins 1.0667 secs	sat, 0.0 mins 0.9896 secs	sat, 0.0 mins 1.2686 secs	sat, 0.0 mins 1.4341 secs
2	sat, 0.0 mins 0.9744 secs	sat, 0.0 mins 1.2083 secs	sat, 0.0 mins 1.0486 secs	sat, 0.0 mins 0.9075 secs	sat, 0.0 mins 0.8084 secs	sat, 0.0 mins 1.3850 secs	sat, 0.0 mins 0.6686 secs	sat, 0.0 mins 0.9141 secs	sat, 0.0 mins 1.0715 secs	sat, 0.0 mins 0.8656 secs
5	sat, 0.0 mins 0.8678 secs	sat, 0.0 mins 0.9403 secs	sat, 0.0 mins 0.8159 secs	sat, 0.0 mins 0.5855 secs	sat, 0.0 mins 0.7962 secs	sat, 0.0 mins 0.6435 secs	sat, 0.0 mins 0.8422 secs	sat, 0.0 mins 0.9494 secs	sat, 0.0 mins 0.8502 secs	sat, 0.0 mins 0.8320 secs

Stats: layer 4

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.1024 secs	unsat, 0.0 mins 0.1183 secs	unsat, 0.0 mins 0.1088 secs	unsat, 0.0 mins 0.1294 secs	unsat, 0.0 mins 0.0881 secs	unsat, 0.0 mins 0.0892 secs	unsat, 0.0 mins 0.0892 secs	unsat, 0.0 mins 0.0884 secs	unsat, 0.0 mins 0.0897 secs	unsat, 0.0 mins 0.0848 secs
0.0002	unsat, 0.0 mins 0.0965 secs	unsat, 0.0 mins 0.0962 secs	unsat, 0.0 mins 0.0868 secs	unsat, 0.0 mins 0.1009 secs	unsat, 0.0 mins 0.1007 secs	unsat, 0.0 mins 0.0887 secs	unsat, 0.0 mins 4.6637 secs	unsat, 0.0 mins 0.0875 secs	unsat, 0.0 mins 0.0871 secs	unsat, 0.0 mins 0.0994 secs
0.0005	unsat, 0.0 mins 0.0883 secs	unsat, 0.0 mins 0.1005 secs	unsat, 0.0 mins 0.0861 secs	unsat, 0.0 mins 0.0932 secs	unsat, 0.0 mins 0.0889 secs	unsat, 0.0 mins 0.1006 secs	unsat, 0.0 mins 8.0859 secs	unsat, 0.0 mins 0.0933 secs	unsat, 0.0 mins 0.0911 secs	unsat, 0.0 mins 0.0889 secs
0.001	unsat, 0.0 mins 0.1068 secs	unsat, 0.0 mins 0.0930 secs	unsat, 0.0 mins 0.0904 secs	unsat, 0.0 mins 0.0930 secs	unsat, 0.0 mins 0.0889 secs	unsat, 0.0 mins 0.1010 secs	unsat, 0.0 mins 4.0242 secs	unsat, 0.0 mins 0.1041 secs	unsat, 0.0 mins 0.0918 secs	unsat, 0.0 mins 0.0907 secs
0.002	unsat, 0.0 mins 0.0903 secs	unsat, 0.0 mins 0.0899 secs	unsat, 0.0 mins 0.0933 secs	unsat, 0.0 mins 2.6588 secs	unsat, 0.0 mins 0.0860 secs	unsat, 0.0 mins 0.0866 secs	sat, 0.0 mins 3.4690 secs	unsat, 0.0 mins 0.0855 secs	unsat, 0.0 mins 0.0922 secs	unsat, 0.0 mins 0.0847 secs
0.005	unsat, 0.0 mins 2.7929 secs	unsat, 0.0 mins 1.8437 secs	unsat, 0.0 mins 16.185 secs	unsat, 1.0 mins 2.9389 secs	unsat, 1.0 mins 48.532 secs	unsat, 1.0 mins 59.553 secs	sat, 0.0 mins 2.8737 secs	unsat, 0.0 mins 0.0913 secs	unsat, 0.0 mins 18.057 secs	unsat, 0.0 mins 13.287 secs
0.01	unsat, 0.0 mins 19.999 secs	unsat, 2.0 mins 20.451 secs	unsat, 2.0 mins 40.438 secs	unsat, 2.0 mins 44.208 secs	unsat, 1.0 mins 14.983 secs	unsat, 4.0 mins 6.4051 secs	sat, 0.0 mins 27.667 secs	unsat, 2.0 mins 19.061 secs	unsat, 4.0 mins 15.019 secs	unsat, 4.0 mins 10.599 secs
0.02	unsat, 5.0 mins 6.6059 secs	unsat, 6.0 mins 25.413 secs	unsat, 10.0 mins 55.53 secs	sat, 0.0 mins 47.211 secs	unsat, 12.0 mins 47.54 secs	TIMEOUT, 30.0 mins 0.302 secs	sat, 0.0 mins 3.5191 secs	TIMEOUT, 30.0 mins 0.239 secs	TIMEOUT, 30.0 mins 0.462 secs	TIMEOUT, 30.0 mins 0.429 secs
0.05	sat, 0.0 mins 5.1374 secs	sat, 25.0 mins 21.60 secs	sat, 1.0 mins 47.909 secs	sat, 17.0 mins 42.37 secs	TIMEOUT, 30.0 mins 0.517 secs	TIMEOUT, 30.0 mins 0.589 secs	sat, 0.0 mins 2.9383 secs	TIMEOUT, 30.0 mins 0.899 secs	TIMEOUT, 30.0 mins 0.487 secs	sat, 2.0 mins 35.504 secs
0.1	sat, 0.0 mins 2.3281 secs	sat, 0.0 mins 14.104 secs	sat, 0.0 mins 3.4818 secs	sat, 0.0 mins 4.1705 secs	sat, 0.0 mins 3.3089 secs	sat, 0.0 mins 2.2358 secs	sat, 0.0 mins 2.8855 secs	TIMEOUT, 30.0 mins 0.710 secs	sat, 0.0 mins 2.2844 secs	sat, 0.0 mins 3.9979 secs
0.2	sat, 0.0 mins 9.6223 secs	sat, 0.0 mins 4.1027 secs	sat, 0.0 mins 27.170 secs	sat, 0.0 mins 2.3102 secs	sat, 0.0 mins 2.9050 secs	sat, 0.0 mins 3.0886 secs	sat, 0.0 mins 2.1870 secs	sat, 0.0 mins 2.5352 secs	sat, 0.0 mins 3.3376 secs	sat, 0.0 mins 3.9930 secs
0.5	sat, 0.0 mins 1.8864 secs	sat, 0.0 mins 1.5995 secs	sat, 0.0 mins 1.5935 secs	sat, 0.0 mins 1.7921 secs	sat, 0.0 mins 1.9794 secs	sat, 0.0 mins 2.5398 secs	sat, 0.0 mins 1.2544 secs	sat, 0.0 mins 2.3371 secs	sat, 0.0 mins 3.1577 secs	sat, 0.0 mins 2.2233 secs
1	sat, 0.0 mins 1.7239 secs	sat, 0.0 mins 1.3910 secs	sat, 0.0 mins 1.7755 secs	sat, 0.0 mins 1.2488 secs	sat, 0.0 mins 1.1894 secs	sat, 0.0 mins 1.2017 secs	sat, 0.0 mins 0.8727 secs	sat, 0.0 mins 1.6386 secs	sat, 0.0 mins 1.2816 secs	sat, 0.0 mins 2.1051 secs
2	sat, 0.0 mins 1.0510 secs	sat, 0.0 mins 0.9897 secs	sat, 0.0 mins 1.0116 secs	sat, 0.0 mins 1.0718 secs	sat, 0.0 mins 1.0573 secs	sat, 0.0 mins 1.0265 secs	sat, 0.0 mins 0.9801 secs	sat, 0.0 mins 1.0184 secs	sat, 0.0 mins 1.2781 secs	sat, 0.0 mins 0.9965 secs
5	sat, 0.0 mins 1.0252 secs	sat, 0.0 mins 1.0677 secs	sat, 0.0 mins 1.5393 secs	sat, 0.0 mins 1.5199 secs	sat, 0.0 mins 0.9951 secs	sat, 0.0 mins 1.5322 secs	sat, 0.0 mins 0.8914 secs	sat, 0.0 mins 1.3719 secs	sat, 0.0 mins 1.3776 secs	sat, 0.0 mins 1.1044 secs

Stats: layer 5

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.1033 secs	unsat, 0.0 mins 0.0968 secs	unsat, 0.0 mins 0.1003 secs	unsat, 0.0 mins 0.1088 secs	unsat, 0.0 mins 0.0931 secs	unsat, 0.0 mins 0.1002 secs	unsat, 0.0 mins 0.0962 secs	unsat, 0.0 mins 0.1269 secs	unsat, 0.0 mins 0.1219 secs	unsat, 0.0 mins 0.1071 secs
0.0002	unsat, 0.0 mins 0.1078 secs	unsat, 0.0 mins 0.1162 secs	unsat, 0.0 mins 0.0993 secs	unsat, 0.0 mins 0.1247 secs	unsat, 0.0 mins 0.0997 secs	unsat, 0.0 mins 0.1006 secs	unsat, 0.0 mins 0.1189 secs	unsat, 0.0 mins 0.1058 secs	unsat, 0.0 mins 0.1152 secs	unsat, 0.0 mins 0.1009 secs
0.0005	unsat, 0.0 mins 0.1019 secs	unsat, 0.0 mins 0.1537 secs	unsat, 0.0 mins 0.0978 secs	unsat, 0.0 mins 0.1047 secs	unsat, 0.0 mins 0.1036 secs	unsat, 0.0 mins 0.0933 secs	unsat, 0.0 mins 0.0989 secs	unsat, 0.0 mins 0.1006 secs	unsat, 0.0 mins 0.0964 secs	unsat, 0.0 mins 0.1116 secs
0.001	unsat, 0.0 mins 0.1033 secs	unsat, 0.0 mins 0.0975 secs	unsat, 0.0 mins 0.1032 secs	unsat, 0.0 mins 0.1052 secs	unsat, 0.0 mins 0.1039 secs	unsat, 0.0 mins 0.1137 secs	unsat, 0.0 mins 0.1075 secs	unsat, 0.0 mins 0.1023 secs	unsat, 0.0 mins 0.1028 secs	unsat, 0.0 mins 0.1009 secs
0.002	unsat, 0.0 mins 0.1006 secs	unsat, 0.0 mins 0.1436 secs	unsat, 0.0 mins 0.1070 secs	unsat, 0.0 mins 0.1046 secs	unsat, 0.0 mins 0.1072 secs	unsat, 0.0 mins 0.1211 secs	unsat, 0.0 mins 10.022 secs	unsat, 0.0 mins 0.1154 secs	unsat, 0.0 mins 0.1126 secs	unsat, 0.0 mins 0.0947 secs
0.005	unsat, 0.0 mins 0.0969 secs	unsat, 0.0 mins 0.1046 secs	unsat, 0.0 mins 0.8315 secs	unsat, 0.0 mins 6.6832 secs	unsat, 0.0 mins 0.0966 secs	unsat, 0.0 mins 2.4072 secs	unsat, 1.0 mins 0.2085 secs	unsat, 0.0 mins 0.0931 secs	unsat, 0.0 mins 1.6711 secs	unsat, 0.0 mins 1.7507 secs
0.01	unsat, 3.0 mins 16.412 secs	unsat, 1.0 mins 2.4623 secs	unsat, 0.0 mins 28.548 secs	unsat, 2.0 mins 2.5149 secs	unsat, 0.0 mins 4.7982 secs	unsat, 0.0 mins 2.3954 secs	unsat, 27.0 mins 7.364 secs	unsat, 1.0 mins 42.391 secs	unsat, 3.0 mins 29.069 secs	unsat, 1.0 mins 52.514 secs
0.02	unsat, 25.0 mins 8.538 secs	unsat, 13.0 mins 47.61 secs	sat, 2.0 mins 53.338 secs	TIMEOUT, 30.0 mins 0.398 secs	unsat, 3.0 mins 35.190 secs	unsat, 1.0 mins 18.688 secs	sat, 22.0 mins 15.38 secs	TIMEOUT, 30.0 mins 0.525 secs	unsat, 4.0 mins 34.288 secs	unsat, 5.0 mins 3.1605 secs
0.05	TIMEOUT, 30.0 mins 0.218 secs	TIMEOUT, 30.0 mins 0.280 secs	TIMEOUT, 30.0 mins 0.402 secs	sat, 2.0 mins 34.071 secs	TIMEOUT, 30.0 mins 0.434 secs	TIMEOUT, 30.0 mins 0.244 secs	sat, 0.0 mins 1.4658 secs	TIMEOUT, 30.0 mins 0.209 secs	TIMEOUT, 30.0 mins 0.630 secs	TIMEOUT, 30.0 mins 0.418 secs
0.1	sat, 0.0 mins 3.0983 secs	TIMEOUT, 30.0 mins 0.690 secs	sat, 0.0 mins 9.7876 secs	TIMEOUT, 30.0 mins 1.160 secs	sat, 3.0 mins 25.737 secs	sat, 0.0 mins 19.477 secs	sat, 0.0 mins 2.4820 secs	TIMEOUT, 30.0 mins 0.392 secs	sat, 0.0 mins 3.2133 secs	sat, 1.0 mins 3.3899 secs
0.2	sat, 0.0 mins 3.0288 secs	sat, 0.0 mins 3.4332 secs	sat, 0.0 mins 2.9325 secs	sat, 0.0 mins 3.4212 secs	sat, 0.0 mins 8.2460 secs	sat, 0.0 mins 3.2176 secs	sat, 0.0 mins 1.8543 secs	sat, 0.0 mins 2.3866 secs	sat, 0.0 mins 3.2851 secs	sat, 0.0 mins 2.4185 secs
0.5	sat, 0.0 mins 3.9988 secs	sat, 0.0 mins 4.6727 secs	sat, 0.0 mins 2.6360 secs	sat, 0.0 mins 2.1210 secs	sat, 0.0 mins 2.1623 secs	sat, 0.0 mins 1.8957 secs	sat, 0.0 mins 1.6975 secs	sat, 0.0 mins 1.9184 secs	sat, 0.0 mins 2.2364 secs	sat, 0.0 mins 2.2421 secs
1	sat, 0.0 mins 2.4994 secs	sat, 0.0 mins 2.5323 secs	sat, 0.0 mins 1.6849 secs	sat, 0.0 mins 1.6703 secs	sat, 0.0 mins 1.4144 secs	sat, 0.0 mins 1.3894 secs	sat, 0.0 mins 0.9661 secs	sat, 0.0 mins 1.6119 secs	sat, 0.0 mins 2.4985 secs	sat, 0.0 mins 1.5208 secs
2	sat, 0.0 mins 1.5219 secs	sat, 0.0 mins 1.0850 secs	sat, 0.0 mins 1.1250 secs	sat, 0.0 mins 1.2985 secs	sat, 0.0 mins 1.0085 secs	sat, 0.0 mins 1.3219 secs	sat, 0.0 mins 1.1237 secs	sat, 0.0 mins 0.8962 secs	sat, 0.0 mins 1.5706 secs	sat, 0.0 mins 1.2421 secs
5	sat, 0.0 mins 1.4857 secs	sat, 0.0 mins 1.4324 secs	sat, 0.0 mins 1.4034 secs	sat, 0.0 mins 1.3379 secs	sat, 0.0 mins 1.2681 secs	sat, 0.0 mins 1.0119 secs	sat, 0.0 mins 1.2941 secs	sat, 0.0 mins 1.6073 secs	sat, 0.0 mins 1.0343 secs	sat, 0.0 mins 1.4071 secs

Stats: layer 6

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0970 secs	unsat, 0.0 mins 0.1103 secs	unsat, 0.0 mins 0.0894 secs	unsat, 0.0 mins 0.0992 secs	unsat, 0.0 mins 0.0890 secs	unsat, 0.0 mins 0.0921 secs	unsat, 0.0 mins 0.0926 secs	unsat, 0.0 mins 0.0930 secs	unsat, 0.0 mins 0.0921 secs	unsat, 0.0 mins 0.0913 secs
0.0002	unsat, 0.0 mins 0.0978 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0899 secs	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.0909 secs	unsat, 0.0 mins 0.0918 secs	unsat, 0.0 mins 0.0948 secs	unsat, 0.0 mins 0.0887 secs	unsat, 0.0 mins 0.0982 secs	unsat, 0.0 mins 0.0935 secs
0.0005	unsat, 0.0 mins 0.0910 secs	unsat, 0.0 mins 0.0906 secs	unsat, 0.0 mins 0.1002 secs	unsat, 0.0 mins 0.0885 secs	unsat, 0.0 mins 0.0986 secs	unsat, 0.0 mins 0.0981 secs	unsat, 0.0 mins 0.6680 secs	unsat, 0.0 mins 0.0887 secs	unsat, 0.0 mins 0.0909 secs	unsat, 0.0 mins 0.0873 secs
0.001	unsat, 0.0 mins 0.0973 secs	unsat, 0.0 mins 0.0920 secs	unsat, 0.0 mins 0.0871 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.1060 secs	unsat, 0.0 mins 0.0983 secs	unsat, 0.0 mins 7.3312 secs	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.0896 secs	unsat, 0.0 mins 0.0876 secs
0.002	unsat, 0.0 mins 0.0965 secs	unsat, 0.0 mins 0.0909 secs	unsat, 0.0 mins 0.0938 secs	unsat, 0.0 mins 0.0958 secs	unsat, 0.0 mins 0.0999 secs	unsat, 0.0 mins 0.0954 secs	unsat, 0.0 mins 6.9476 secs	unsat, 0.0 mins 0.0975 secs	unsat, 0.0 mins 0.0912 secs	unsat, 0.0 mins 0.0953 secs
0.005	unsat, 0.0 mins 0.0897 secs	unsat, 0.0 mins 0.0929 secs	unsat, 0.0 mins 0.0914 secs	unsat, 0.0 mins 12.986 secs	unsat, 0.0 mins 0.0999 secs	unsat, 0.0 mins 2.0689 secs	sat, 0.0 mins 2.4286 secs	unsat, 0.0 mins 0.0944 secs	unsat, 0.0 mins 0.0886 secs	unsat, 0.0 mins 0.5915 secs
0.01	unsat, 1.0 mins 22.734 secs	unsat, 0.0 mins 7.3184 secs	unsat, 2.0 mins 48.462 secs	unsat, 1.0 mins 38.490 secs	unsat, 0.0 mins 15.560 secs	unsat, 0.0 mins 9.5316 secs	sat, 0.0 mins 19.346 secs	unsat, 0.0 mins 18.406 secs	unsat, 2.0 mins 11.938 secs	unsat, 0.0 mins 23.091 secs
0.02	unsat, 4.0 mins 8.9842 secs	unsat, 0.0 mins 55.880 secs	unsat, 4.0 mins 15.174 secs	unsat, 9.0 mins 56.276 secs	unsat, 4.0 mins 29.596 secs	unsat, 1.0 mins 6.9195 secs	sat, 0.0 mins 3.5654 secs	sat, 10.0 mins 29.59 secs	unsat, 7.0 mins 31.267 secs	unsat, 3.0 mins 1.4507 secs
0.05	sat, 0.0 mins 10.379 secs	sat, 10.0 mins 1.220 secs	sat, 0.0 mins 18.954 secs	sat, 26.0 mins 37.90 secs	TIMEOUT, 30.0 mins 0.506 secs	sat, 3.0 mins 10.506 secs	sat, 0.0 mins 12.500 secs	TIMEOUT, 30.0 mins 0.215 secs	TIMEOUT, 30.0 mins 0.758 secs	unsat, 17.0 mins 49.07 secs
0.1	sat, 0.0 mins 2.3981 secs	sat, 0.0 mins 19.580 secs	sat, 0.0 mins 10.000 secs	sat, 0.0 mins 8.5773 secs	TIMEOUT, 30.0 mins 0.503 secs	sat, 0.0 mins 18.465 secs	sat, 0.0 mins 1.7718 secs	sat, 2.0 mins 20.858 secs	sat, 0.0 mins 2.9809 secs	sat, 0.0 mins 2.5962 secs
0.2	sat, 0.0 mins 2.6212 secs	sat, 0.0 mins 3.7918 secs	sat, 0.0 mins 41.339 secs	sat, 0.0 mins 2.3285 secs	sat, 0.0 mins 3.2777 secs	sat, 0.0 mins 2.2044 secs	sat, 0.0 mins 1.9136 secs	sat, 0.0 mins 47.723 secs	sat, 0.0 mins 3.5147 secs	sat, 0.0 mins 3.4435 secs
0.5	sat, 0.0 mins 2.8817 secs	sat, 2.0 mins 26.358 secs	sat, 0.0 mins 2.1433 secs	sat, 0.0 mins 2.1570 secs	sat, 0.0 mins 2.1718 secs	sat, 0.0 mins 2.1023 secs	sat, 0.0 mins 13.865 secs	sat, 0.0 mins 2.9552 secs	sat, 0.0 mins 3.6305 secs	sat, 0.0 mins 2.9751 secs
1	sat, 0.0 mins 1.8677 secs	sat, 0.0 mins 47.822 secs	sat, 0.0 mins 3.8178 secs	sat, 0.0 mins 2.2613 secs	sat, 0.0 mins 1.4777 secs	sat, 0.0 mins 51.864 secs	sat, 0.0 mins 1.6950 secs	sat, 0.0 mins 2.0132 secs	sat, 0.0 mins 2.3197 secs	sat, 0.0 mins 53.320 secs
2	sat, 0.0 mins 1.3277 secs	sat, 0.0 mins 1.6542 secs	sat, 0.0 mins 1.4177 secs	sat, 0.0 mins 1.7589 secs	sat, 0.0 mins 52.846 secs	sat, 0.0 mins 2.2586 secs	sat, 0.0 mins 1.3300 secs	sat, 0.0 mins 1.0636 secs	sat, 0.0 mins 54.767 secs	sat, 0.0 mins 1.6159 secs
5	sat, 0.0 mins 1.0387 secs	sat, 0.0 mins 1.0594 secs	sat, 0.0 mins 55.677 secs	sat, 0.0 mins 1.1699 secs	sat, 0.0 mins 1.1275 secs	sat, 0.0 mins 1.3641 secs	sat, 0.0 mins 1.1654 secs	sat, 0.0 mins 54.465 secs	sat, 0.0 mins 1.0943 secs	sat, 0.0 mins 1.1172 secs

Stats: layer 7

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0890 secs	unsat, 0.0 mins 0.0894 secs	unsat, 0.0 mins 0.1091 secs	unsat, 0.0 mins 0.0925 secs	unsat, 0.0 mins 0.0901 secs	unsat, 0.0 mins 0.0903 secs	sat, 0.0 mins 2.4264 secs	unsat, 0.0 mins 0.0917 secs	unsat, 0.0 mins 0.0922 secs	unsat, 0.0 mins 0.0945 secs
0.0002	unsat, 0.0 mins 0.0897 secs	unsat, 0.0 mins 0.0932 secs	unsat, 0.0 mins 0.1000 secs	unsat, 0.0 mins 0.0970 secs	unsat, 0.0 mins 0.0897 secs	unsat, 0.0 mins 0.0911 secs	sat, 0.0 mins 51.161 secs	unsat, 0.0 mins 0.0936 secs	unsat, 0.0 mins 0.1029 secs	unsat, 0.0 mins 0.0880 secs
0.0005	unsat, 0.0 mins 0.0924 secs	unsat, 0.0 mins 0.0903 secs	unsat, 0.0 mins 0.0955 secs	unsat, 0.0 mins 0.0866 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0905 secs	sat, 0.0 mins 2.9032 secs	unsat, 0.0 mins 0.0964 secs	unsat, 0.0 mins 0.0930 secs	unsat, 0.0 mins 0.0958 secs
0.001	unsat, 0.0 mins 0.0975 secs	unsat, 0.0 mins 0.0920 secs	unsat, 0.0 mins 0.0887 secs	unsat, 0.0 mins 1.5677 secs	unsat, 0.0 mins 0.1057 secs	unsat, 0.0 mins 0.0881 secs	sat, 0.0 mins 4.1334 secs	unsat, 0.0 mins 0.0959 secs	unsat, 0.0 mins 0.0981 secs	unsat, 0.0 mins 0.0917 secs
0.002	unsat, 0.0 mins 0.0952 secs	unsat, 0.0 mins 0.1094 secs	unsat, 0.0 mins 0.0885 secs	unsat, 0.0 mins 8.1398 secs	unsat, 0.0 mins 0.0892 secs	unsat, 0.0 mins 0.0901 secs	sat, 0.0 mins 4.5440 secs	unsat, 0.0 mins 0.1056 secs	unsat, 0.0 mins 0.0975 secs	unsat, 0.0 mins 0.0917 secs
0.005	unsat, 0.0 mins 6.7523 secs	unsat, 0.0 mins 0.1043 secs	unsat, 0.0 mins 1.3385 secs	unsat, 0.0 mins 29.426 secs	unsat, 0.0 mins 0.0890 secs	unsat, 0.0 mins 2.2828 secs	sat, 0.0 mins 2.8529 secs	unsat, 0.0 mins 0.0891 secs	unsat, 0.0 mins 3.8190 secs	unsat, 0.0 mins 0.9917 secs
0.01	unsat, 0.0 mins 31.609 secs	unsat, 0.0 mins 3.9467 secs	unsat, 0.0 mins 43.585 secs	sat, 0.0 mins 3.4814 secs	unsat, 0.0 mins 6.1113 secs	unsat, 0.0 mins 2.7176 secs	sat, 0.0 mins 2.3868 secs	unsat, 1.0 mins 6.1900 secs	unsat, 3.0 mins 28.316 secs	unsat, 0.0 mins 44.073 secs
0.02	unsat, 1.0 mins 10.652 secs	unsat, 0.0 mins 24.153 secs	unsat, 4.0 mins 2.2198 secs	sat, 0.0 mins 58.033 secs	unsat, 3.0 mins 14.157 secs	unsat, 0.0 mins 20.890 secs	sat, 0.0 mins 2.3489 secs	sat, 1.0 mins 58.601 secs	unsat, 4.0 mins 23.233 secs	unsat, 3.0 mins 32.565 secs
0.05	sat, 16.0 mins 20.05 secs	sat, 13.0 mins 7.614 secs	sat, 21.0 mins 22.57 secs	sat, 0.0 mins 3.8664 secs	TIMEOUT, 30.0 mins 0.231 secs	sat, 0.0 mins 38.019 secs	sat, 0.0 mins 2.3180 secs	unsat, 16.0 mins 32.31 secs	TIMEOUT, 30.0 mins 0.377 secs	sat, 28.0 mins 44.47 secs
0.1	sat, 0.0 mins 8.2814 secs	sat, 0.0 mins 3.8573 secs	sat, 0.0 mins 3.8075 secs	sat, 0.0 mins 20.864 secs	sat, 5.0 mins 13.183 secs	sat, 0.0 mins 3.3599 secs	sat, 0.0 mins 1.7905 secs	sat, 0.0 mins 10.292 secs	sat, 0.0 mins 2.4599 secs	sat, 0.0 mins 9.5376 secs
0.2	sat, 0.0 mins 3.1597 secs	sat, 0.0 mins 3.4285 secs	sat, 0.0 mins 2.7925 secs	sat, 0.0 mins 2.8962 secs	sat, 0.0 mins 1.8174 secs	sat, 0.0 mins 3.7307 secs	sat, 0.0 mins 2.4771 secs	sat, 0.0 mins 2.6012 secs	sat, 0.0 mins 4.3456 secs	sat, 0.0 mins 2.3492 secs
0.5	sat, 0.0 mins 26.477 secs	sat, 0.0 mins 27.834 secs	sat, 0.0 mins 3.6600 secs	sat, 0.0 mins 2.4774 secs	sat, 0.0 mins 4.3693 secs	sat, 2.0 mins 25.014 secs	sat, 0.0 mins 2.7370 secs	sat, 0.0 mins 3.9790 secs	sat, 0.0 mins 3.5916 secs	sat, 0.0 mins 42.082 secs
1	sat, 0.0 mins 4.4859 secs	sat, 0.0 mins 2.8472 secs	sat, 0.0 mins 2.7879 secs	sat, 0.0 mins 2.6721 secs	sat, 0.0 mins 3.2165 secs	sat, 0.0 mins 1.9287 secs	sat, 0.0 mins 1.3435 secs	sat, 0.0 mins 2.7608 secs	sat, 0.0 mins 3.2149 secs	sat, 0.0 mins 2.6467 secs
2	sat, 0.0 mins 4.0707 secs	sat, 0.0 mins 1.7485 secs	sat, 0.0 mins 2.3456 secs	sat, 0.0 mins 1.8088 secs	sat, 0.0 mins 1.8164 secs	sat, 0.0 mins 1.8083 secs	sat, 0.0 mins 2.1895 secs	sat, 0.0 mins 1.6105 secs	sat, 0.0 mins 1.7428 secs	sat, 0.0 mins 1.1580 secs
5	sat, 0.0 mins 1.4623 secs	sat, 0.0 mins 1.6933 secs	sat, 0.0 mins 1.0922 secs	sat, 0.0 mins 1.5958 secs	sat, 0.0 mins 1.1092 secs	sat, 0.0 mins 1.9493 secs	sat, 0.0 mins 0.9815 secs	sat, 0.0 mins 1.3563 secs	sat, 0.0 mins 1.7156 secs	sat, 0.0 mins 1.8918 secs

Stats: layer 8

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0918 secs	unsat, 0.0 mins 0.0886 secs	unsat, 0.0 mins 0.1250 secs	unsat, 0.0 mins 3.0243 secs	unsat, 0.0 mins 0.0879 secs	unsat, 0.0 mins 0.0940 secs	unsat, 0.0 mins 0.0992 secs	unsat, 0.0 mins 0.0934 secs	unsat, 0.0 mins 0.1247 secs	unsat, 0.0 mins 0.1290 secs
0.0002	unsat, 0.0 mins 0.0973 secs	unsat, 0.0 mins 0.1009 secs	unsat, 0.0 mins 0.0980 secs	unsat, 0.0 mins 4.1853 secs	unsat, 0.0 mins 0.0904 secs	unsat, 0.0 mins 0.0884 secs	unsat, 0.0 mins 0.1090 secs	unsat, 0.0 mins 0.1181 secs	unsat, 0.0 mins 0.0934 secs	unsat, 0.0 mins 0.0927 secs
0.0005	unsat, 0.0 mins 0.0887 secs	unsat, 0.0 mins 0.0912 secs	unsat, 0.0 mins 0.0995 secs	unsat, 0.0 mins 2.2100 secs	unsat, 0.0 mins 0.0948 secs	unsat, 0.0 mins 0.0918 secs	unsat, 0.0 mins 0.0984 secs	unsat, 0.0 mins 0.1000 secs	unsat, 0.0 mins 0.0982 secs	unsat, 0.0 mins 0.0973 secs
0.001	unsat, 0.0 mins 0.0940 secs	unsat, 0.0 mins 0.0922 secs	unsat, 0.0 mins 0.0929 secs	sat, 0.0 mins 2.2476 secs	unsat, 0.0 mins 0.0878 secs	unsat, 0.0 mins 0.0907 secs	unsat, 0.0 mins 0.5429 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0983 secs	unsat, 0.0 mins 0.1002 secs
0.002	unsat, 0.0 mins 0.0969 secs	unsat, 0.0 mins 0.0985 secs	unsat, 0.0 mins 0.0889 secs	sat, 0.0 mins 2.7328 secs	unsat, 0.0 mins 0.0945 secs	unsat, 0.0 mins 0.0947 secs	unsat, 0.0 mins 0.6989 secs	unsat, 0.0 mins 0.1167 secs	unsat, 0.0 mins 1.4957 secs	unsat, 0.0 mins 0.0923 secs
0.005	unsat, 0.0 mins 0.5394 secs	unsat, 0.0 mins 0.0953 secs	unsat, 0.0 mins 12.494 secs	sat, 0.0 mins 5.6295 secs	unsat, 0.0 mins 0.0993 secs	unsat, 0.0 mins 2.8308 secs	unsat, 0.0 mins 12.956 secs	unsat, 0.0 mins 2.0036 secs	unsat, 0.0 mins 2.7251 secs	unsat, 0.0 mins 1.9492 secs
0.01	unsat, 0.0 mins 31.166 secs	unsat, 1.0 mins 3.7679 secs	unsat, 0.0 mins 24.298 secs	sat, 0.0 mins 4.9791 secs	unsat, 0.0 mins 58.799 secs	unsat, 0.0 mins 4.2126 secs	unsat, 3.0 mins 29.712 secs	unsat, 0.0 mins 6.4995 secs	unsat, 0.0 mins 3.3026 secs	unsat, 2.0 mins 6.3125 secs
0.02	unsat, 4.0 mins 3.1702 secs	unsat, 8.0 mins 40.536 secs	unsat, 7.0 mins 8.0234 secs	sat, 0.0 mins 4.7759 secs	sat, 14.0 mins 17.77 secs	unsat, 0.0 mins 32.930 secs	sat, 8.0 mins 19.401 secs	unsat, 4.0 mins 22.420 secs	sat, 3.0 mins 12.355 secs	unsat, 5.0 mins 9.9711 secs
0.05	sat, 1.0 mins 19.449 secs	TIMEOUT, 30.0 mins 1.017 secs	sat, 12.0 mins 9.238 secs	sat, 0.0 mins 27.392 secs	TIMEOUT, 30.0 mins 0.563 secs	sat, 0.0 mins 25.131 secs	sat, 0.0 mins 3.1057 secs	TIMEOUT, 30.0 mins 0.431 secs	sat, 1.0 mins 23.490 secs	sat, 0.0 mins 3.6915 secs
0.1	sat, 0.0 mins 3.0540 secs	sat, 0.0 mins 3.9948 secs	sat, 2.0 mins 21.785 secs	sat, 0.0 mins 2.3695 secs	TIMEOUT, 30.0 mins 1.037 secs	sat, 0.0 mins 20.048 secs	sat, 0.0 mins 3.5771 secs	sat, 10.0 mins 42.93 secs	sat, 0.0 mins 26.917 secs	sat, 0.0 mins 3.5631 secs
0.2	sat, 0.0 mins 2.7607 secs	sat, 0.0 mins 4.3097 secs	sat, 0.0 mins 4.5660 secs	sat, 0.0 mins 2.9794 secs	sat, 0.0 mins 4.5325 secs	sat, 0.0 mins 4.7707 secs	sat, 0.0 mins 5.0292 secs	sat, 0.0 mins 5.2862 secs	sat, 0.0 mins 5.7307 secs	sat, 0.0 mins 5.4265 secs
0.5	sat, 0.0 mins 4.1034 secs	sat, 0.0 mins 3.6594 secs	sat, 0.0 mins 5.1966 secs	sat, 0.0 mins 2.3892 secs	sat, 0.0 mins 3.3920 secs	sat, 0.0 mins 5.4374 secs	sat, 0.0 mins 5.2267 secs	sat, 0.0 mins 4.2977 secs	sat, 0.0 mins 4.2109 secs	sat, 0.0 mins 3.2477 secs
1	sat, 0.0 mins 3.0497 secs	sat, 0.0 mins 3.7197 secs	sat, 0.0 mins 2.9317 secs	sat, 0.0 mins 2.6521 secs	sat, 0.0 mins 2.6057 secs	sat, 0.0 mins 3.3988 secs	sat, 0.0 mins 2.3479 secs	sat, 0.0 mins 4.2049 secs	sat, 0.0 mins 4.3605 secs	sat, 0.0 mins 4.9138 secs
2	sat, 0.0 mins 3.6101 secs	sat, 0.0 mins 2.8386 secs	sat, 0.0 mins 2.8488 secs	sat, 0.0 mins 2.7290 secs	sat, 0.0 mins 2.8130 secs	sat, 0.0 mins 3.0453 secs	sat, 0.0 mins 2.6920 secs	sat, 0.0 mins 3.3869 secs	sat, 0.0 mins 2.0837 secs	sat, 0.0 mins 2.3107 secs
5	sat, 0.0 mins 2.4637 secs	sat, 0.0 mins 2.2858 secs	sat, 0.0 mins 2.0960 secs	sat, 0.0 mins 2.2460 secs	sat, 0.0 mins 2.1175 secs	sat, 0.0 mins 1.7610 secs	sat, 0.0 mins 2.5189 secs	sat, 0.0 mins 2.0965 secs	sat, 0.0 mins 1.7894 secs	sat, 0.0 mins 1.6967 secs

Stats: layer1

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0906 secs	unsat, 0.0 mins 0.0899 secs	unsat, 0.0 mins 0.0799 secs	unsat, 0.0 mins 0.0800 secs	unsat, 0.0 mins 0.0825 secs	unsat, 0.0 mins 0.0829 secs	sat, 0.0 mins 3.2187 secs	unsat, 0.0 mins 0.0844 secs	unsat, 0.0 mins 0.0838 secs	unsat, 0.0 mins 0.0819 secs
0.0002	unsat, 0.0 mins 0.0891 secs	unsat, 0.0 mins 0.0807 secs	unsat, 0.0 mins 0.0930 secs	unsat, 0.0 mins 0.1074 secs	unsat, 0.0 mins 0.1024 secs	unsat, 0.0 mins 0.0936 secs	sat, 0.0 mins 3.0305 secs	unsat, 0.0 mins 0.0816 secs	unsat, 0.0 mins 0.0811 secs	unsat, 0.0 mins 0.0799 secs
0.0005	unsat, 0.0 mins 0.0839 secs	unsat, 0.0 mins 0.0827 secs	unsat, 0.0 mins 0.0859 secs	unsat, 0.0 mins 0.0823 secs	unsat, 0.0 mins 0.0932 secs	unsat, 0.0 mins 0.1055 secs	sat, 0.0 mins 1.6827 secs	unsat, 0.0 mins 0.0818 secs	unsat, 0.0 mins 0.0831 secs	unsat, 0.0 mins 0.0821 secs
0.001	unsat, 0.0 mins 0.0828 secs	unsat, 0.0 mins 0.0820 secs	unsat, 0.0 mins 2.0361 secs	unsat, 0.0 mins 1.0267 secs	unsat, 0.0 mins 0.0809 secs	unsat, 0.0 mins 0.0824 secs	sat, 0.0 mins 1.8022 secs	unsat, 0.0 mins 0.0813 secs	unsat, 0.0 mins 0.0843 secs	unsat, 0.0 mins 0.0837 secs
0.002	unsat, 0.0 mins 3.6648 secs	unsat, 0.0 mins 0.0819 secs	unsat, 0.0 mins 4.9106 secs	unsat, 0.0 mins 12.831 secs	unsat, 0.0 mins 0.0801 secs	unsat, 0.0 mins 2.0903 secs	sat, 0.0 mins 25.598 secs	unsat, 0.0 mins 6.8834 secs	unsat, 0.0 mins 4.0324 secs	unsat, 0.0 mins 8.6407 secs
0.005	unsat, 4.0 mins 21.191 secs	unsat, 5.0 mins 44.153 secs	unsat, 2.0 mins 19.139 secs	TIMEOUT, 30.0 mins 0.250 secs	TIMEOUT, 30.0 mins 0.388 secs	unsat, 1.0 mins 4.3283 secs	sat, 0.0 mins 1.7346 secs	unsat, 6.0 mins 34.522 secs	sat, 1.0 mins 40.593 secs	unsat, 4.0 mins 52.408 secs
0.01	unsat, 18.0 mins 31.24 secs	TIMEOUT, 30.0 mins 0.512 secs	sat, 3.0 mins 2.3702 secs	TIMEOUT, 30.0 mins 0.220 secs	TIMEOUT, 30.0 mins 0.427 secs	unsat, 1.0 mins 27.293 secs	sat, 0.0 mins 3.0819 secs	TIMEOUT, 30.0 mins 0.385 secs	unsat, 10.0 mins 52.80 secs	TIMEOUT, 30.0 mins 0.243 secs
0.02	TIMEOUT, 30.0 mins 0.268 secs	TIMEOUT, 30.0 mins 0.395 secs	TIMEOUT, 30.0 mins 0.571 secs	sat, 0.0 mins 56.216 secs	TIMEOUT, 30.0 mins 0.468 secs	sat, 1.0 mins 3.3759 secs	sat, 0.0 mins 2.6434 secs	TIMEOUT, 30.0 mins 0.290 secs	sat, 8.0 mins 54.926 secs	sat, 0.0 mins 14.855 secs
0.05	sat, 0.0 mins 2.3627 secs	sat, 0.0 mins 2.8020 secs	sat, 0.0 mins 2.9556 secs	sat, 0.0 mins 2.6494 secs	sat, 0.0 mins 45.602 secs	sat, 0.0 mins 2.5526 secs	sat, 0.0 mins 2.0757 secs	sat, 0.0 mins 1.6959 secs	sat, 0.0 mins 3.3848 secs	sat, 0.0 mins 47.132 secs
0.1	sat, 0.0 mins 2.0275 secs	sat, 0.0 mins 2.7816 secs	sat, 0.0 mins 2.4591 secs	sat, 0.0 mins 52.105 secs	sat, 0.0 mins 1.6122 secs	sat, 0.0 mins 34.435 secs	sat, 0.0 mins 2.7949 secs	sat, 0.0 mins 20.582 secs	sat, 0.0 mins 3.5517 secs	sat, 0.0 mins 2.0423 secs
0.2	sat, 0.0 mins 2.0539 secs	sat, 0.0 mins 51.768 secs	sat, 0.0 mins 2.6323 secs	sat, 0.0 mins 1.4921 secs	sat, 0.0 mins 1.7233 secs	sat, 0.0 mins 1.9222 secs	sat, 0.0 mins 51.511 secs	sat, 0.0 mins 1.2353 secs	sat, 0.0 mins 1.3643 secs	sat, 0.0 mins 1.3904 secs
0.5	sat, 0.0 mins 55.172 secs	sat, 0.0 mins 0.8514 secs	sat, 0.0 mins 1.3636 secs	sat, 0.0 mins 1.0037 secs	sat, 0.0 mins 56.178 secs	sat, 0.0 mins 1.1054 secs	sat, 0.0 mins 0.7873 secs	sat, 0.0 mins 1.0043 secs	sat, 0.0 mins 0.7543 secs	sat, 0.0 mins 55.636 secs
1	sat, 0.0 mins 0.9626 secs	sat, 0.0 mins 0.6349 secs	sat, 0.0 mins 0.9954 secs	sat, 0.0 mins 56.820 secs	sat, 0.0 mins 0.9882 secs	sat, 0.0 mins 0.9323 secs	sat, 0.0 mins 0.6983 secs	sat, 0.0 mins 56.804 secs	sat, 0.0 mins 1.0006 secs	sat, 0.0 mins 0.6920 secs
2	sat, 0.0 mins 0.6231 secs	sat, 0.0 mins 0.6180 secs	sat, 0.0 mins 56.206 secs	sat, 0.0 mins 0.7974 secs	sat, 0.0 mins 0.5711 secs	sat, 0.0 mins 0.5779 secs	sat, 0.0 mins 57.448 secs	sat, 0.0 mins 0.6130 secs	sat, 0.0 mins 0.6266 secs	sat, 0.0 mins 0.6659 secs
5	sat, 0.0 mins 57.482 secs	sat, 0.0 mins 0.5494 secs	sat, 0.0 mins 0.6041 secs	sat, 0.0 mins 0.5997 secs	sat, 0.0 mins 0.6505 secs	sat, 0.0 mins 56.855 secs	sat, 0.0 mins 0.6914 secs	sat, 0.0 mins 0.7101 secs	sat, 0.0 mins 0.5757 secs	sat, 0.0 mins 57.441 secs

layer1 probe's verification results,

Stats: layer 2

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0898 secs	unsat, 0.0 mins 0.0849 secs	unsat, 0.0 mins 0.0864 secs	sat, 0.0 mins 3.6760 secs	unsat, 0.0 mins 0.0873 secs	unsat, 0.0 mins 0.0880 secs	unsat, 0.0 mins 0.0853 secs	unsat, 0.0 mins 0.0857 secs	unsat, 0.0 mins 0.0883 secs	unsat, 0.0 mins 0.0850 secs
0.0002	unsat, 0.0 mins 0.0855 secs	unsat, 0.0 mins 0.0861 secs	unsat, 0.0 mins 0.0859 secs	sat, 0.0 mins 2.7818 secs	unsat, 0.0 mins 0.0869 secs	unsat, 0.0 mins 0.0858 secs	unsat, 0.0 mins 0.0853 secs	unsat, 0.0 mins 0.0876 secs	unsat, 0.0 mins 0.0899 secs	unsat, 0.0 mins 0.0932 secs
0.0005	unsat, 0.0 mins 0.0927 secs	unsat, 0.0 mins 0.0934 secs	unsat, 0.0 mins 0.0887 secs	sat, 0.0 mins 2.2539 secs	unsat, 0.0 mins 0.0927 secs	unsat, 0.0 mins 0.0896 secs	unsat, 0.0 mins 0.0949 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0878 secs	unsat, 0.0 mins 0.0890 secs
0.001	unsat, 0.0 mins 0.0844 secs	unsat, 0.0 mins 0.0853 secs	unsat, 0.0 mins 0.0846 secs	sat, 0.0 mins 43.437 secs	unsat, 0.0 mins 0.1073 secs	unsat, 0.0 mins 0.0844 secs	unsat, 0.0 mins 4.4018 secs	unsat, 0.0 mins 0.0880 secs	unsat, 0.0 mins 0.0876 secs	unsat, 0.0 mins 0.0902 secs
0.002	unsat, 0.0 mins 6.5829 secs	unsat, 0.0 mins 0.0891 secs	unsat, 0.0 mins 0.0925 secs	sat, 0.0 mins 3.5735 secs	unsat, 0.0 mins 0.0967 secs	unsat, 0.0 mins 0.0891 secs	unsat, 0.0 mins 24.631 secs	unsat, 0.0 mins 0.0838 secs	unsat, 0.0 mins 0.0835 secs	unsat, 0.0 mins 0.0887 secs
0.005	unsat, 2.0 mins 49.547 secs	unsat, 0.0 mins 58.605 secs	unsat, 0.0 mins 37.104 secs	sat, 0.0 mins 7.5527 secs	unsat, 0.0 mins 11.373 secs	unsat, 0.0 mins 45.551 secs	TIMEOUT, 30.0 mins 0.504 secs	unsat, 1.0 mins 8.4356 secs	unsat, 3.0 mins 28.946 secs	unsat, 1.0 mins 37.990 secs
0.01	unsat, 5.0 mins 35.892 secs	unsat, 5.0 mins 33.329 secs	unsat, 2.0 mins 43.136 secs	sat, 0.0 mins 2.9827 secs	TIMEOUT, 30.0 mins 0.409 secs	sat, 3.0 mins 7.6875 secs	sat, 13.0 mins 27.82 secs	TIMEOUT, 30.0 mins 0.194 secs	unsat, 18.0 mins 9.945 secs	unsat, 11.0 mins 38.43 secs
0.02	sat, 0.0 mins 14.455 secs	TIMEOUT, 30.0 mins 0.262 secs	TIMEOUT, 30.0 mins 0.547 secs	sat, 0.0 mins 2.4221 secs	TIMEOUT, 30.0 mins 0.219 secs	TIMEOUT, 30.0 mins 0.372 secs	sat, 25.0 mins 42.58 secs	TIMEOUT, 30.0 mins 0.431 secs	TIMEOUT, 30.0 mins 0.228 secs	TIMEOUT, 30.0 mins 0.502 secs
0.05	sat, 0.0 mins 8.4541 secs	TIMEOUT, 30.0 mins 0.379 secs	sat, 0.0 mins 8.1331 secs	sat, 0.0 mins 2.6136 secs	TIMEOUT, 30.0 mins 0.335 secs	sat, 0.0 mins 4.5944 secs	sat, 0.0 mins 4.5079 secs	TIMEOUT, 30.0 mins 0.360 secs	sat, 0.0 mins 5.2766 secs	TIMEOUT, 30.0 mins 0.802 secs
0.1	sat, 0.0 mins 3.3468 secs	sat, 0.0 mins 4.3998 secs	sat, 0.0 mins 3.7675 secs	sat, 0.0 mins 4.2930 secs	sat, 0.0 mins 5.0982 secs	sat, 0.0 mins 4.1022 secs	sat, 0.0 mins 3.0407 secs	sat, 0.0 mins 4.6253 secs	sat, 0.0 mins 4.0001 secs	sat, 0.0 mins 4.0038 secs
0.2	sat, 0.0 mins 5.1935 secs	sat, 0.0 mins 2.8348 secs	sat, 0.0 mins 3.9562 secs	sat, 0.0 mins 2.5927 secs	sat, 0.0 mins 2.9237 secs	sat, 0.0 mins 2.2723 secs	sat, 0.0 mins 2.3327 secs	sat, 0.0 mins 2.3148 secs	sat, 0.0 mins 2.6492 secs	sat, 0.0 mins 3.0633 secs
0.5	sat, 0.0 mins 1.4293 secs	sat, 0.0 mins 1.4022 secs	sat, 0.0 mins 1.9546 secs	sat, 0.0 mins 2.0481 secs	sat, 0.0 mins 2.0058 secs	sat, 0.0 mins 3.3722 secs	sat, 0.0 mins 1.8055 secs	sat, 0.0 mins 2.4364 secs	sat, 0.0 mins 2.4856 secs	sat, 0.0 mins 2.3083 secs
1	sat, 0.0 mins 1.2093 secs	sat, 0.0 mins 1.3875 secs	sat, 0.0 mins 1.1490 secs	sat, 0.0 mins 1.2079 secs	sat, 0.0 mins 1.5589 secs	sat, 0.0 mins 1.8465 secs	sat, 0.0 mins 1.8032 secs	sat, 0.0 mins 2.1249 secs	sat, 0.0 mins 2.1064 secs	sat, 0.0 mins 1.6937 secs
2	sat, 0.0 mins 1.2572 secs	sat, 0.0 mins 1.1223 secs	sat, 0.0 mins 1.2150 secs	sat, 0.0 mins 1.5537 secs	sat, 0.0 mins 1.4016 secs	sat, 0.0 mins 2.4014 secs	sat, 0.0 mins 0.9793 secs	sat, 0.0 mins 1.1405 secs	sat, 0.0 mins 1.0409 secs	sat, 0.0 mins 1.2242 secs
5	sat, 0.0 mins 1.0014 secs	sat, 0.0 mins 1.3894 secs	sat, 0.0 mins 1.1243 secs	sat, 0.0 mins 1.1066 secs	sat, 0.0 mins 1.0209 secs	sat, 0.0 mins 0.8863 secs	sat, 0.0 mins 0.7773 secs	sat, 0.0 mins 0.7249 secs	sat, 0.0 mins 0.8793 secs	sat, 0.0 mins 0.8472 secs

Stats: layer 3

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.1127 secs	unsat, 0.0 mins 0.1162 secs	unsat, 0.0 mins 0.1109 secs	unsat, 0.0 mins 0.1090 secs	unsat, 0.0 mins 0.1133 secs	unsat, 0.0 mins 0.1070 secs	unsat, 0.0 mins 0.1107 secs	unsat, 0.0 mins 0.1039 secs	unsat, 0.0 mins 0.1203 secs	unsat, 0.0 mins 0.1116 secs
0.0002	unsat, 0.0 mins 0.1189 secs	unsat, 0.0 mins 0.1223 secs	unsat, 0.0 mins 0.1382 secs	unsat, 0.0 mins 0.1273 secs	unsat, 0.0 mins 0.1278 secs	unsat, 0.0 mins 0.1212 secs	unsat, 0.0 mins 0.1126 secs	unsat, 0.0 mins 0.1216 secs	unsat, 0.0 mins 0.1319 secs	unsat, 0.0 mins 0.1157 secs
0.0005	unsat, 0.0 mins 0.1269 secs	unsat, 0.0 mins 0.1131 secs	unsat, 0.0 mins 0.1166 secs	unsat, 0.0 mins 0.1094 secs	unsat, 0.0 mins 0.1135 secs	unsat, 0.0 mins 0.1120 secs	unsat, 0.0 mins 0.1152 secs	unsat, 0.0 mins 0.1156 secs	unsat, 0.0 mins 0.1146 secs	unsat, 0.0 mins 0.1110 secs
0.001	unsat, 0.0 mins 0.1223 secs	unsat, 0.0 mins 0.1330 secs	unsat, 0.0 mins 0.1216 secs	unsat, 0.0 mins 2.6342 secs	unsat, 0.0 mins 0.1193 secs	unsat, 0.0 mins 0.1186 secs	unsat, 0.0 mins 0.1275 secs	unsat, 0.0 mins 0.1469 secs	unsat, 0.0 mins 0.1458 secs	unsat, 0.0 mins 0.1203 secs
0.002	unsat, 0.0 mins 0.1152 secs	unsat, 0.0 mins 0.1191 secs	unsat, 0.0 mins 0.1169 secs	unsat, 0.0 mins 15.143 secs	unsat, 0.0 mins 0.1165 secs	unsat, 0.0 mins 0.1145 secs	unsat, 0.0 mins 10.980 secs	unsat, 0.0 mins 0.1175 secs	unsat, 0.0 mins 0.1269 secs	unsat, 0.0 mins 0.1167 secs
0.005	unsat, 0.0 mins 23.971 secs	unsat, 0.0 mins 2.4096 secs	unsat, 2.0 mins 12.567 secs	unsat, 2.0 mins 39.416 secs	unsat, 0.0 mins 0.0866 secs	unsat, 1.0 mins 41.996 secs	unsat, 13.0 mins 41.19 secs	unsat, 0.0 mins 1.2870 secs	unsat, 0.0 mins 8.4912 secs	unsat, 0.0 mins 11.803 secs
0.01	unsat, 2.0 mins 52.384 secs	unsat, 2.0 mins 38.410 secs	unsat, 4.0 mins 20.362 secs	sat, 0.0 mins 9.4340 secs	unsat, 15.0 mins 37.40 secs	unsat, 3.0 mins 1.9078 secs	sat, 2.0 mins 28.296 secs	unsat, 6.0 mins 38.607 secs	unsat, 4.0 mins 30.834 secs	unsat, 4.0 mins 33.038 secs
0.02	sat, 12.0 mins 37.12 secs	TIMEOUT, 30.0 mins 0.393 secs	TIMEOUT, 30.0 mins 0.371 secs	sat, 0.0 mins 26.303 secs	TIMEOUT, 30.0 mins 0.503 secs	TIMEOUT, 30.0 mins 0.290 secs	TIMEOUT, 30.0 mins 0.299 secs	TIMEOUT, 30.0 mins 0.231 secs	sat, 11.0 mins 11.78 secs	TIMEOUT, 30.0 mins 0.483 secs
0.05	sat, 1.0 mins 0.5858 secs	TIMEOUT, 30.0 mins 0.232 secs	TIMEOUT, 30.0 mins 0.458 secs	sat, 0.0 mins 2.0171 secs	TIMEOUT, 30.0 mins 0.208 secs	sat, 0.0 mins 15.150 secs	sat, 0.0 mins 2.9326 secs	TIMEOUT, 30.0 mins 0.381 secs	TIMEOUT, 30.0 mins 0.386 secs	TIMEOUT, 30.0 mins 0.472 secs
0.1	sat, 0.0 mins 8.3795 secs	sat, 0.0 mins 2.8943 secs	sat, 0.0 mins 2.9554 secs	sat, 0.0 mins 2.5426 secs	sat, 0.0 mins 2.4658 secs	sat, 0.0 mins 2.1640 secs	sat, 0.0 mins 2.1276 secs	sat, 0.0 mins 1.9402 secs	sat, 0.0 mins 2.4254 secs	sat, 0.0 mins 3.2265 secs
0.2	sat, 0.0 mins 26.150 secs	sat, 0.0 mins 2.8531 secs	sat, 0.0 mins 2.4868 secs	sat, 0.0 mins 2.4221 secs	sat, 0.0 mins 1.8106 secs	sat, 0.0 mins 2.3193 secs	sat, 0.0 mins 2.4229 secs	sat, 0.0 mins 2.2586 secs	sat, 0.0 mins 2.0632 secs	sat, 0.0 mins 1.7562 secs
0.5	sat, 0.0 mins 1.6700 secs	sat, 0.0 mins 1.0083 secs	sat, 0.0 mins 2.0921 secs	sat, 0.0 mins 2.0380 secs	sat, 0.0 mins 1.7619 secs	sat, 0.0 mins 1.5059 secs	sat, 0.0 mins 1.8631 secs	sat, 0.0 mins 1.9087 secs	sat, 0.0 mins 2.0655 secs	sat, 0.0 mins 2.5286 secs
1	sat, 0.0 mins 1.3807 secs	sat, 0.0 mins 0.9577 secs	sat, 0.0 mins 1.3432 secs	sat, 0.0 mins 1.1557 secs	sat, 0.0 mins 1.2038 secs	sat, 0.0 mins 0.8867 secs	sat, 0.0 mins 1.4169 secs	sat, 0.0 mins 1.5396 secs	sat, 0.0 mins 1.5345 secs	sat, 0.0 mins 1.9854 secs
2	sat, 0.0 mins 1.5137 secs	sat, 0.0 mins 0.9204 secs	sat, 0.0 mins 1.3538 secs	sat, 0.0 mins 1.4057 secs	sat, 0.0 mins 1.2399 secs	sat, 0.0 mins 1.3764 secs	sat, 0.0 mins 1.3473 secs	sat, 0.0 mins 1.2195 secs	sat, 0.0 mins 1.2481 secs	sat, 0.0 mins 1.3272 secs
5	sat, 0.0 mins 0.8888 secs	sat, 0.0 mins 0.7628 secs	sat, 0.0 mins 0.8462 secs	sat, 0.0 mins 0.7973 secs	sat, 0.0 mins 0.7940 secs	sat, 0.0 mins 0.8273 secs	sat, 0.0 mins 0.8318 secs	sat, 0.0 mins 0.8415 secs	sat, 0.0 mins 0.7421 secs	sat, 0.0 mins 0.8550 secs

Stats: layer 4

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0887 secs	unsat, 0.0 mins 0.0924 secs	unsat, 0.0 mins 0.0875 secs	unsat, 0.0 mins 0.1002 secs	unsat, 0.0 mins 0.0876 secs	unsat, 0.0 mins 0.0853 secs	unsat, 0.0 mins 0.0868 secs	unsat, 0.0 mins 0.0907 secs	unsat, 0.0 mins 0.0840 secs	unsat, 0.0 mins 0.0890 secs
0.0002	unsat, 0.0 mins 0.0854 secs	unsat, 0.0 mins 0.0879 secs	unsat, 0.0 mins 0.0862 secs	unsat, 0.0 mins 0.0895 secs	unsat, 0.0 mins 0.0838 secs	unsat, 0.0 mins 0.0854 secs	unsat, 0.0 mins 0.0832 secs	unsat, 0.0 mins 0.0854 secs	unsat, 0.0 mins 0.0884 secs	unsat, 0.0 mins 0.0867 secs
0.0005	unsat, 0.0 mins 0.0859 secs	unsat, 0.0 mins 0.0941 secs	unsat, 0.0 mins 0.0974 secs	unsat, 0.0 mins 6.4925 secs	unsat, 0.0 mins 0.0901 secs	unsat, 0.0 mins 0.0914 secs	unsat, 0.0 mins 0.0904 secs	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.0900 secs	unsat, 0.0 mins 0.0877 secs
0.001	unsat, 0.0 mins 0.0874 secs	unsat, 0.0 mins 0.0860 secs	unsat, 0.0 mins 0.0849 secs	unsat, 0.0 mins 5.2547 secs	unsat, 0.0 mins 0.0921 secs	unsat, 0.0 mins 0.0898 secs	unsat, 0.0 mins 0.0892 secs	unsat, 0.0 mins 0.0894 secs	unsat, 0.0 mins 0.1011 secs	unsat, 0.0 mins 0.0968 secs
0.002	unsat, 0.0 mins 0.1014 secs	unsat, 0.0 mins 0.1087 secs	unsat, 0.0 mins 0.0912 secs	unsat, 0.0 mins 24.994 secs	unsat, 0.0 mins 0.0896 secs	unsat, 0.0 mins 6.5758 secs	unsat, 0.0 mins 0.0902 secs	unsat, 0.0 mins 0.1005 secs	unsat, 0.0 mins 0.0933 secs	unsat, 0.0 mins 0.0910 secs
0.005	unsat, 0.0 mins 11.971 secs	unsat, 0.0 mins 1.8541 secs	unsat, 0.0 mins 6.7596 secs	sat, 0.0 mins 3.2798 secs	unsat, 0.0 mins 0.0866 secs	unsat, 0.0 mins 15.879 secs	unsat, 1.0 mins 39.832 secs	unsat, 0.0 mins 1.6782 secs	unsat, 0.0 mins 4.8188 secs	unsat, 0.0 mins 3.4859 secs
0.01	unsat, 1.0 mins 12.292 secs	unsat, 4.0 mins 7.2513 secs	unsat, 5.0 mins 11.768 secs	sat, 0.0 mins 3.0321 secs	unsat, 3.0 mins 42.164 secs	unsat, 4.0 mins 47.490 secs	TIMEOUT, 30.0 mins 0.568 secs	unsat, 7.0 mins 35.214 secs	unsat, 2.0 mins 53.979 secs	unsat, 1.0 mins 17.954 secs
0.02	sat, 2.0 mins 49.397 secs	sat, 16.0 mins 46.11 secs	sat, 23.0 mins 5.949 secs	sat, 0.0 mins 2.6648 secs	TIMEOUT, 30.0 mins 0.307 secs	sat, 0.0 mins 25.508 secs	TIMEOUT, 30.0 mins 0.474 secs	TIMEOUT, 30.0 mins 0.495 secs	TIMEOUT, 30.0 mins 0.246 secs	unsat, 8.0 mins 21.727 secs
0.05	sat, 0.0 mins 27.275 secs	TIMEOUT, 30.0 mins 0.219 secs	TIMEOUT, 30.0 mins 0.197 secs	sat, 0.0 mins 2.7929 secs	TIMEOUT, 30.0 mins 0.367 secs	sat, 1.0 mins 42.647 secs	TIMEOUT, 30.0 mins 0.291 secs	TIMEOUT, 30.0 mins 0.433 secs	TIMEOUT, 30.0 mins 0.475 secs	TIMEOUT, 30.0 mins 0.375 secs
0.1	sat, 0.0 mins 2.8039 secs	sat, 0.0 mins 3.3627 secs	sat, 0.0 mins 3.5714 secs	sat, 0.0 mins 2.2444 secs	sat, 0.0 mins 2.9700 secs	sat, 0.0 mins 7.8216 secs	sat, 0.0 mins 2.0599 secs	TIMEOUT, 30.0 mins 0.487 secs	sat, 0.0 mins 2.1906 secs	sat, 26.0 mins 16.16 secs
0.2	sat, 0.0 mins 2.7439 secs	sat, 0.0 mins 5.3357 secs	sat, 0.0 mins 2.9212 secs	sat, 0.0 mins 3.5401 secs	sat, 0.0 mins 4.1898 secs	sat, 0.0 mins 5.6803 secs	sat, 0.0 mins 2.4719 secs	sat, 0.0 mins 3.1643 secs	sat, 0.0 mins 2.6713 secs	sat, 0.0 mins 4.0844 secs
0.5	sat, 0.0 mins 2.3695 secs	sat, 0.0 mins 2.3798 secs	sat, 0.0 mins 2.4872 secs	sat, 0.0 mins 1.7391 secs	sat, 0.0 mins 1.9889 secs	sat, 0.0 mins 2.5374 secs	sat, 0.0 mins 2.0285 secs	sat, 0.0 mins 2.8203 secs	sat, 0.0 mins 1.6378 secs	sat, 0.0 mins 2.7681 secs
1	sat, 0.0 mins 1.4982 secs	sat, 0.0 mins 1.9759 secs	sat, 0.0 mins 1.4657 secs	sat, 0.0 mins 1.5320 secs	sat, 0.0 mins 2.0029 secs	sat, 0.0 mins 1.6463 secs	sat, 0.0 mins 1.2585 secs	sat, 0.0 mins 2.2160 secs	sat, 0.0 mins 1.6561 secs	sat, 0.0 mins 1.9523 secs
2	sat, 0.0 mins 1.2343 secs	sat, 0.0 mins 1.4390 secs	sat, 0.0 mins 1.3454 secs	sat, 0.0 mins 1.0218 secs	sat, 0.0 mins 1.2782 secs	sat, 0.0 mins 1.3374 secs	sat, 0.0 mins 1.0459 secs	sat, 0.0 mins 1.5028 secs	sat, 0.0 mins 1.0525 secs	sat, 0.0 mins 1.2002 secs
5	sat, 0.0 mins 1.3585 secs	sat, 0.0 mins 1.1480 secs	sat, 0.0 mins 1.3261 secs	sat, 0.0 mins 1.4376 secs	sat, 0.0 mins 1.3129 secs	sat, 0.0 mins 0.7907 secs	sat, 0.0 mins 0.7550 secs	sat, 0.0 mins 1.0035 secs	sat, 0.0 mins 1.3027 secs	sat, 0.0 mins 1.0180 secs

Stats: layer 5

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0986 secs	unsat, 0.0 mins 0.0970 secs	unsat, 0.0 mins 0.0883 secs	unsat, 0.0 mins 0.0885 secs	unsat, 0.0 mins 0.0924 secs	unsat, 0.0 mins 0.0903 secs	unsat, 0.0 mins 0.0932 secs	unsat, 0.0 mins 0.0945 secs	unsat, 0.0 mins 0.0965 secs	unsat, 0.0 mins 0.0946 secs
0.0002	unsat, 0.0 mins 0.0979 secs	unsat, 0.0 mins 0.0925 secs	unsat, 0.0 mins 0.0925 secs	unsat, 0.0 mins 0.0892 secs	unsat, 0.0 mins 0.0895 secs	unsat, 0.0 mins 0.1075 secs	unsat, 0.0 mins 0.1040 secs	unsat, 0.0 mins 0.0940 secs	unsat, 0.0 mins 0.0931 secs	unsat, 0.0 mins 0.0914 secs
0.0005	unsat, 0.0 mins 0.1077 secs	unsat, 0.0 mins 0.0946 secs	unsat, 0.0 mins 0.0963 secs	unsat, 0.0 mins 0.1014 secs	unsat, 0.0 mins 0.0919 secs	unsat, 0.0 mins 0.0922 secs	unsat, 0.0 mins 0.0950 secs	unsat, 0.0 mins 0.0868 secs	unsat, 0.0 mins 0.0996 secs	unsat, 0.0 mins 0.1092 secs
0.001	unsat, 0.0 mins 0.0890 secs	unsat, 0.0 mins 0.0885 secs	unsat, 0.0 mins 0.0887 secs	unsat, 0.0 mins 0.0919 secs	unsat, 0.0 mins 0.0917 secs	unsat, 0.0 mins 0.0933 secs	unsat, 0.0 mins 0.0999 secs	unsat, 0.0 mins 0.0956 secs	unsat, 0.0 mins 0.0891 secs	unsat, 0.0 mins 0.1002 secs
0.002	unsat, 0.0 mins 0.0935 secs	unsat, 0.0 mins 0.0910 secs	unsat, 0.0 mins 0.0976 secs	unsat, 0.0 mins 0.6436 secs	unsat, 0.0 mins 0.0943 secs	unsat, 0.0 mins 0.0967 secs	unsat, 0.0 mins 0.1143 secs	unsat, 0.0 mins 0.0915 secs	unsat, 0.0 mins 0.0877 secs	unsat, 0.0 mins 0.0916 secs
0.005	unsat, 0.0 mins 0.9791 secs	unsat, 0.0 mins 0.0918 secs	unsat, 0.0 mins 0.7173 secs	unsat, 0.0 mins 12.293 secs	unsat, 0.0 mins 0.0921 secs	unsat, 0.0 mins 4.1004 secs	unsat, 11.0 mins 44.13 secs	unsat, 0.0 mins 0.1010 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0880 secs
0.01	unsat, 0.0 mins 14.281 secs	unsat, 0.0 mins 21.444 secs	unsat, 2.0 mins 32.174 secs	unsat, 3.0 mins 16.741 secs	unsat, 2.0 mins 38.511 secs	unsat, 3.0 mins 23.480 secs	unsat, 23.0 mins 36.93 secs	unsat, 1.0 mins 26.922 secs	unsat, 2.0 mins 52.063 secs	unsat, 3.0 mins 42.533 secs
0.02	unsat, 3.0 mins 28.538 secs	unsat, 5.0 mins 37.525 secs	unsat, 5.0 mins 27.114 secs	sat, 0.0 mins 19.755 secs	unsat, 20.0 mins 2.634 secs	sat, 9.0 mins 35.466 secs	sat, 0.0 mins 5.5070 secs	unsat, 27.0 mins 34.40 secs	sat, 9.0 mins 59.185 secs	unsat, 4.0 mins 11.117 secs
0.05	TIMEOUT, 30.0 mins 0.236 secs	TIMEOUT, 30.0 mins 0.252 secs	TIMEOUT, 30.0 mins 0.393 secs	sat, 0.0 mins 23.749 secs	TIMEOUT, 30.0 mins 0.256 secs	sat, 2.0 mins 44.972 secs	sat, 0.0 mins 2.4680 secs	TIMEOUT, 30.0 mins 0.224 secs	TIMEOUT, 30.0 mins 0.214 secs	TIMEOUT, 30.0 mins 0.526 secs
0.1	sat, 0.0 mins 5.3910 secs	sat, 0.0 mins 4.1826 secs	sat, 0.0 mins 4.5927 secs	TIMEOUT, 30.0 mins 0.416 secs	sat, 0.0 mins 9.5560 secs	sat, 0.0 mins 2.1136 secs	sat, 0.0 mins 2.1485 secs	TIMEOUT, 30.0 mins 0.505 secs	sat, 0.0 mins 9.7081 secs	sat, 0.0 mins 9.2489 secs
0.2	sat, 0.0 mins 3.0212 secs	sat, 0.0 mins 3.2270 secs	sat, 0.0 mins 3.3945 secs	sat, 0.0 mins 3.9471 secs	sat, 0.0 mins 3.6463 secs	sat, 0.0 mins 3.0187 secs	sat, 0.0 mins 2.7049 secs	sat, 0.0 mins 3.3874 secs	sat, 0.0 mins 2.6570 secs	sat, 0.0 mins 2.7239 secs
0.5	sat, 0.0 mins 26.894 secs	sat, 0.0 mins 2.6964 secs	sat, 0.0 mins 3.0114 secs	sat, 0.0 mins 2.2368 secs	sat, 0.0 mins 2.6852 secs	sat, 0.0 mins 3.5854 secs	sat, 0.0 mins 1.8894 secs	sat, 0.0 mins 1.8004 secs	sat, 0.0 mins 2.5981 secs	sat, 0.0 mins 3.2831 secs
1	sat, 0.0 mins 2.0745 secs	sat, 0.0 mins 1.6574 secs	sat, 0.0 mins 1.6402 secs	sat, 0.0 mins 2.1516 secs	sat, 0.0 mins 2.4288 secs	sat, 0.0 mins 2.0560 secs	sat, 0.0 mins 1.4695 secs	sat, 0.0 mins 1.5124 secs	sat, 0.0 mins 1.8661 secs	sat, 0.0 mins 1.6705 secs
2	sat, 0.0 mins 2.0549 secs	sat, 0.0 mins 1.8225 secs	sat, 0.0 mins 1.9134 secs	sat, 0.0 mins 1.3677 secs	sat, 0.0 mins 1.4053 secs	sat, 0.0 mins 1.5383 secs	sat, 0.0 mins 1.4481 secs	sat, 0.0 mins 2.1949 secs	sat, 0.0 mins 1.4217 secs	sat, 0.0 mins 1.3664 secs
5	sat, 0.0 mins 1.2647 secs	sat, 0.0 mins 1.2753 secs	sat, 0.0 mins 1.5232 secs	sat, 0.0 mins 1.1070 secs	sat, 0.0 mins 1.2348 secs	sat, 0.0 mins 1.1816 secs	sat, 0.0 mins 1.2737 secs	sat, 0.0 mins 1.1195 secs	sat, 0.0 mins 1.5213 secs	sat, 0.0 mins 1.3362 secs

Stats: layer 6

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0860 secs	unsat, 0.0 mins 0.0875 secs	unsat, 0.0 mins 0.0847 secs	unsat, 0.0 mins 0.0852 secs	unsat, 0.0 mins 0.0879 secs	unsat, 0.0 mins 0.0881 secs	unsat, 0.0 mins 0.0858 secs	unsat, 0.0 mins 0.0858 secs	unsat, 0.0 mins 0.0937 secs	unsat, 0.0 mins 0.0896 secs
0.0002	unsat, 0.0 mins 0.0870 secs	unsat, 0.0 mins 0.0881 secs	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.0848 secs	unsat, 0.0 mins 0.0896 secs	unsat, 0.0 mins 0.0845 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0856 secs	unsat, 0.0 mins 0.0899 secs	unsat, 0.0 mins 0.0898 secs
0.0005	unsat, 0.0 mins 0.0863 secs	unsat, 0.0 mins 0.0877 secs	unsat, 0.0 mins 0.1124 secs	unsat, 0.0 mins 0.1121 secs	unsat, 0.0 mins 0.0877 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 0.0950 secs	unsat, 0.0 mins 0.0890 secs	unsat, 0.0 mins 0.1021 secs	unsat, 0.0 mins 0.0887 secs
0.001	unsat, 0.0 mins 0.0926 secs	unsat, 0.0 mins 0.0897 secs	unsat, 0.0 mins 0.0949 secs	unsat, 0.0 mins 0.0891 secs	unsat, 0.0 mins 0.0902 secs	unsat, 0.0 mins 0.0917 secs	unsat, 0.0 mins 0.1008 secs	unsat, 0.0 mins 0.1039 secs	unsat, 0.0 mins 0.0986 secs	unsat, 0.0 mins 0.0869 secs
0.002	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.1054 secs	unsat, 0.0 mins 0.1185 secs	unsat, 0.0 mins 0.0867 secs	unsat, 0.0 mins 0.0869 secs	unsat, 0.0 mins 0.0892 secs	unsat, 0.0 mins 0.0926 secs	unsat, 0.0 mins 0.0906 secs	unsat, 0.0 mins 0.0862 secs	unsat, 0.0 mins 0.0893 secs
0.005	unsat, 0.0 mins 9.7690 secs	unsat, 0.0 mins 0.0920 secs	unsat, 0.0 mins 0.7500 secs	unsat, 0.0 mins 38.702 secs	unsat, 0.0 mins 0.0893 secs	unsat, 0.0 mins 6.9676 secs	unsat, 0.0 mins 38.881 secs	unsat, 0.0 mins 0.0876 secs	unsat, 0.0 mins 3.4507 secs	unsat, 0.0 mins 4.3559 secs
0.01	unsat, 1.0 mins 6.1976 secs	unsat, 0.0 mins 21.018 secs	unsat, 0.0 mins 11.289 secs	unsat, 2.0 mins 2.2562 secs	unsat, 0.0 mins 7.6013 secs	unsat, 0.0 mins 48.474 secs	unsat, 4.0 mins 7.9096 secs	unsat, 1.0 mins 18.777 secs	unsat, 0.0 mins 3.0112 secs	unsat, 0.0 mins 22.120 secs
0.02	unsat, 4.0 mins 19.447 secs	unsat, 3.0 mins 38.830 secs	unsat, 1.0 mins 33.147 secs	unsat, 10.0 mins 16.54 secs	unsat, 3.0 mins 14.576 secs	unsat, 4.0 mins 0.0896 secs	TIMEOUT, 30.0 mins 0.553 secs	TIMEOUT, 30.0 mins 0.306 secs	unsat, 4.0 mins 45.507 secs	unsat, 4.0 mins 42.114 secs
0.05	sat, 0.0 mins 14.779 secs	TIMEOUT, 30.0 mins 0.563 secs	sat, 1.0 mins 28.130 secs	sat, 2.0 mins 24.819 secs	TIMEOUT, 30.0 mins 0.497 secs	sat, 1.0 mins 59.052 secs	sat, 0.0 mins 52.531 secs	TIMEOUT, 30.0 mins 0.224 secs	TIMEOUT, 30.0 mins 0.250 secs	sat, 16.0 mins 37.06 secs
0.1	sat, 0.0 mins 9.1047 secs	sat, 0.0 mins 4.9563 secs	sat, 0.0 mins 4.5432 secs	sat, 10.0 mins 38.97 secs	TIMEOUT, 30.0 mins 0.743 secs	sat, 0.0 mins 3.2410 secs	sat, 0.0 mins 2.9746 secs	TIMEOUT, 30.0 mins 0.338 secs	sat, 29.0 mins 23.83 secs	sat, 0.0 mins 25.429 secs
0.2	sat, 0.0 mins 1.9754 secs	sat, 0.0 mins 3.3170 secs	sat, 0.0 mins 2.8244 secs	sat, 0.0 mins 2.6336 secs	sat, 0.0 mins 2.7241 secs	sat, 0.0 mins 3.1601 secs	sat, 0.0 mins 3.5024 secs	sat, 0.0 mins 5.1142 secs	sat, 0.0 mins 2.0810 secs	sat, 0.0 mins 2.8682 secs
0.5	sat, 0.0 mins 2.8116 secs	sat, 0.0 mins 2.8816 secs	sat, 0.0 mins 27.847 secs	sat, 0.0 mins 3.9189 secs	sat, 0.0 mins 3.1816 secs	sat, 0.0 mins 5.0275 secs	sat, 0.0 mins 2.6007 secs	sat, 0.0 mins 3.0074 secs	sat, 0.0 mins 3.4816 secs	sat, 0.0 mins 3.1366 secs
1	sat, 0.0 mins 2.3588 secs	sat, 0.0 mins 1.9962 secs	sat, 0.0 mins 1.8378 secs	sat, 0.0 mins 2.4724 secs	sat, 0.0 mins 2.2754 secs	sat, 0.0 mins 2.0298 secs	sat, 0.0 mins 2.1815 secs	sat, 0.0 mins 1.8897 secs	sat, 0.0 mins 2.2791 secs	sat, 0.0 mins 2.5993 secs
2	sat, 0.0 mins 1.6252 secs	sat, 0.0 mins 1.5798 secs	sat, 0.0 mins 1.5047 secs	sat, 0.0 mins 0.9333 secs	sat, 0.0 mins 0.8751 secs	sat, 0.0 mins 0.8961 secs	sat, 0.0 mins 1.4856 secs	sat, 0.0 mins 1.6984 secs	sat, 0.0 mins 2.1388 secs	sat, 0.0 mins 1.4937 secs
5	sat, 0.0 mins 1.4321 secs	sat, 0.0 mins 1.5206 secs	sat, 0.0 mins 1.5580 secs	sat, 0.0 mins 1.3559 secs	sat, 0.0 mins 1.2962 secs	sat, 0.0 mins 1.3452 secs	sat, 0.0 mins 1.4786 secs	sat, 0.0 mins 1.3365 secs	sat, 0.0 mins 1.2773 secs	sat, 0.0 mins 1.5303 secs

Stats: layer 7

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0870 secs	unsat, 0.0 mins 0.0912 secs	unsat, 0.0 mins 0.0907 secs	sat, 0.0 mins 3.9697 secs	unsat, 0.0 mins 0.0866 secs	unsat, 0.0 mins 0.0881 secs	unsat, 0.0 mins 0.0889 secs	unsat, 0.0 mins 0.0901 secs	unsat, 0.0 mins 0.0858 secs	unsat, 0.0 mins 0.0967 secs
0.0002	unsat, 0.0 mins 0.0886 secs	unsat, 0.0 mins 0.0874 secs	unsat, 0.0 mins 0.0988 secs	sat, 0.0 mins 3.8521 secs	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.0966 secs	unsat, 0.0 mins 0.0927 secs	unsat, 0.0 mins 0.1013 secs	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.0925 secs
0.0005	unsat, 0.0 mins 0.0977 secs	unsat, 0.0 mins 0.0891 secs	unsat, 0.0 mins 0.0938 secs	sat, 0.0 mins 3.9650 secs	unsat, 0.0 mins 0.1025 secs	unsat, 0.0 mins 0.0896 secs	unsat, 0.0 mins 0.0954 secs	unsat, 0.0 mins 0.0901 secs	unsat, 0.0 mins 0.0897 secs	unsat, 0.0 mins 0.0912 secs
0.001	unsat, 0.0 mins 0.0988 secs	unsat, 0.0 mins 0.0957 secs	unsat, 0.0 mins 0.0953 secs	sat, 0.0 mins 3.8472 secs	unsat, 0.0 mins 0.0996 secs	unsat, 0.0 mins 0.0908 secs	unsat, 0.0 mins 0.0955 secs	unsat, 0.0 mins 0.0902 secs	unsat, 0.0 mins 0.1017 secs	unsat, 0.0 mins 0.0954 secs
0.002	unsat, 0.0 mins 0.0948 secs	unsat, 0.0 mins 0.0922 secs	unsat, 0.0 mins 0.0938 secs	sat, 0.0 mins 4.0630 secs	unsat, 0.0 mins 0.0903 secs	unsat, 0.0 mins 0.0981 secs	unsat, 0.0 mins 0.1003 secs	unsat, 0.0 mins 0.1034 secs	unsat, 0.0 mins 0.0924 secs	unsat, 0.0 mins 0.0940 secs
0.005	unsat, 0.0 mins 3.7956 secs	unsat, 0.0 mins 0.0911 secs	unsat, 0.0 mins 0.7070 secs	sat, 0.0 mins 3.9321 secs	unsat, 0.0 mins 0.0980 secs	unsat, 0.0 mins 1.1261 secs	unsat, 2.0 mins 26.301 secs	unsat, 0.0 mins 0.0896 secs	unsat, 0.0 mins 0.0957 secs	unsat, 0.0 mins 5.0269 secs
0.01	unsat, 0.0 mins 3.7847 secs	unsat, 0.0 mins 11.435 secs	unsat, 0.0 mins 3.8096 secs	sat, 0.0 mins 3.0300 secs	unsat, 0.0 mins 4.0174 secs	unsat, 0.0 mins 31.123 secs	unsat, 2.0 mins 27.019 secs	unsat, 0.0 mins 56.119 secs	unsat, 0.0 mins 3.6000 secs	unsat, 0.0 mins 4.5037 secs
0.02	unsat, 1.0 mins 25.600 secs	unsat, 1.0 mins 54.697 secs	unsat, 1.0 mins 26.374 secs	sat, 0.0 mins 6.5978 secs	unsat, 0.0 mins 33.761 secs	unsat, 3.0 mins 33.496 secs	unsat, 7.0 mins 9.6910 secs	unsat, 20.0 mins 55.48 secs	unsat, 3.0 mins 21.485 secs	unsat, 0.0 mins 19.967 secs
0.05	sat, 0.0 mins 5.1678 secs	sat, 11.0 mins 52.27 secs	sat, 1.0 mins 0.4788 secs	sat, 0.0 mins 4.5492 secs	unsat, 2.0 mins 52.469 secs	sat, 2.0 mins 13.375 secs	sat, 0.0 mins 14.127 secs	TIMEOUT, 30.0 mins 0.284 secs	TIMEOUT, 30.0 mins 0.883 secs	sat, 0.0 mins 40.920 secs
0.1	sat, 0.0 mins 4.5128 secs	sat, 0.0 mins 40.429 secs	TIMEOUT, 30.0 mins 0.264 secs	sat, 0.0 mins 3.6368 secs	unsat, 17.0 mins 32.28 secs	sat, 0.0 mins 3.5728 secs	sat, 0.0 mins 2.9800 secs	sat, 6.0 mins 38.539 secs	sat, 2.0 mins 0.6203 secs	sat, 0.0 mins 19.375 secs
0.2	sat, 0.0 mins 8.1454 secs	sat, 0.0 mins 3.2062 secs	sat, 0.0 mins 3.4176 secs	sat, 0.0 mins 3.0692 secs	sat, 0.0 mins 7.8577 secs	sat, 0.0 mins 3.6533 secs	sat, 0.0 mins 1.7905 secs	sat, 0.0 mins 1.4315 secs	sat, 0.0 mins 2.0518 secs	sat, 0.0 mins 2.0376 secs
0.5	sat, 0.0 mins 27.871 secs	sat, 0.0 mins 3.1687 secs	sat, 0.0 mins 3.1750 secs	sat, 2.0 mins 22.658 secs	sat, 13.0 mins 25.53 secs	sat, 0.0 mins 4.6637 secs	sat, 0.0 mins 26.322 secs	sat, 0.0 mins 2.6752 secs	sat, 0.0 mins 3.0361 secs	sat, 0.0 mins 21.969 secs
1	sat, 0.0 mins 2.3174 secs	sat, 0.0 mins 2.2881 secs	sat, 0.0 mins 4.7082 secs	sat, 0.0 mins 2.6731 secs	sat, 0.0 mins 46.924 secs	sat, 0.0 mins 2.2704 secs	sat, 0.0 mins 2.7092 secs	sat, 0.0 mins 1.8377 secs	sat, 0.0 mins 52.589 secs	sat, 0.0 mins 2.0149 secs
2	sat, 0.0 mins 1.6868 secs	sat, 0.0 mins 1.5478 secs	sat, 0.0 mins 33.925 secs	sat, 0.0 mins 2.2958 secs	sat, 0.0 mins 1.7938 secs	sat, 0.0 mins 2.2154 secs	sat, 0.0 mins 2.7128 secs	sat, 0.0 mins 1.5994 secs	sat, 0.0 mins 1.7693 secs	sat, 0.0 mins 1.4676 secs
5	sat, 0.0 mins 1.4275 secs	sat, 0.0 mins 1.6482 secs	sat, 0.0 mins 1.3987 secs	sat, 0.0 mins 2.1718 secs	sat, 0.0 mins 1.7334 secs	sat, 0.0 mins 1.6775 secs	sat, 0.0 mins 2.3645 secs	sat, 0.0 mins 1.3814 secs	sat, 0.0 mins 1.5476 secs	sat, 0.0 mins 1.2121 secs

Stats: layer 8

sample ids

ϵ

	0	16	99	123	233	500	666	777	888	1000
0.0001	unsat, 0.0 mins 0.0921 secs	unsat, 0.0 mins 0.1057 secs	unsat, 0.0 mins 0.1076 secs	unsat, 0.0 mins 0.0959 secs	unsat, 0.0 mins 0.0903 secs	unsat, 0.0 mins 0.0898 secs	unsat, 0.0 mins 0.0905 secs	unsat, 0.0 mins 0.0899 secs	unsat, 0.0 mins 0.0889 secs	unsat, 0.0 mins 0.1075 secs
0.0002	unsat, 0.0 mins 0.0921 secs	unsat, 0.0 mins 0.0979 secs	unsat, 0.0 mins 0.1125 secs	unsat, 0.0 mins 0.0920 secs	unsat, 0.0 mins 0.0950 secs	unsat, 0.0 mins 0.0935 secs	unsat, 0.0 mins 0.0922 secs	unsat, 0.0 mins 0.0923 secs	unsat, 0.0 mins 0.1060 secs	unsat, 0.0 mins 0.1015 secs
0.0005	unsat, 0.0 mins 0.0925 secs	unsat, 0.0 mins 0.0985 secs	unsat, 0.0 mins 0.0941 secs	unsat, 0.0 mins 0.0979 secs	unsat, 0.0 mins 0.0989 secs	unsat, 0.0 mins 0.1006 secs	unsat, 0.0 mins 0.1024 secs	unsat, 0.0 mins 0.1002 secs	unsat, 0.0 mins 0.1056 secs	unsat, 0.0 mins 0.1080 secs
0.001	unsat, 0.0 mins 0.0982 secs	unsat, 0.0 mins 0.0977 secs	unsat, 0.0 mins 0.1002 secs	unsat, 0.0 mins 0.0972 secs	unsat, 0.0 mins 0.0968 secs	unsat, 0.0 mins 0.0958 secs	unsat, 0.0 mins 0.0972 secs	unsat, 0.0 mins 0.0999 secs	unsat, 0.0 mins 0.0976 secs	unsat, 0.0 mins 0.1242 secs
0.002	unsat, 0.0 mins 4.8015 secs	unsat, 0.0 mins 0.1006 secs	unsat, 0.0 mins 0.0991 secs	unsat, 0.0 mins 4.2379 secs	unsat, 0.0 mins 0.0919 secs	unsat, 0.0 mins 0.0940 secs	unsat, 0.0 mins 0.1020 secs	unsat, 0.0 mins 0.0915 secs	unsat, 0.0 mins 0.0937 secs	unsat, 0.0 mins 0.1010 secs
0.005	unsat, 0.0 mins 3.7669 secs	unsat, 0.0 mins 0.0937 secs	unsat, 0.0 mins 16.927 secs	unsat, 0.0 mins 4.7429 secs	unsat, 0.0 mins 1.1234 secs	unsat, 0.0 mins 17.126 secs	unsat, 0.0 mins 59.201 secs	unsat, 0.0 mins 0.0958 secs	unsat, 0.0 mins 0.0976 secs	unsat, 0.0 mins 3.9719 secs
0.01	sat, 0.0 mins 5.0207 secs	unsat, 1.0 mins 32.422 secs	unsat, 2.0 mins 49.618 secs	unsat, 1.0 mins 19.518 secs	unsat, 0.0 mins 6.4053 secs	unsat, 2.0 mins 26.877 secs	unsat, 18.0 mins 29.48 secs	unsat, 1.0 mins 17.493 secs	unsat, 1.0 mins 34.884 secs	unsat, 0.0 mins 43.415 secs
0.02	sat, 0.0 mins 39.019 secs	unsat, 2.0 mins 42.346 secs	unsat, 19.0 mins 19.43 secs	sat, 0.0 mins 26.951 secs	unsat, 4.0 mins 28.106 secs	unsat, 19.0 mins 54.02 secs	sat, 7.0 mins 20.858 secs	TIMEOUT, 30.0 mins 0.314 secs	unsat, 4.0 mins 34.847 secs	unsat, 0.0 mins 13.907 secs
0.05	sat, 0.0 mins 15.918 secs	TIMEOUT, 38.0 mins 0.239 secs	sat, 2.0 mins 41.771 secs	sat, 0.0 mins 2.9998 secs	TIMEOUT, 30.0 mins 0.750 secs	sat, 5.0 mins 9.2604 secs	TIMEOUT, 30.0 mins 0.476 secs	TIMEOUT, 30.0 mins 0.237 secs	TIMEOUT, 30.0 mins 0.396 secs	sat, 3.0 mins 46.533 secs
0.1	sat, 0.0 mins 5.5852 secs	sat, 5.0 mins 42.532 secs	sat, 13.0 mins 47.54 secs	sat, 0.0 mins 3.4158 secs	sat, 18.0 mins 51.02 secs	sat, 8.0 mins 44.016 secs	sat, 0.0 mins 3.0710 secs	TIMEOUT, 30.0 mins 0.220 secs	sat, 0.0 mins 5.1121 secs	sat, 0.0 mins 4.6951 secs
0.2	sat, 0.0 mins 3.1863 secs	sat, 0.0 mins 2.6289 secs	sat, 0.0 mins 3.0203 secs	sat, 0.0 mins 3.1118 secs	sat, 0.0 mins 2.8920 secs	sat, 0.0 mins 2.9299 secs	sat, 0.0 mins 4.6405 secs	sat, 0.0 mins 4.0211 secs	sat, 0.0 mins 4.0424 secs	sat, 0.0 mins 3.1441 secs
0.5	sat, 0.0 mins 3.5424 secs	sat, 0.0 mins 4.4753 secs	sat, 0.0 mins 3.2057 secs	sat, 0.0 mins 3.1624 secs	sat, 0.0 mins 3.9593 secs	sat, 0.0 mins 3.3335 secs	sat, 0.0 mins 15.386 secs	sat, 0.0 mins 2.7801 secs	sat, 0.0 mins 2.7029 secs	sat, 0.0 mins 3.1667 secs
1	sat, 0.0 mins 2.0794 secs	sat, 0.0 mins 2.4824 secs	sat, 0.0 mins 2.3170 secs	sat, 0.0 mins 2.6057 secs	sat, 0.0 mins 2.6165 secs	sat, 0.0 mins 2.1784 secs	sat, 0.0 mins 1.9465 secs	sat, 0.0 mins 1.6106 secs	sat, 0.0 mins 2.2328 secs	sat, 0.0 mins 2.3040 secs
2	sat, 0.0 mins 1.8163 secs	sat, 0.0 mins 2.5110 secs	sat, 0.0 mins 2.3178 secs	sat, 0.0 mins 2.0853 secs	sat, 0.0 mins 2.2837 secs	sat, 0.0 mins 2.0815 secs	sat, 0.0 mins 2.3859 secs	sat, 0.0 mins 2.0039 secs	sat, 0.0 mins 1.9621 secs	sat, 0.0 mins 2.3605 secs
5	sat, 0.0 mins 1.9230 secs	sat, 0.0 mins 1.8785 secs	sat, 0.0 mins 2.2026 secs	sat, 0.0 mins 1.7922 secs	sat, 0.0 mins 2.1812 secs	sat, 0.0 mins 1.4921 secs	sat, 0.0 mins 1.4409 secs	sat, 0.0 mins 1.5343 secs	sat, 0.0 mins 1.9815 secs	sat, 0.0 mins 2.2245 secs

Table 1
Overview of eXplainable AI (XAI) techniques used in medical image analysis, classified by the framework from Section 2.

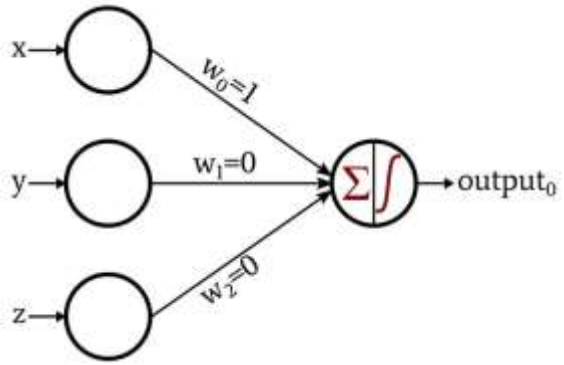
Technique	Section	Authors	Model- based	Post hoc	Model-specific	Model-agnostic	Global	Local
Visual explanation	3.1.							
Backpropagation-based approaches	3.1.1							
Backpropagation	3.1.1.1.	Simonyan et al. (2013)		√	√			√
Deconvolution	3.1.1.1.	Zeiler and Fergus (2014)		√	√			√
Guided backpropagation	3.1.1.1.	Springenberg et al. (2014)		√	√			√
Class activation mapping (CAM)	3.1.1.2.	Zhou et al. (2016)		√	√			√
Gradient-weighted class activation mapping (Grad-CAM)	3.1.1.3.	Selvaraju et al. (2017)		√	√			√
Layer-wise relevance propagation (LRP)	3.1.1.4.	Bach et al. (2015)		√	√			√
Deep SHapley Additive exPlanations (Deep SHAP)	3.1.1.5.	Lundberg and Lee (2017)		√	√	√*	√*	√
Trainable attention	3.1.1.6.	Jetley et al. (2018)	√		√			√
Perturbation-based approaches	3.1.2							
Occlusion sensitivity	3.1.2.1.	Zeiler and Fergus (2014)		√		√		√
Local Interpretable Model-agnostic Explanations (LIME)	3.1.2.2.	Ribeiro et al. (2016)		√		√		√
Meaningful Perturbation	3.1.2.3.	Fong and Vedaldi (2017)		√		√		√
Prediction difference analysis	3.1.2.4.	Zintgraf et al. (2017)		√		√		√
Textual explanation	3.2.							
Image captioning	3.2.1.	Vinyals et al. (2015)	√		√			√
Image captioning with visual explanation	3.2.2.	Zhang et al. (2017a)	√		√			√
Testing with Concept Activation Vectors (TCAV)	3.2.3.	Kim et al. (2018)		√		√	√	√
Example-based explanation	3.3.							
Triplet networks	3.3.1.	Hoffer and Ailon (2015)	√		√		√	√
Influence functions	3.3.2.	Wei Koh and Liang (2017)		√		√	√	
Prototypes	3.3.3	Chen et al. 2019	√		√			√

Survey:
Neural Activations & Applications

Yichuan Song

Outline

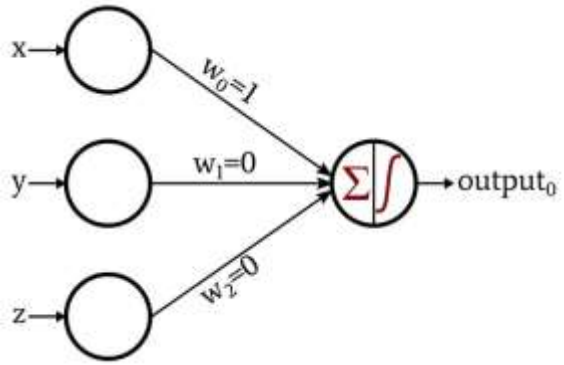
- Def. of activations:



perceptron

Outline

- Def. of activations:

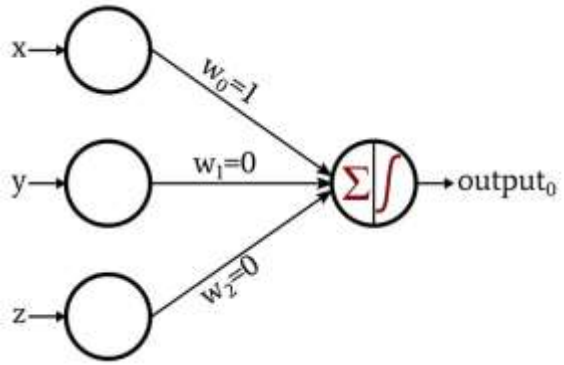


perceptron

Let's generalize the conceptio

Outline

- Def. of activations:
  - how much dependency the model put on a bunch of inner representations in the process of generating the output
  - Properties: inner, non-linear



perceptron

Let's generalize the conceptio

Outline

- Def. of activations:
  - how much dependency the model put on a bunch of inner representations in the process of generating the output
  - Properties: inner, non-linear
- Types of inner representations -> their fields:

  a. Feature maps -> CNN

  b. Hidden states (e.g. q, k, v) -> Transformers' attention, LM decoding

  c. Network connectiveness -> Model quantization

Outline

- Def. of activations:
  - how much dependency the model put on a bunch of inner representations in the process of generating the output
  - Properties: inner, non-linear
- Types of inner representations -> their fields:
  a. Feature maps -> CNN
  b. Hidden states (e.g. q, k, v), Attention Heads-> Transformers' attention
  c. Network connectiveness -> Model quantization
- Applications:
  - Intepretability (uncertainty, understanding)
  - Faster inference
  - …

Part a

CNNs - feature maps

1. Class Activation Maps (CAM)

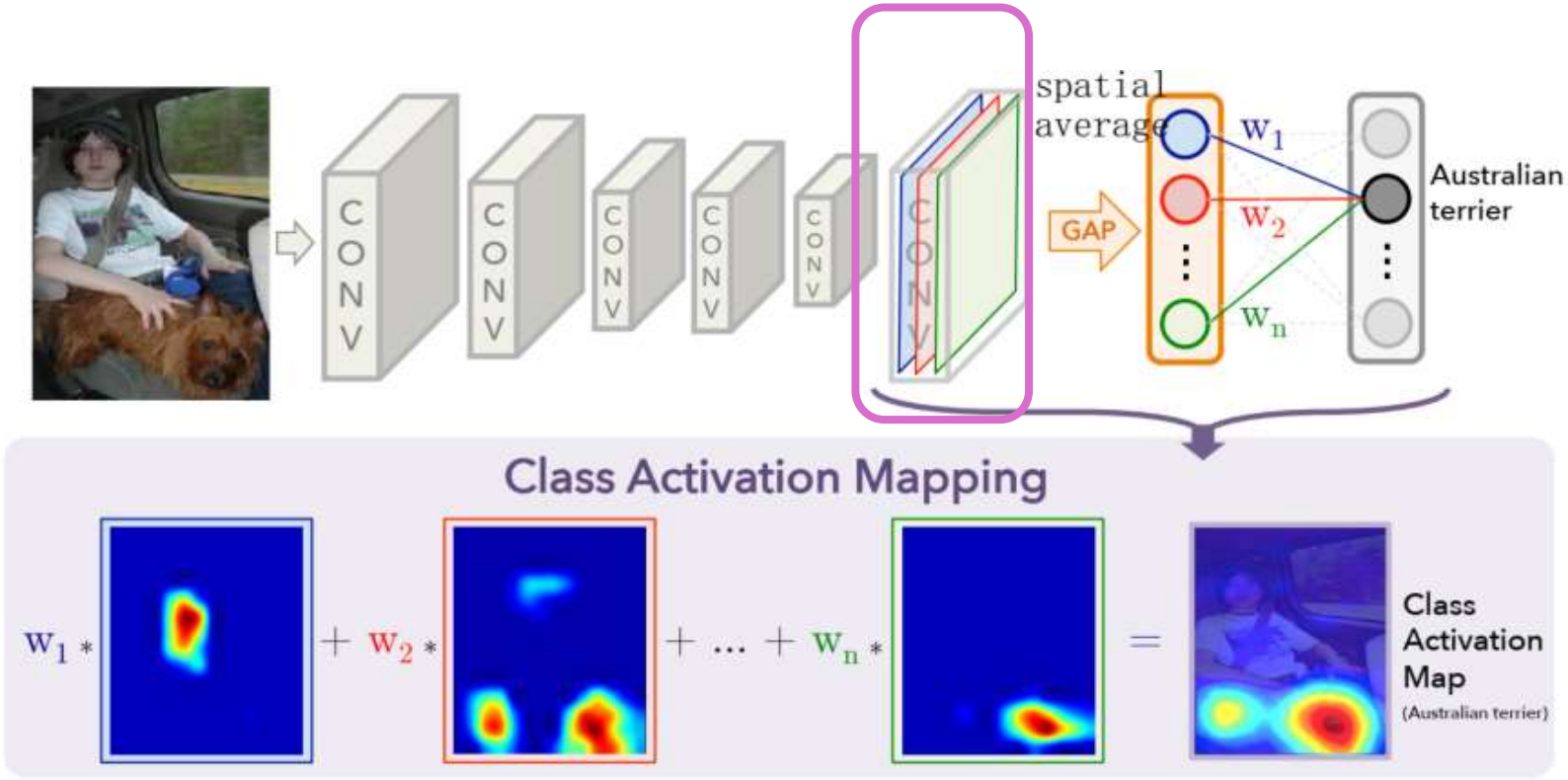


Figure 2. Class Activation Mapping: the predicted class score is mapped back to the previous convolutional layer to generate the class activation maps (CAMs). The CAM highlights the class-specific discriminative regions.

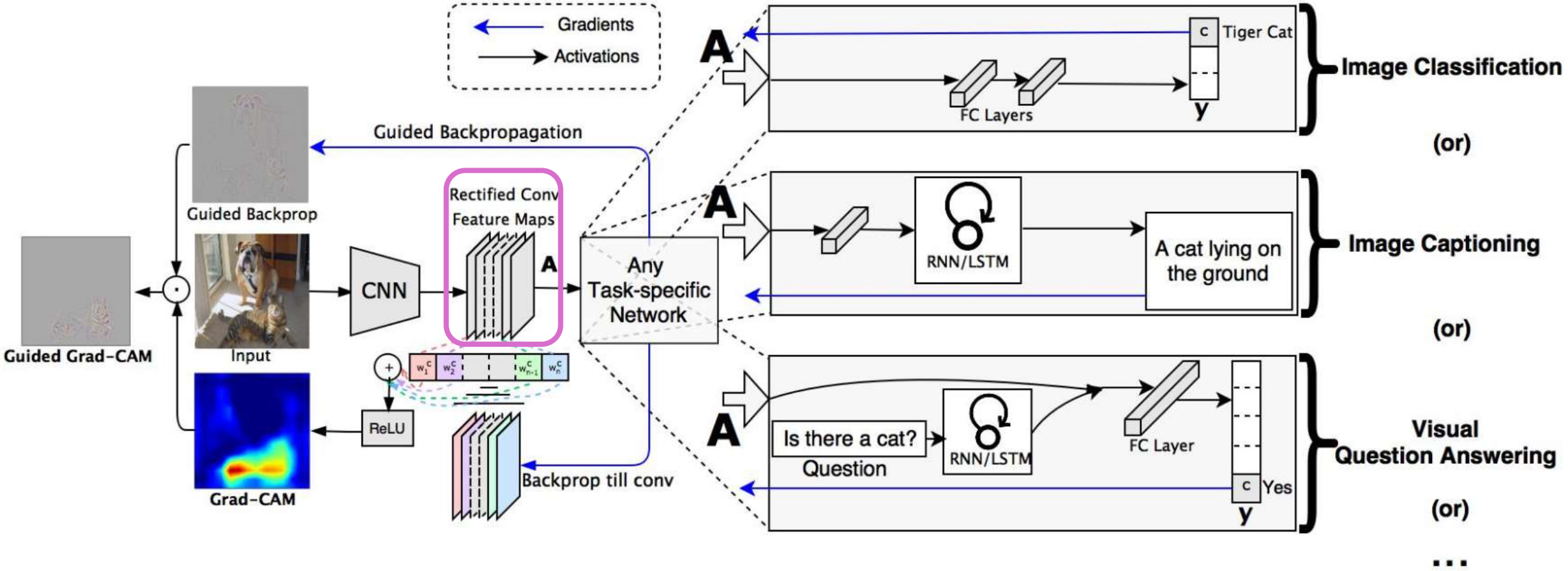
- Field: CV(CNN)
- Activation: weighted sum of feature maps (i.e. CAM)
- Application: CNN, discriminative localization, weakly-supervised tasks

Ref: Learning Deep Features for Discriminative

2. Grad-CAM

Field: CV(CNN)

- Activation: rectified Conv feature maps (i.e. CAM)
- Application: CNN discriminative localization

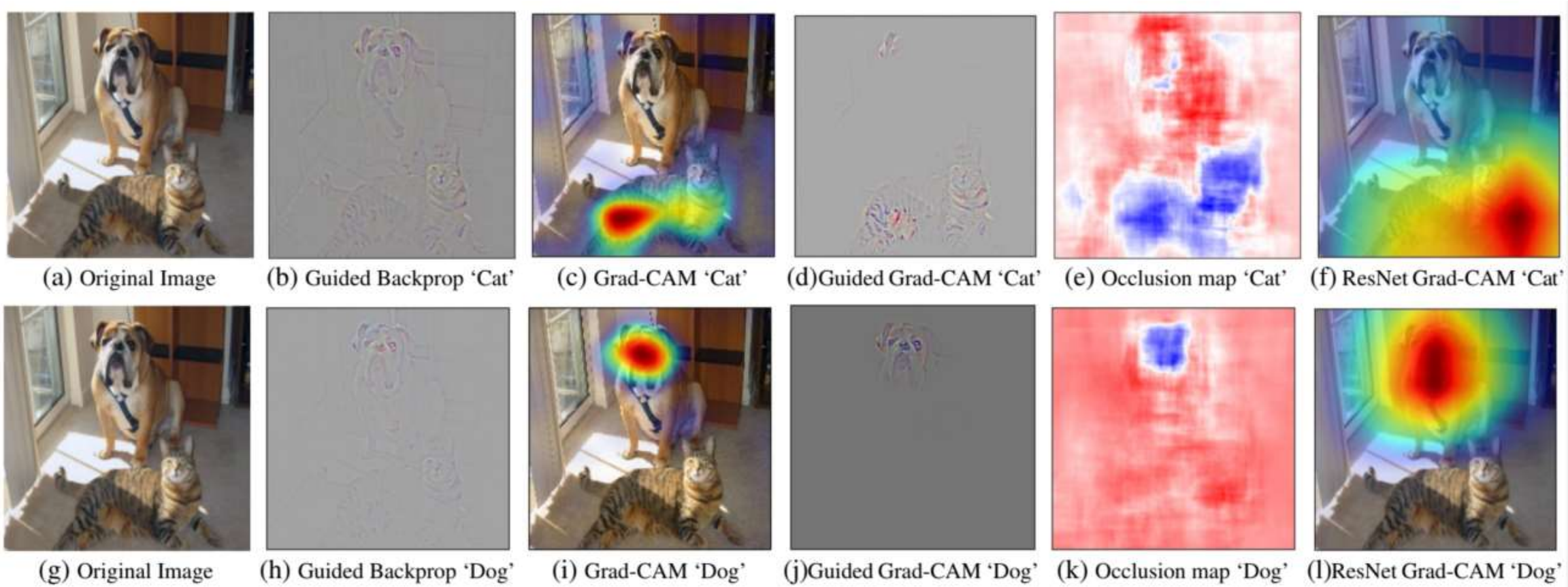


Ref: Grad-CAM: Visual Explanations from Dee Networks via Gradient-based

Guided-

2. Grad-CAM

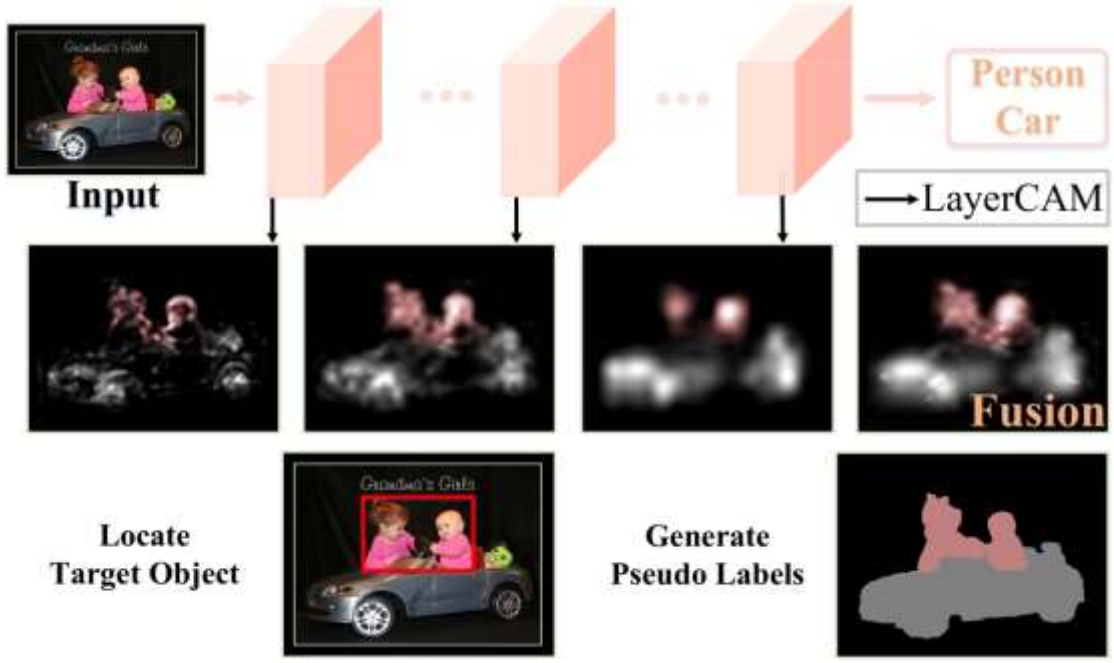
(d,j): Combining high-resolution (b, h) and class-discrimination (c, i)

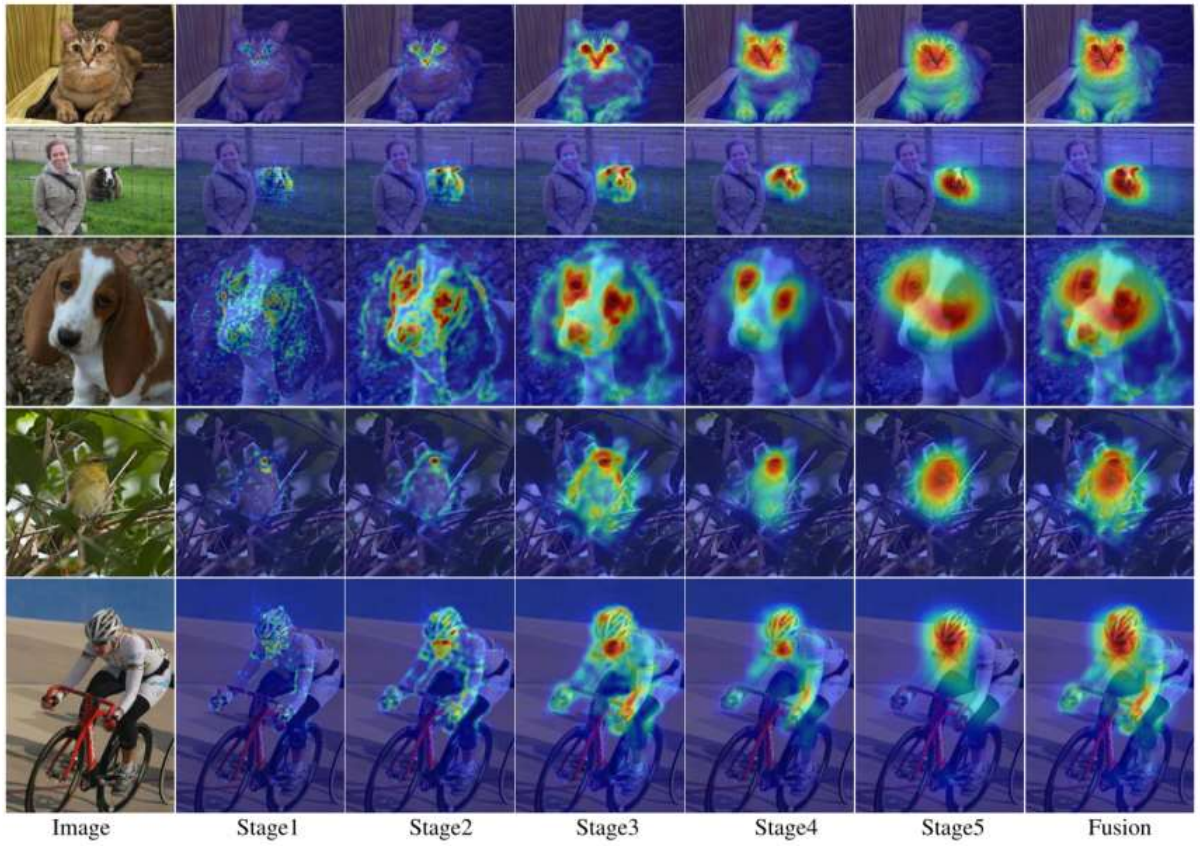


Ref: Grad-CAM: Visual Explanations from Dee Networks via Gradient-based

3. LayerCAM ~more fine-grained localization

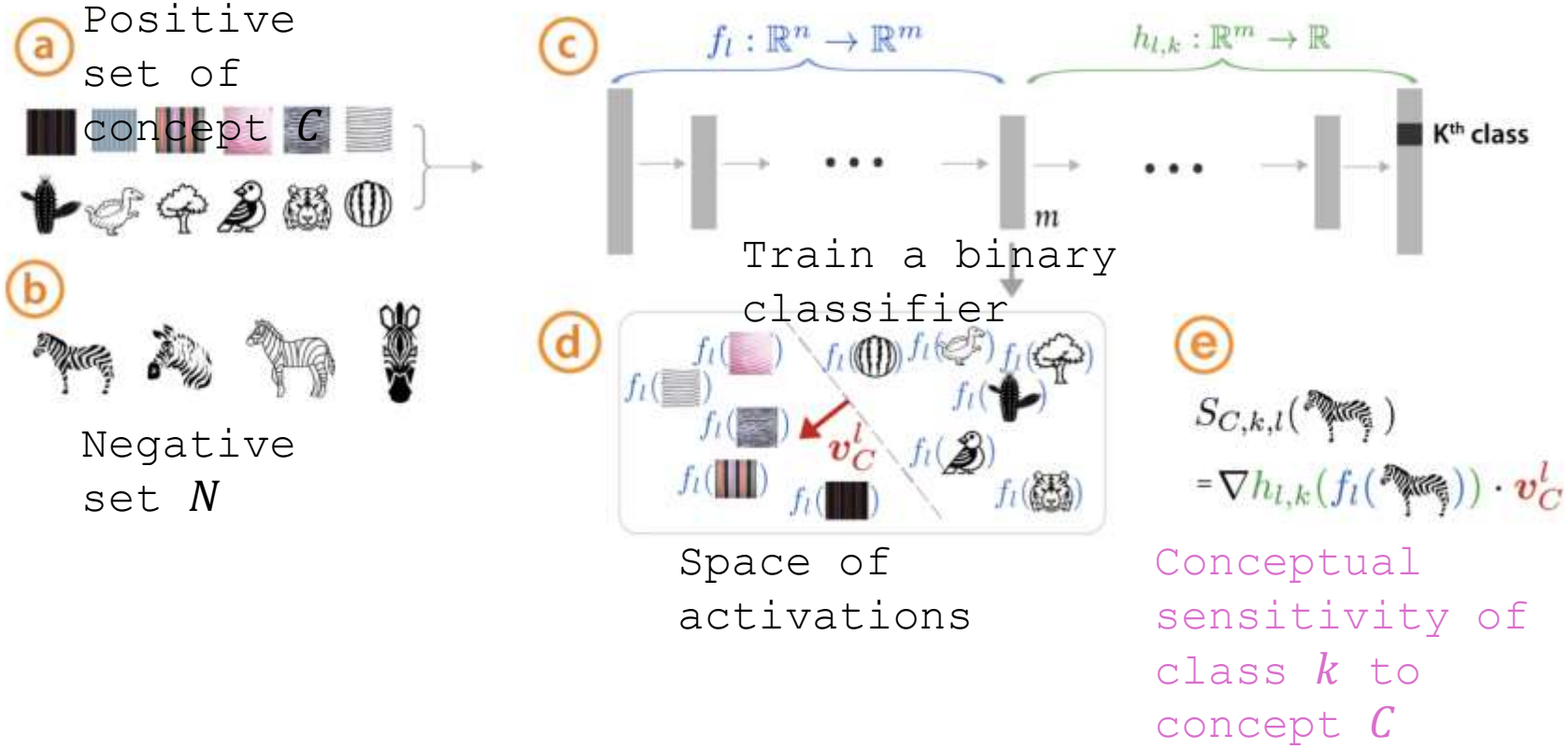
- Field: CV(CNN)
- Activation: weighted sum of feature maps (weights are positive gradients)
- Application: pixel-accurate object





Ref: LayerCAM: Exploring Hierarchical Class Activation Maps for Localization (*IE*

4. Testing with Concept Activation Vectors (TCAV)



- Field: CV(CNN), Model Interpretability
- Activation: outputs of each hidden layer in a network $f_l(x)$
- Application: "conceptual sensitivity"

Ref: Interpretability Beyond Feature Attribution: Quantitative Testing with Concep

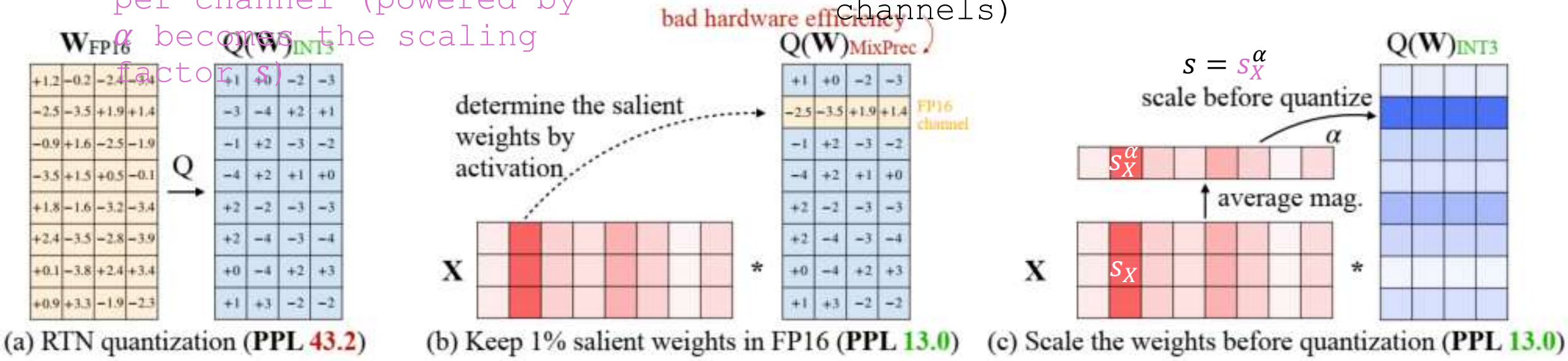
Part b

Quantization - connectiveness

5. Activation-aware Weight Quantization (AWQ)

- Field: ML Sys
- Activation: the average magnitude of activation per channel (powered by α becomes the scaling factor s)
- Application: on-device LLM & VLM

(finding salient weight channels)



(a) RTN quantization (**PPL 43.2**)

(b) Keep 1% salient weights in FP16 (**PPL 13.0**)

(c) Scale the weights before quantization (**PPL 13.0**)

Method1: Round To Nearest

Method2: Mix Precision

Method3: AWQ

Ref: AWQ for On-Device LLM Compression and

Part c

Transformers – attention & decoding

6. Retrieval Head

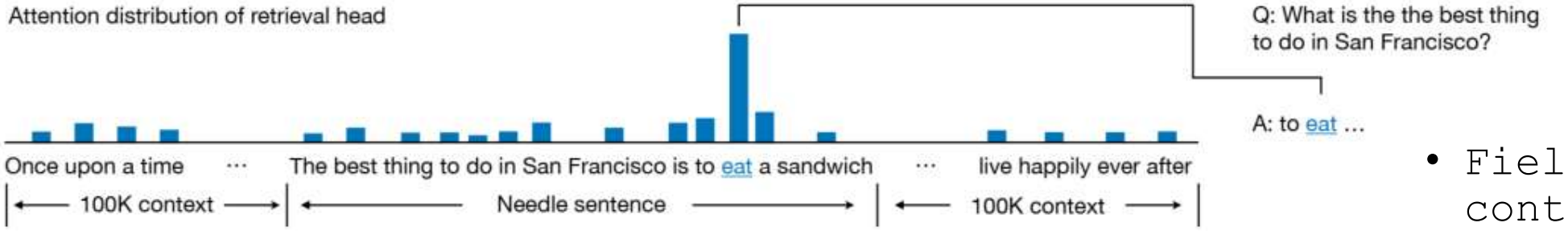


Fig 1. Illustration of Needle-In-a-Haystack test

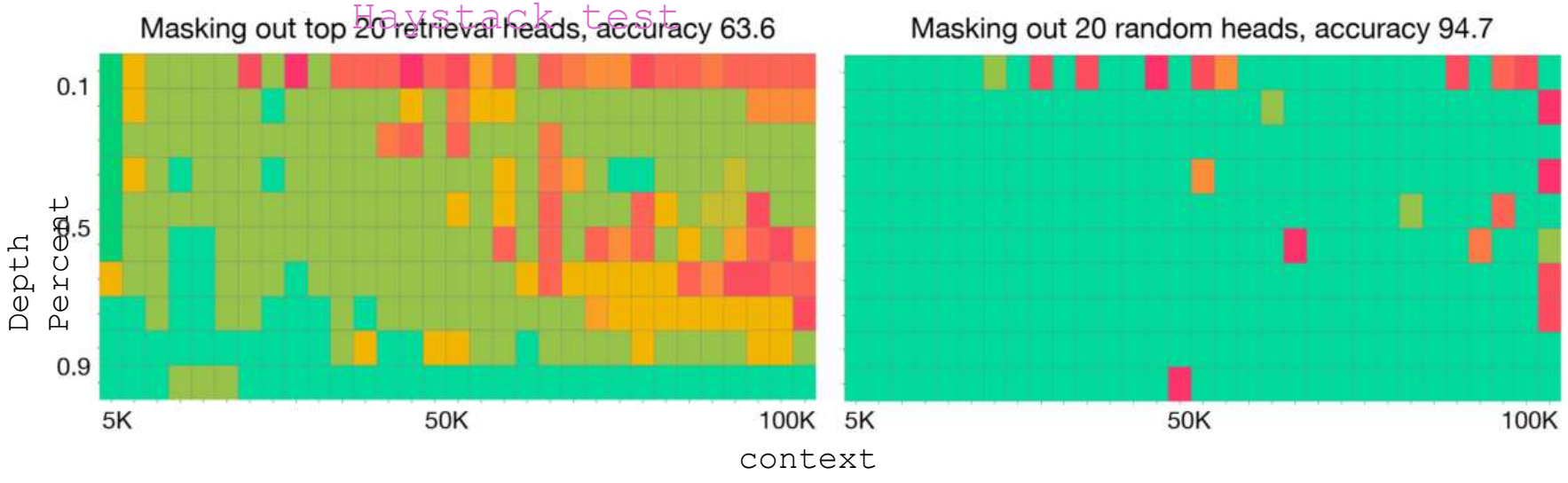


Fig 2. Masking out retrieval heads from LLaMA 2 7B 80K

- Field: NLP (long-context models)
- Activation: certain set of attention heads which frequently "copy-and-paste" tokens from the context (i.e. retrieval head)
- Appendix:
  - "copy-and-paste"
  - retrieval score

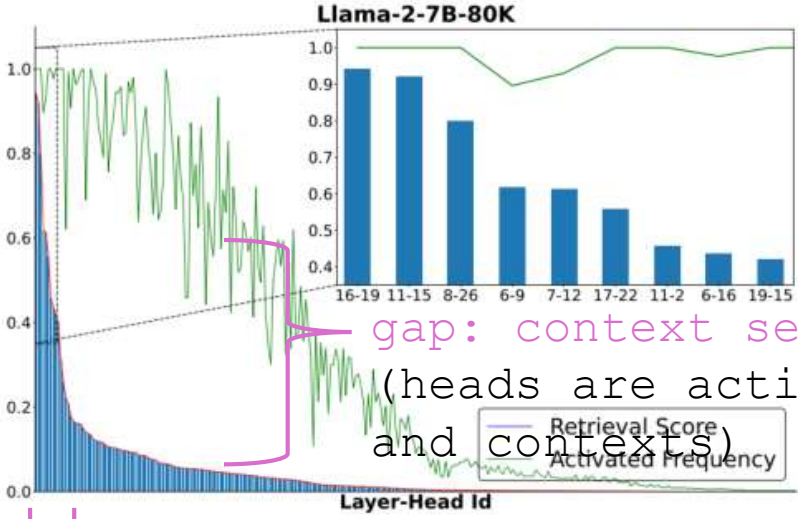
Ref: Retrieval Head Mechanistically Explains Long-

6. Retrieval Head

Application:

- explainability of model hallucination for long-context tasks
- CoT reasoning

Fig 3. explainability of retrieval errors



gap: context sensitivity

(heads are activated on certain tokens and contexts)

Fig 4. heads layouts

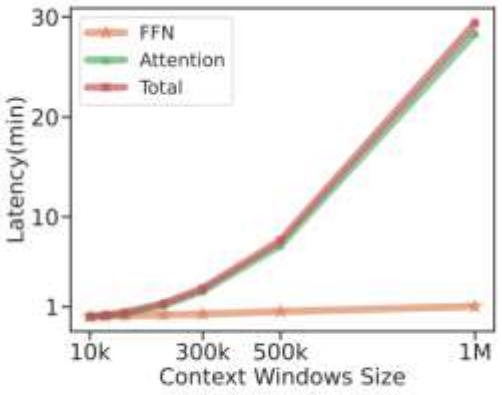
retrieval head (retrieval score above

Properties of retrieval heads:

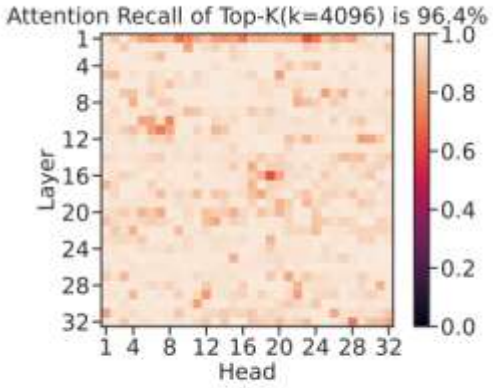
- Universal & scarse
- Dynamically activated
- Intrinsic
- Causal

Ref: Retrieval Head Mechanistically Explains Long-

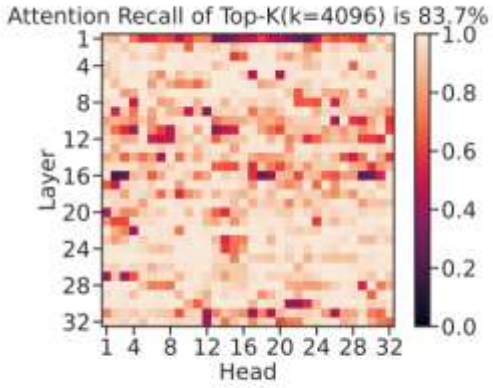
7. Dynamic Sparse Attention



(a) Attention incurs heavy cost.



(b) Attention is sparse.



(c) Sparsity of attention is dynamic.

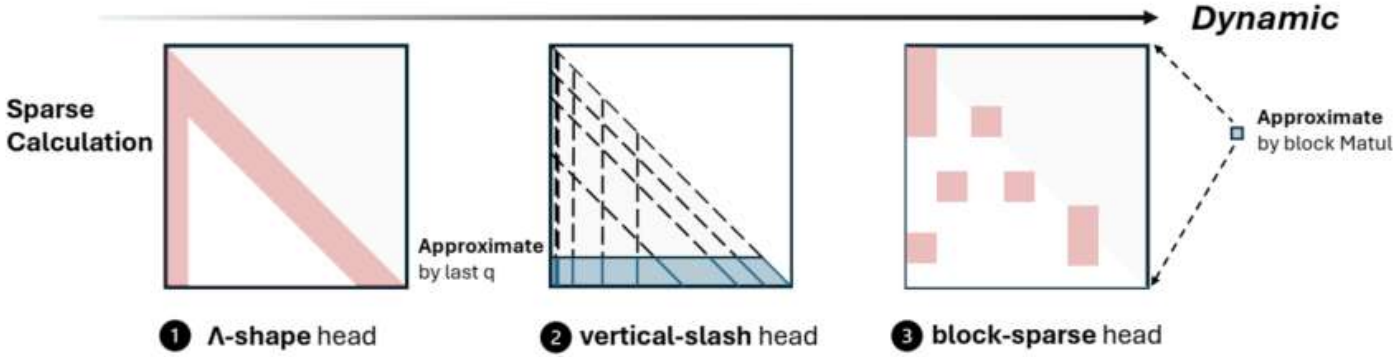


Figure 4: The three sparse methods in MInference.

- Field: NLP (long-context models), ML system
- Activation: certain attention sparse patterns
- Application: accelerating the pre-filling stage of Long-Context LLMs

Attention Sparse Patterns

Ref: MInference 1.0: Accelerating Pre-filling for Long-Context LLMs via Dynamic Sparse Attention (preprint)

7. Dynamic Sparse Attention

Minference contains three steps:

1) Offline attention pattern identification for each head
2) Dynamic build of sparse indices w.r.t. the pattern
3) Sparse attention calculation with optimized GPU kernels.

Table 1: Comparison of different sparse patterns.

Patterns	A-shape	Vertical-Slash	Block-Sparse	Top-K
Spatial Distribution	Static structured	Dynamic structured	Dynamic structured	Dynamic fine-grained
Latency on GPU	Low	Medium	Low	High
Time to build the index	Zero	Small	Small	High

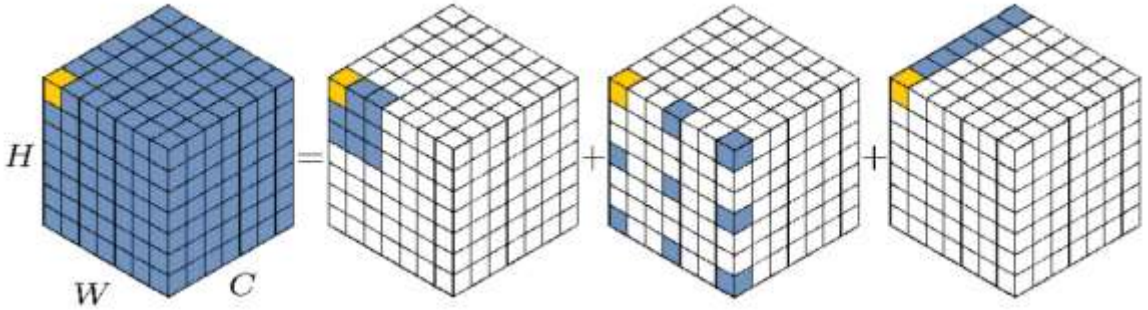
Attention Sparse Patterns

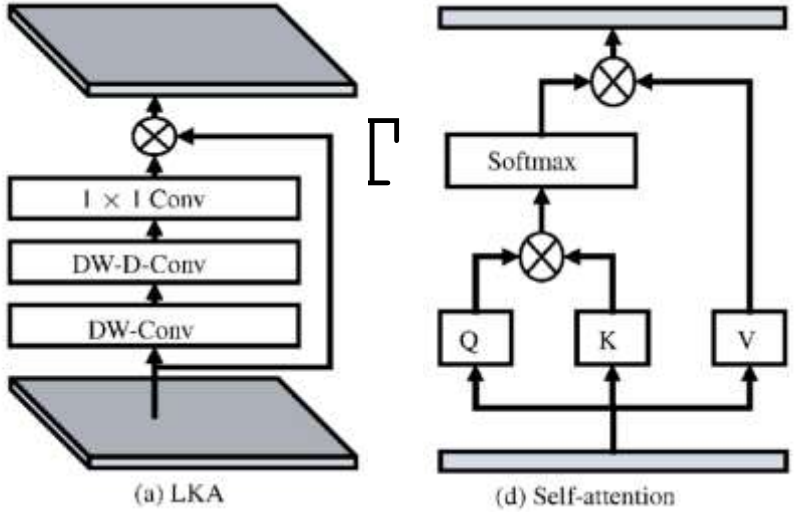
Ref: MInference 1.0: Accelerating Pre-filling for Long-Context LLMs via Dynamic Sparse Attention (preprint)

Thanks!

6. Vision Transforme

- Field: CV(CNN)
- Activation: Large Kernel Activation (LKA)
- Application: CNN, discriminative localization





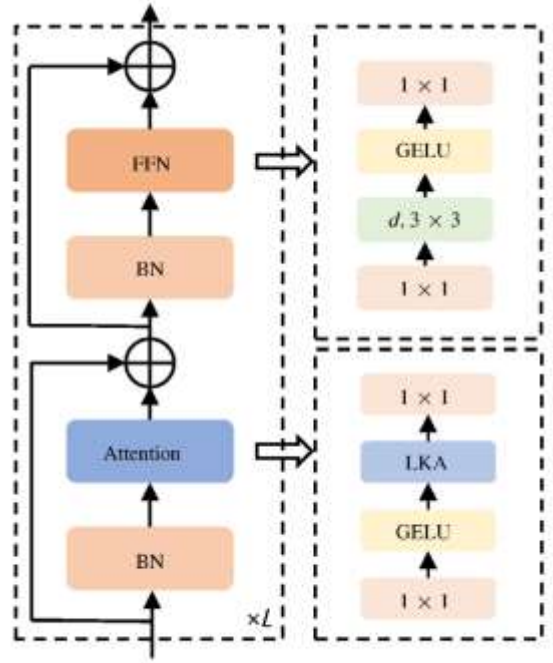


Fig. 4 A stage of VAN. d means depth-wise convolution. $k \times k$ denotes $k \times k$ convolution.

Ref: Learning Deep Features for Discriminative

7. Conformer

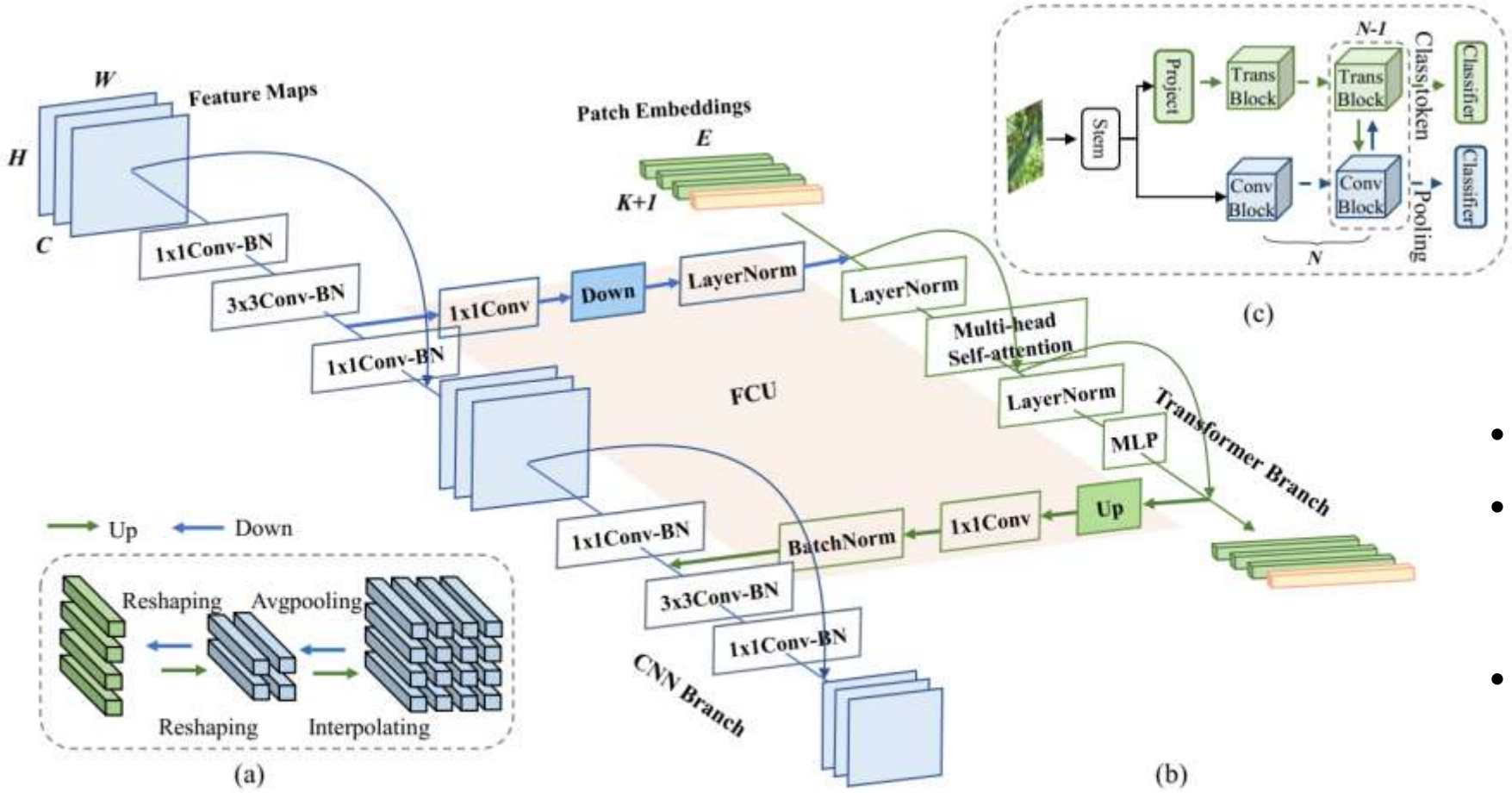


Figure 2: Network architecture of the proposed Conformer. (a) Up-sampling and down-sampling for spatial alignment of feature maps and patch embeddings. (b) Implementation details of the CNN block, the transformer block, and the Feature Coupling Unit (FCU). (c) Thumbnail of Conformer.

- Field: CV(CNN)
- Activation: Large Kernel Activation (LKA)
- Application: CNN, discriminative localization

Ref: Learning Deep Features for Discriminative

Appendix: More on Marabou

- Marabou is an SMT-based tool that answers queries about neural networks and their properties.
- Marabou first applies multiple pre-processing steps to infer bounds for each node in the network. Next it applies a combination of Simplex search over linear constraints with SMT techniques directing the search over non-linear constraints. Marabou also implements Split-and-Conquer mode, which decomposes the verification query into a set of smaller queries, which can be solved in parallel.
- Supplied network formats: tensorflow, ONNX, NNet

Table 6: Overall Score

#	Tool	Score
1	α-β-CROWN	930.9
2	Marabou	594.1
3	PyRAT	585.5
4	NeuralSAT	547.0
5	nnenum	441.9
6	NNV	176.4
7	FastBATLLNN	100.0

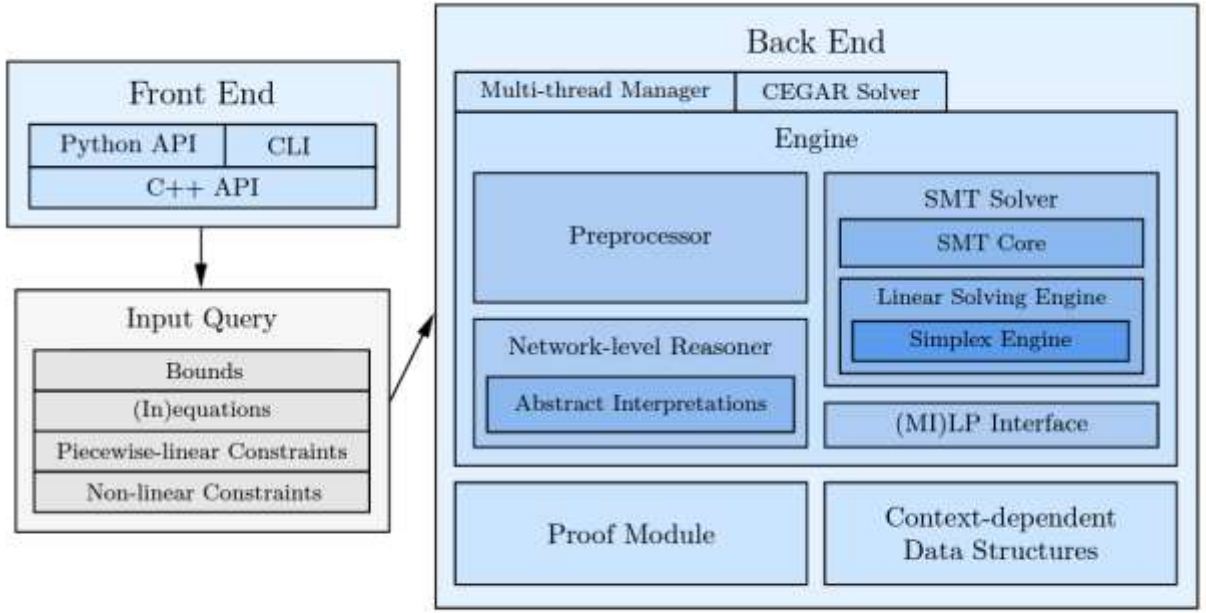


Fig. 1: High-level overview of Marabou 2.0's system architecture.

Marabou 2.0: A Versatile Formal Analyzer of Neural Networks

Appendix: More on CAM

- $M_c(x,y) = \sum_k w_k^c f_k(x,y)$
- $S_c = \sum_{x,y} M_c(x,y)$
- $P_c = \frac{\exp(S_c)}{\sum_c \exp(S_c)}$

- $M_c(x,y) = \sum_k w_k^c f_k(x,y)$
- $S_c = \sum_{x,y} M_c(x,y)$
- $P_c = \frac{\exp(S_c)}{\sum_c \exp(S_c)}$

- $M_c(x,y)$: the class activation map for class c at spatial location (x,y).
- w_k^c: the weight corresponding to class c for unit k.
- $f_k(x,y)$: the activation of unit k in the last convolutional layer at spatial location (x,y).
- S_c: the class score.
- P_c: the output of softmax for class c.

Appendix: More on AWQ

$$\bullet\ y = Q(\boldsymbol{w})\boldsymbol{x}$$

$$\bullet\ Q(\boldsymbol{w}) = \Delta \cdot Round\left(\frac{\boldsymbol{w}}{\Delta}\right), \Delta = \frac{\max(|\boldsymbol{w}|)}{2^{\{N-1\}}}$$

$$\bullet\ Q(w \cdot s) \cdot \frac{x}{s} = \Delta' \cdot Round\left(\frac{ws}{\Delta'}\right) \cdot x \cdot \frac{1}{s}, s > 1, w \in \boldsymbol{w} \quad \text{(AWQ)}$$

- y : the quantized counterpart of $\mathbf{w}\boldsymbol{x}$.
- N: the number of quantization bits.
- Δ: the quantization scaler determined by the absolute maximum value.
- $\Delta' \approx \Delta$:
  - $RoundErr(\cdot) \sim 0.25$
  - Scaling up a single element weight element w usually

Appendix: More on AWQ

- $\boldsymbol{s}^* = argmin_{\boldsymbol{s}}\mathcal{L}(\boldsymbol{s}),\ \ \mathcal{L}(\boldsymbol{s}) = ||\mathrm{Q}\big(\mathbf{W}\cdot diag(\boldsymbol{s})\big)(diag(\boldsymbol{s})^{-1}\cdot\boldsymbol{X}) - \boldsymbol{WX}||$
- $\boldsymbol{s} = \boldsymbol{s}_{\boldsymbol{X}}^{\alpha}, \alpha^* = argmin_{\alpha}\mathcal{L}(\boldsymbol{s}_{\boldsymbol{X}}^{\alpha})$

- $\boldsymbol{s}_{\boldsymbol{X}}$: the average magnitude of activation (per-channel).
- Apply weight clipping to minimize the MSE error of quantization to find the optimal $\boldsymbol{s}$ and $\boldsymbol{\alpha}$.
- $\boldsymbol{X}$: the input features ca

OPT-6.7B	$s=1$	$s=1.25$	$s=1.5$	$s=2$	$s=4$
proportion of $\Delta' \neq \Delta$	0%	2.8%	4.4%	8.2%	21.2%
average Δ'/Δ	1	1.005	1.013	1.038	1.213
average $\frac{\Delta'}{\Delta}\cdot\frac{1}{s}$	1	0.804	0.676	0.519	**0.303**
Wiki-2 PPL	23.54	12.87	12.48	**11.92**	12.36

The best PPL appears

Appendix: More on Retrieval Heads

- Algorithm to find retrieval heads:
  - "copy-and-paste" behavior of attention heads:
    - The token that the head attended to is the same token currently being generated
    - Given question $\boldsymbol{q}$, answer (needle) $\boldsymbol{k}$, and context (haystack) $\boldsymbol{x}$
    - Let w: current token being generated, $\boldsymbol{a} \in \mathbb{R}^{|\boldsymbol{x}|}$: the attention distribution of a head
    - Conditions of a "copy-and-paste" on w:
      - $w \in \boldsymbol{k}$: the token being generated is also in the needle
      - $\boldsymbol{x}_j = w, j = argmax(\boldsymbol{a})$: the token being generated is also the most attended token from the context
  - Retrieval score for head h and needle k:
    - $= \frac{|\boldsymbol{g}_h \cap k|}{|k|}$
    - $\boldsymbol{g}_h$: the set of all tokens copy-and-pasted by a given head h
  - Retrieval heads are attention heads with a retrieval score above a certain threshold

Appendix: More on Retrieval Heads

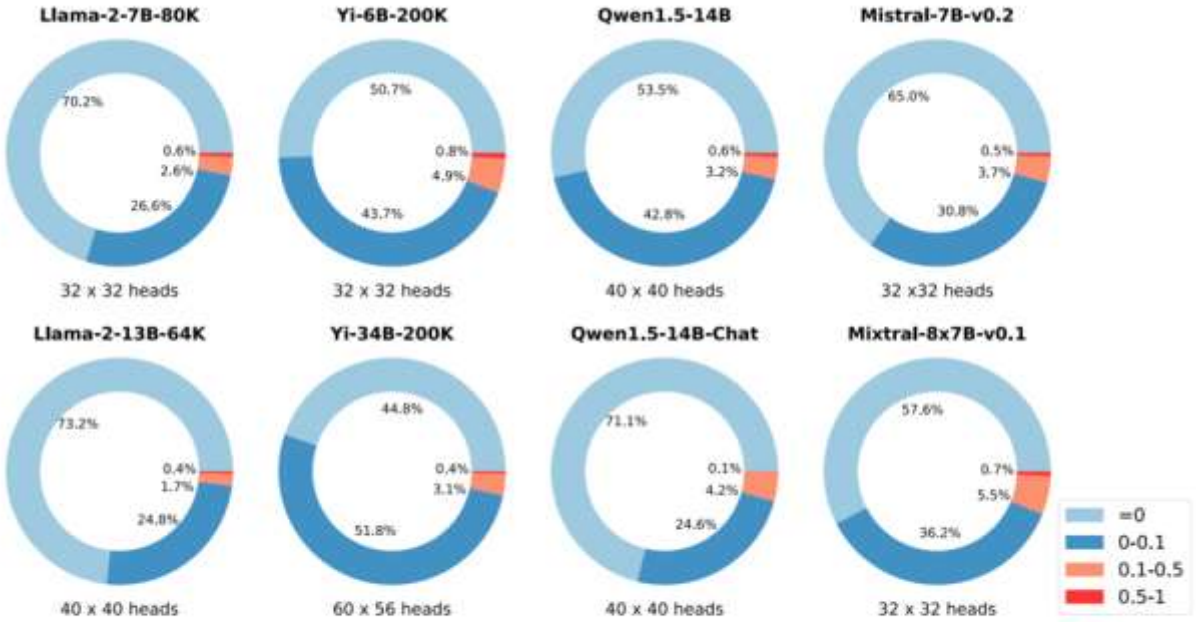


Figure 3: Retrieval heads are universal and sparse across model family and scale. For all models we consider, less than 5% of the attention heads are activated more than 50% of the time (with a retrieval score higher than 0.5) when retrieval is required.

Illustration of universal and scarcity

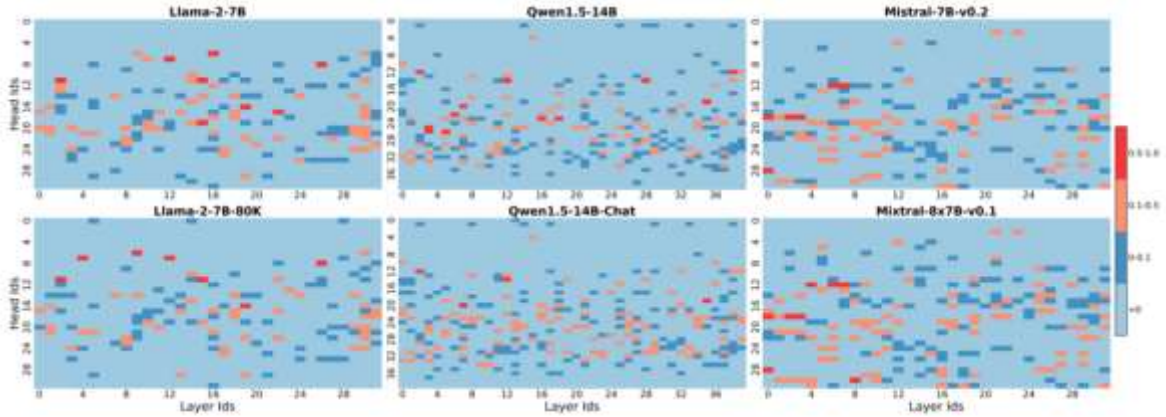
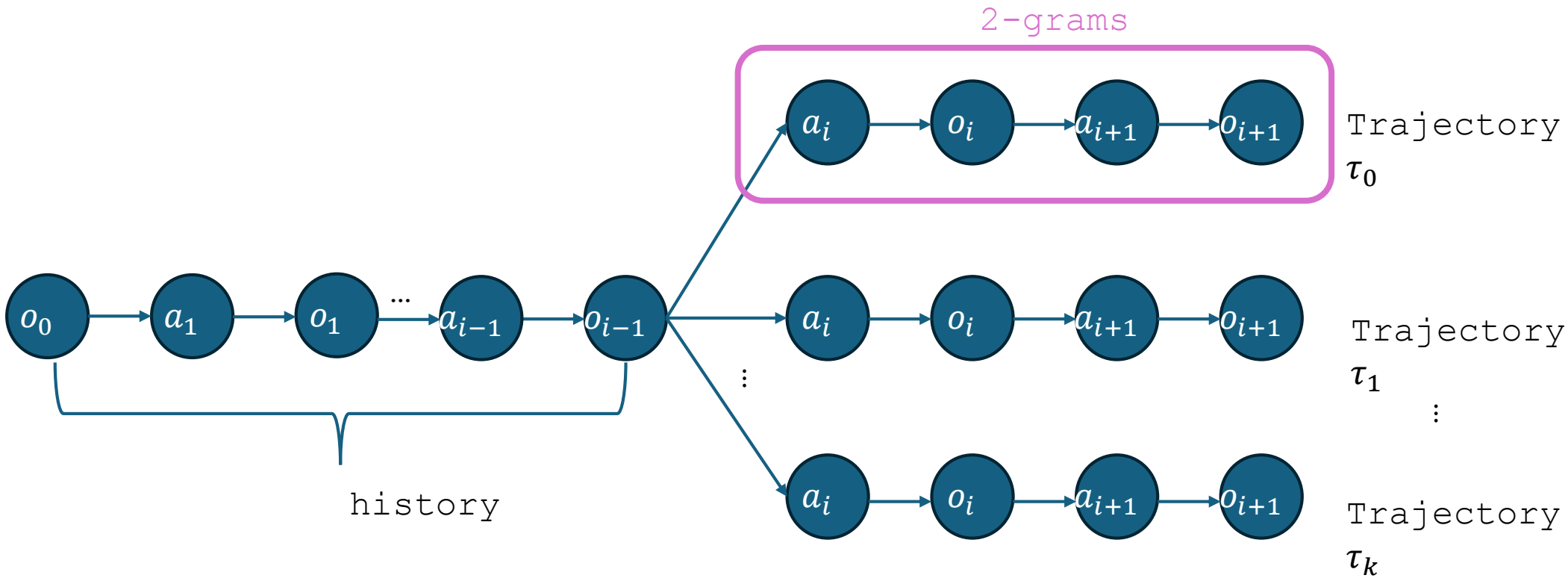


Figure 5: Retrieval head is intrinsic and already within the base model. The subsequent model derivations, either by continue pretraining (LLaMA 2 7B 80K) or chat finetuning (Qwen 1.5 14B Chat) or sparse upcycling (Mixtral 8×7B), use the same set of retrieval head as the base model, as demonstrated by a high level of similarity between the heatmap patterns.

Illustration of intrinsic


2-grams
o_0
a_1
o_1
...
a_{i-1}
o_{i-1}
a_i
o_i
a_{i+1}
o_{i+1}
Trajectory τ_0
Trajectory τ_1
Trajectory τ_k
history