Hardware Trojan Detection using Shapley Ensemble Boosting

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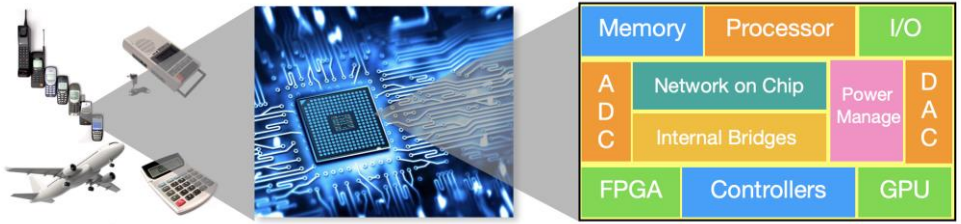
This work was partially supported by the
National Science Foundation (NSF) grant SaTC-1936040

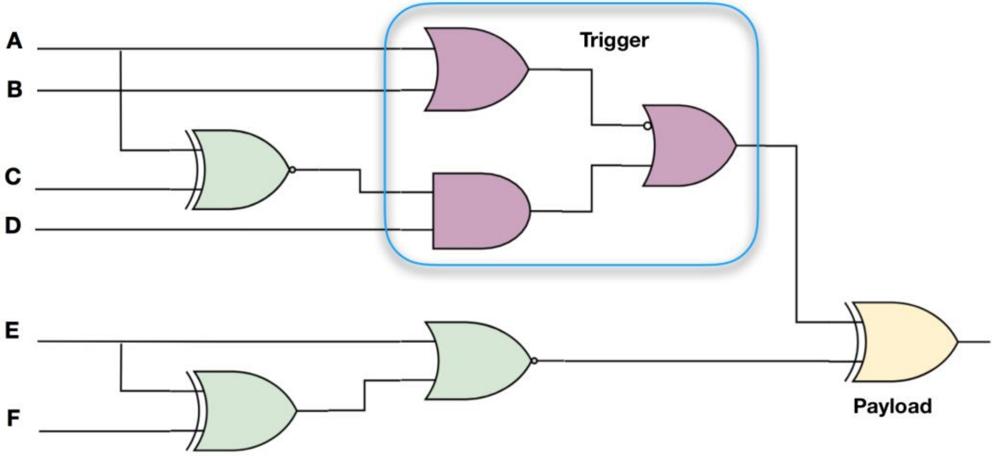
Outline

- <u>Introduction</u>
- Related Work
- Proposed Method
- Experimental Results
- Conclusion

Introduction



Hardware Trojan



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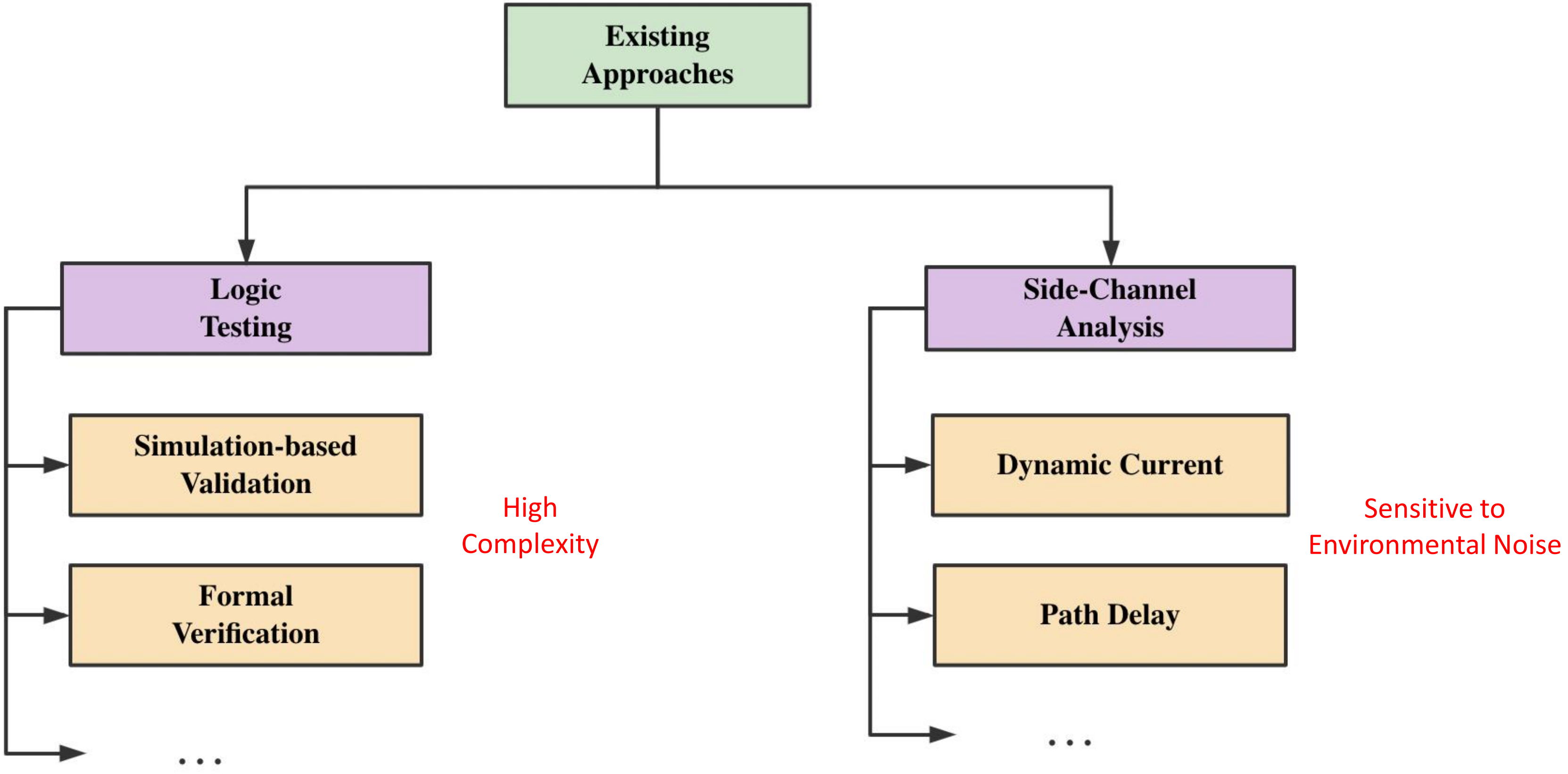
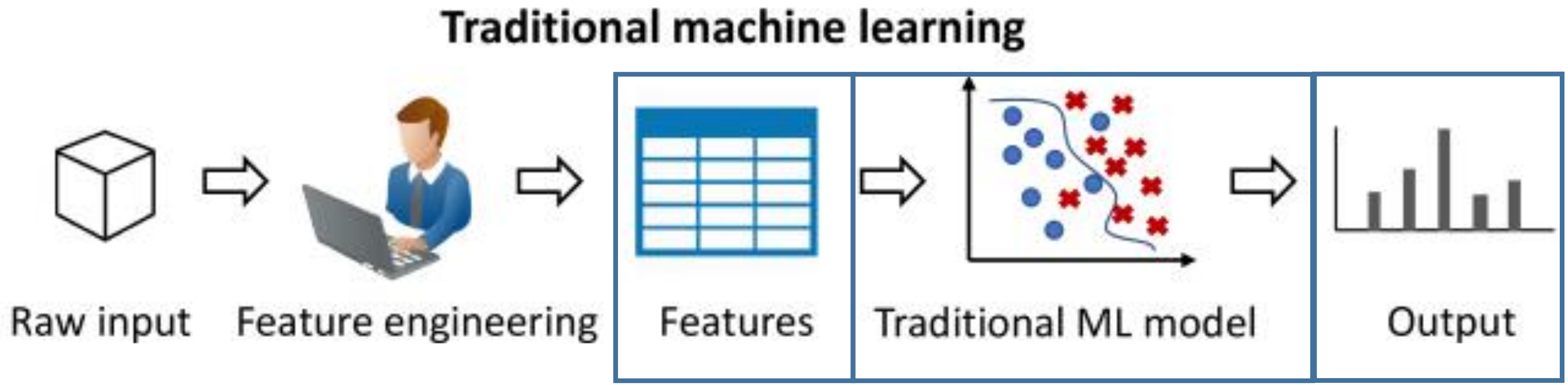
Related Work



Machine Learning



- No guideline for feature selection
- Expensive training cost and high model complexity
- Model can only provide result without interpretation (black-box nature)

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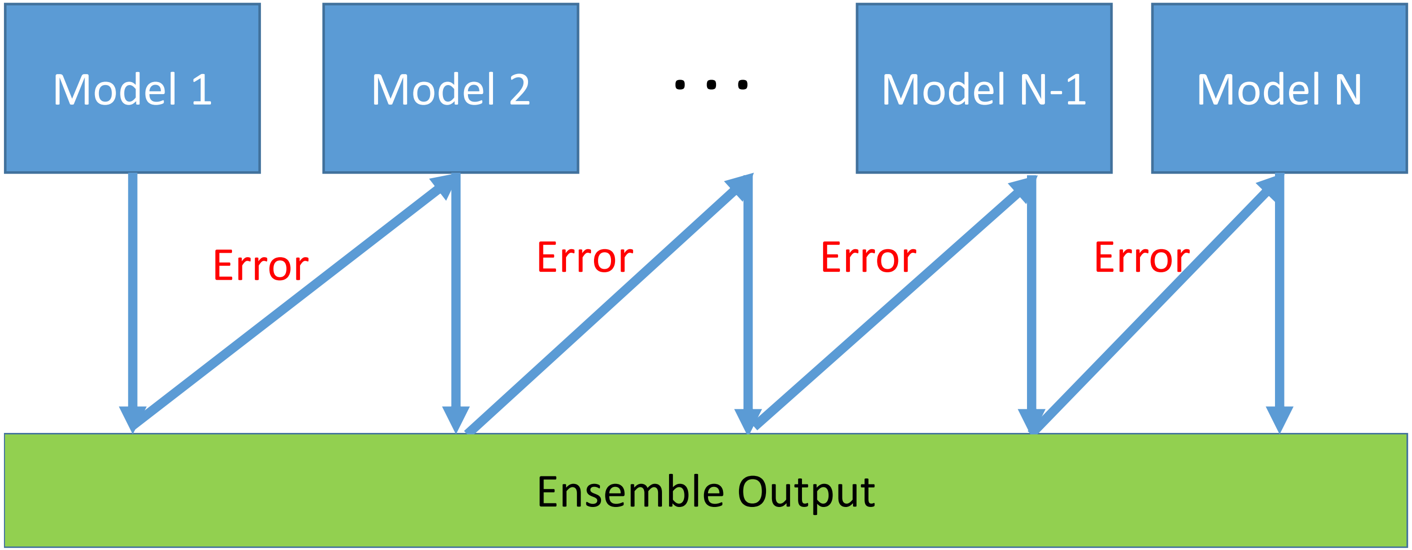
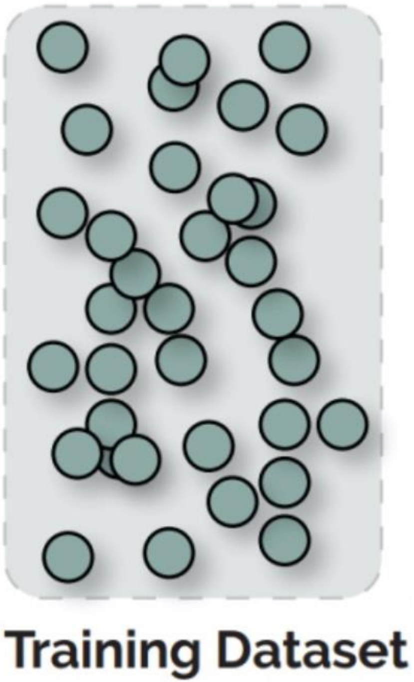
Ensemble Boosting



Interpret the results



Shapley value can tell the contribution of each individual input.

Winter, Eyal. "The shapley value." *Handbook of game theory with economic applications* 3 (2002): 2025-2054.

Shapley Value Analysis

Shapley Values: Key idea → Marginal Contributions

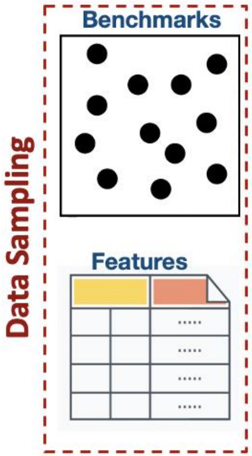
$$\phi_i(v) = \varphi_i = \sum_{S\subseteq N\setminus\{i\}} \frac{|S|!(|N|-|S|-1)!}{|N|!}\left(v(S\cup\{i\}) - v(S)\right)$$

Marginal Contributions of Feature 1

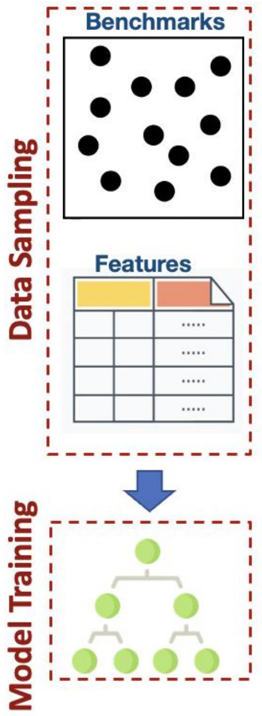
Sequences	Marginal Contributions
1,2,3	$\mathcal{L}(\{1\}) - \mathcal{L}(\emptyset)$
1,3,2	$\mathcal{L}(\{1\}) - \mathcal{L}(\emptyset)$
2,1,3	$\mathcal{L}(\{1,2\}) - \mathcal{L}(\{2\})$
2,3,1	$\mathcal{L}(\{1,2,3\}) - \mathcal{L}(\{2,3\})$
3,1,2	$\mathcal{L}(\{1,3\}) - \mathcal{L}(\{3\})$
3,2,1	$\mathcal{L}(\{1,2,3\}) - \mathcal{L}(\{3,2\})$

Average

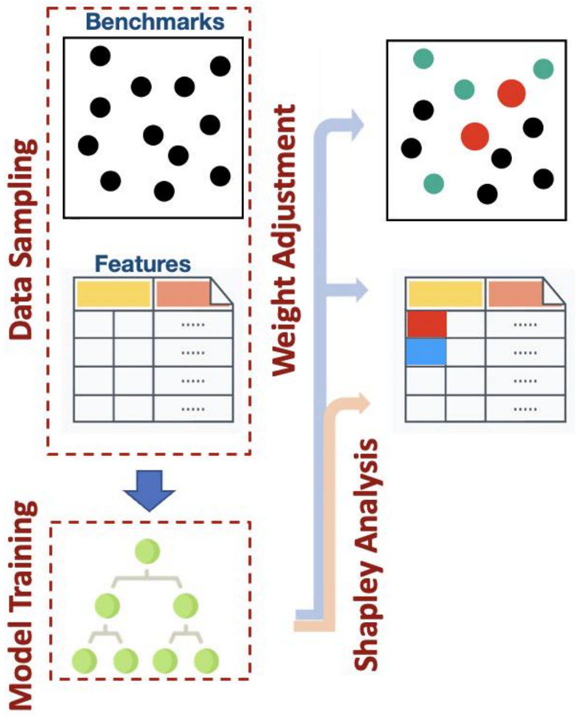
Proposed Framework



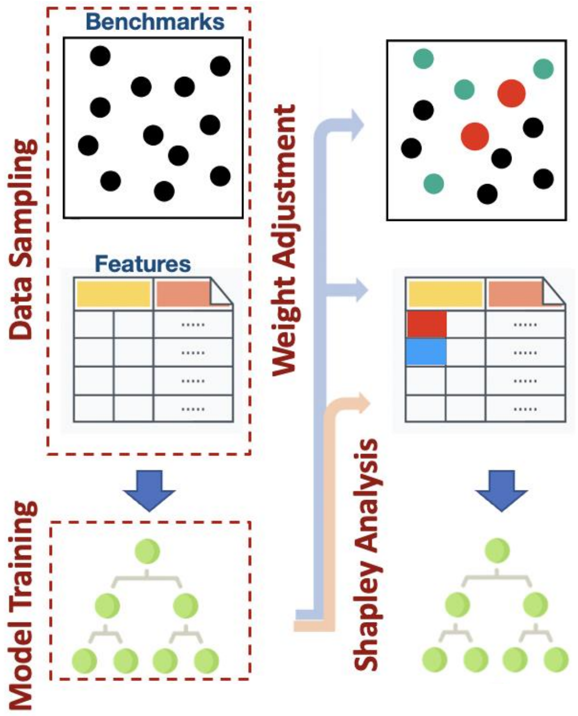
Proposed Framework

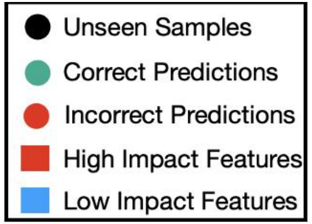


Proposed Framework

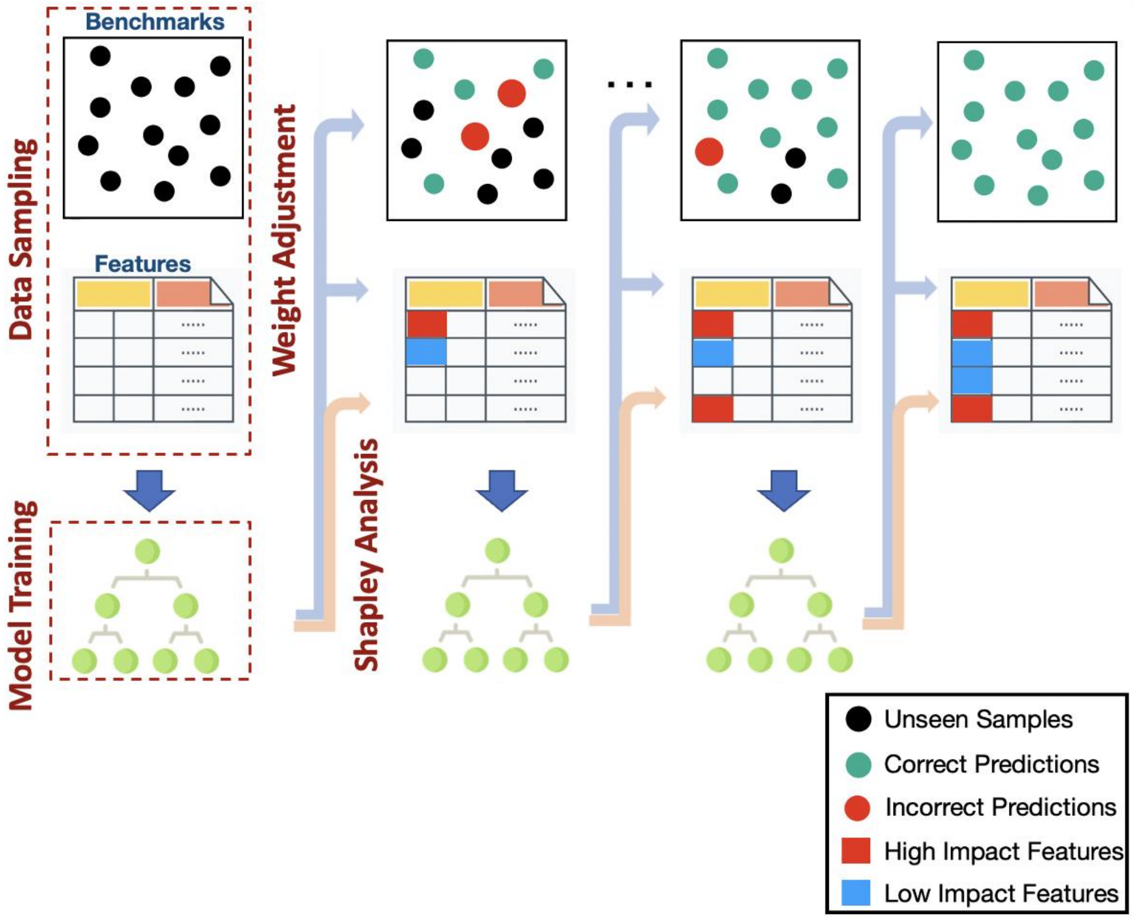


Proposed Framework

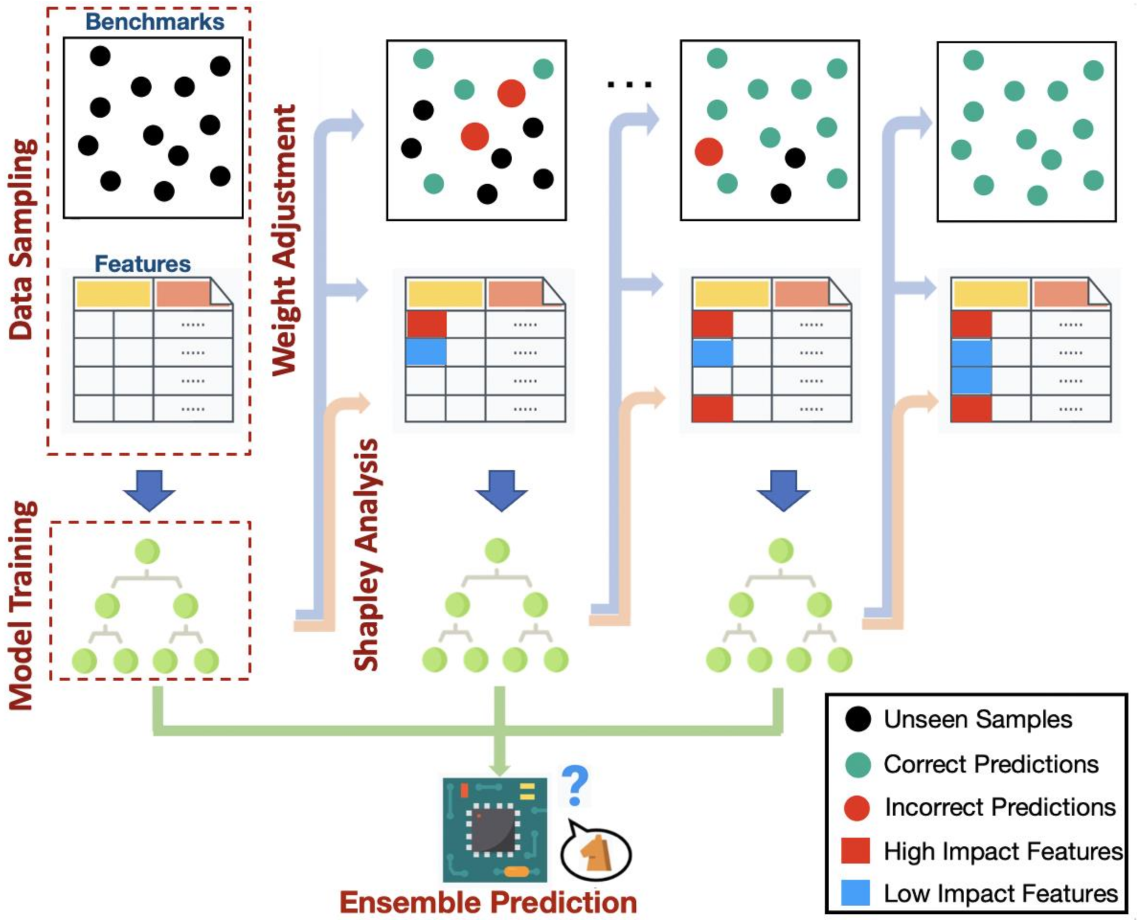




Proposed Framework



Proposed Framework



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Experimental Setup

- Intel i7 3.70GHz CPU, 32 GB RAM and RTX 2080 256-bit GPU
- PyTorch for ML library
- Compare the performance of 4 different models
    - RFC: Random Forest Classifier.
    - CNN: Convolution Neural Network (CNN)
    - TGRL: State-of-the-art Test generation using reinforcement learning
    - SEB: Proposed Shapley ensemble boosting framework

Performance Evaluation

Detection Accuracy:

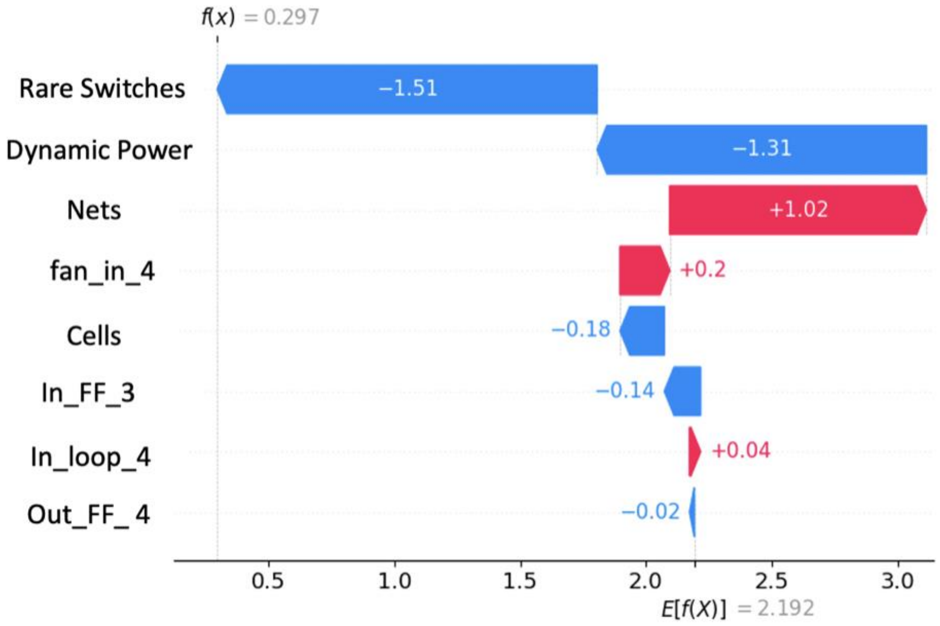
	RFC				CNN				TGRL				SEB (Proposed Approach)				
Bench	**Acc**	**Rec**	**Pre**	**F1**	**Acc**	**Rec**	**Pre**	**F1**	**Acc**	**Rec**	**Prec**	**F1**	**Acc**	**Rec**	**Pre**	**F1**	**impr/TGRL**
c2670	83.1%	0.87	0.89	0.88	90.7%	0.90	0.90	0.90	96.2%	0.97	0.94	0.96	100.0%	1.0	1.0	1.0	3.8%
c5315	75.4%	0.78	0.83	0.81	87.6%	0.85	0.88	0.86	91.4%	0.92	0.91	0.92	100.0%	1.0	1.0	1.0	8.6%
c6288	64.5%	0.68	0.63	0.65	80.5%	0.85	0.79	0.85	88.8%	0.89	0.85	0.87	99.8%	0.99	0.99	0.99	11.0%
c7552	77.2%	0.74	0.79	0.76	84.9%	0.81	0.86	0.83	91.2%	0.89	0.91	0.90	100.0%	1.0	1.0	1.0	8.8%
s13207	78.5%	0.77	0.79	0.78	90.4%	0.91	0.92	0.92	95.6%	0.94	0.95	0.95	100.0%	1.0	1.0	1.0	4.4%
s15850	68.8%	0.65	0.73	0.68	83.0%	0.75	0.86	0.80	92.7%	0.93	0.95	0.94	99.8%	0.99	0.99	0.99	7.1%
s35932	73.1%	0.78	0.53	0.63	75.5%	0.72	0.76	0.74	83.6%	0.88	0.81	0.84	99.9%	0.97	0.99	0.98	16.3%
AES-T100	85.9%	0.93	0.79	0.85	89.2%	0.84	0.86	0.85	96.9%	0.97	0.97	0.97	100.0%	1.0	1.0	1.0	3.1%
AES-T200	79.3%	0.88	0.73	0.79	90.2%	0.85	0.92	0.88	95.8%	0.98	0.91	0.94	99.9%	1.0	1.0	1.0	4.1%
AES-T1000	67.2%	0.84	0.63	0.72	80.5%	0.72	0.76	0.74	90.1%	0.95	0.95	0.95	99.9%	1.0	1.0	1.0	9.8%
Average	**75.3 %**	**0.79**	**0.73**	**0.76**	**85.3%**	**0.82**	**0.85**	**0.83**	**92.2%**	**0.93**	**0.91**	**0.92**	**99.9%**	**0.99**	**1.0**	**1.0**	**6.1**

Time Efficiency:

Methods	**RFC**	**TGRL**	**CNN**	**SEB**	**SEB/RFC**	**SEB/TGRL**	**SEB/CNN**
Training	4430	30019	10396	1767	2.6x	17.4x	5.8x
Testing	1284	2014	559	1339	2.3x	3.6x	3.6x
Total	**5714**	**31033**	**11735**	**2326**	**2.5x**	**13.4x**	**5.1x**

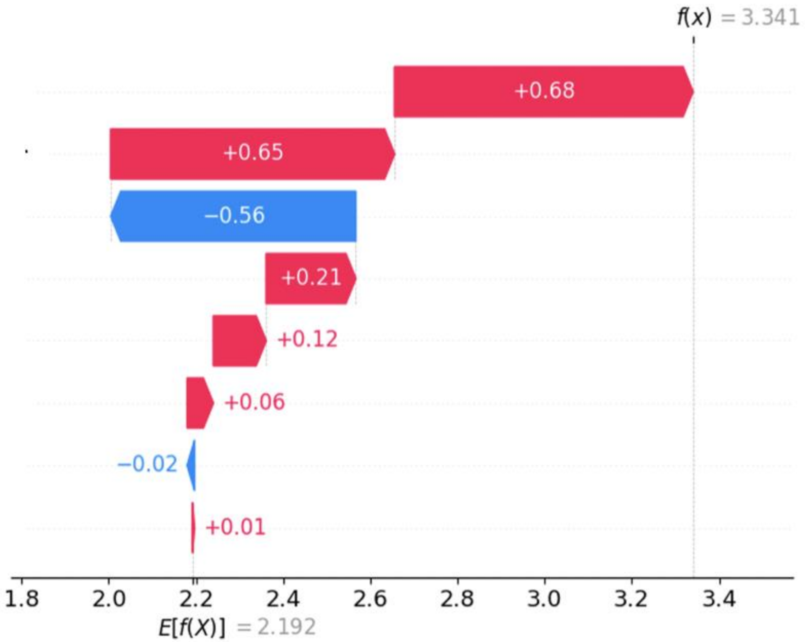
Explainability Evaluation

Example of S13207



(a)

Trojan Free



(b)

Trojan Implanted

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Conclusion

- Hardware Trojan attacks are dangerous threat to systems.
- AI/ML techniques have serious limitations.
- We propose an efficient and explainable detection scheme based on Shapley ensemble boosting.
  - Efficient training of a sequence of lightweight model
  - Result Interpretation using Shapley Values
  - Ensemble prediction for better performance
- Our approach significantly improves detection efficiency (24.6%) compared to state-of-the-art techniques.

Questions?