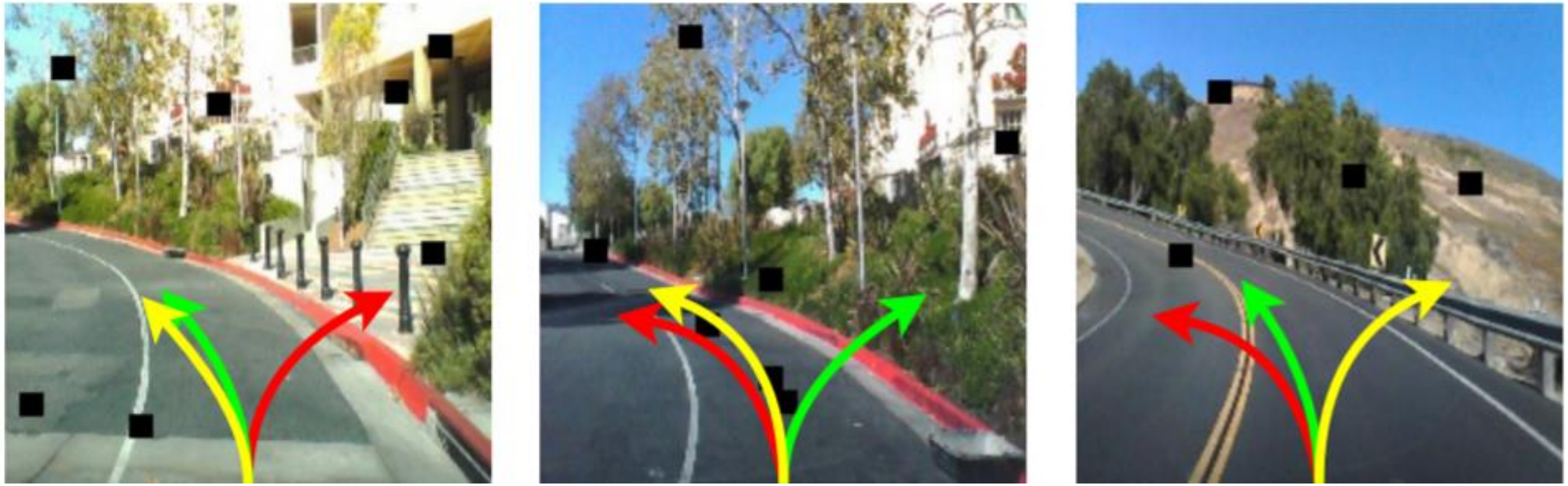
AI2: SAFETY AND ROBUSTNESS CERTIFICATION OF NEURAL NETWORKS WITH ABSTRACT INTERPRETATION

FEBRUARY 11, 2019
PREPARED BY: ALI HARAKEH

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

HOW GOOD IS YOUR NEURAL NETWORK ?



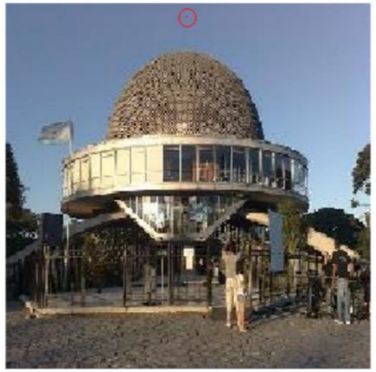
Pei, Kexin, et al. "Deepxplore: Automated whitebox testing of deep learning systems." *Proceedings of the 26th Symposium on Operating Systems Principles*. ACM, 2017.

HOW GOOD IS YOUR NEURAL NETWORK ?

- Neural networks are not robust to input perturbations.

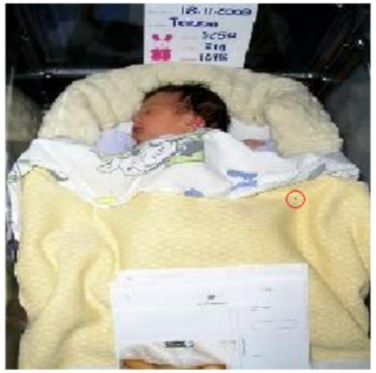
- **Pushing the limit**: One Pixel Attack !
  - Su et. al. "One pixel attack for fooling deep neural networks." IEEE Transactions on Evolutionary Computation (2019).

- **Conclusion:** There is a need for an **automated** and **scalable** analysis to certify realistic neural networks against such input perturbations.



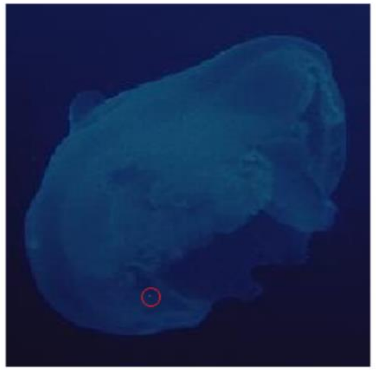
Planetarium

Mosque(7.81%)



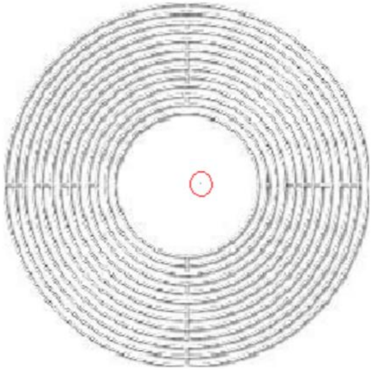
Comforter

Pillow(6.83%)



Jellyfish

Bathing tub(21.18%)



Whorl

Blower (37.00%)

AUTOMATED AND SCALABLE ANALYSIS

- Used to **certify** large scale cyber-physical systems that use NNs.

HOW TO CERTIFY NEURAL NETWORKS ?

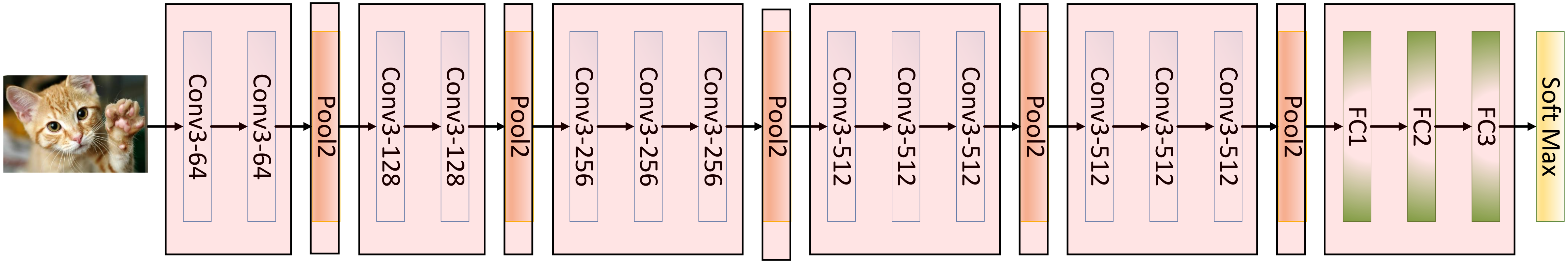
- Given:
  - Neural Network $N(x)$.
  - A set of inputs $x \in \mathcal{X}$, and a property over this set ϕ.
  - A property over outputs ψ.

- To certify a neural network, check whether:

$$\forall x \in \mathcal{X},\ x \in \phi \implies N(x) \in \psi.$$

- **Challenges**:
  - ϕ captures an **unbounded** set of inputs. $Over - approximation$
  - Traditional symbolic solutions **do not scale** to deep neural networks. $Abstract\ Interpretation$

NEURAL NETWORKS AS CATS



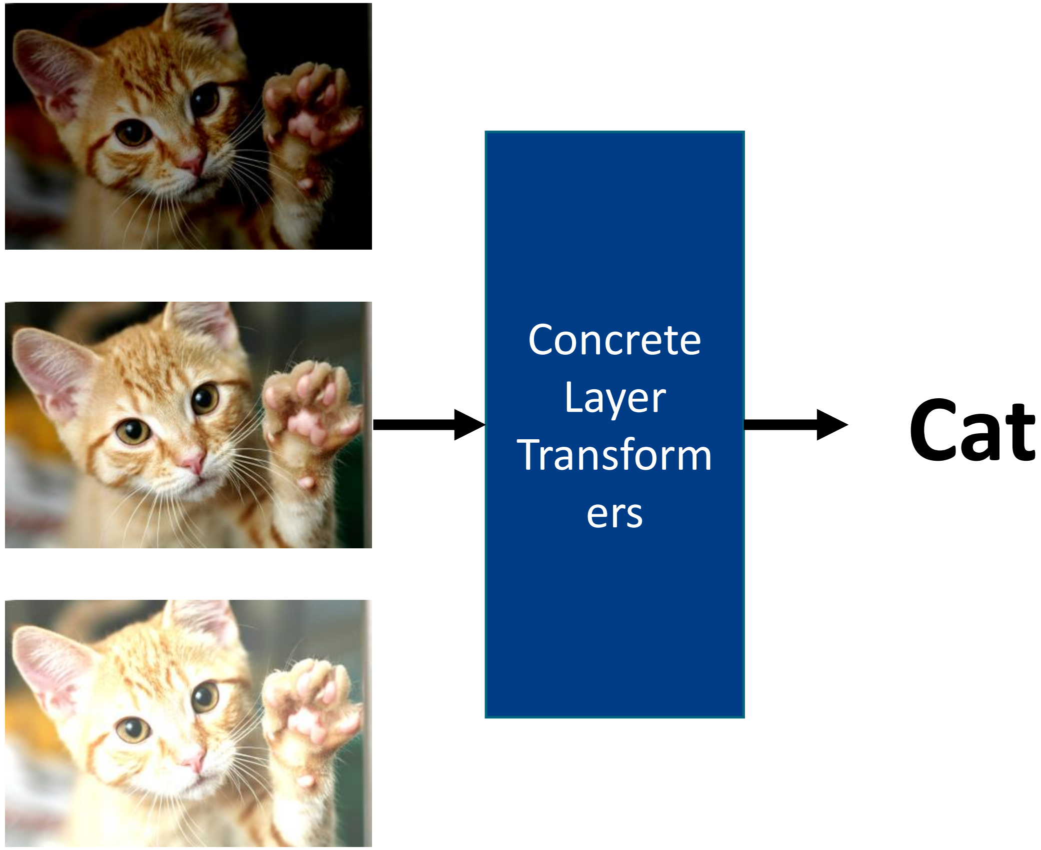
- Convolutional and Fully Connected layers are just **affine transforms** followed by a **restricted non-linearity,** in this case the ReLU**.** Pooling layers can also be expressed this way.

- Such neural network architecture can be described with a **composition** of **C**onditional **A**ffine **T**ransforms (CATs).

ABSTRACT INTERPRETATION (AI) FOR AI

- Certify that neural network is robust to brightness variations:

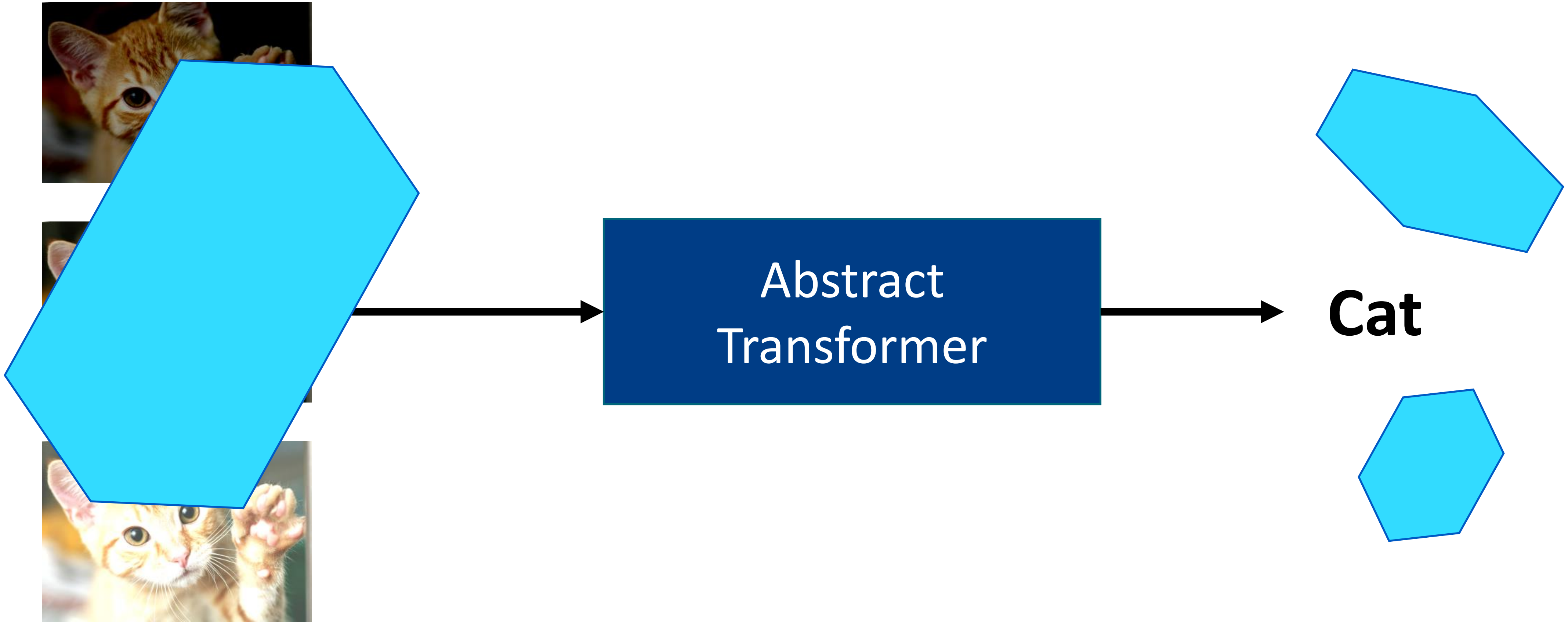
$$\forall x \in \mathcal{X},\ x \in \phi \implies N(x) \in \psi.$$



Concrete Layer Transform ers

Cat

ABSTRACT INTERPRETATION (AI) FOR AI

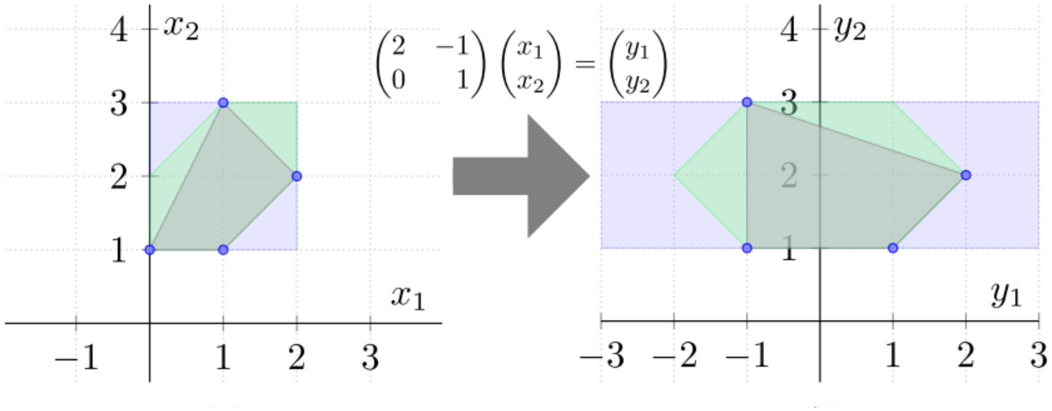


Abstract Transformer

Cat

PROPERTIES OF ABSTRACT INTERPRETATION

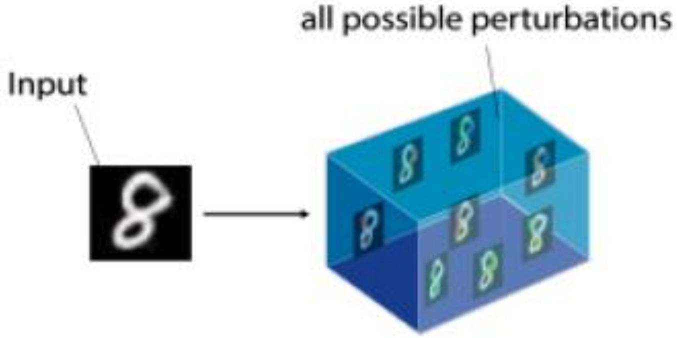
- If the abstract output proves a property, we know that the property holds for all concrete values.
- Every CAT function used in classification NNs can be over-approximated by Abstract Interpretation.
- Various forms of abstract domain can be used, each resulting in a different precision at the expense of scalability.
  - Box.
  - Zonotope.
  - Polyhedron.


$\begin{pmatrix} 2 & -1 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} y_1 \\ y_2 \end{pmatrix}$
x_1
x_2
y_1
y_2
4
3
2
1
−1
1
2
3
4
3
2
1
−3
−2
−1
1
2
3

USE CASE OF AI2: PROVE ABSENCE OF ADVERSARIAL ATTACK

- **Step 1:** Define adversarial region around input **x** based on the perturbation of interest. For example:

$$L_\infty \ \mathbf{ball}: \ \ Ball_\epsilon(x) = \{y \mid ||x - y||_\infty < \epsilon\}$$

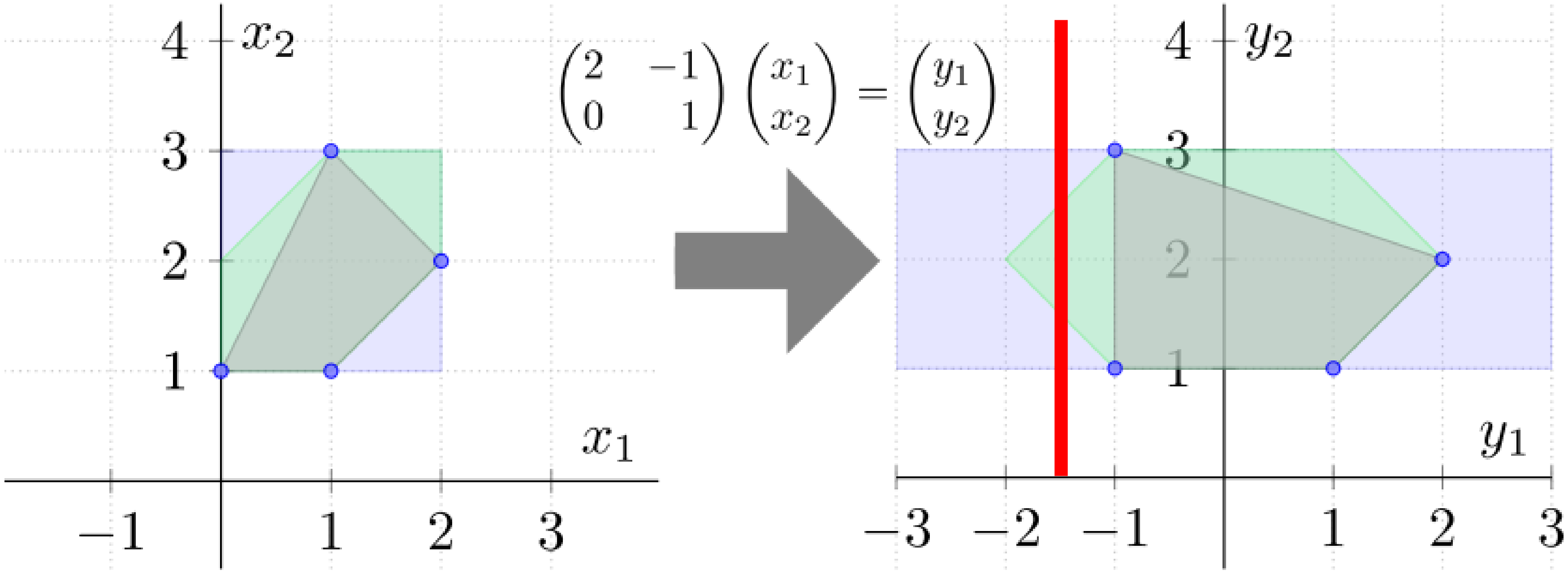


- **Step 2:** Prove that there exists no image **y** in the adversarial region where NN(x) not equal NN(y) using AI2.

WEAK POINTS OF AI2

- Abstract interpretation is sound but imprecise.

DANGER !



$$\begin{pmatrix} 2 & -1 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} y_1 \\ y_2 \end{pmatrix}$$

WEAK POINTS OF AI2

- Abstract interpretation is sound but imprecise.

- Perturbation needs to be capturable by a set of zonotopes in a precise manner, **without adding too many inputs that do not capture actual perturbations to the robustness region**.

- **Every new type of layer or activation function** in a neural network will require the process to transform it to a CAT function, then to a concrete transformer, then to an abstract transformer.

CONCLUSION

- AI2 is an opensource software capable of certifying shallow to mediumly deep classification neural networks.
- Follow up work on AI2 provides more generalizable and faster ways to perform network certification.
- Authors' website: http://safeai.ethz.ch/