SIGMA: Secure GPT Inference with Function Secret Sharing

Kanav Gupta, Neha Jawalkar, Ananta Mukherjee, Nishanth Chandran, Divya Gupta, Ashish Panwar, Rahul Sharma

Real World Crypto 2024

AI effects everyday life

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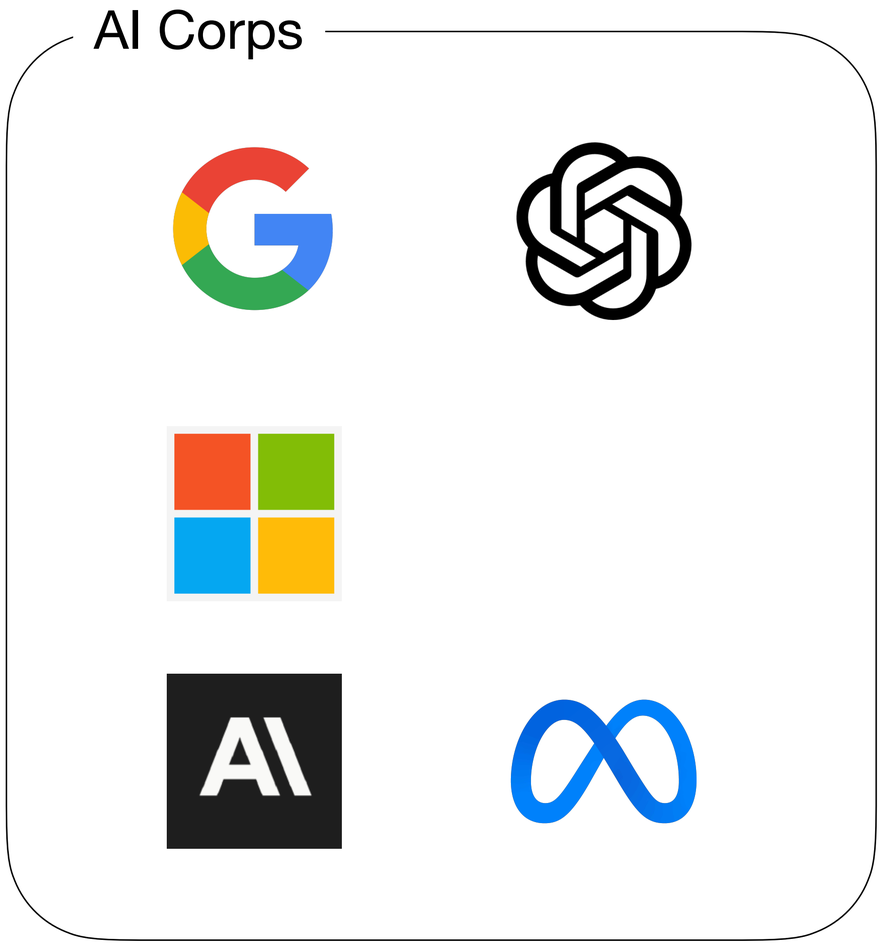

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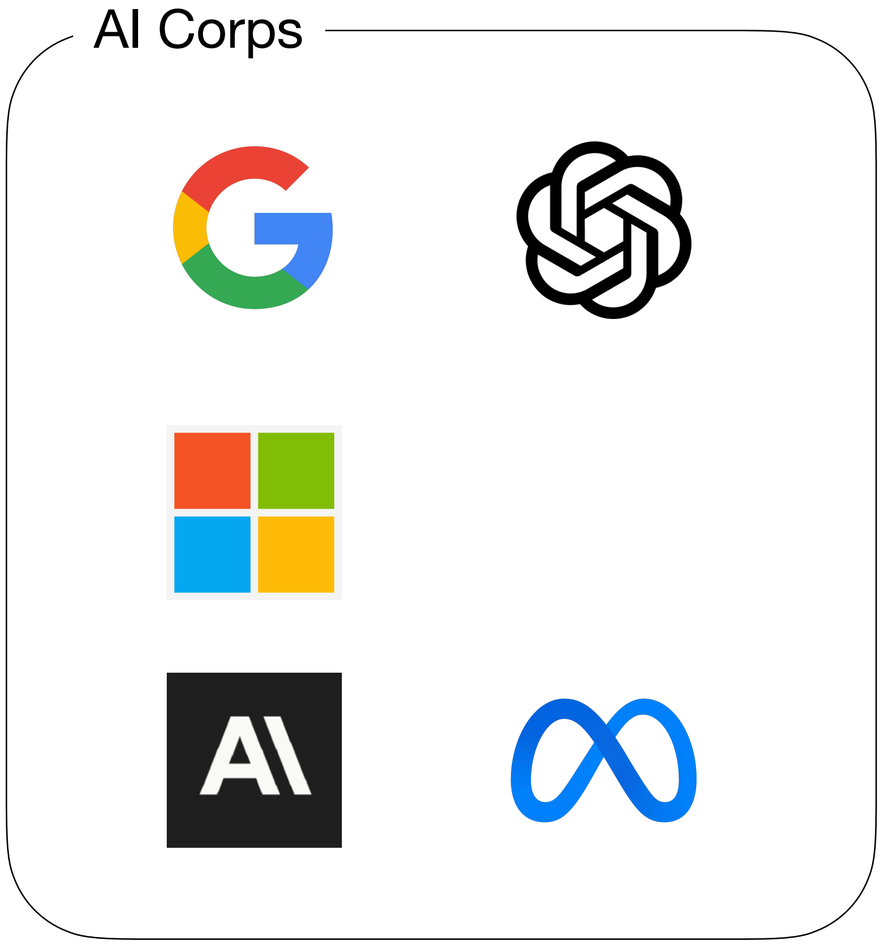
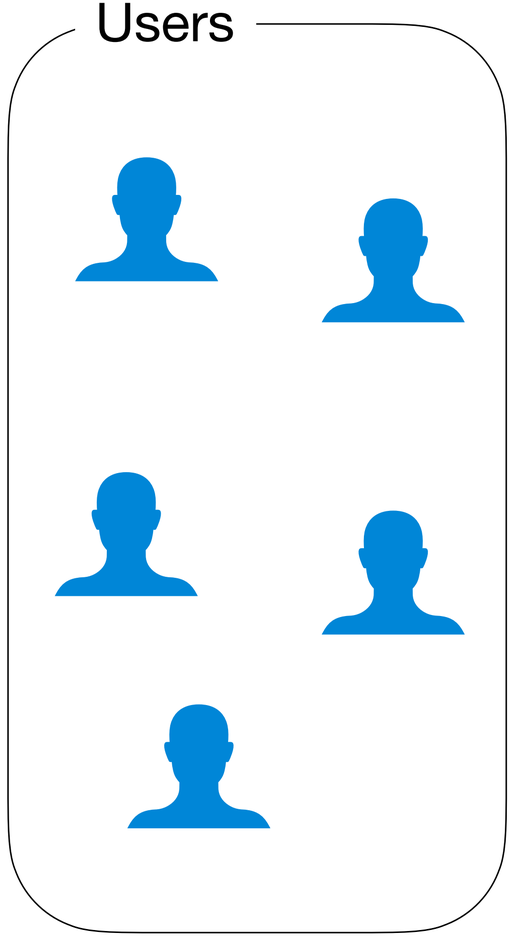
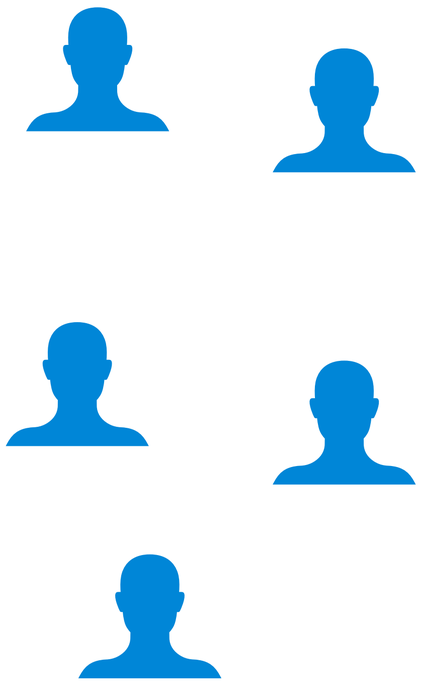




AI effects everyday life

AI Corps

Users



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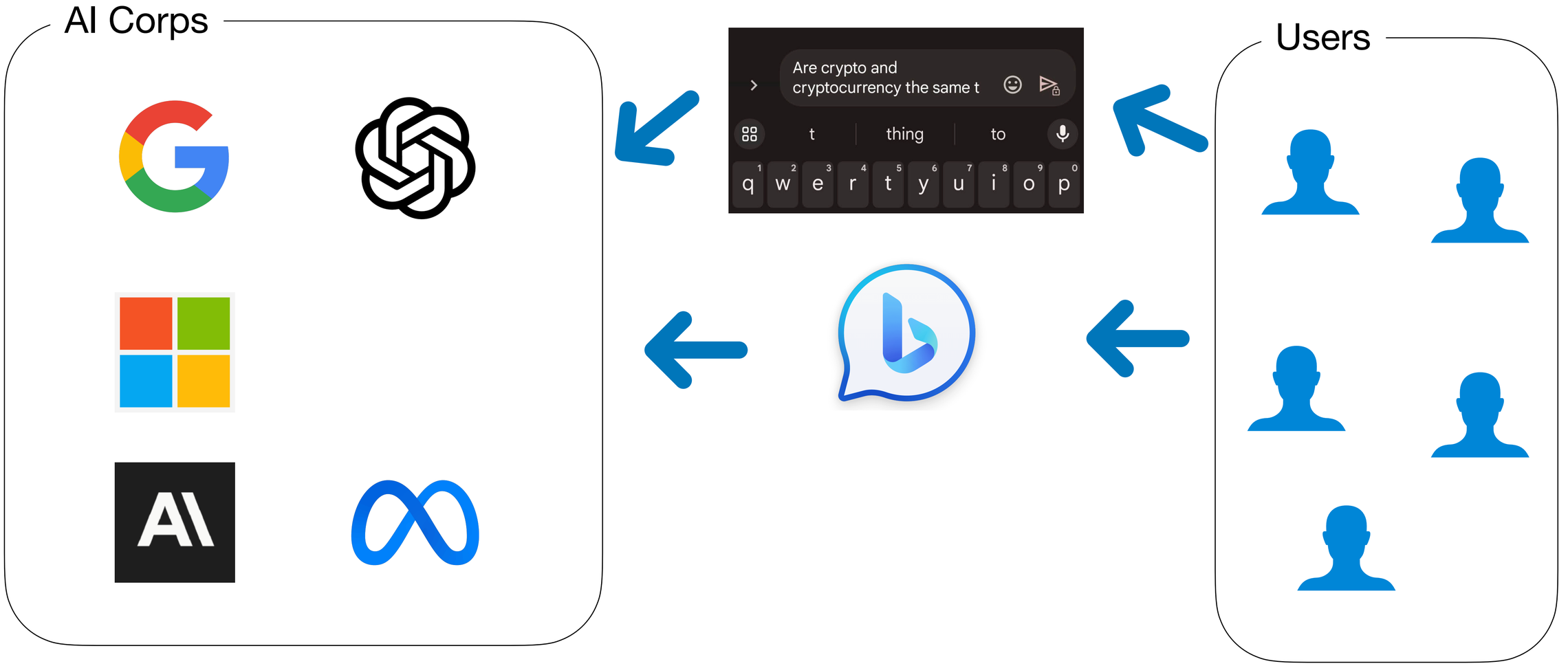

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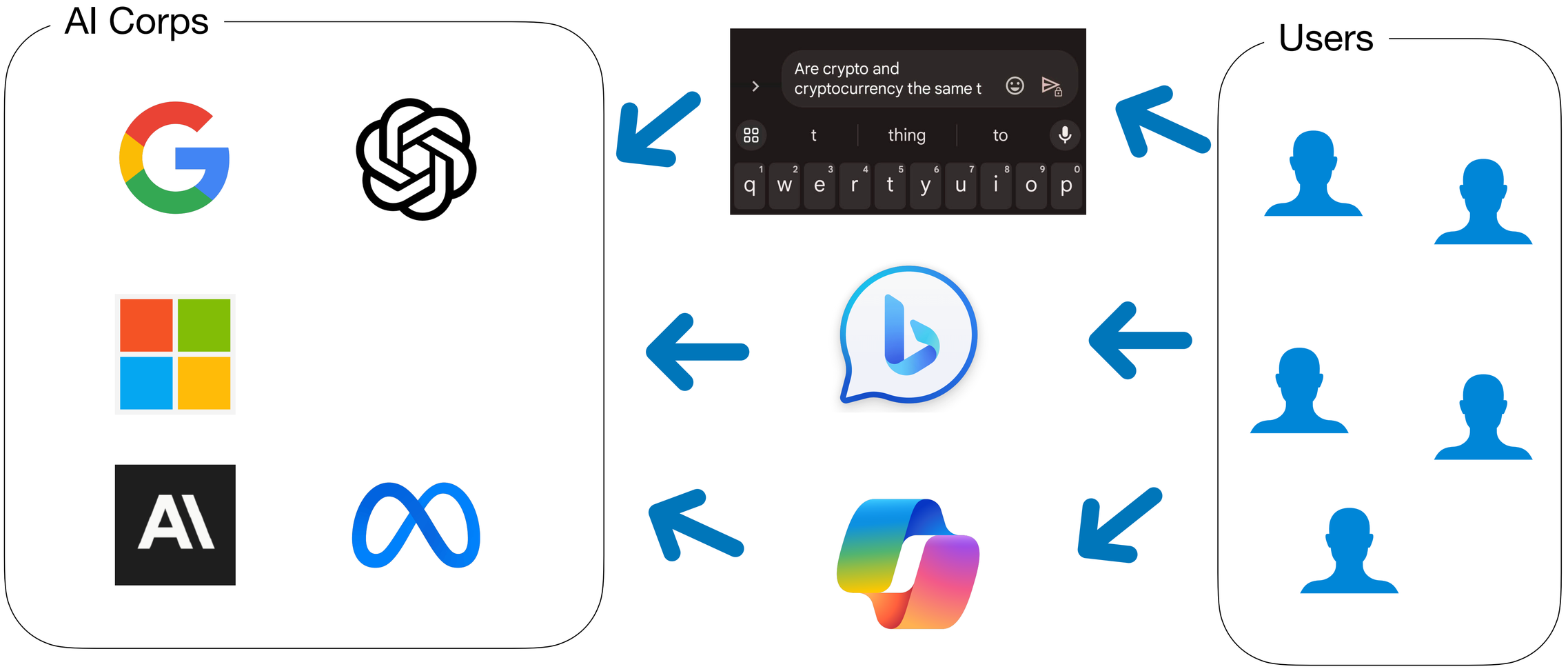

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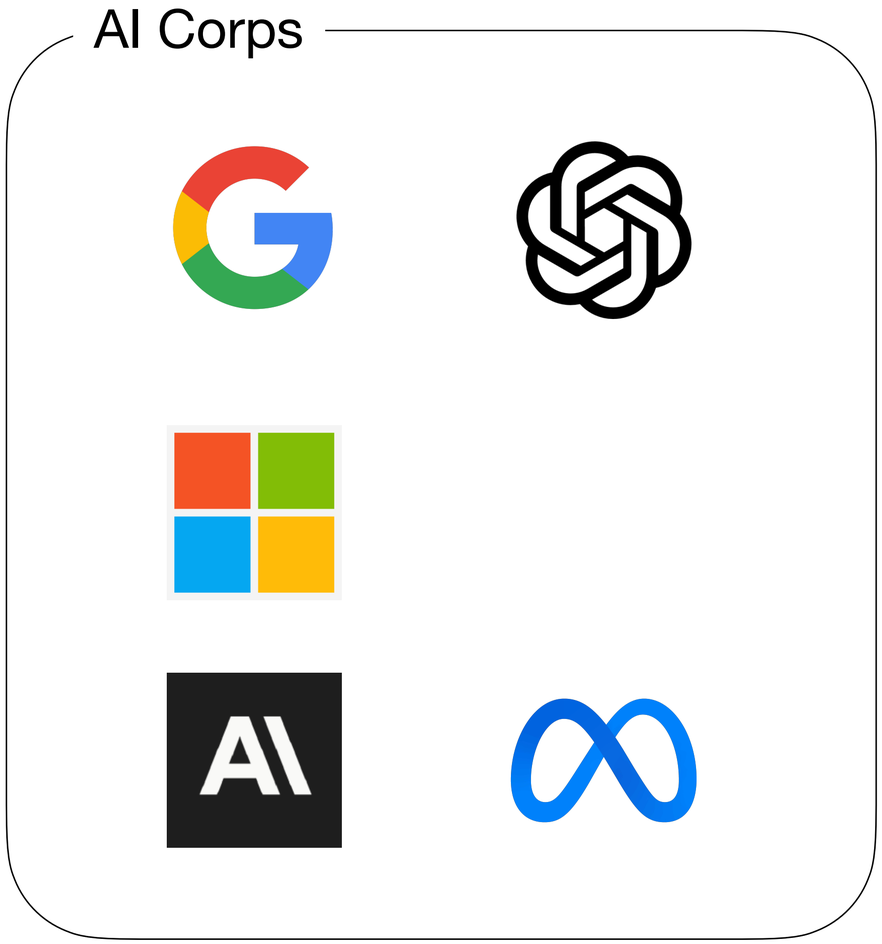

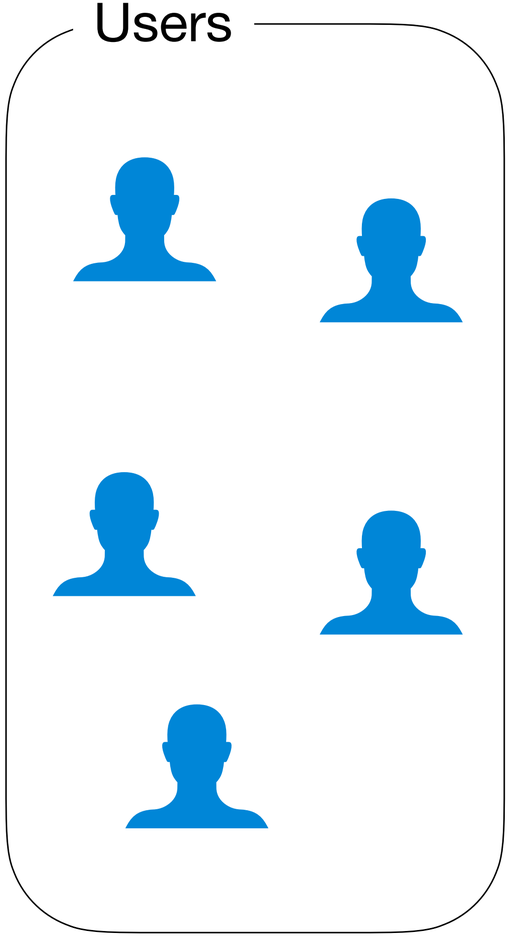

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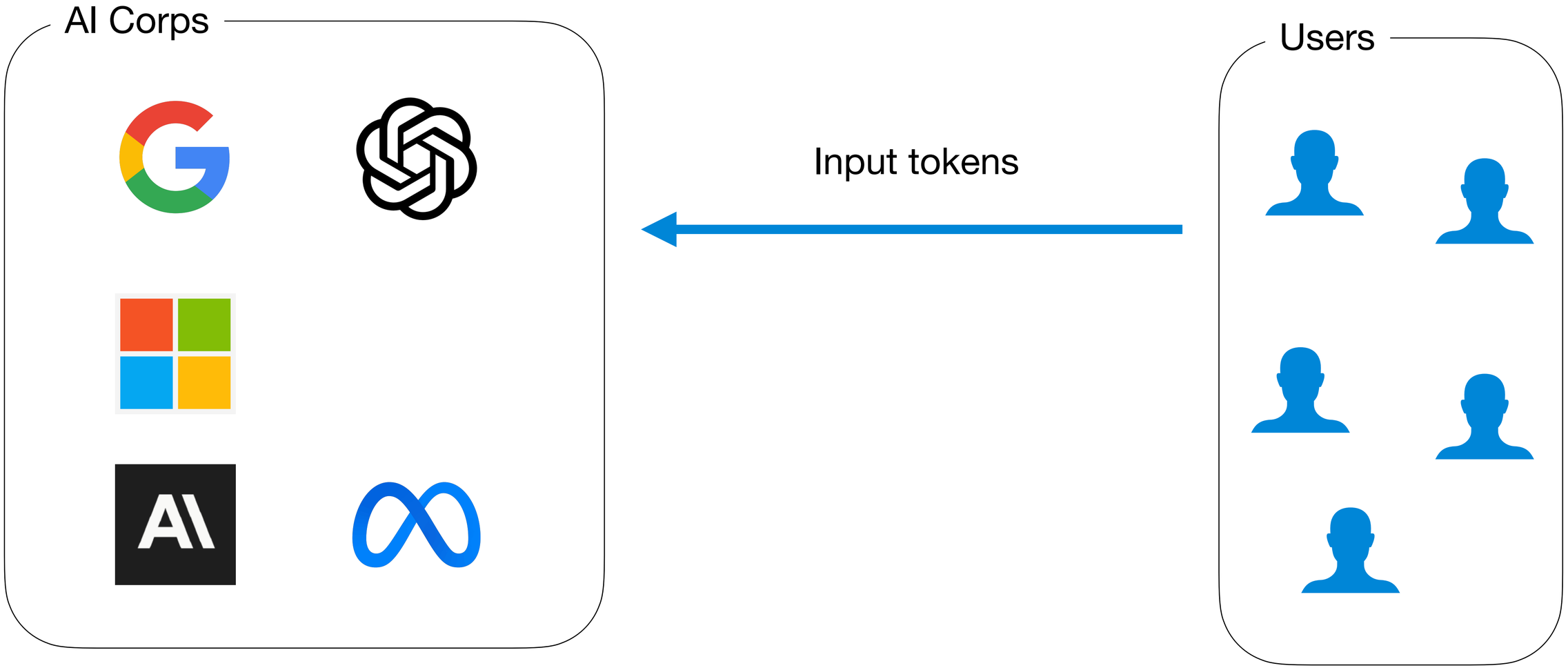

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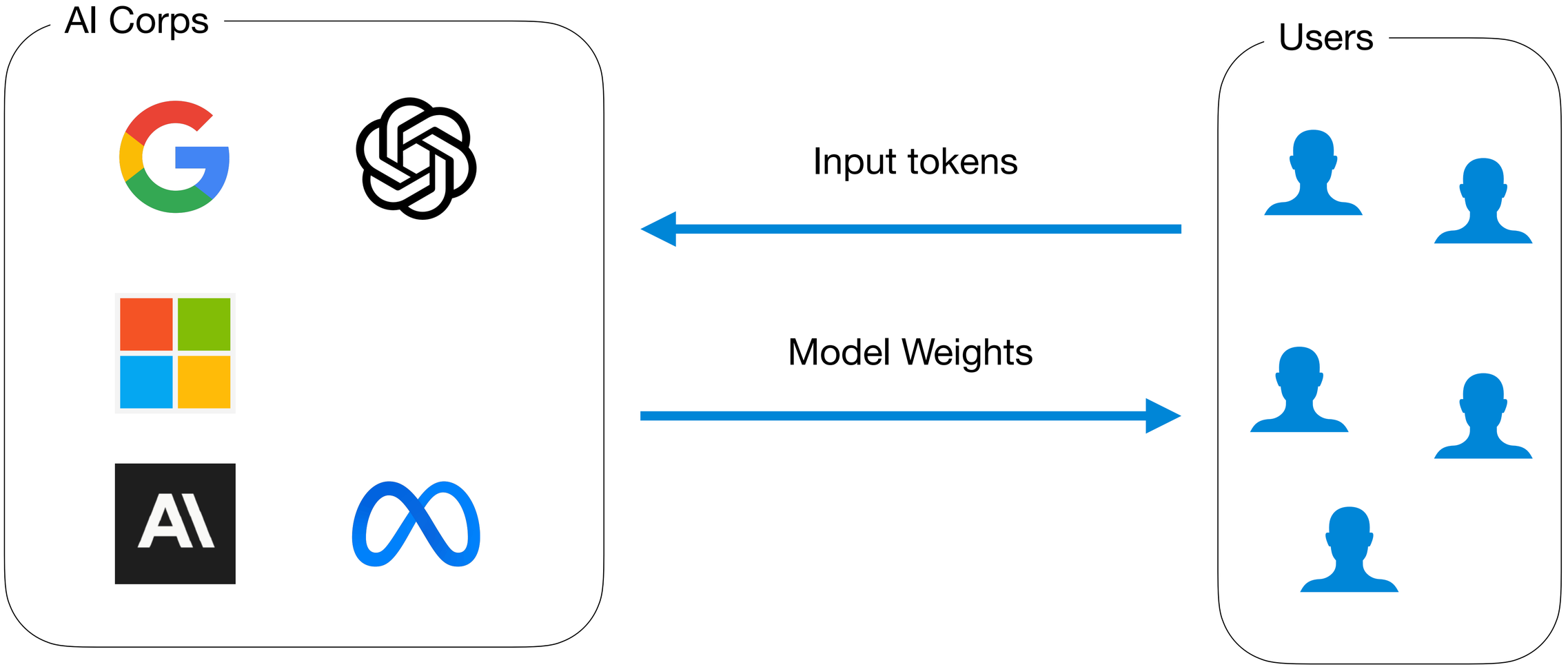

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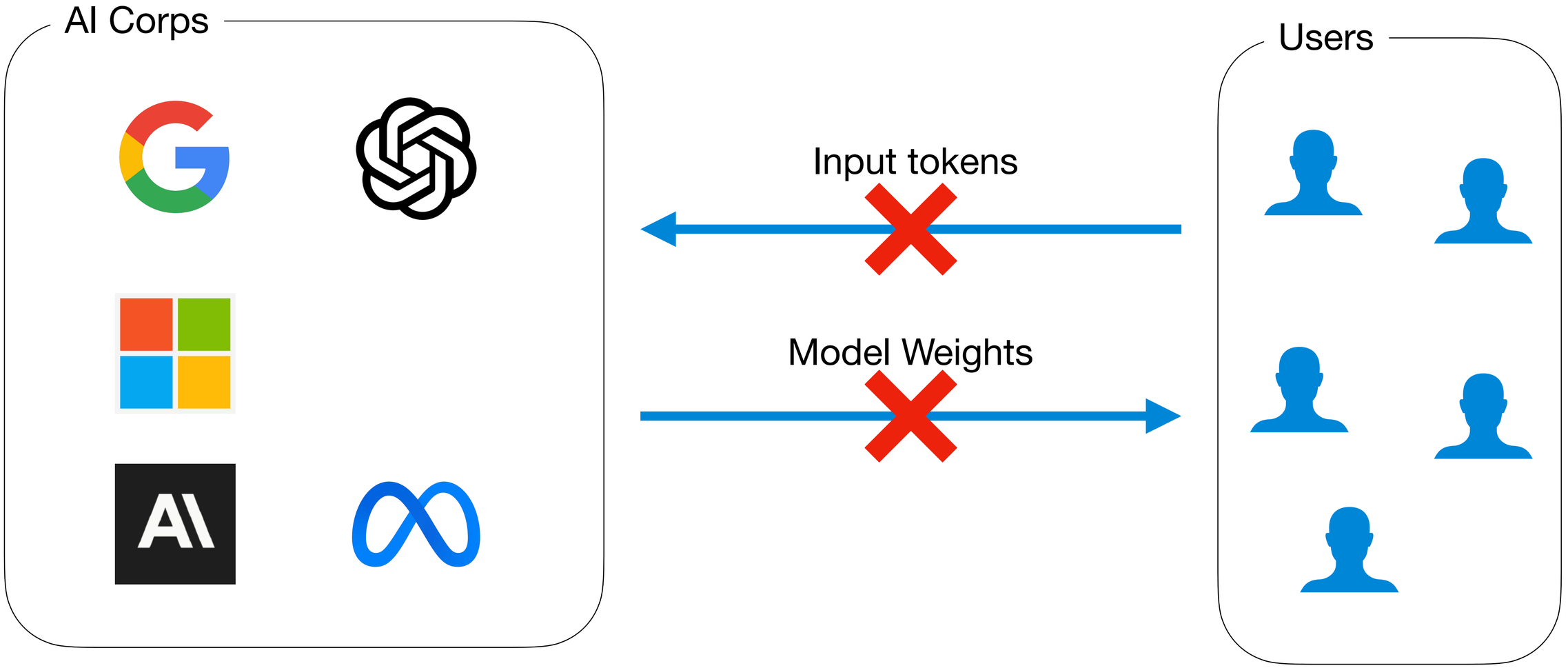
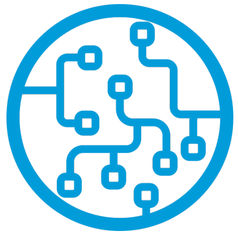


Secure Inference

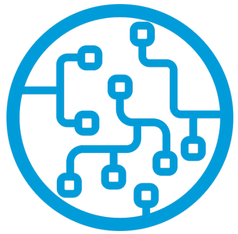


W

x

“What are some good places to visit in Toronto?”

Secure Inference



W

x

2PC

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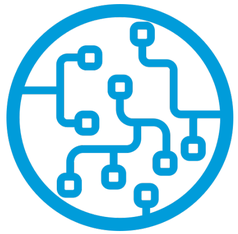
Secure Inference



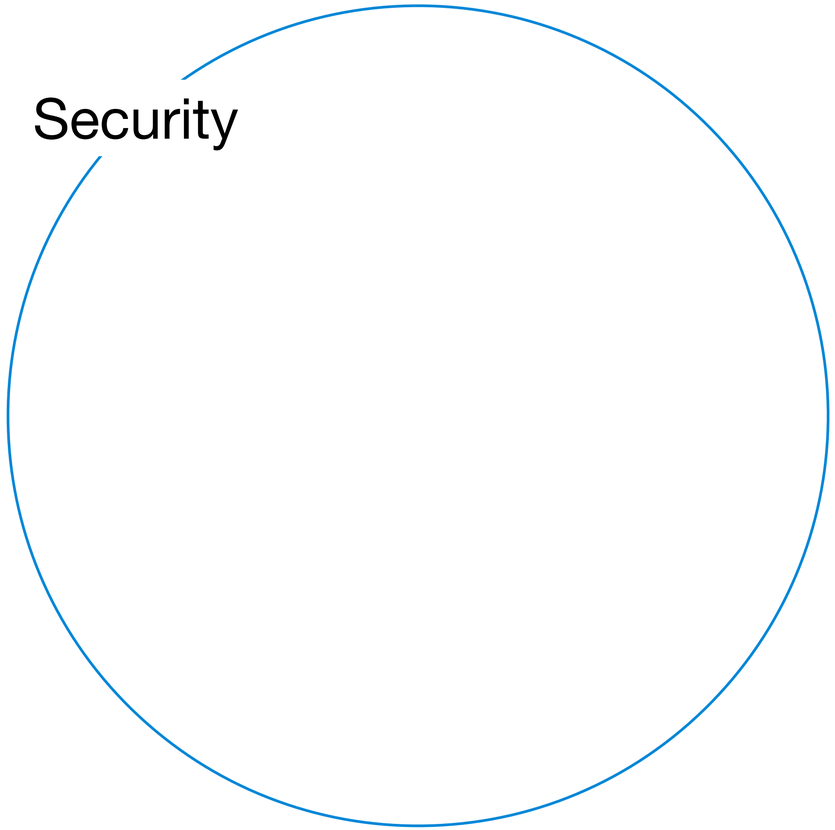
W

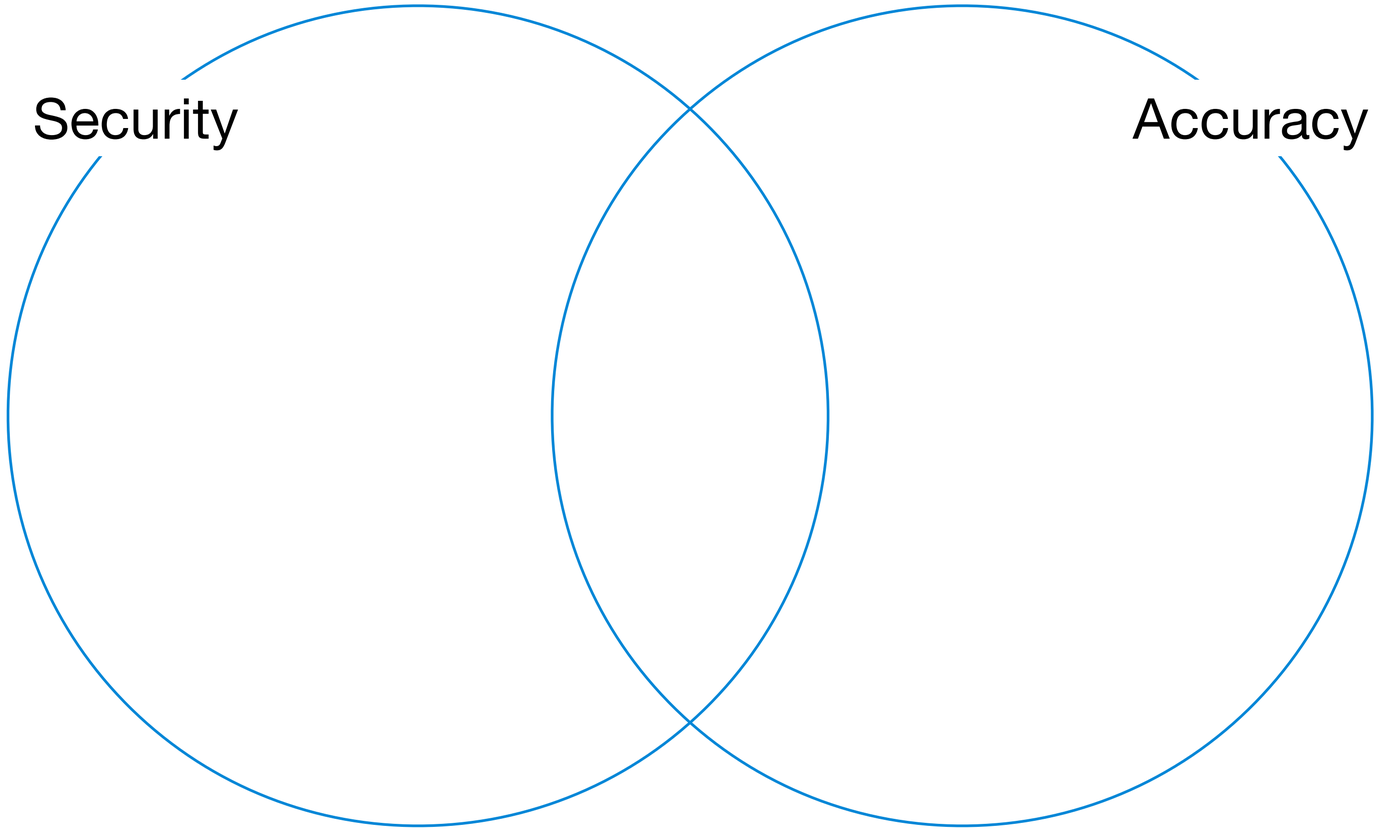
x

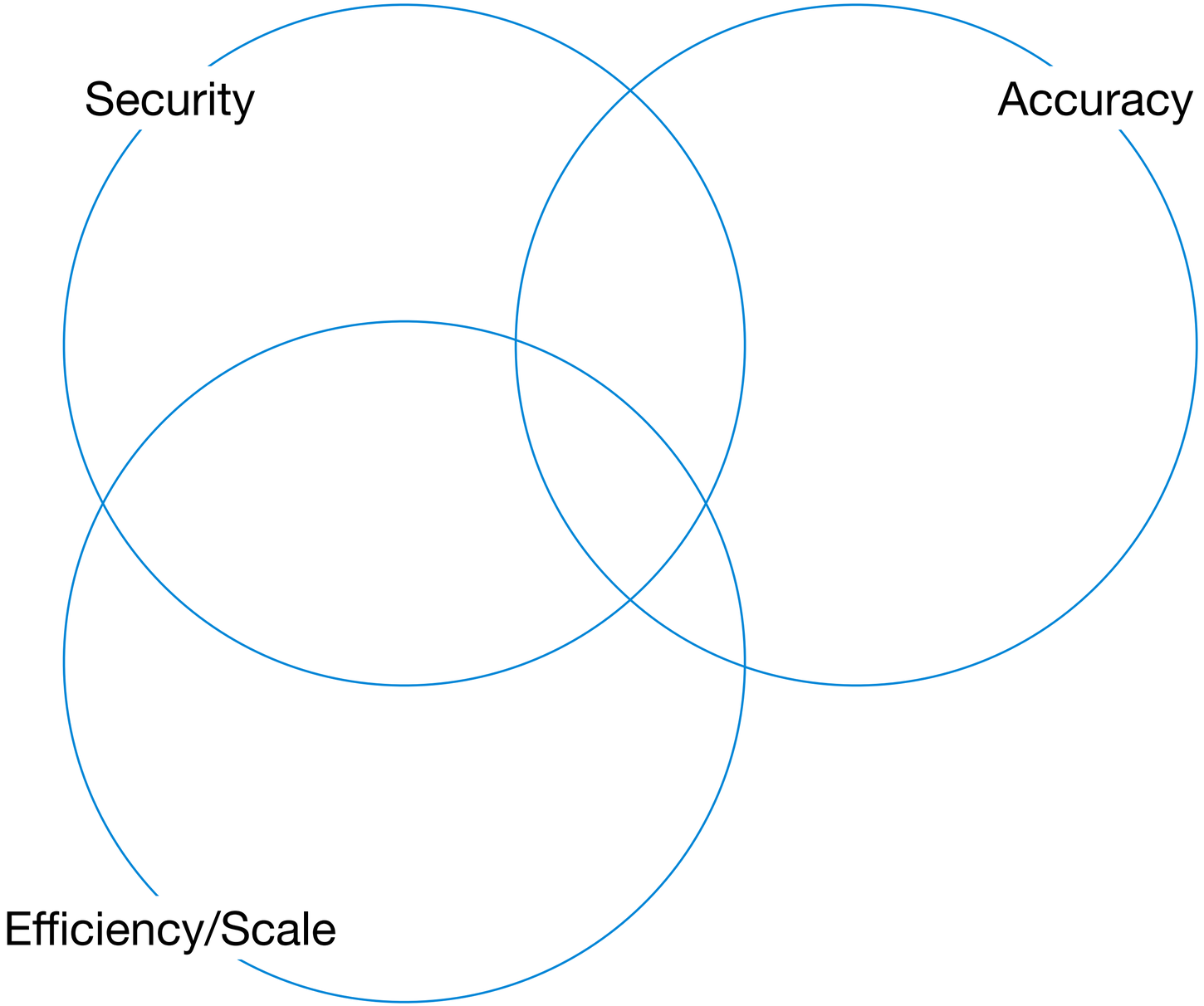
2PC

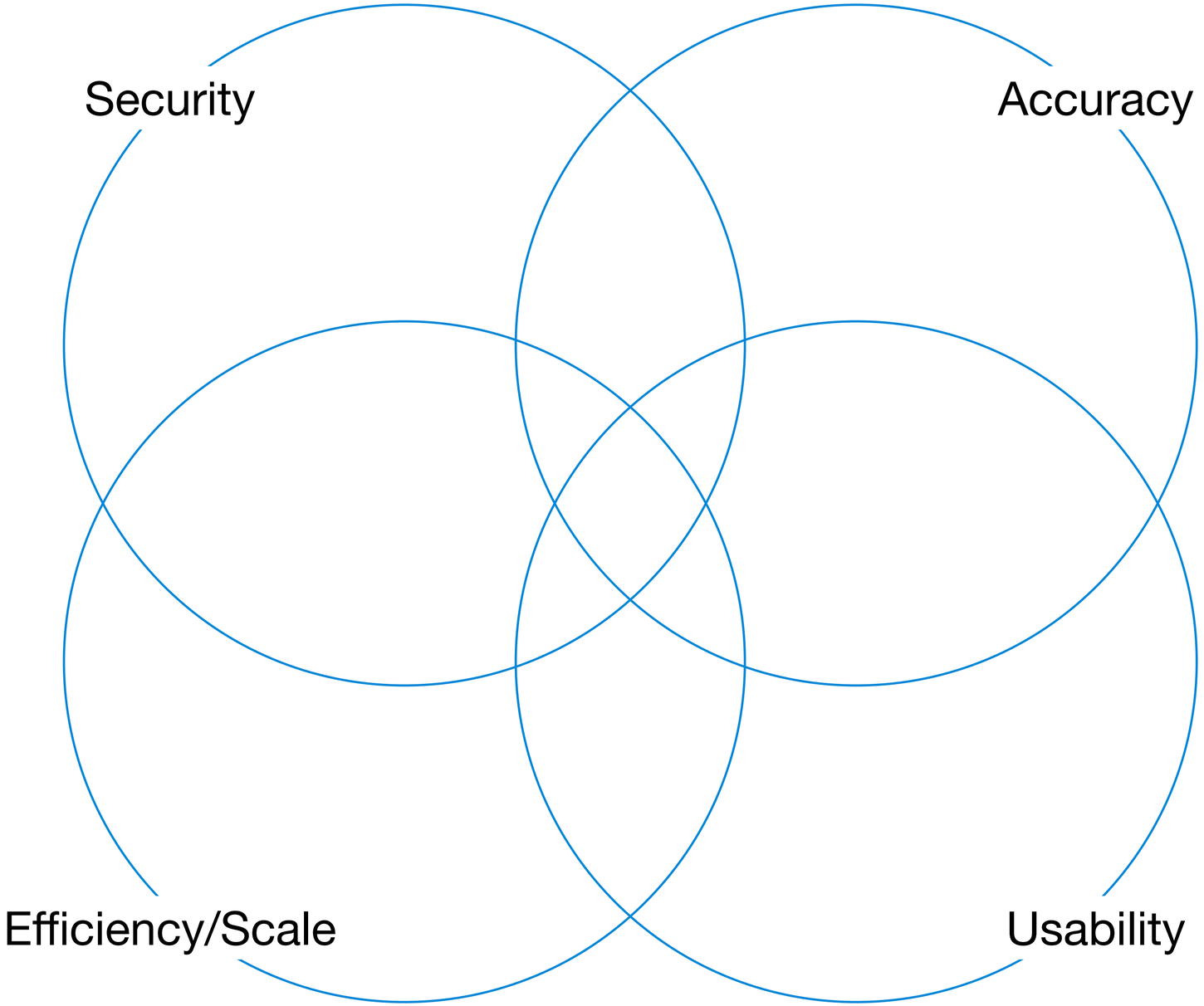
$y = M(W, x)$

"What are some good places to visit in Toronto?"


Security


Security
Accuracy


Security
Accuracy
Efficiency/Scale


Security
Accuracy
Efficiency/Scale
Usability

	Accuracy	Security	Efficiency/ Scalability	Usability

	Accuracy	Security	Efficiency/ Scalability	Usability
Iron	✓	✓		✓

	Accuracy	Security	Efficiency/ Scalability	Usability
Iron	✓	✓		✓
CrypTen			⋱	✓

	Accuracy	Security	Efficiency/ Scalability	Usability
Iron	✓	✓		✓
CrypTen			⋰	✓
MPCFormer	✓		✓	

	Accuracy	Security	Efficiency/ Scalability	Usability
Iron	✓	✓		✓
CrypTen			⋰	✓
MPCFormer	✓		✓	
SIGMA	✓	✓	✓	✓

Results

	PyTorch	SIGMA
GPT2		
GPT Neo		
LLaMA2-7B		
LLaMA2-13B		

Accuracy on LAMBADA dataset

Results

	PyTorch	SIGMA
GPT2	32.46	33.28
GPT Neo	57.46	57.81
LLaMA2-7B	70.17	70.01
LLaMA2-13B	73.14	72.98

Accuracy on LAMBADA dataset

Results

	CrypTen	MPCFormer	SIGMA
BERT Base			
BERT Large			
GPT2			
GPT Neo			
LLAMA-7B			
LLAMA-13B			

Performance comparison for next-token generation

Results

	CrypTen	MPCFormer	SIGMA
BERT Base	21.55	11.06	1.84
BERT Large	54.53	29.21	4.73
GPT2			
GPT Neo			
LLAMA-7B			
LLAMA-13B			

Performance comparison for next-token generation

Results

	CrypTen	MPCFormer	SIGMA
BERT Base	21.55	11.06	1.84
BERT Large	54.53	29.21	4.73
GPT2	20.45	-	1.61
GPT Neo		-	
LLAMA-7B		-	
LLAMA-13B		-	

Performance comparison for next-token generation

Results

	CrypTen	MPCFormer	SIGMA
BERT Base	21.55	11.06	1.84
BERT Large	54.53	29.21	4.73
GPT2	20.45	-	1.61
GPT Neo	108.30	-	7.43
LLAMA-7B		-	
LLAMA-13B		-	

Performance comparison for next-token generation

Results

	CrypTen	MPCFormer	SIGMA
BERT Base	21.55	11.06	1.84
BERT Large	54.53	29.21	4.73
GPT2	20.45	-	1.61
GPT Neo	108.30	-	7.43
LLAMA-7B	overflow	-	27.01
LLAMA-13B	overflow	-	44.13

Performance comparison for next-token generation

Results

	PyTorch w/ Google Colab	SIGMA
GPT2		
GPT Neo		

Comparison with insecure execution

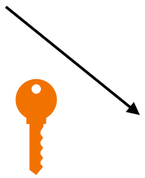
Results

	PyTorch w/ Google Colab	SIGMA
GPT2	0.04	1.61
GPT Neo	0.14	7.43

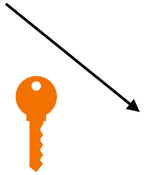
Comparison with insecure execution

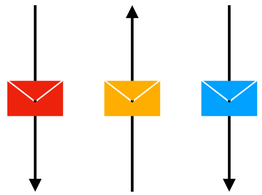
Threat Model

Threat Model



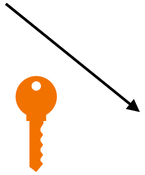
Threat Model

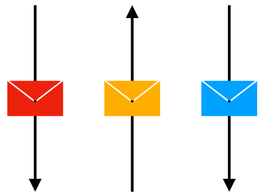




“What are some good places to visit in Toronto?”

Threat Model





“What are some good places to visit in Toronto?”

$A($  $)$

Leak()

Function Secret Sharing (FSS) based 2PC

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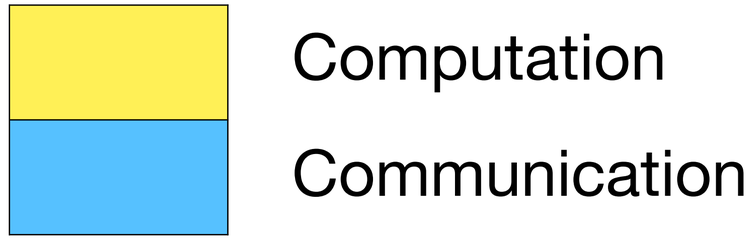
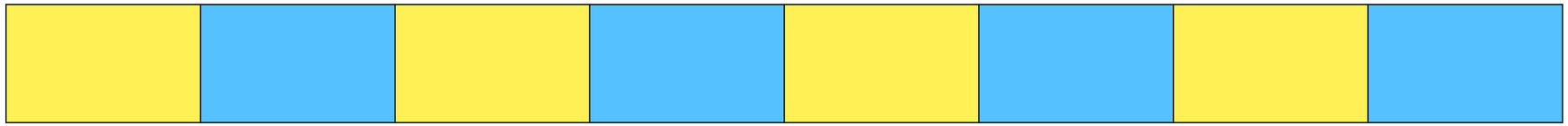
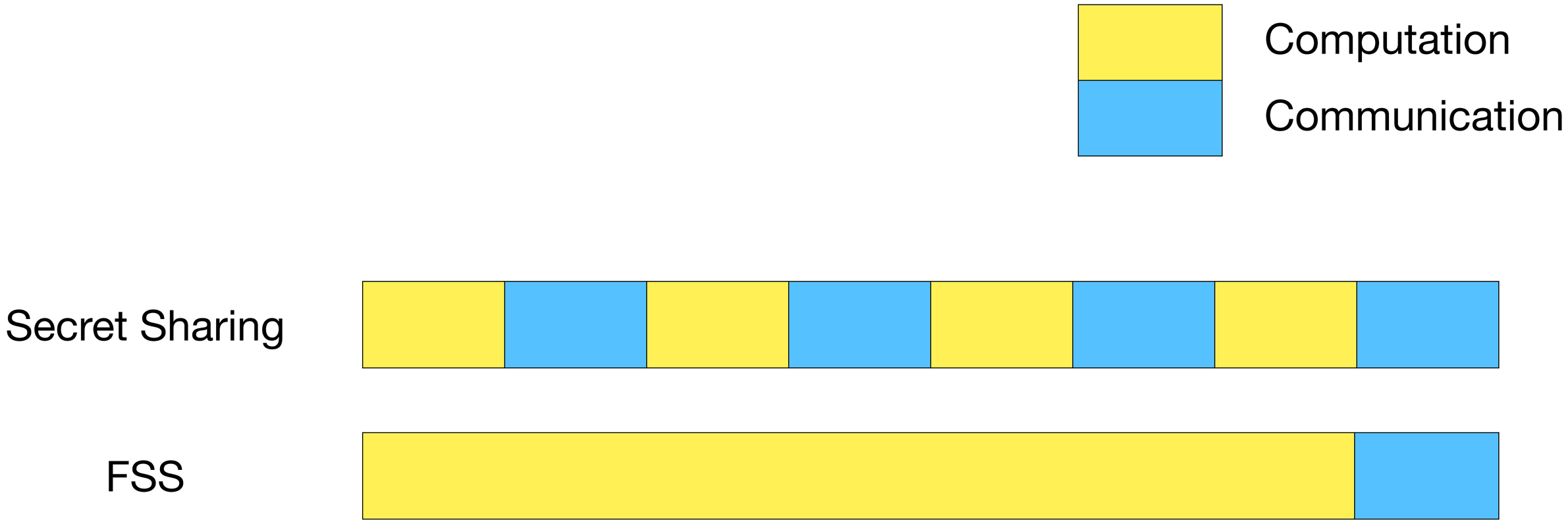


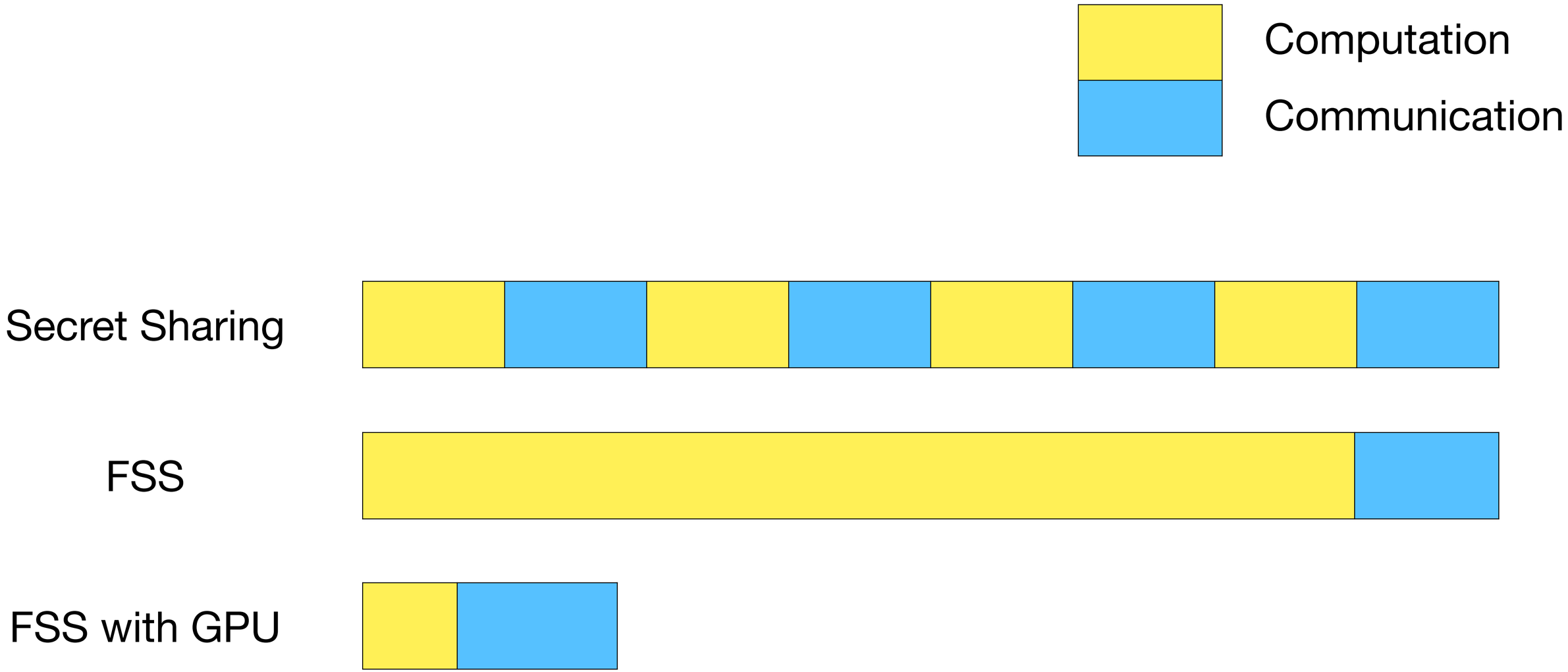
Secret Sharing



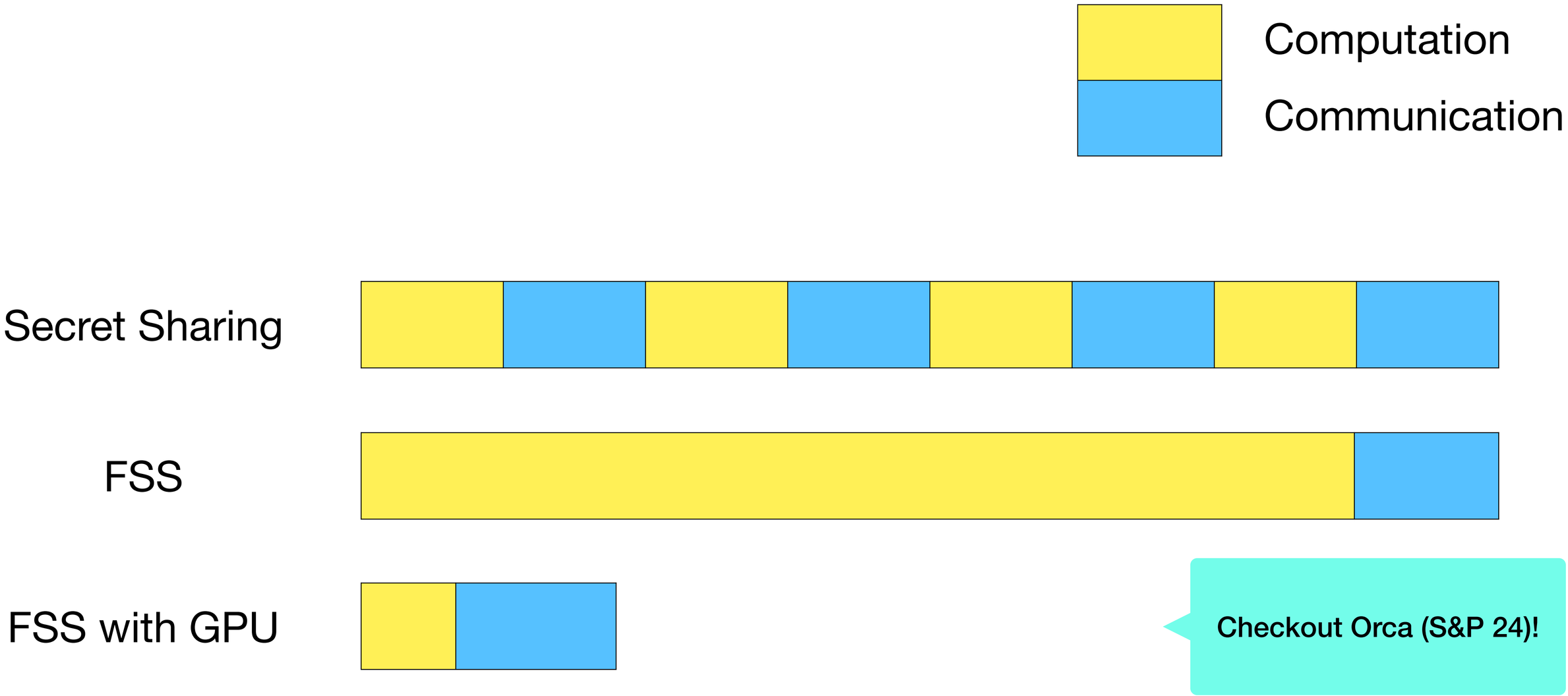
Function Secret Sharing (FSS) based 2PC



Function Secret Sharing (FSS) based 2PC



Function Secret Sharing (FSS) based 2PC



Existing Protocols

Existing Protocols

Integer Multiplication

Key size: $3n$

Comm.: $2n$

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Comm.: $2n$

Truncation

Key size: $\sim\lambda n$
Comm.: $4n$

Existing Protocols

Integer Multiplication

Key size: $3n$
Comm.: $2n$

Truncation

Key size: $\sim\lambda n$
Comm.: $4n$

Comparison

Key size: $\sim\lambda n$
Comm.: 2

Fixed-Point Arithmetic

n bit width, s scale

$$N = 2^n$$

Fixed-Point Arithmetic

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$$x \in \mathbb{R}$$

Encode

$$y = \lfloor x \cdot 2^s \rfloor \in \mathbb{U}_N$$

Fixed-Point Arithmetic

n bit width, s scale

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$x \in \mathbb{R}$

Encode

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$y \in \mathbb{U}_N$

Decode

$x = \frac{y}{2^s} \in \mathbb{R}$

Fixed-Point Arithmetic

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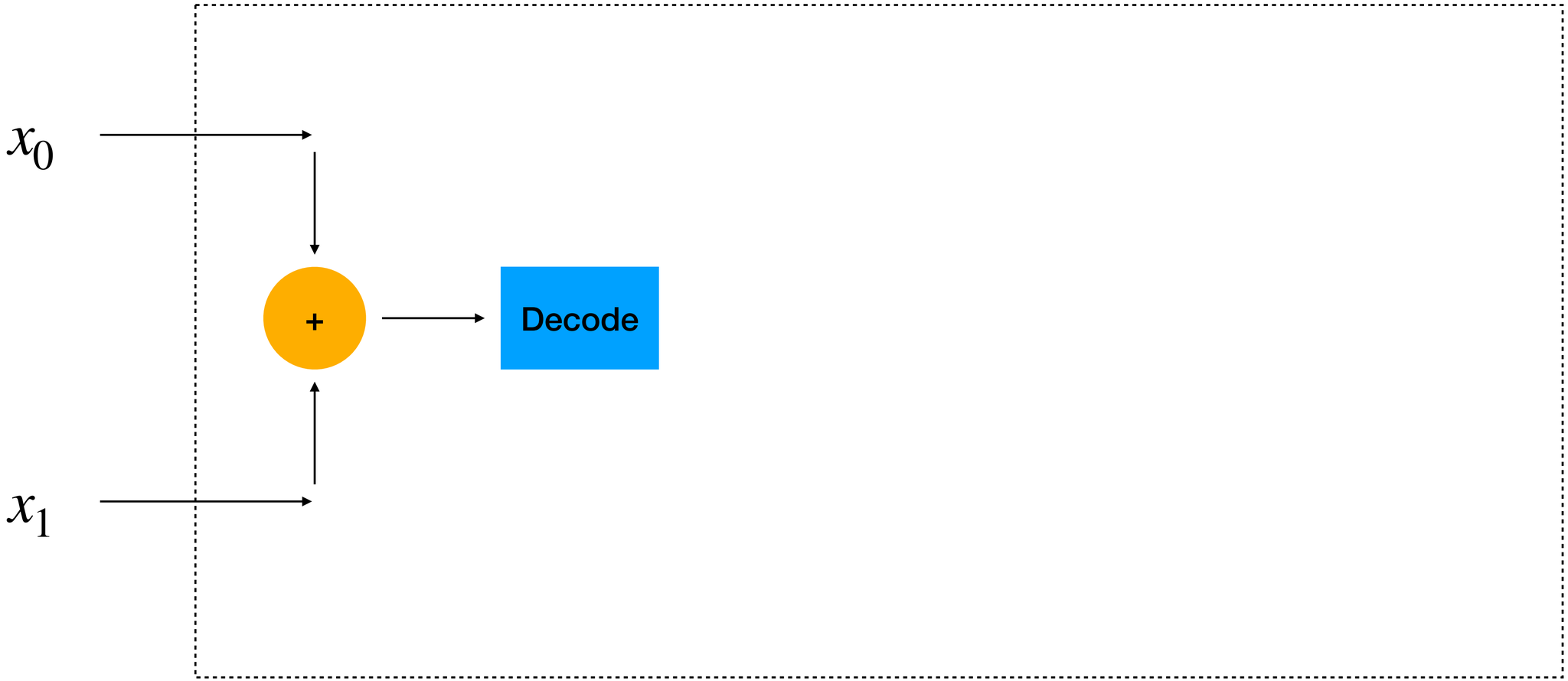

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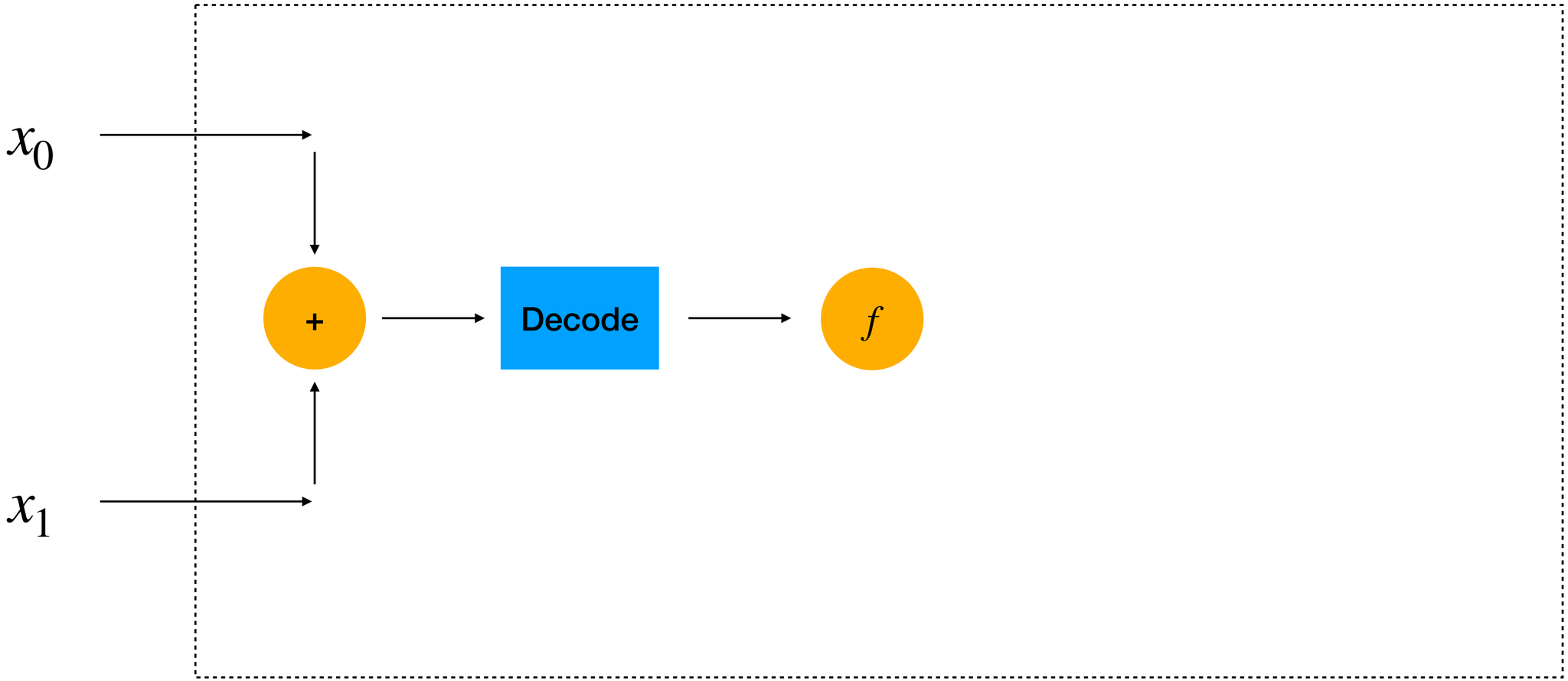

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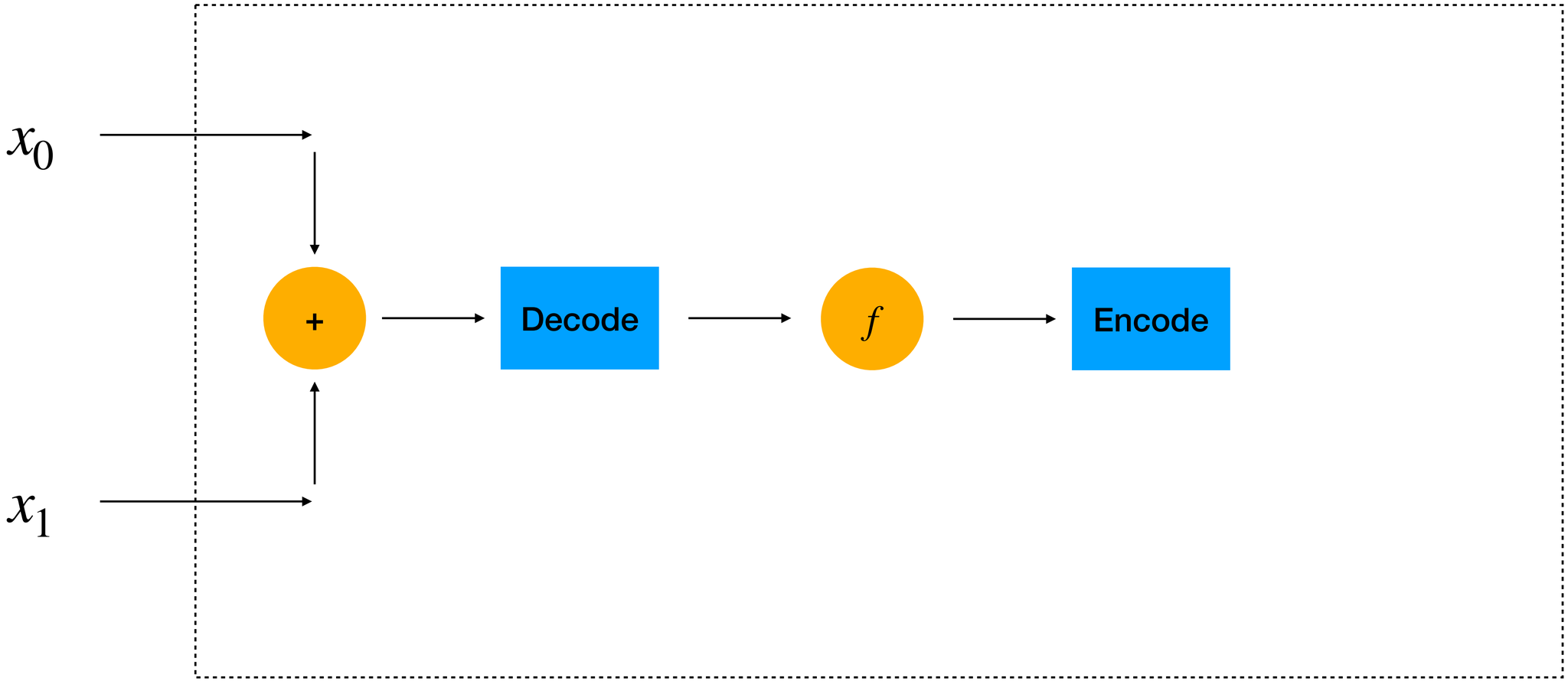

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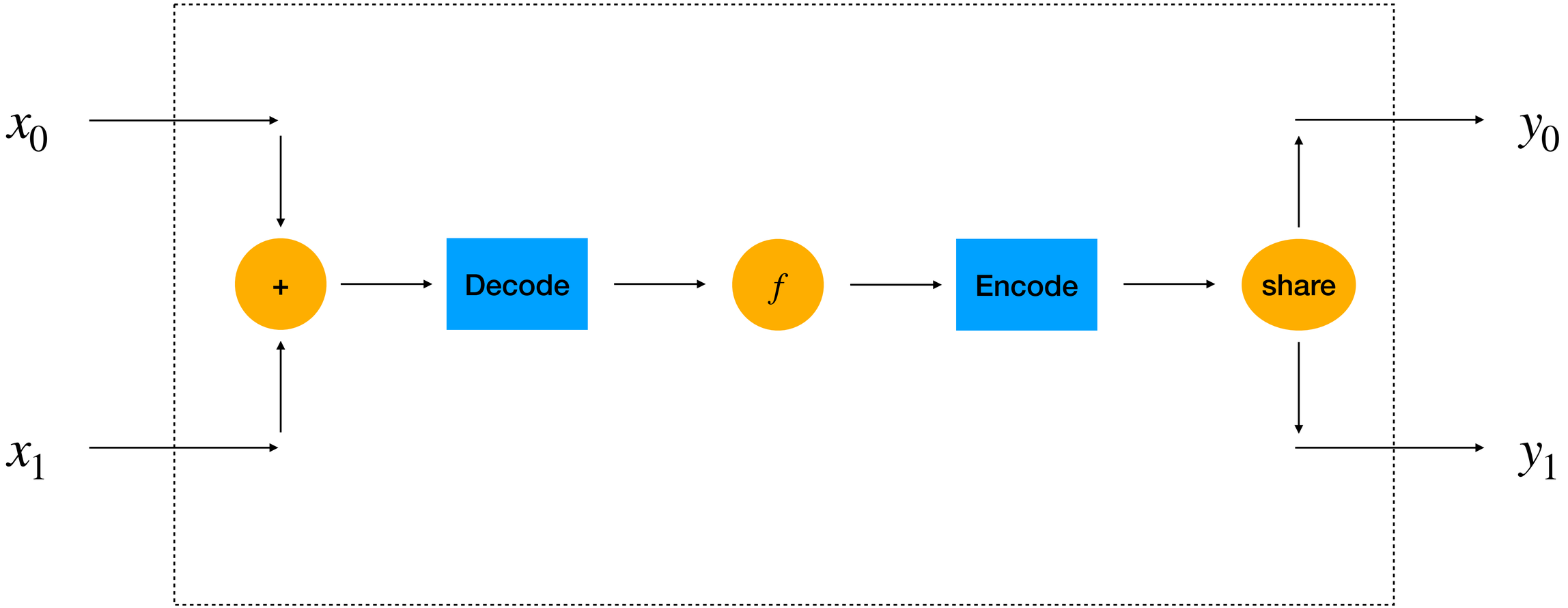

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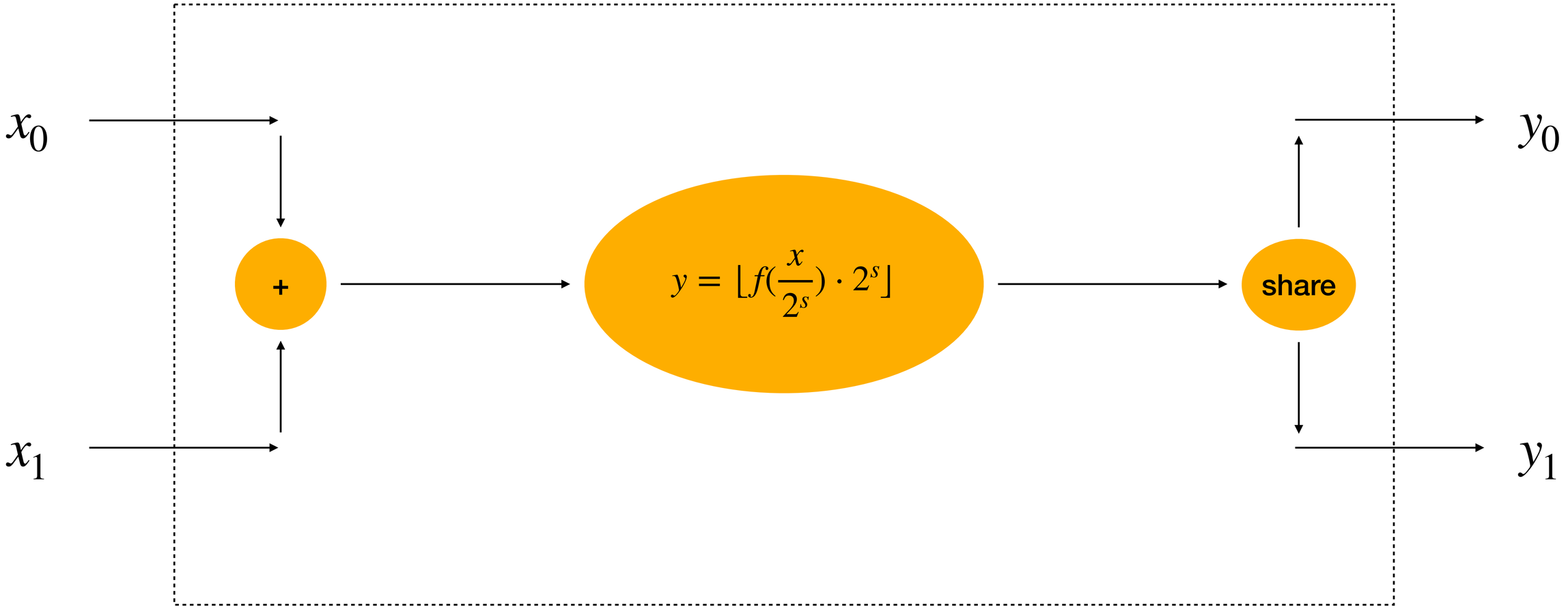
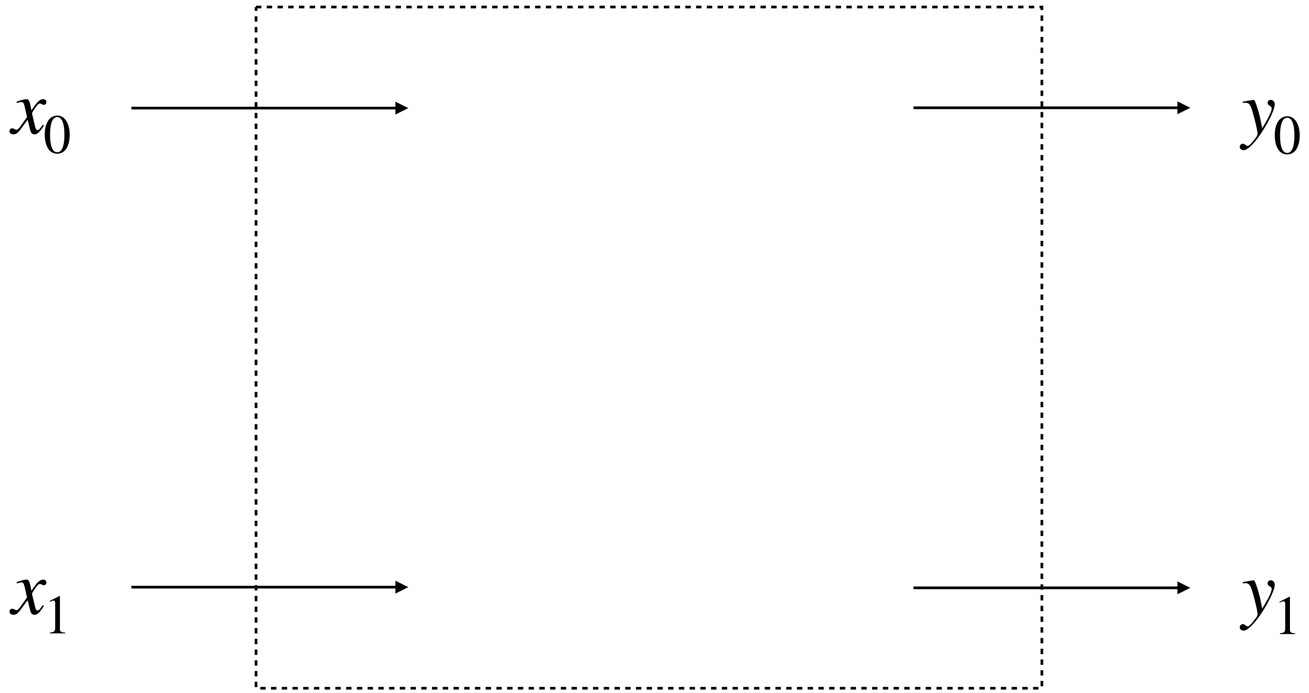
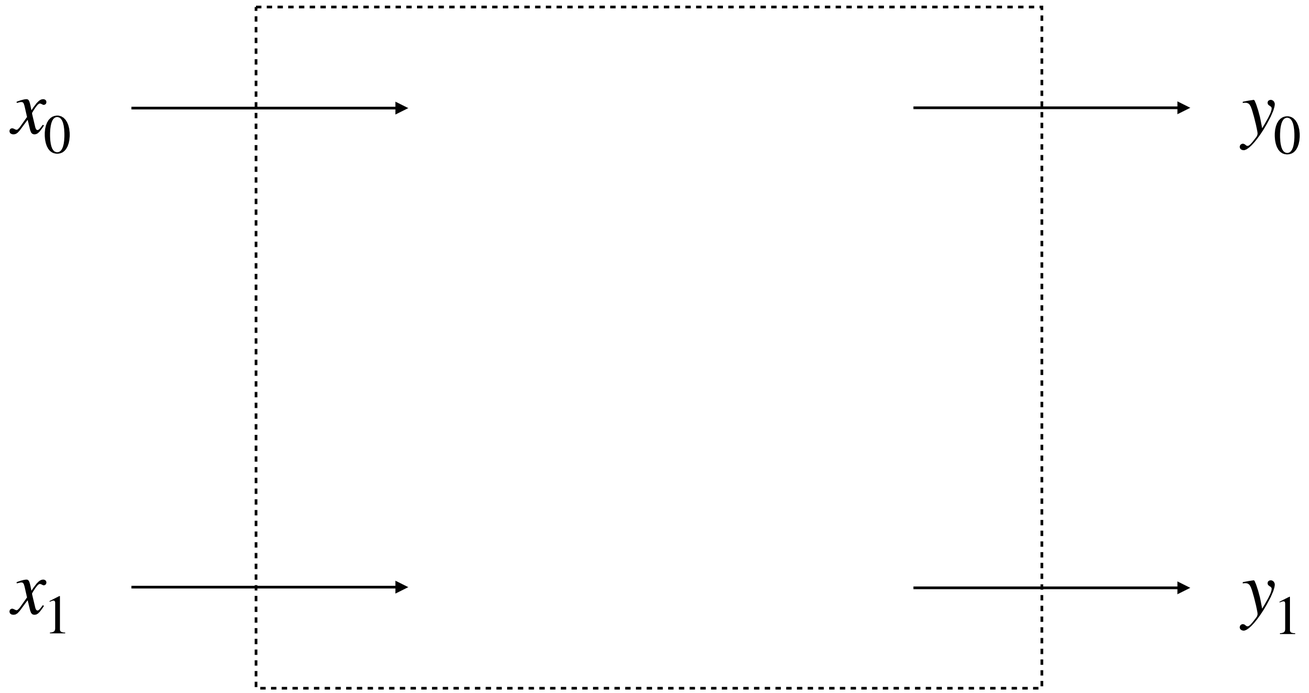


Look-Up Table based Protocol



Look-Up Table based Protocol

$$T[i] = \lfloor f(\frac{i}{2^s}) \cdot 2^s \rfloor$$



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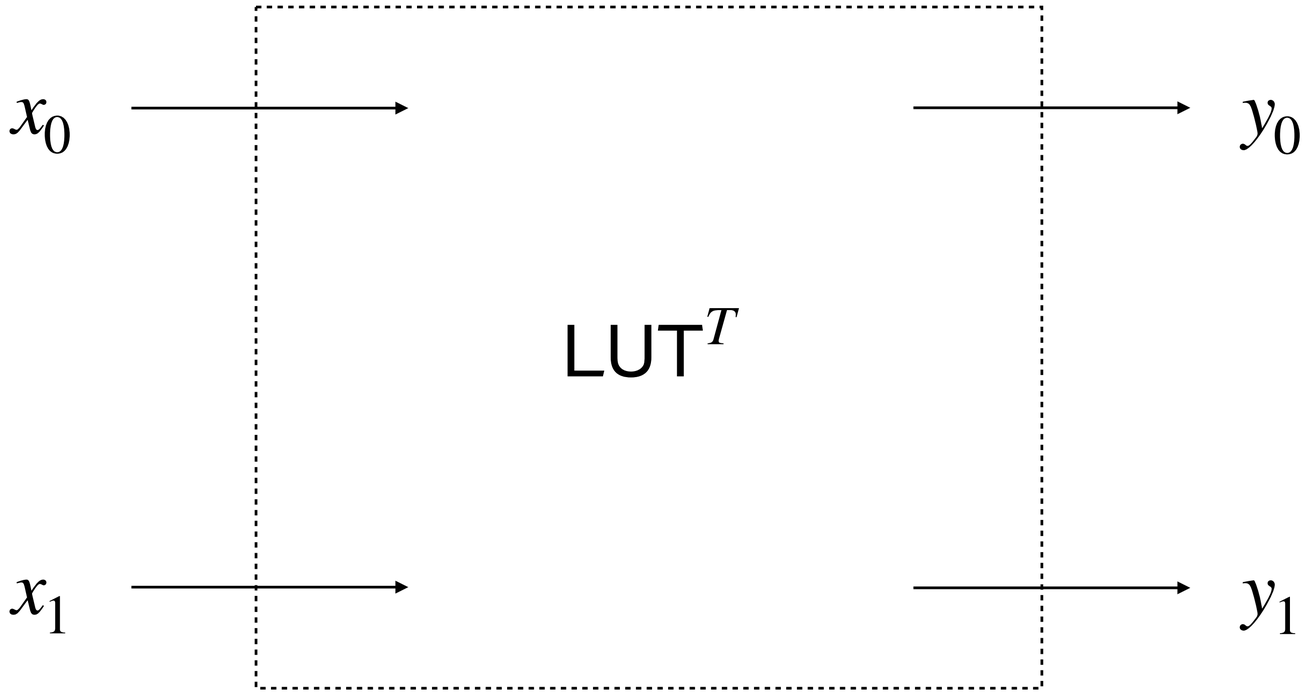

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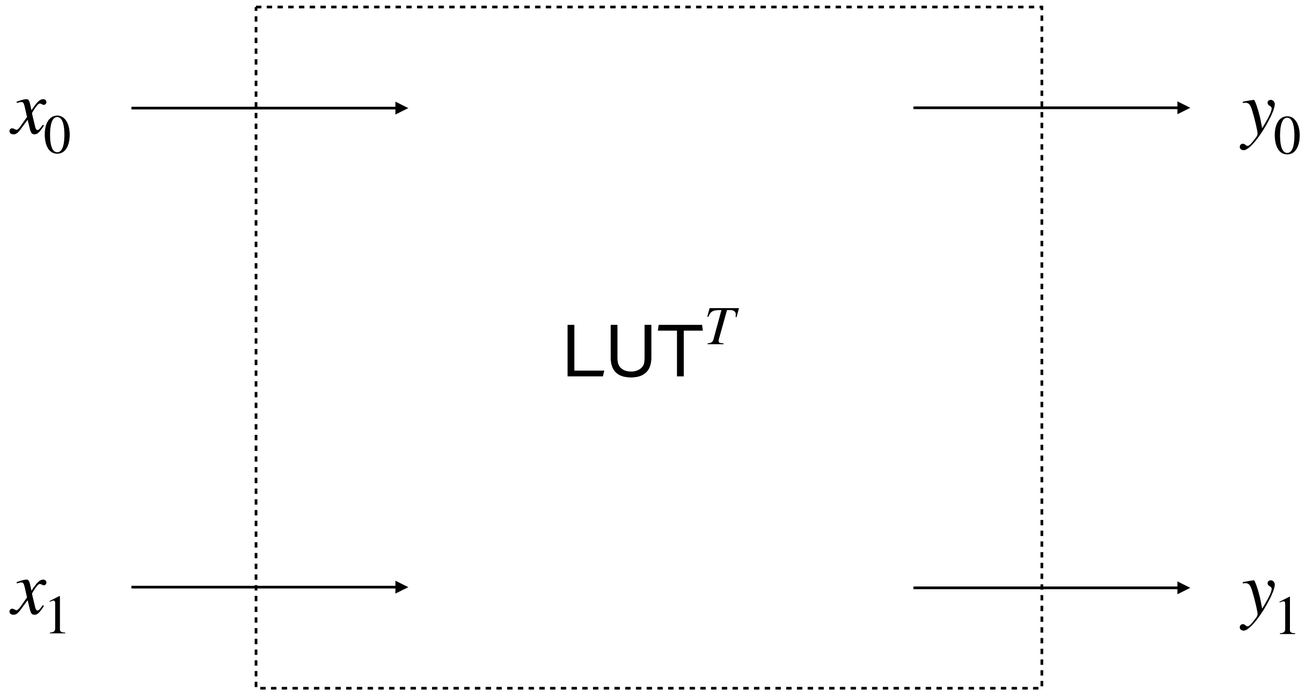


Pika (Wagh, 22)

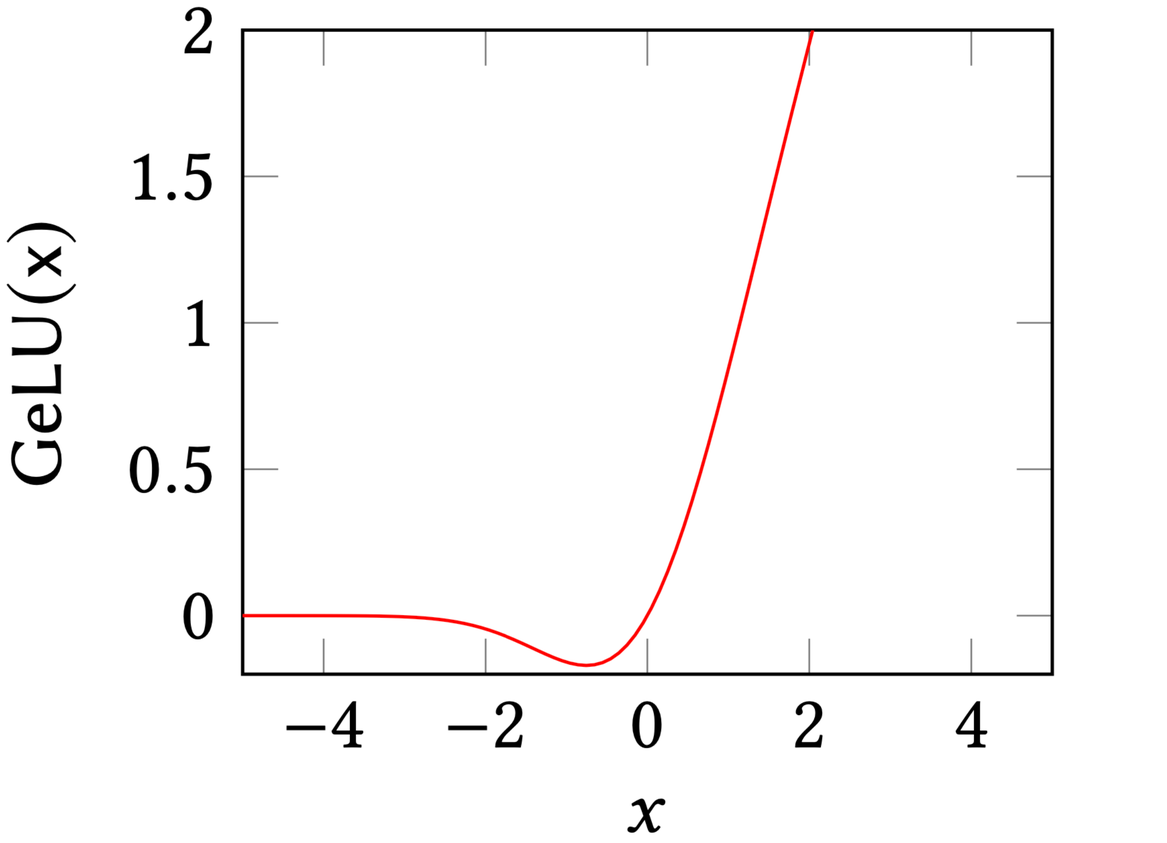
Key Size.: $O(n\lambda)$

Comm.: $O(n)$

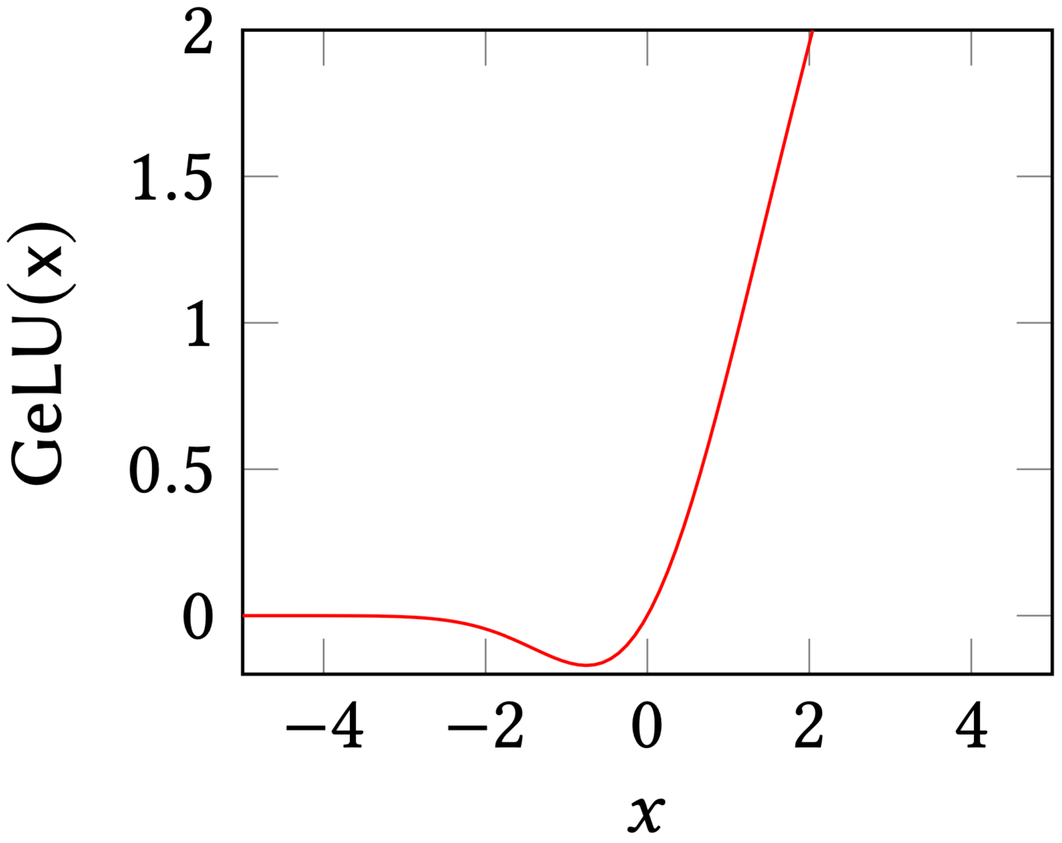
Comp.: $O(2^n)$

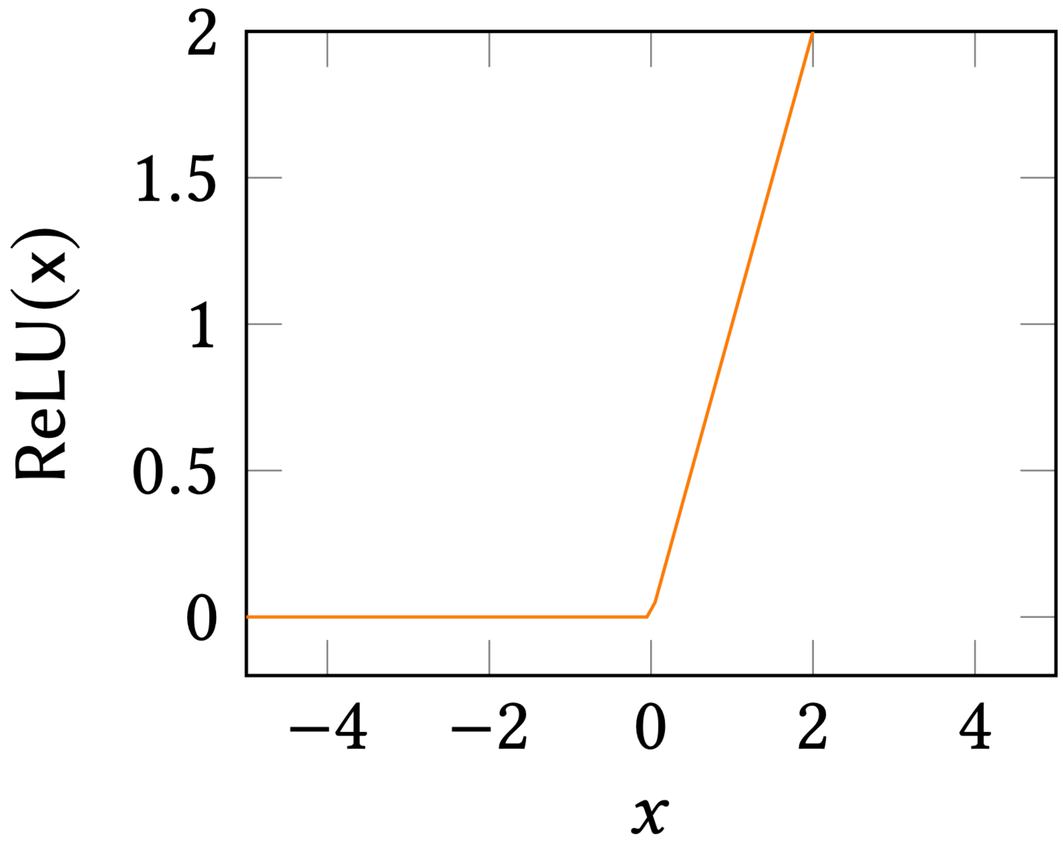
GeLU

GeLU



GeLU

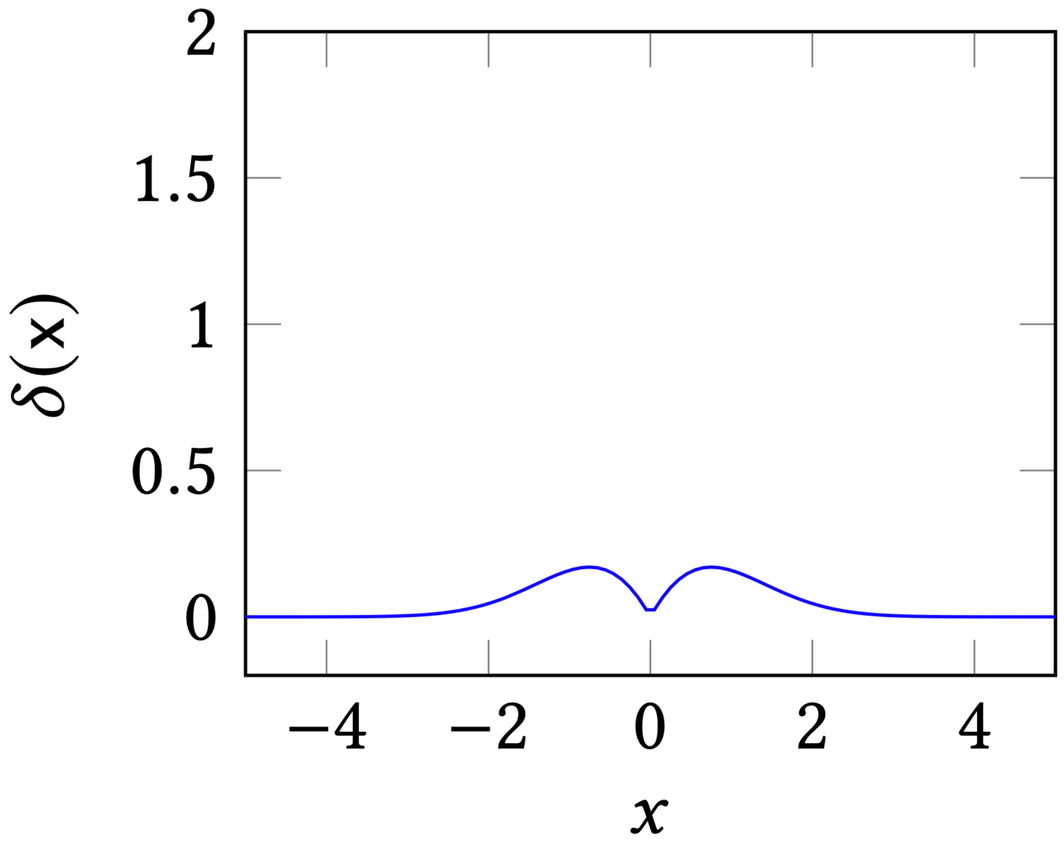




$$\mathrm{ReLU}(x) = \max(x, 0)$$

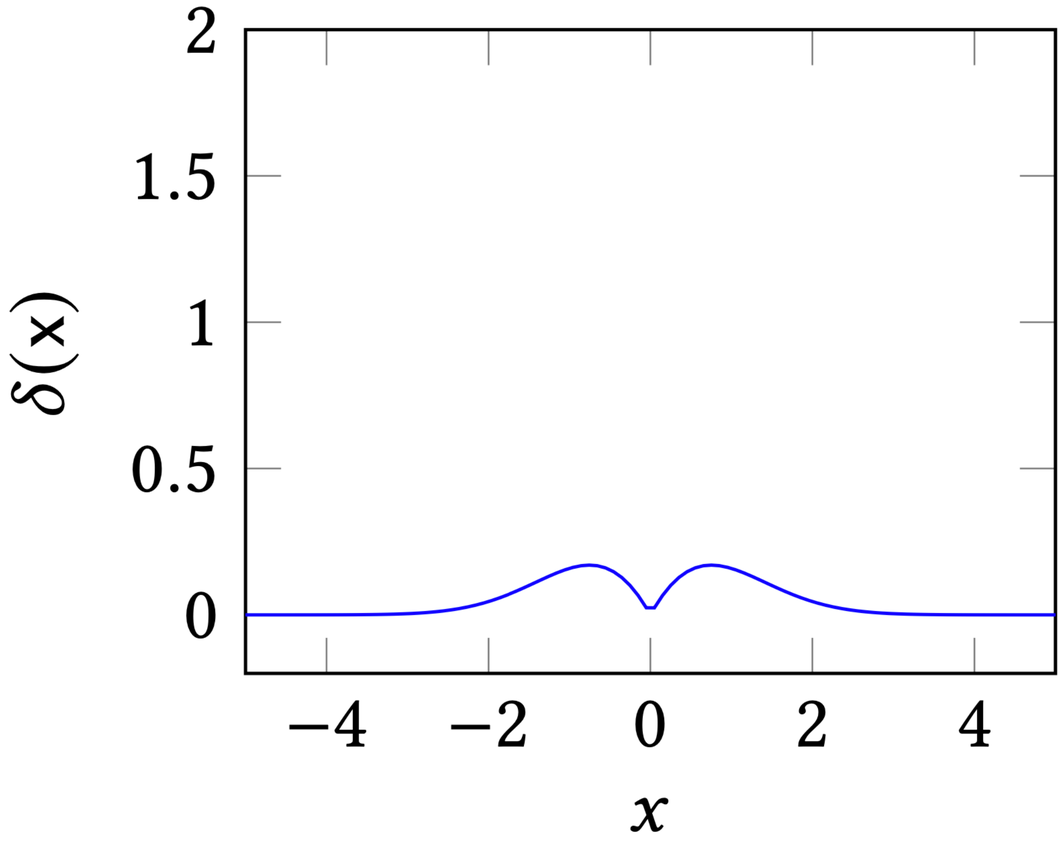
GeLU

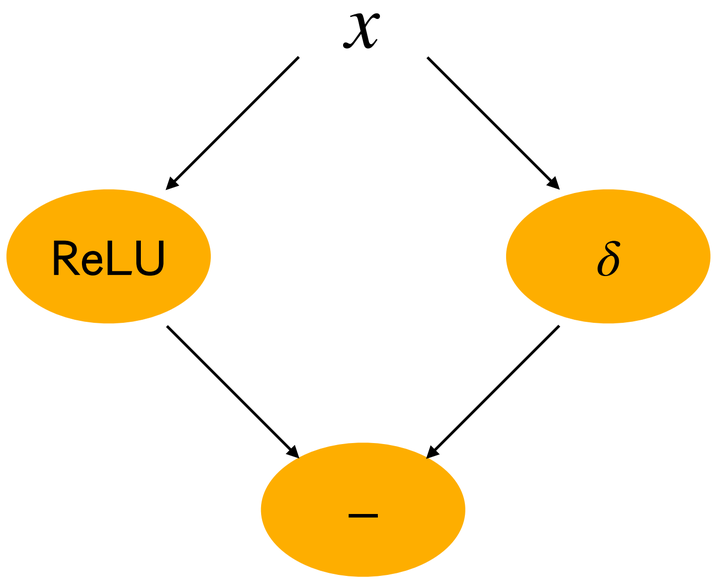
GeLU



$$\delta(x) = \mathrm{ReLU}(x) - \mathrm{GeLU}(x)$$

GeLU





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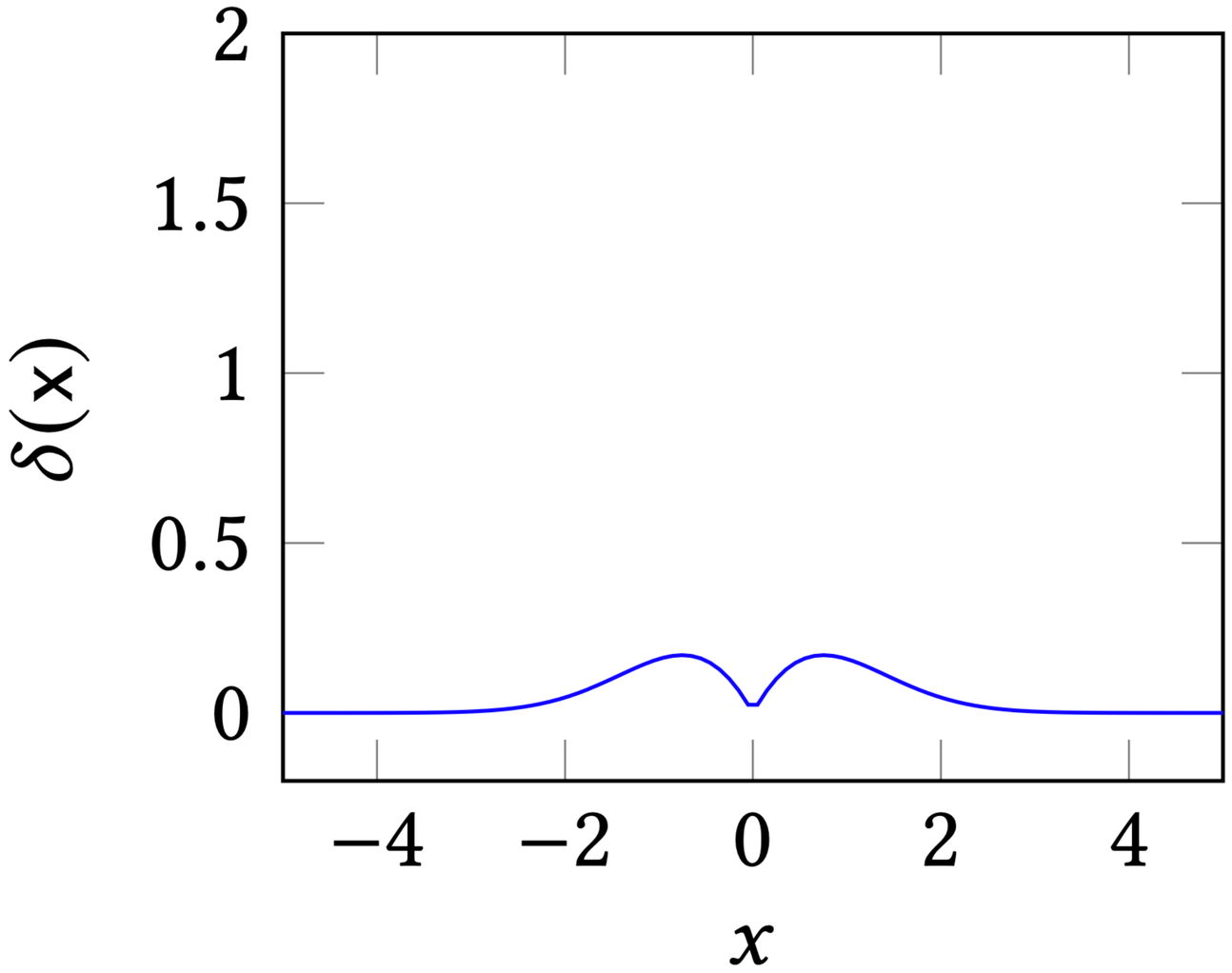
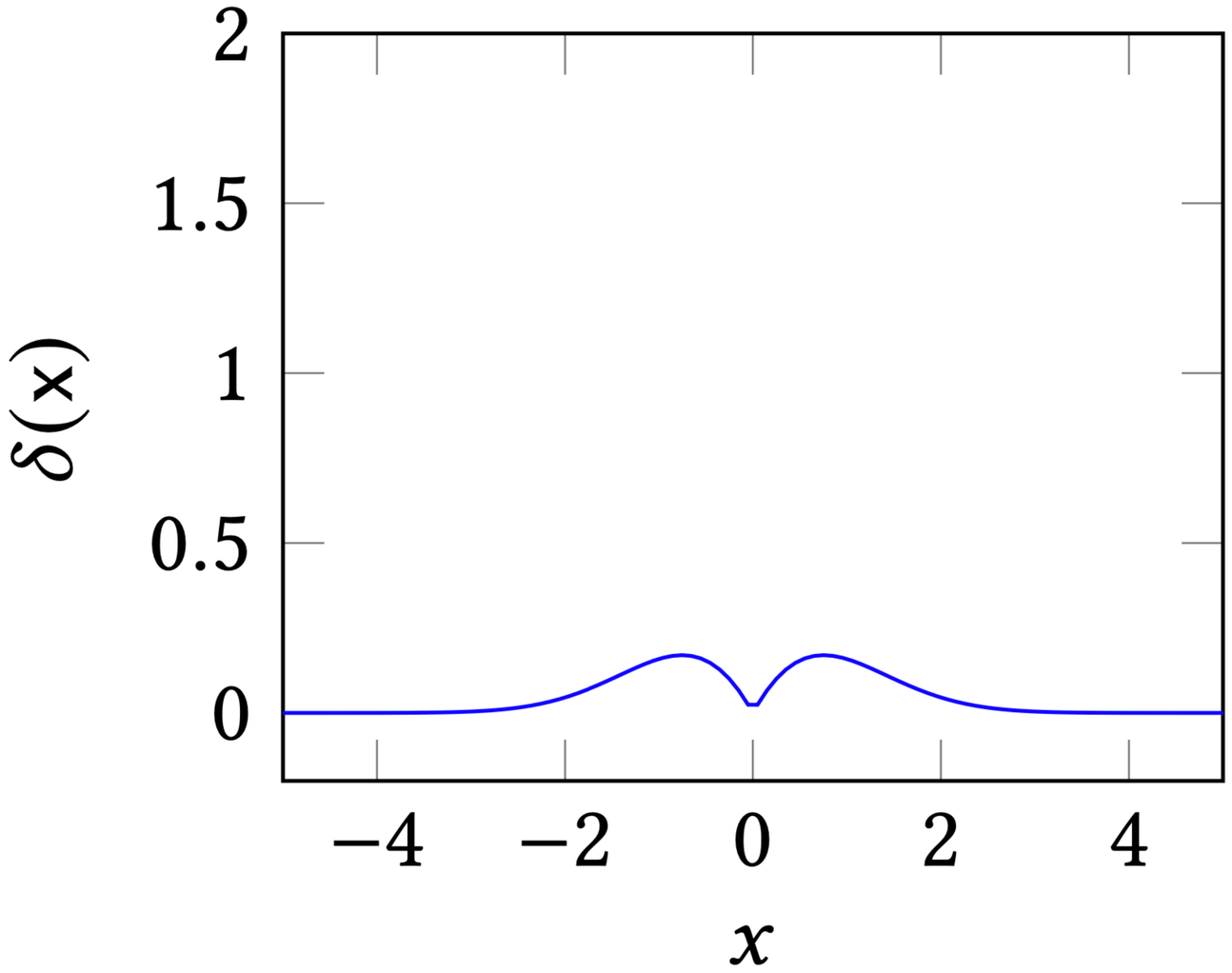
GeLU



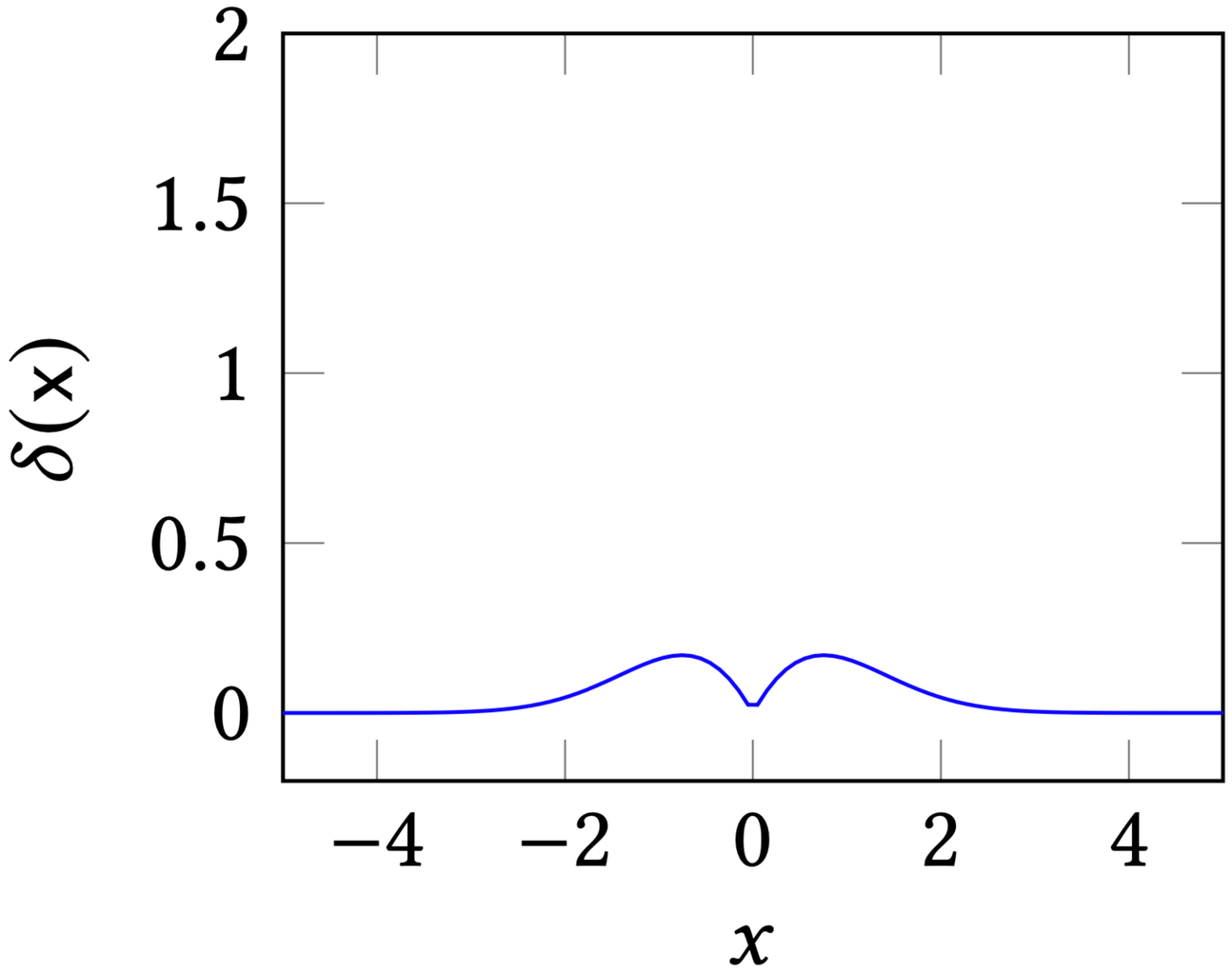
GeLU



1. “Looks” symmetric

$$\delta(x) = \delta(-x)$$

GeLU



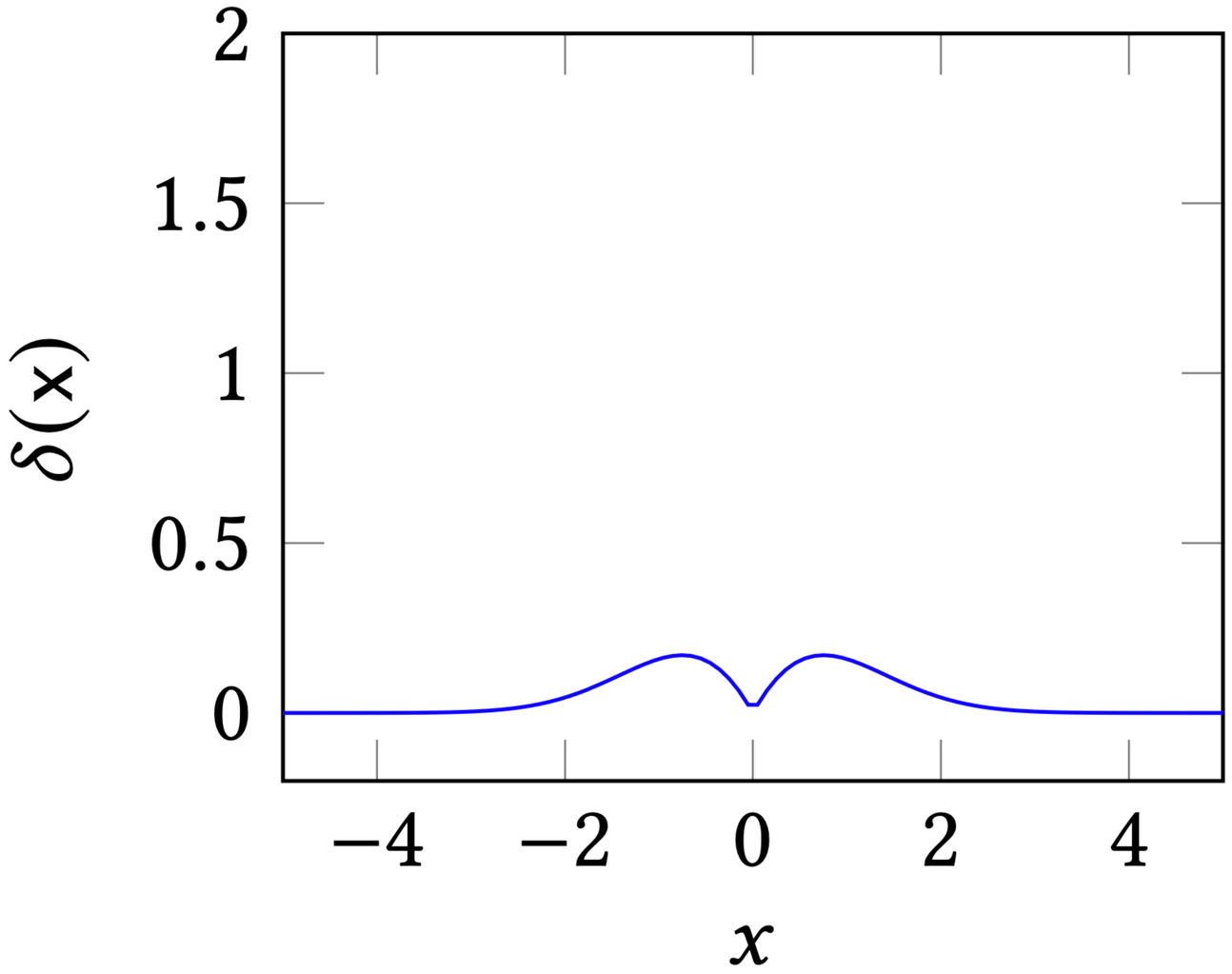
1. “Looks” symmetric

$$\delta(x) = \delta(-x)$$

2. Damps away after 4

$$\delta(4) \approx 0$$

GeLU



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$$\delta(x) = \delta(-x)$$

2. Damps away after 4

$$\delta(4) \approx 0$$

3. Fixed point scale 6 suffices

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6. **return** $d \cdot x - T^{\delta}[c]$ ▷ Calculate $\text{ReLU}(x) - \delta(x)$

Other Optimisations

Better Truncation Protocol

Better ReLU Protocol

Protocol tailored for GPUs

Effective Bitwidth Optimisation

Attention Mask Optimisation

SyTorch

SyTorch

```cpp
template <typename T>
class FFN : public SytorchModule<T>
{
    using SytorchModule<T>::gelu;

    u64 in;
    u64 hidden;
public:
    FC<T> *up;
    FC<T> *down;

    FFN(u64 in, u64 hidden) : in(in), hidden(hidden)
    {
        up = new FC<T>(in, hidden, true);
        down = new FC<T>(hidden, in, true);
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    Tensor<T> &_forward(Tensor<T> &input)
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    GPT2SequenceClassification<T> bert(n_layer, n_head, n_embd);
    bert.init(scale);
    bert.setBackend(new SigmaCPU<T>());
    // bert.setBackend(new Piranha<T>);
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    bert.optimize();
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- Easy backend integration
- Training (CNNs only)
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Releases soon!™

Thank you!

https://eprint.iacr.org/2023/1269