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Making Fully Homomorphic Encryption practical

Construction and Cryptanalysis of lattice-based schemes

@ School on Correct and Secure implementation, Crete, 13.10.2017

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hgi Horst Görtz Institut für IT-Sicherheit

1 Fully Homomorphic Encryption
- Practical FHE
- Privacy-Preserving Image Classification
- Torus Fully Homomorphic Encryption (TFHE)
  - Introduction of acronyms: TFHE, TLWE, and TGSW.
  - Evaluating the multisum
  - Bootstrapping the multisum
  - 2D Torus

2 Learning with Errors (LWE)

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- Joint work (currently in submission) by:

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MNIST

- MNIST database: 60 000 training and 10 000 testing images,
- 28×28 pixels in 8 [bit] gray-scale.

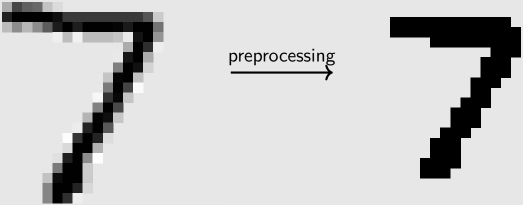


Figure: Preprocessing one MNIST's test set images.

Discretized Neural Networks are suited for FHE.

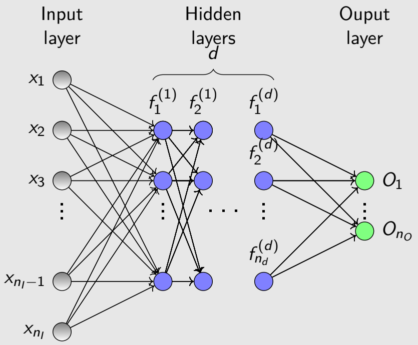


Figure: A Deep DiNN.

Close-up on a single neuron.

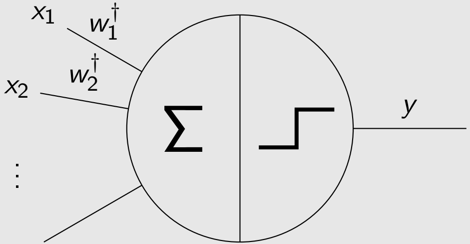
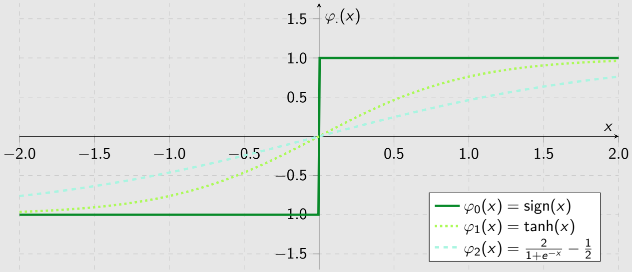


Figure: Evaluation of a single neuron. The output value is $y = \text{sign}(\langle \vec{w}^\dagger, \vec{x} \rangle)$, where $w_i^\dagger$ are the preprocessed (clear or encrypted) weights associated to the incoming wires and x_i are the corresponding (clear or encrypted) input values.

Neural Network activation functions.



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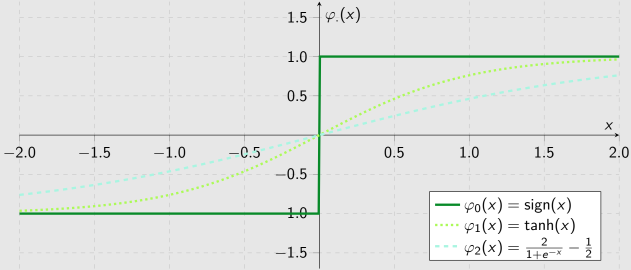

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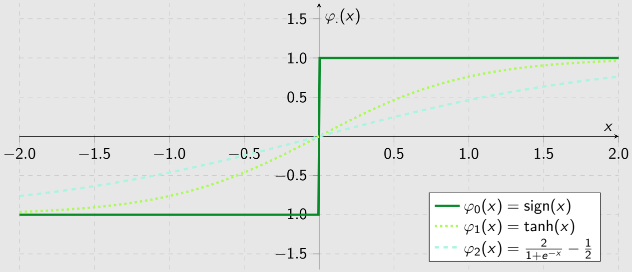

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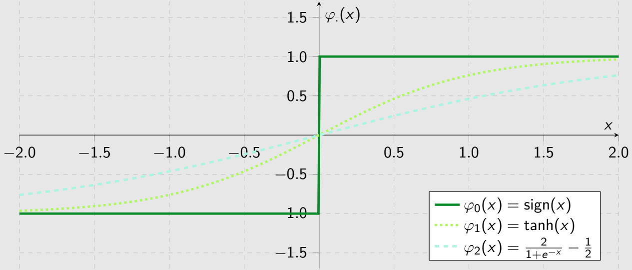

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- Experiments with clear vs. encrypted inputs and clear weights.

Homomorphic Evaluation of Deep Discretized NNs

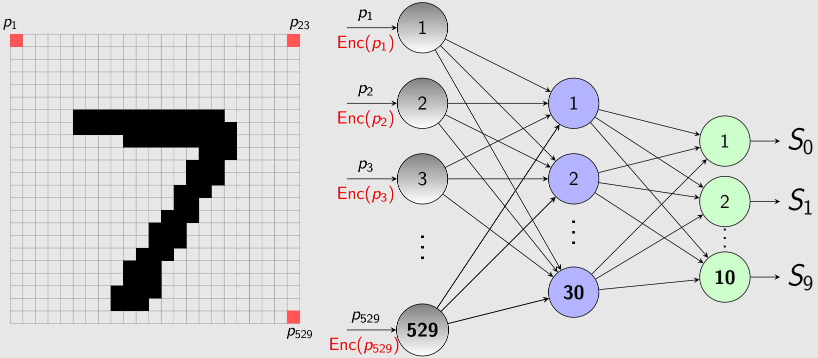

Figure: Running an experiment on our neural network with 529:30:10–topology. Classifies the depicted shape (without leaking privacy of the input data), and outputs the (encrypted) scores S_i assigned to each digit. The highest score is compared to the known label evaluating our success.

Results: It's a seven!

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scale-invariance allows computing on encrypted data over many layers.

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LWE assumption (over the Torus)

Given a secret $\mathbf{s} \xleftarrow{\$} \{0,1\}^n$, it is hard to distinguish between $(\mathbf{a}, b)$, where $\mathbf{a} \xleftarrow{\$} \mathbb{T}^n$ and $b = \langle \mathbf{s}, \mathbf{a} \rangle + e \in \mathbb{T}$, with $e \leftarrow \chi$, and $(\mathbf{u}, v) \xleftarrow{\$} \mathbb{T}^{n+1}$.

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  1. Message space (accommodates encryption scheme's largest results),
  2. Noise level (control growth to ensure correctness).

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Our Homomorphism (Fixing secret key $\mathbf{s}$)

For $c_1 = (\mathbf{a}_1, b_1) \leftarrow \mathrm{Enc}(\mathbf{s}, \mu_1)$, $c_2 = (\mathbf{a}_2, b_2) \leftarrow \mathrm{Enc}(\mathbf{s}, \mu_2)$, $w \in \mathbb{Z}$:

$$\mathrm{Dec}(\mathbf{s}, (\mathbf{a}_1 + w \cdot \mathbf{a}_2, b_1 + w \cdot b_2)) = \mu_1 + w \cdot \mu_2.$$

Bootstrapping the multisum

Consider the torus $\mathbb{R}/\mathbb{Z} =: \mathbb{T} = (\mathbb{T}, +, *)$:

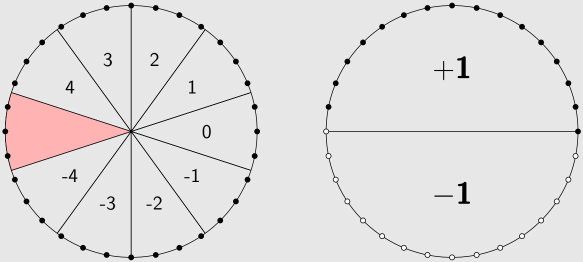

Figure: On the left, discretize torus elements onto the wheel (the $2N$ dots on it) by rounding to the closest dot. Each slice corresponds to one of the possible results of the multisum operation (the colored slice represents the forbidden zone). On the right, final result of the bootstrapping: each dot of the top (resp. bottom) part of the wheel is mapped to $+1$ and -1, respectively.

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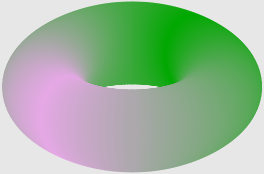

Figure: 2D Torus.

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Best current (primal) attack: BDD

First LLL/BKZ-reduction of the basis matrix, then enumerate points.

Learning with Errors (LWE) Problem

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Current Best Asymptotic Complexity of Attacking LWE.

Let $q = n^{\alpha}, \|\mathbf{e}\| = n^{\beta} \in \mathcal{O}(\text{poly}(n))$:

$$T_{LWE} = 2^{c_{\text{LWE}} \cdot n \cdot \frac{\log n}{\log(q/\|\mathbf{e}\|)}},$$

with c_{LWE} a function of c_{BKZ} and poly(n)- or 2^n-space requirements.

Attacking LWE In Practice Step 1

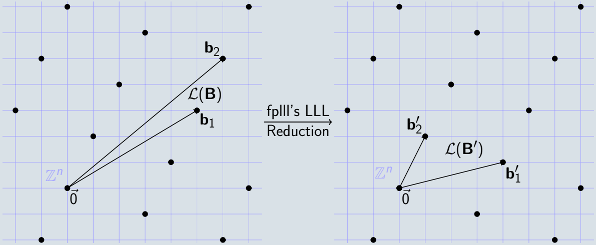

Figure: Step 1: Find a ‘good’ basis for lattice $\Lambda_q(\mathbf{A})$, i.e. using fplll.

LWE in Theory / Practice

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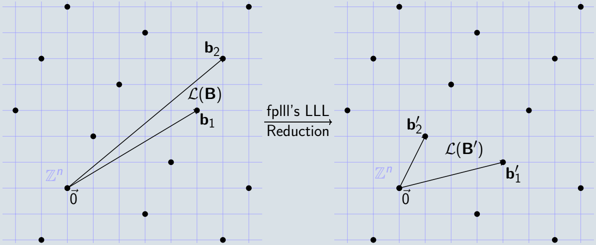

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Attacking LWE In Practice Step 2

Enumerate all points within radius $||\mathbf{e}||$ relative to $\mathbf{t}$.

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Thank you for your attention!

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