Optimization
for Machine Learning in Practice I

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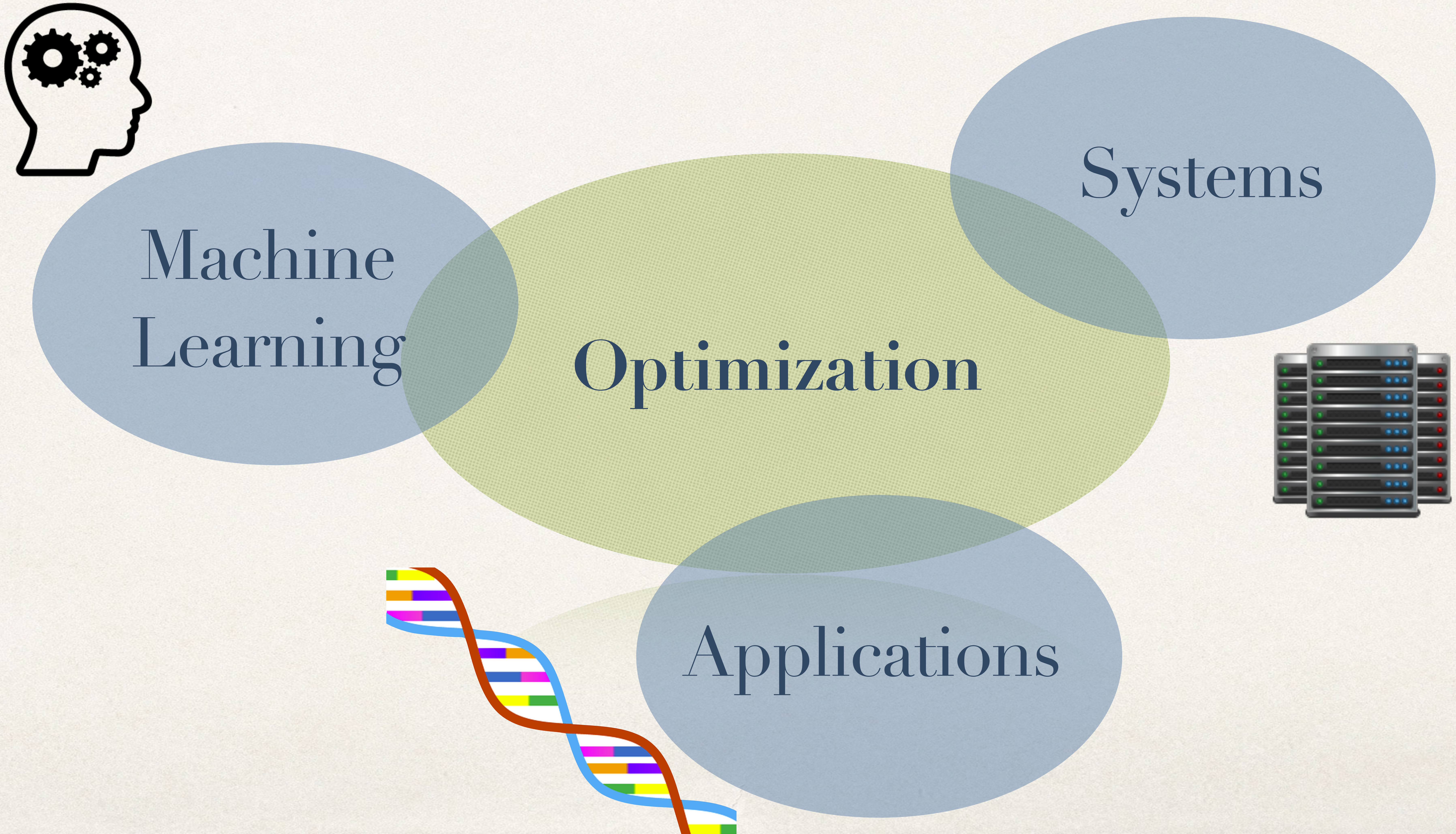
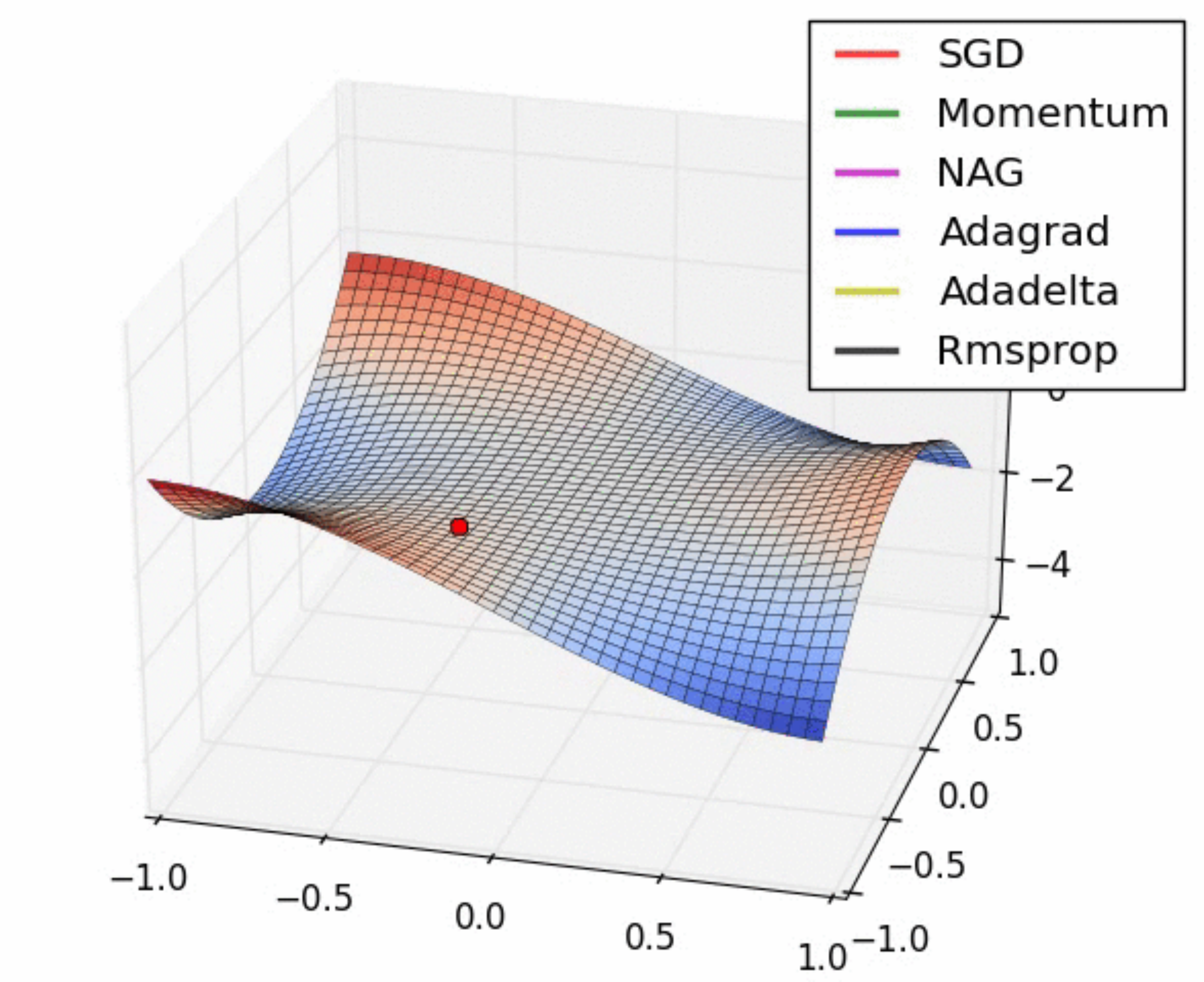
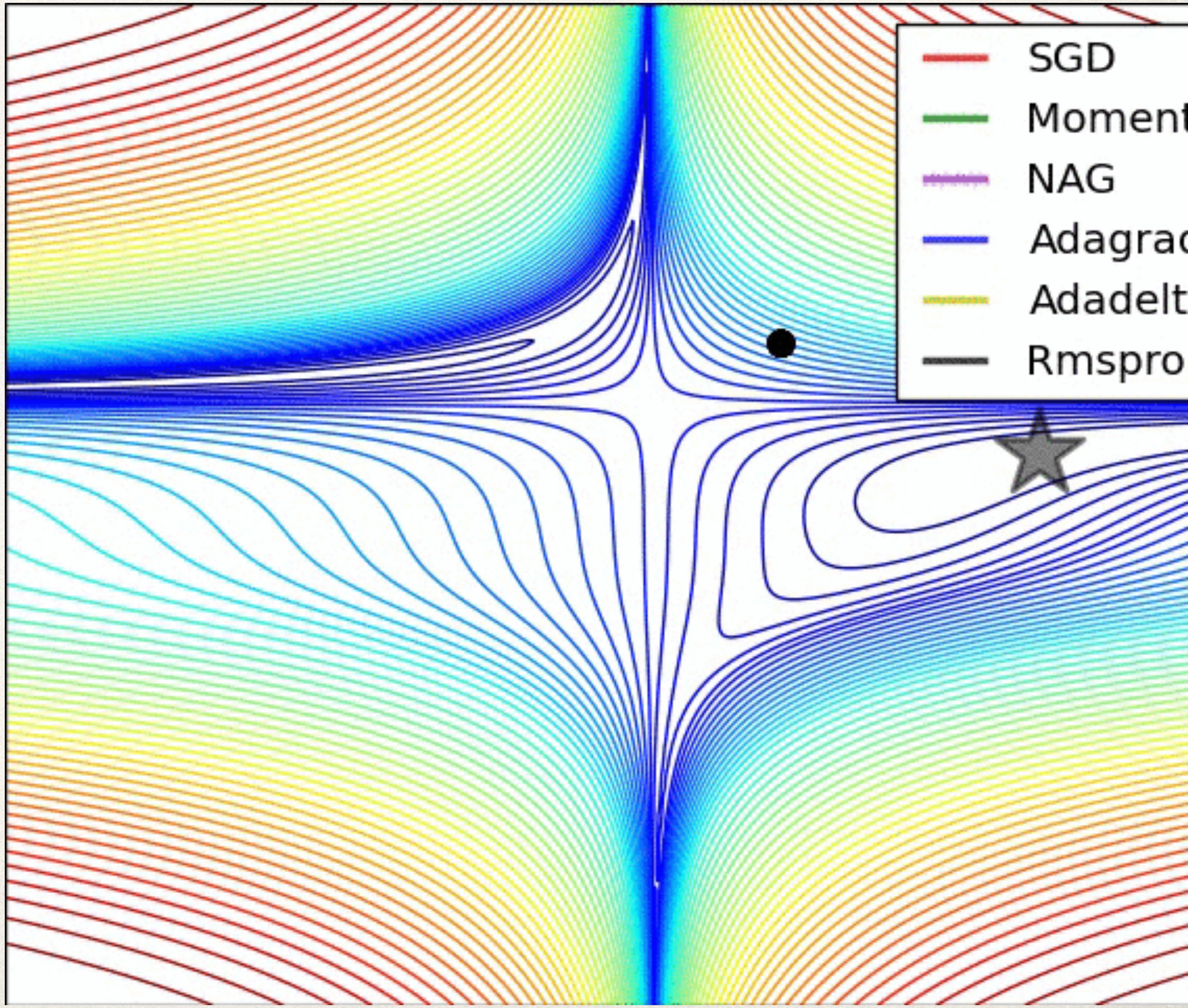
Where are we?



Practical comparison of algorithms





https://imgur.com/a/Hqolp#2dKCQHh

Trends - General

- **Custom AI hardware & systems**
- **Federated or decentralized training**
- **Privacy**
- **Interpretability**
- **trust, fairness and robustness in ML**

  (e.g. robust & secure against adversaries)

Optimization is a key element of most above topics

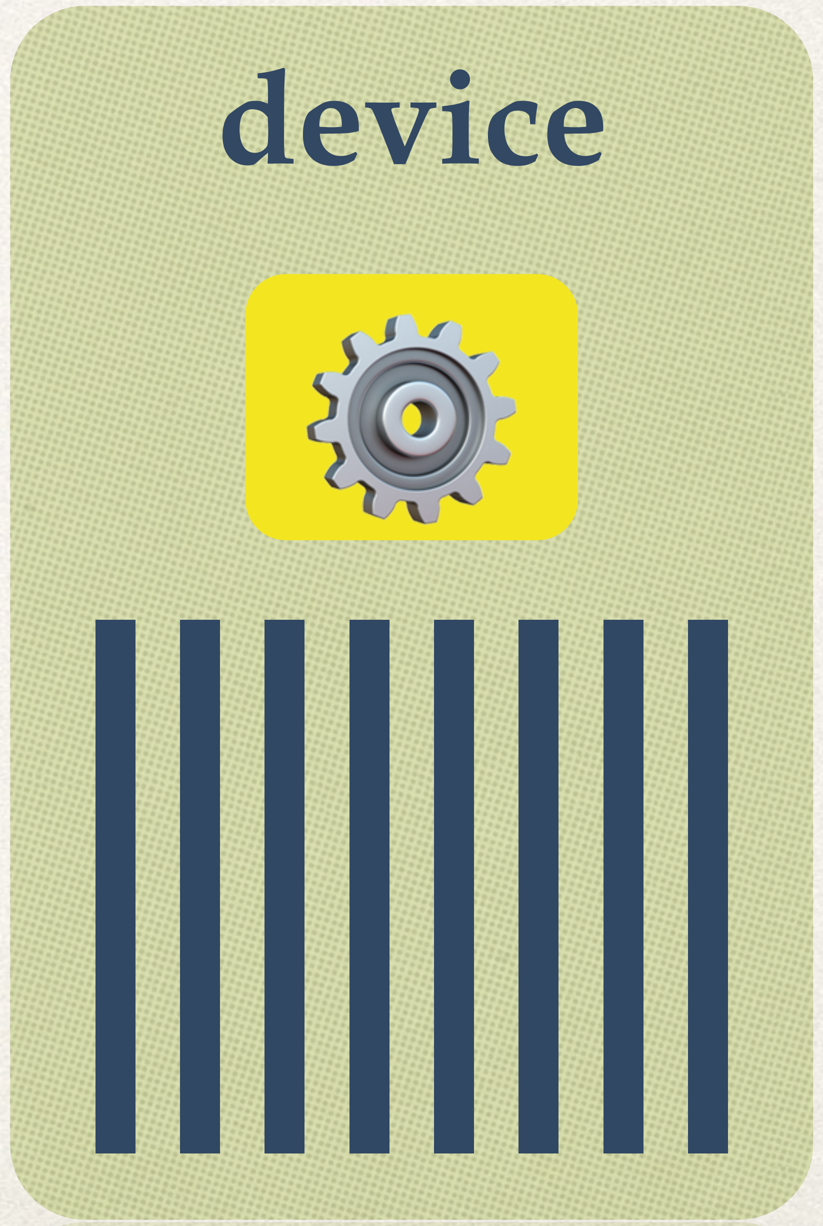
ML Training

$$\min_{\boldsymbol{x}} \; f(\boldsymbol{x}) = \frac{1}{|data|} \sum_{i \in data} f_i(\boldsymbol{x})$$

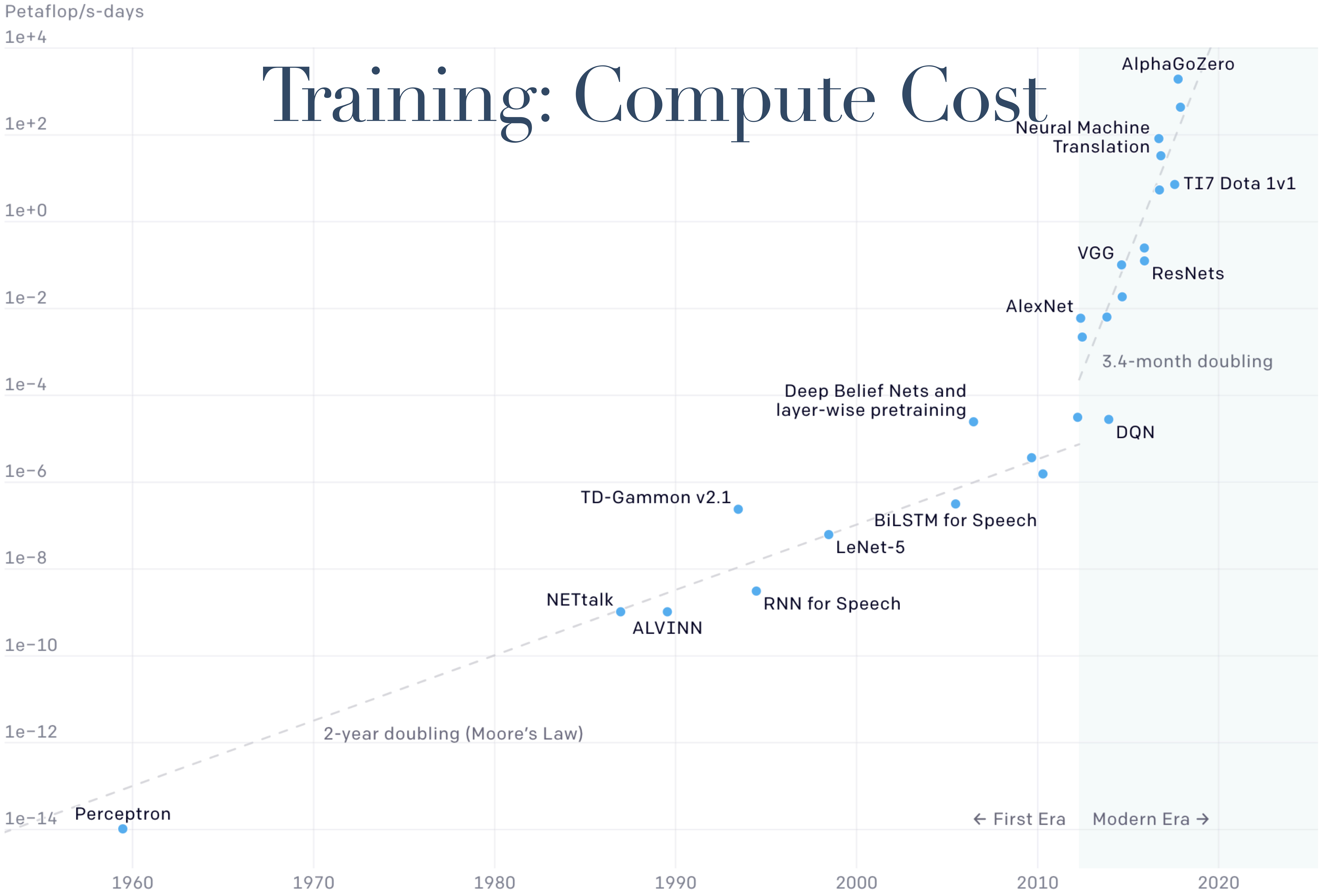
Training algorithms: SGD-based

$$i_t \sim \text{Uniform}(1, |data|)$$

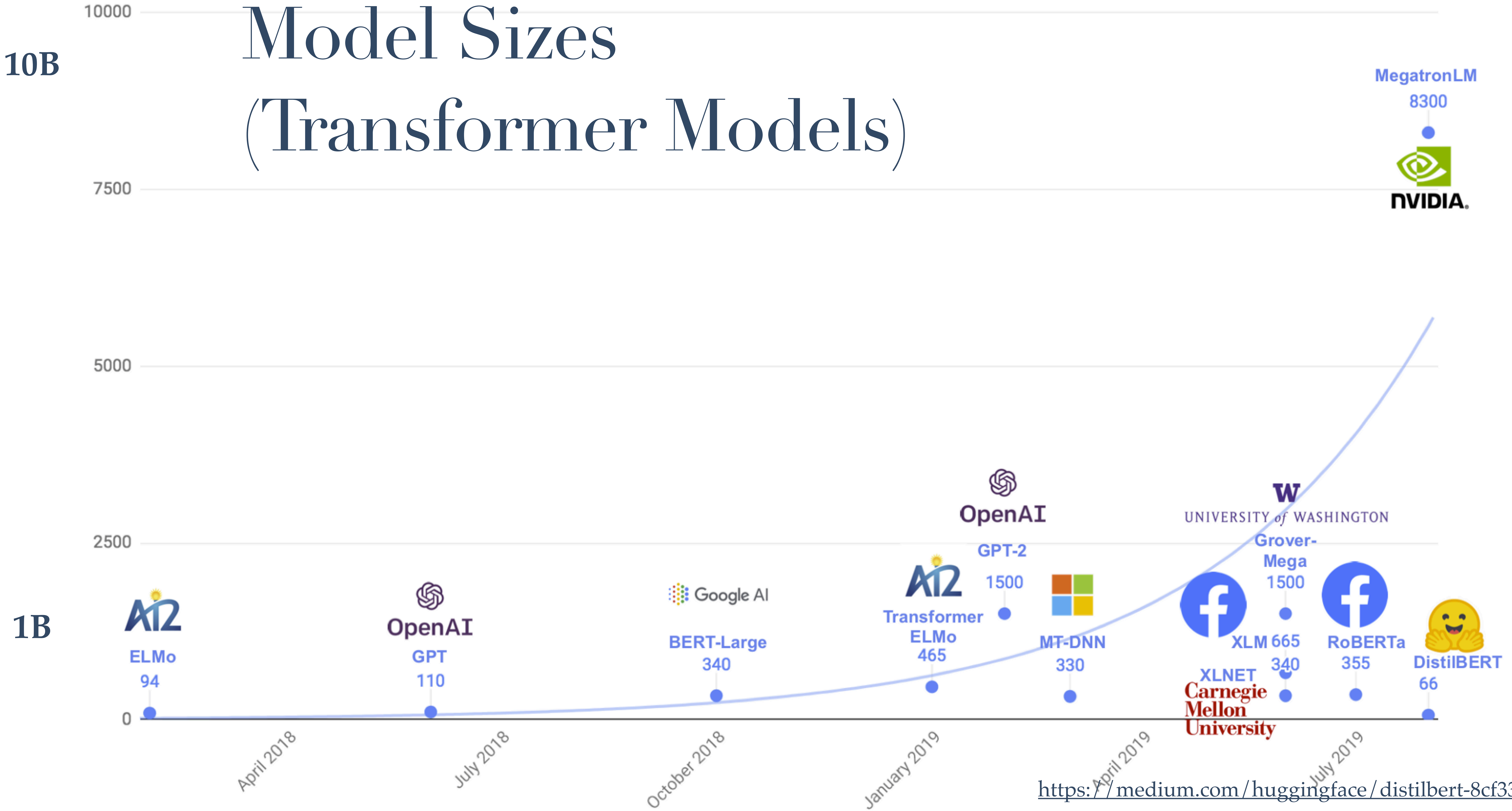
$$\boldsymbol{x}_{t+1} := \boldsymbol{x}_t - \gamma_t \nabla f_{i_t}(\boldsymbol{x}_t)$$



Training: Compute Cost

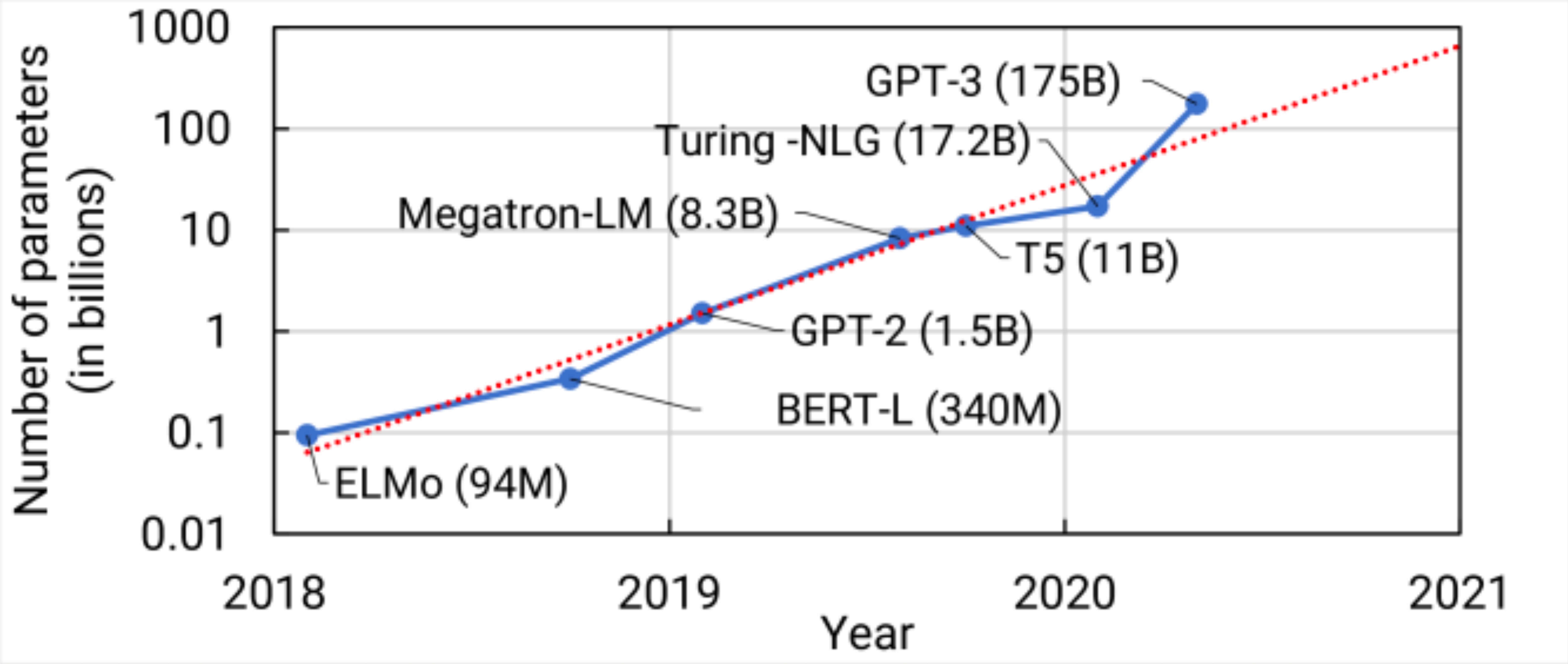


Model Sizes (Transformer Models)



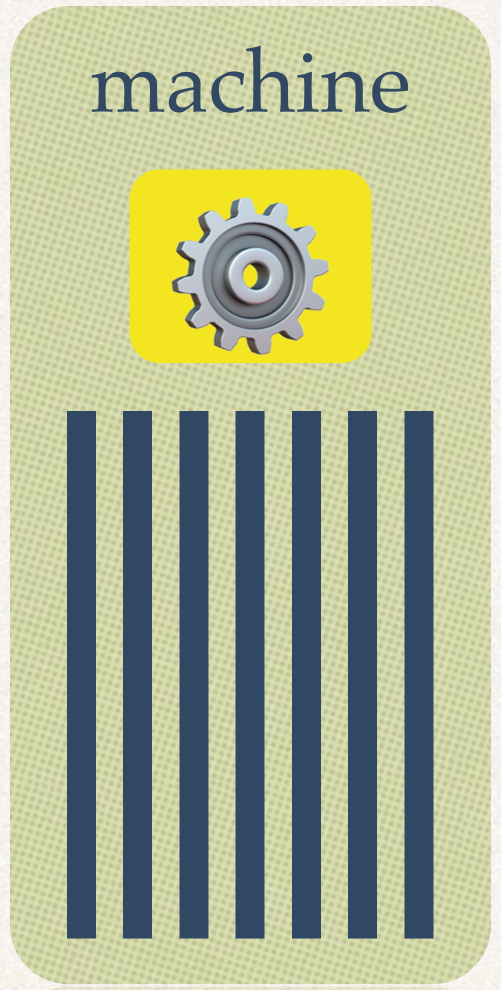
https://medium.com/huggingface/distilbert-8cf3380

Model Sizes (Transformer Models)

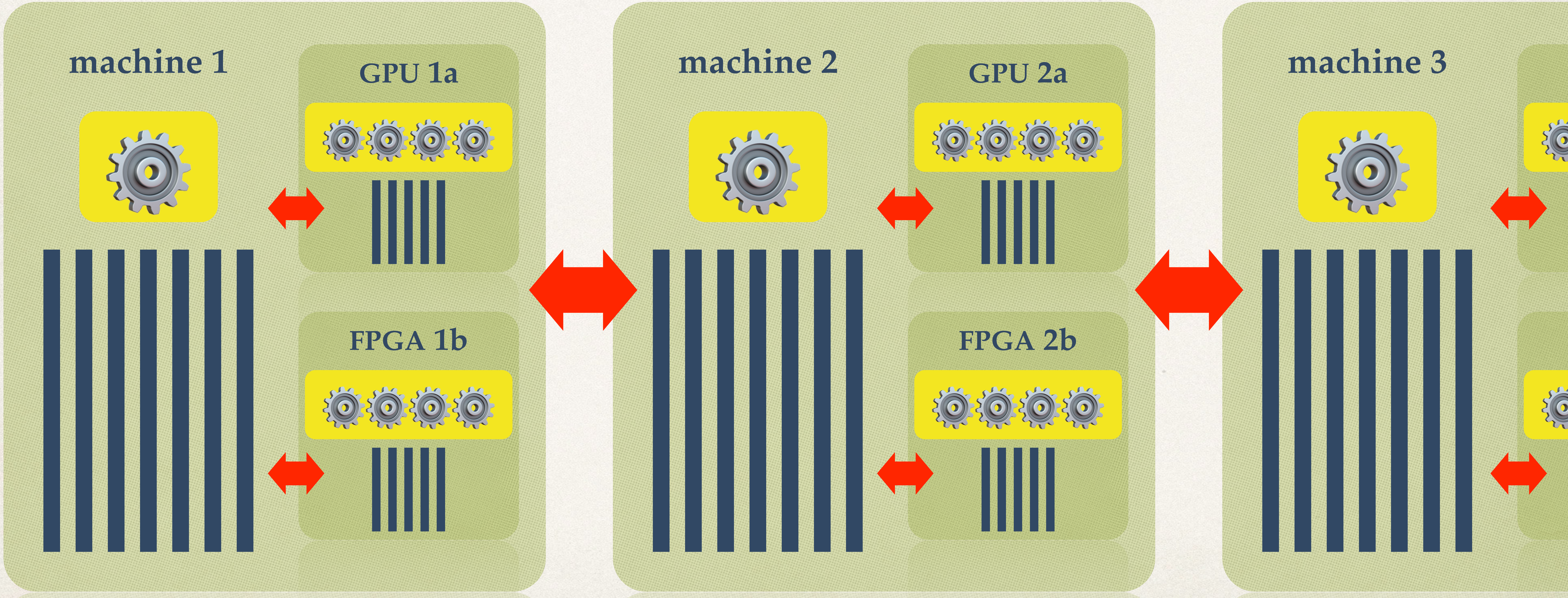


https://www.arxiv-vanity.com/papers/2104.04473/

Systems …then



Systems …now

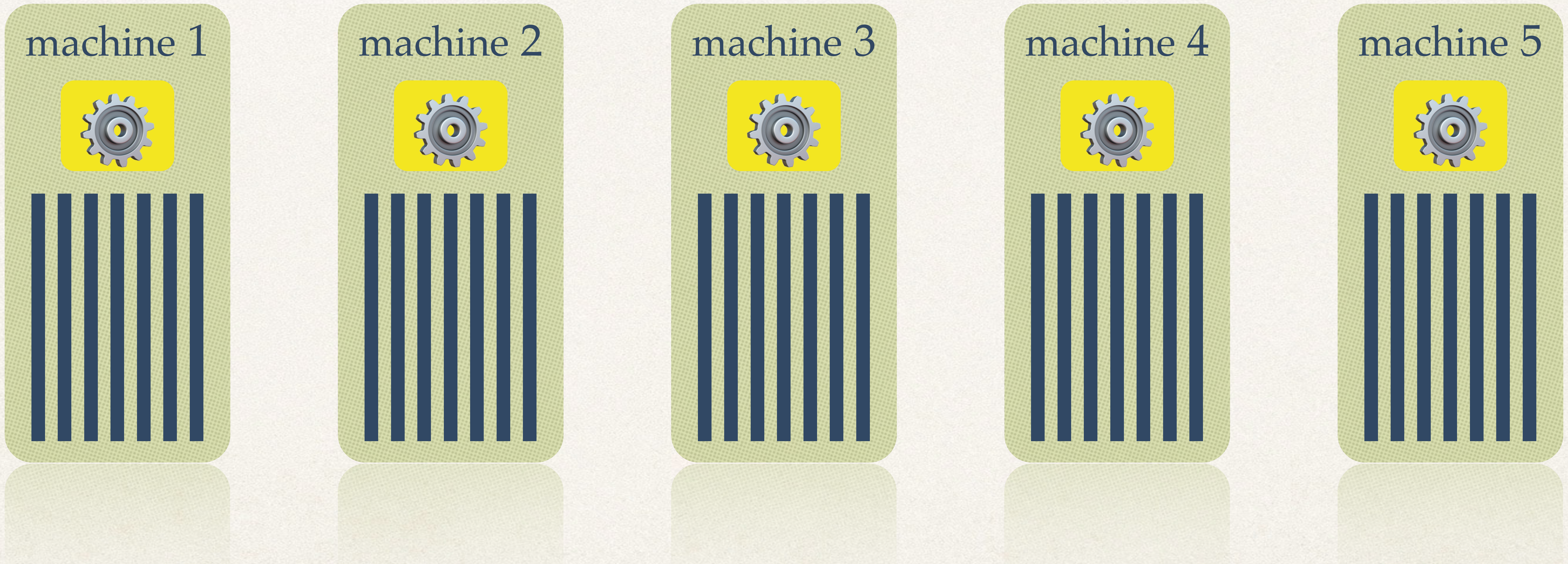


What are the fundamental limits of **parallelizing** the training of neural networks?

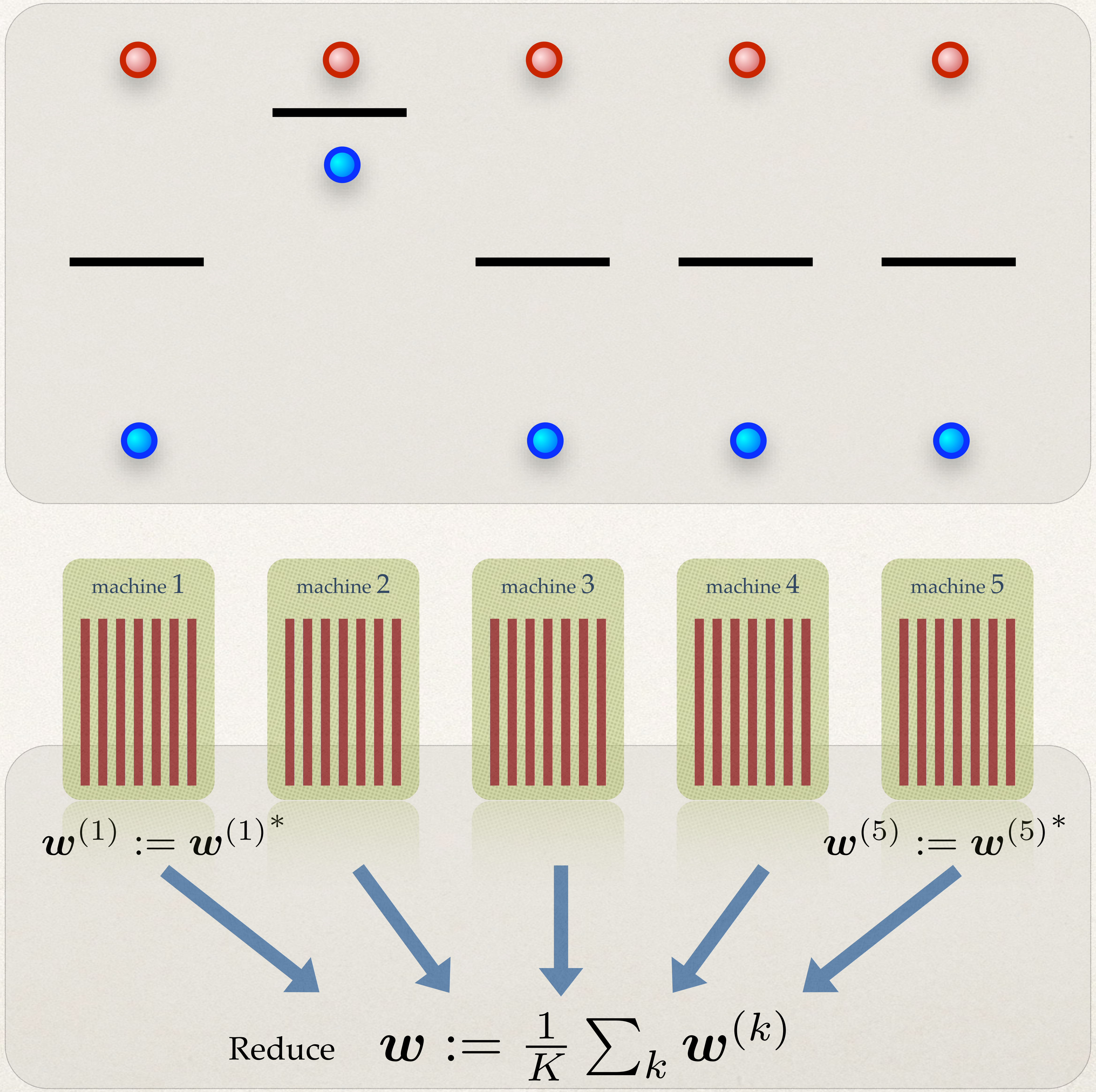
1

Parallel & Distributed Training

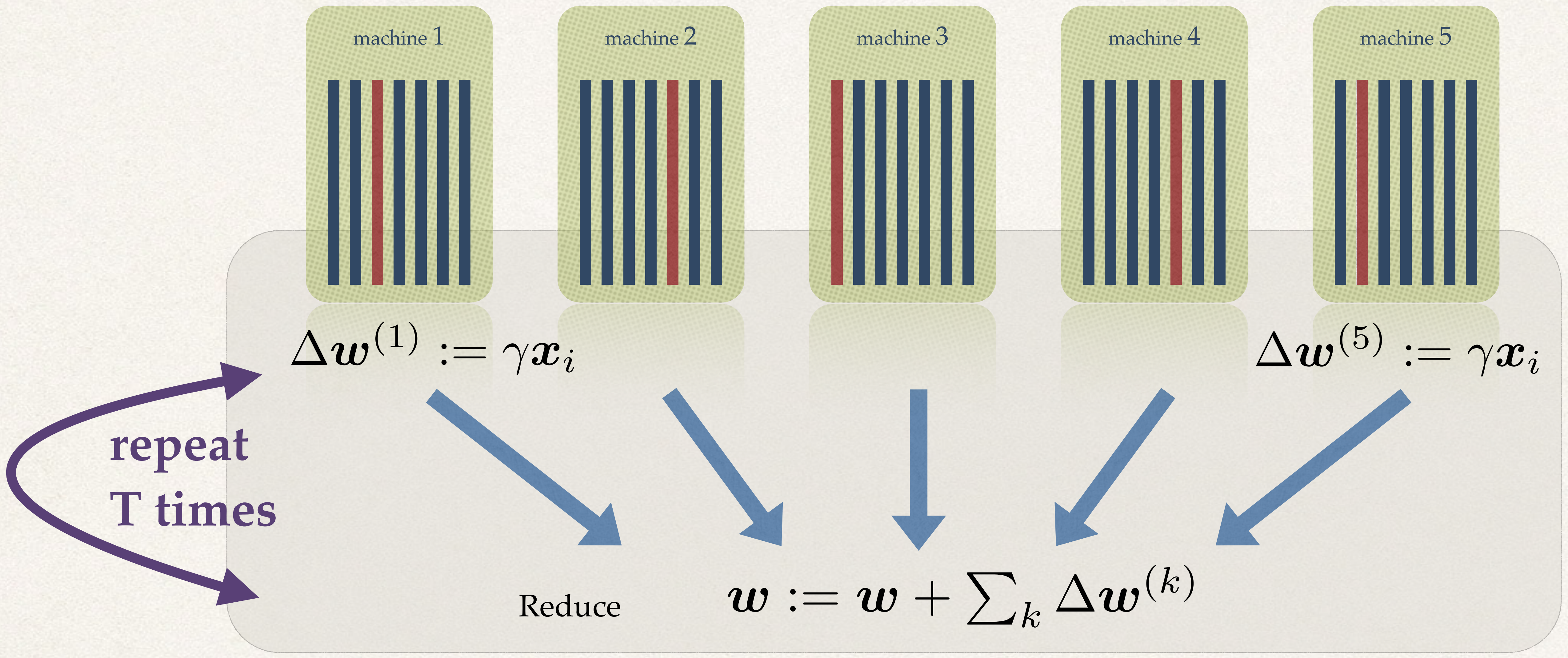
Distribute compute & memory across many devices



One-Shot Averaging Does Not Work



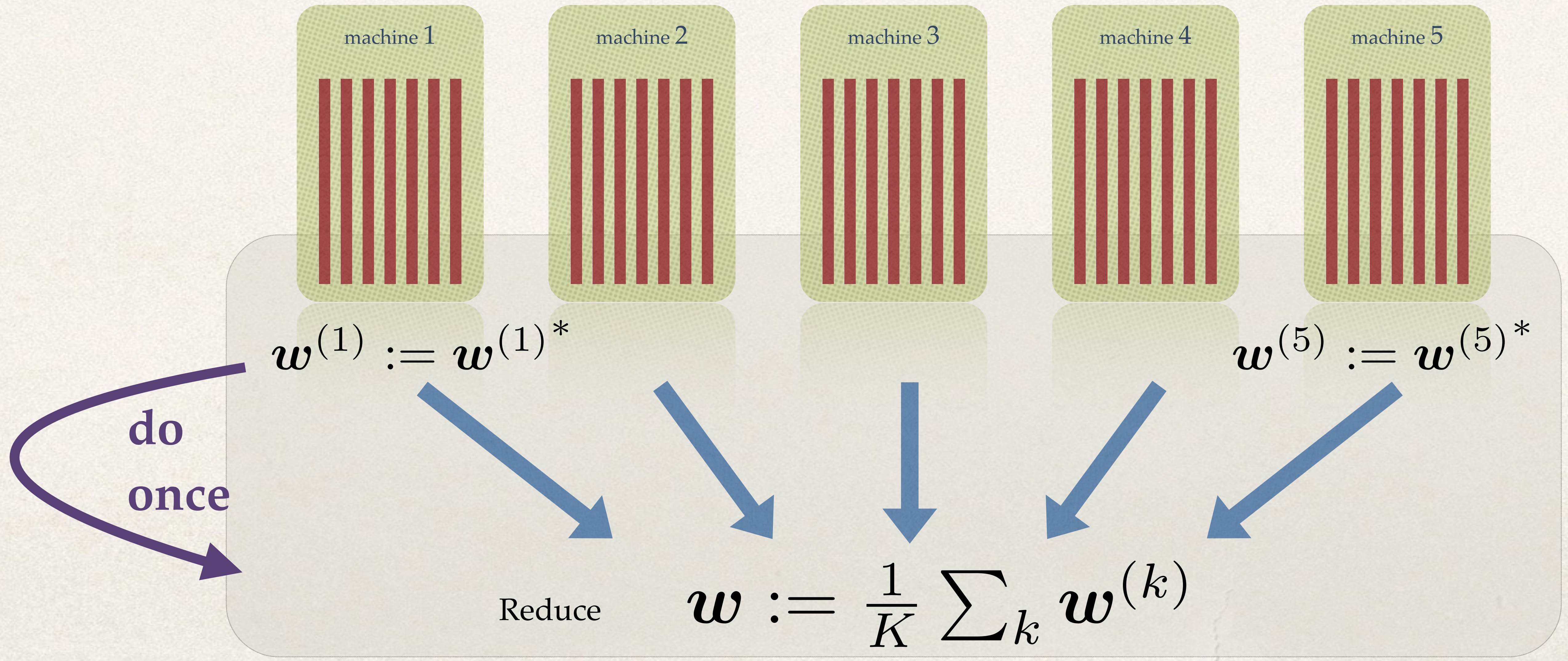
Communication: Always / Never



Naive Distributed SGD

 # local datapoints read: T
 # communications: T
convergence: ✓

"always communicate"

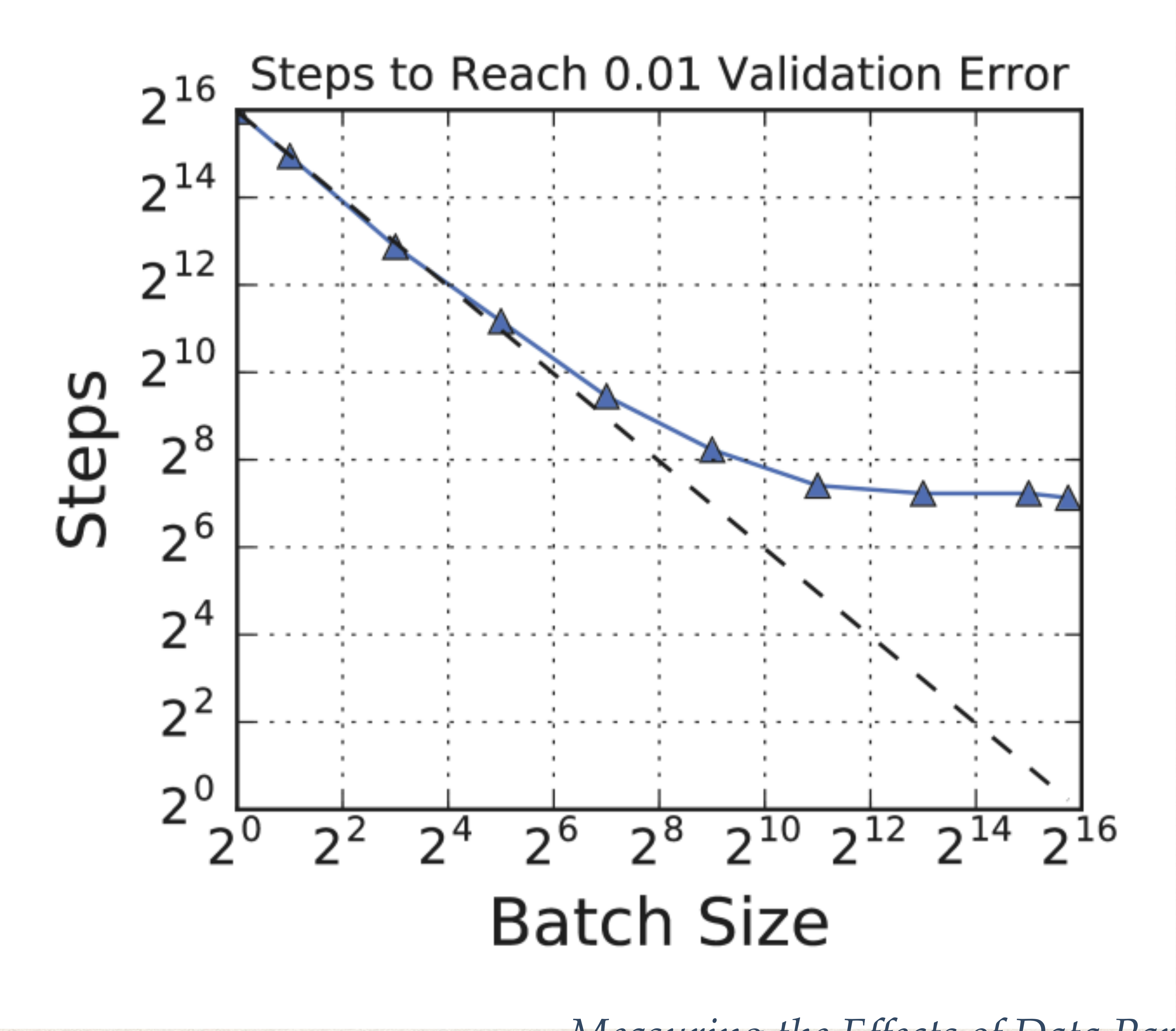


One-Shot Averaged Distributed Optimization

 # local datapoints read: T
 # communications: 1
convergence: ✗

"never communicate"

Just increase the batch size!



Measuring the Effects of Data Parallelism on Neural Network Training
Shallue et al., 2018

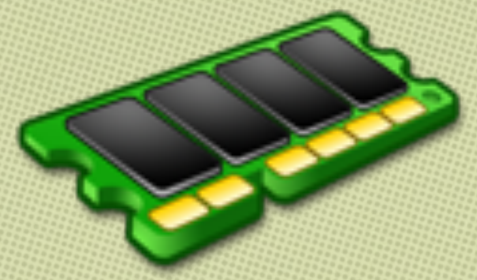
Challenge

The Cost of Communication

$\boldsymbol{v} \in \mathbb{R}^{100}$

- Reading $\boldsymbol{v}$ from memory (RAM)

  100 ns



- Sending $\boldsymbol{v}$ to another machine

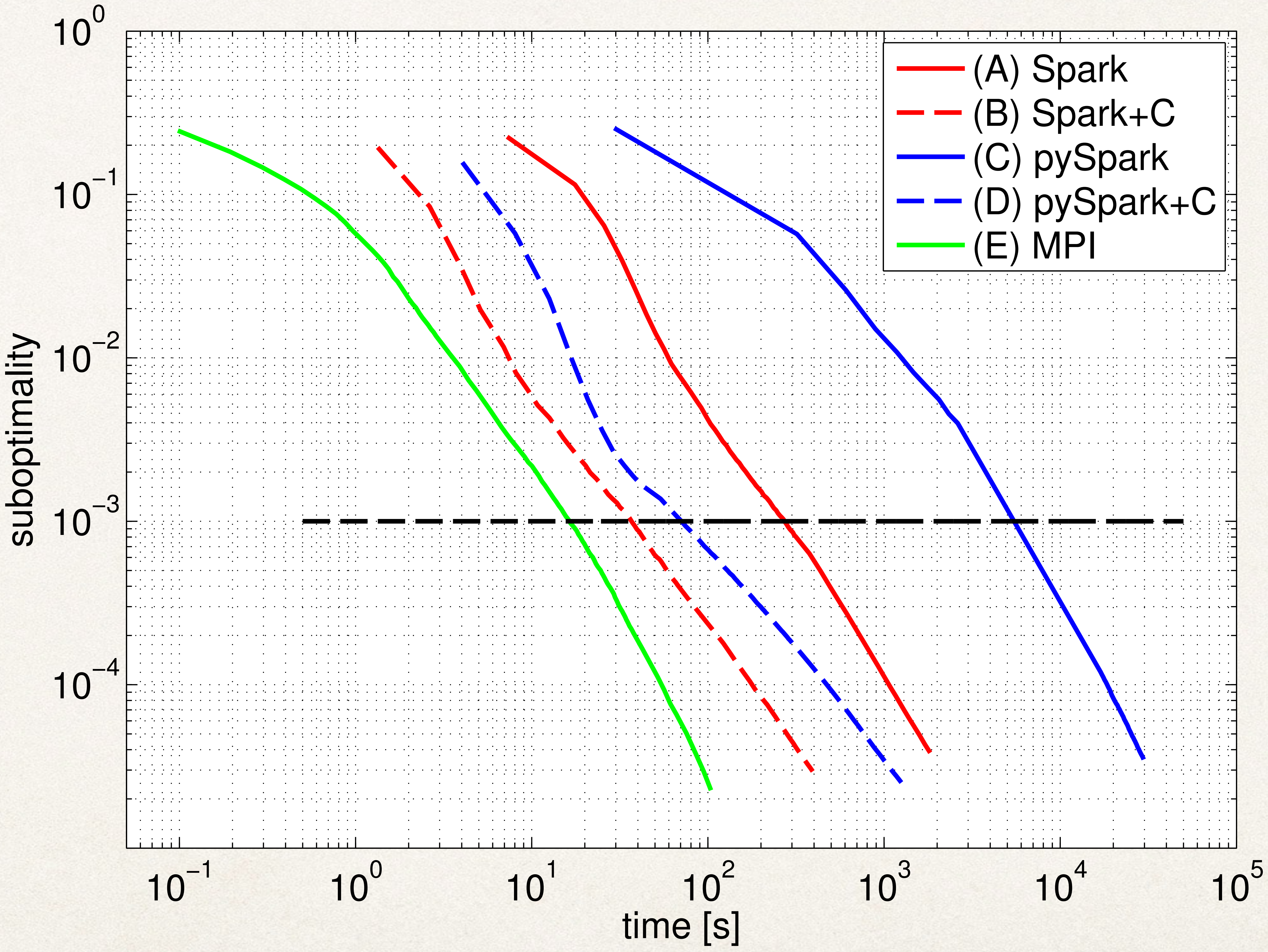
  500’000 ns

- Typical Map-Reduce iteration

  10’000’000’000 ns

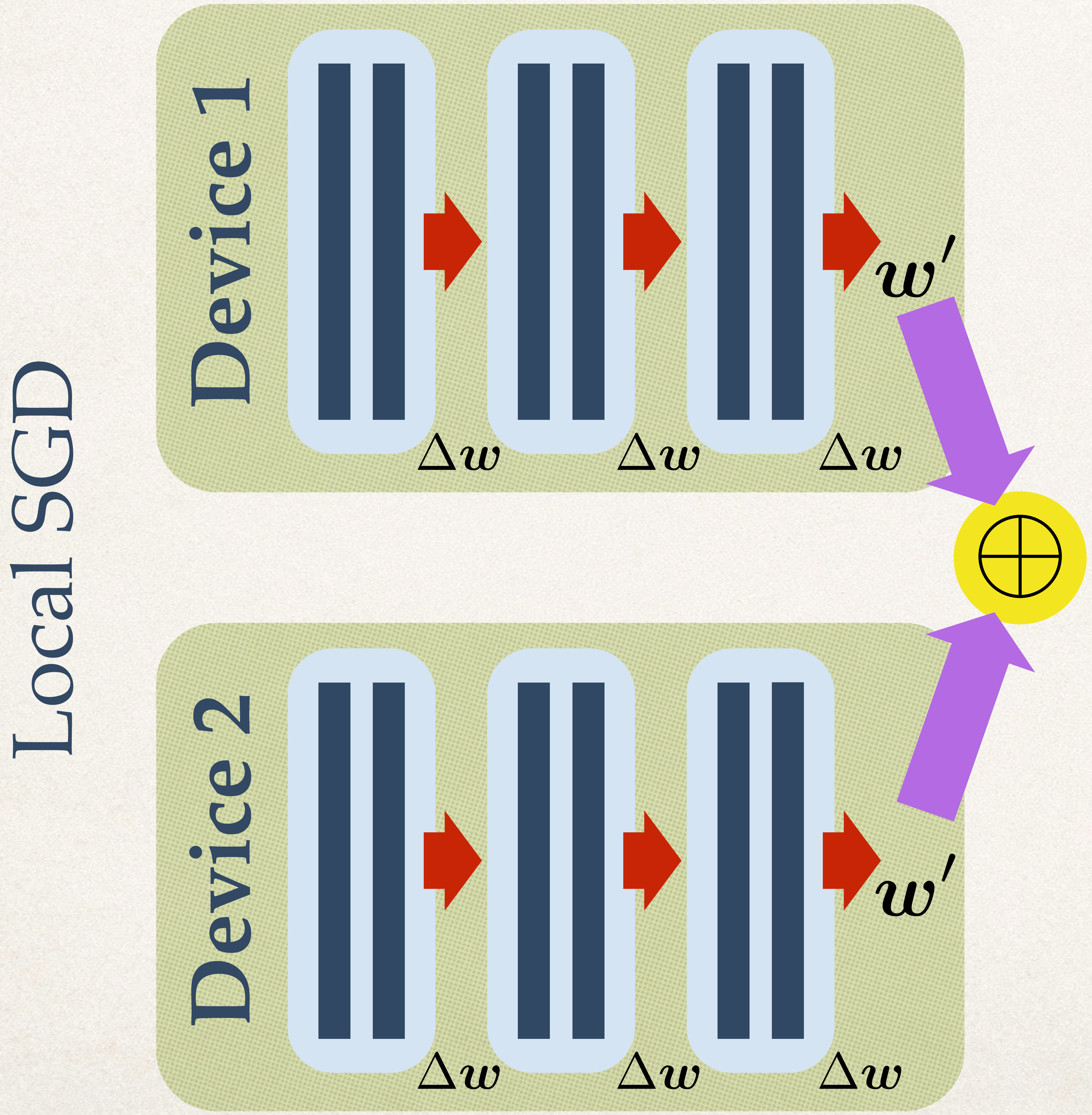
Challenge

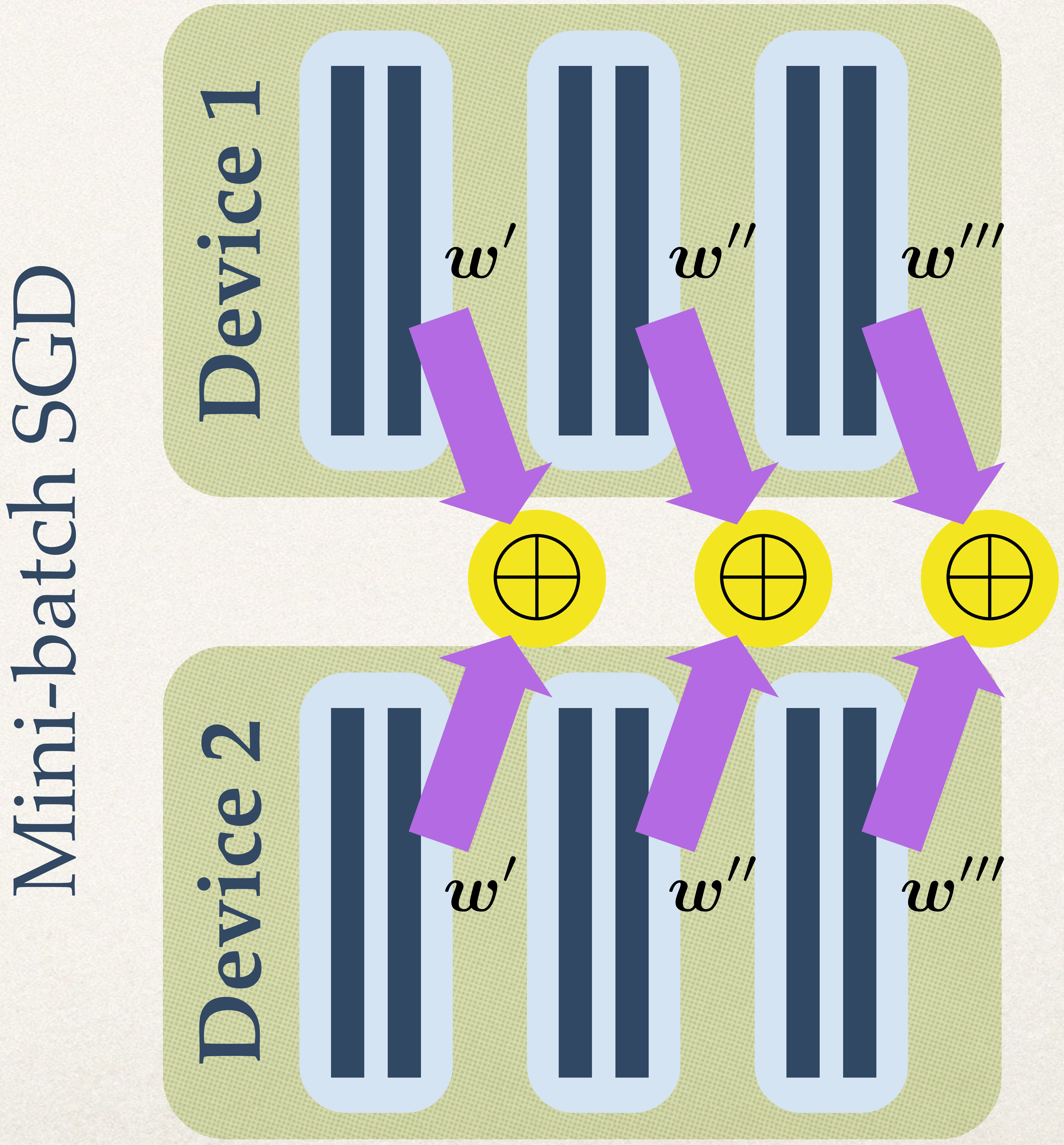
The Cost of Communication



High-Performance Distributed Machine Learning using Apache Spark
Dünner et al. 2016, arxiv.org/abs/1612.01437

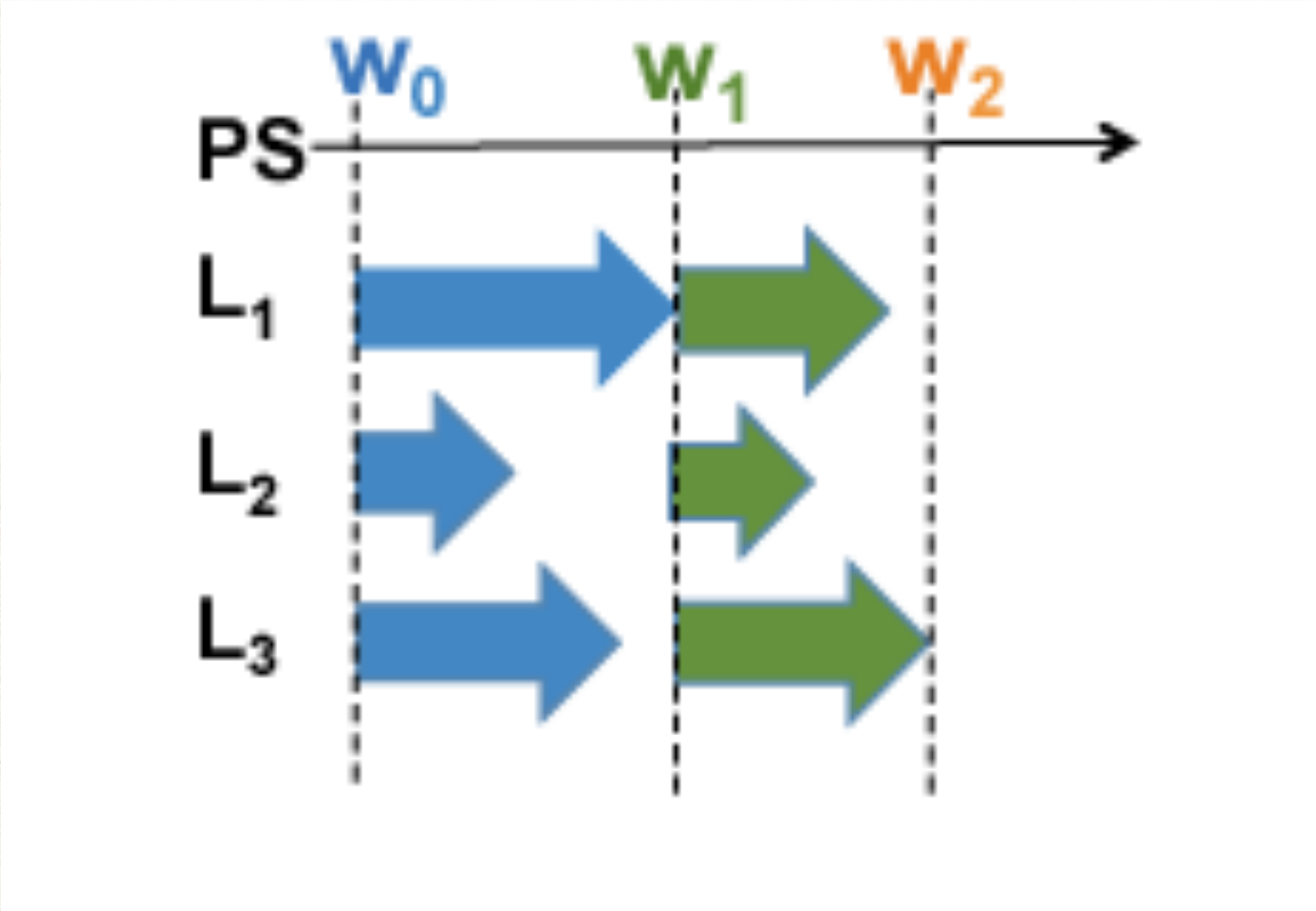
Data Parallel DL, Local Update Steps

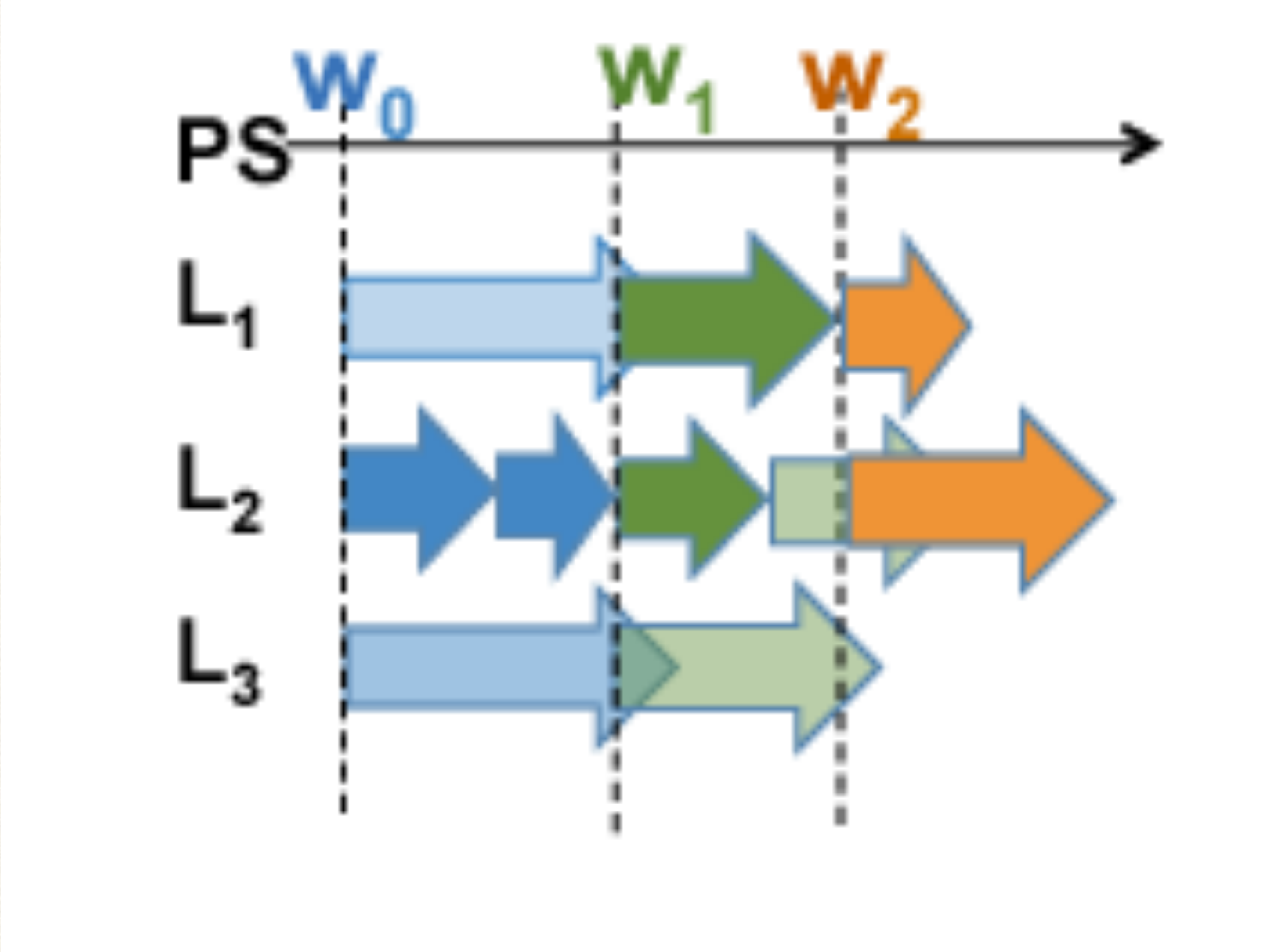




Asynchronous Parallel SGD

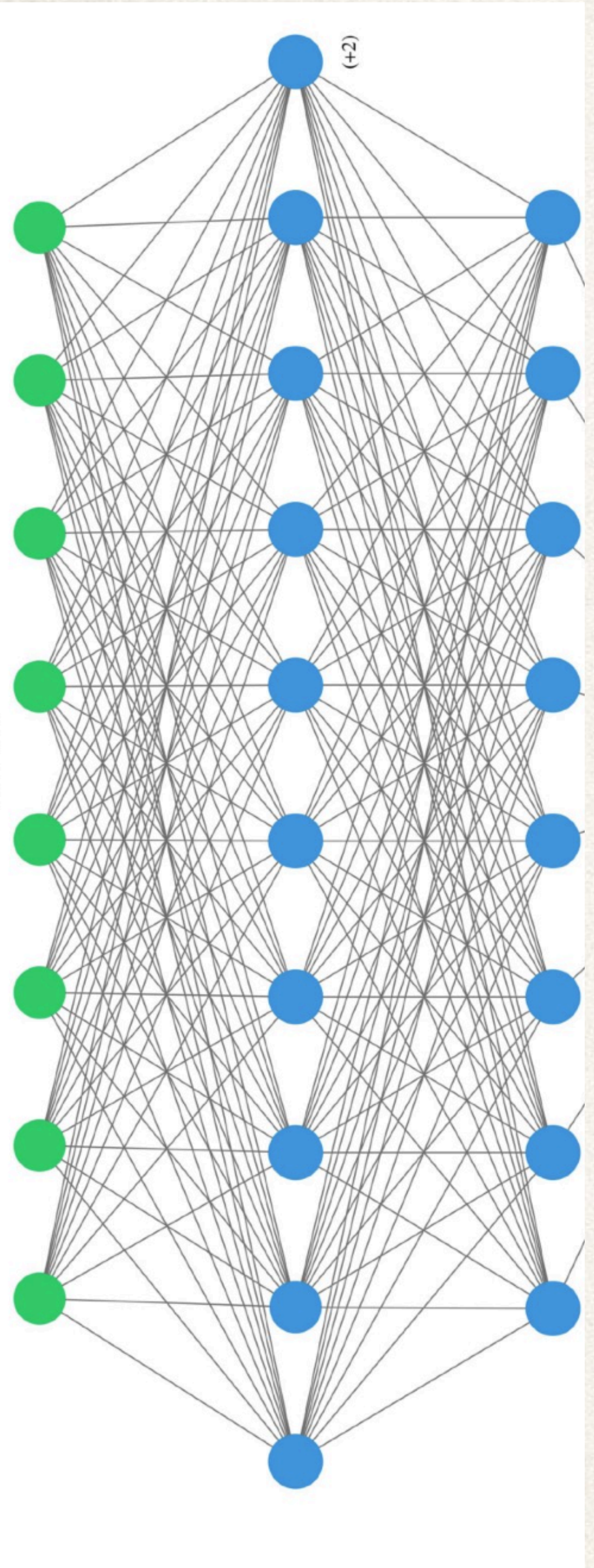
- **Synchronous**
- **Asynchronous**





Mini-Batch!

Communication Compression

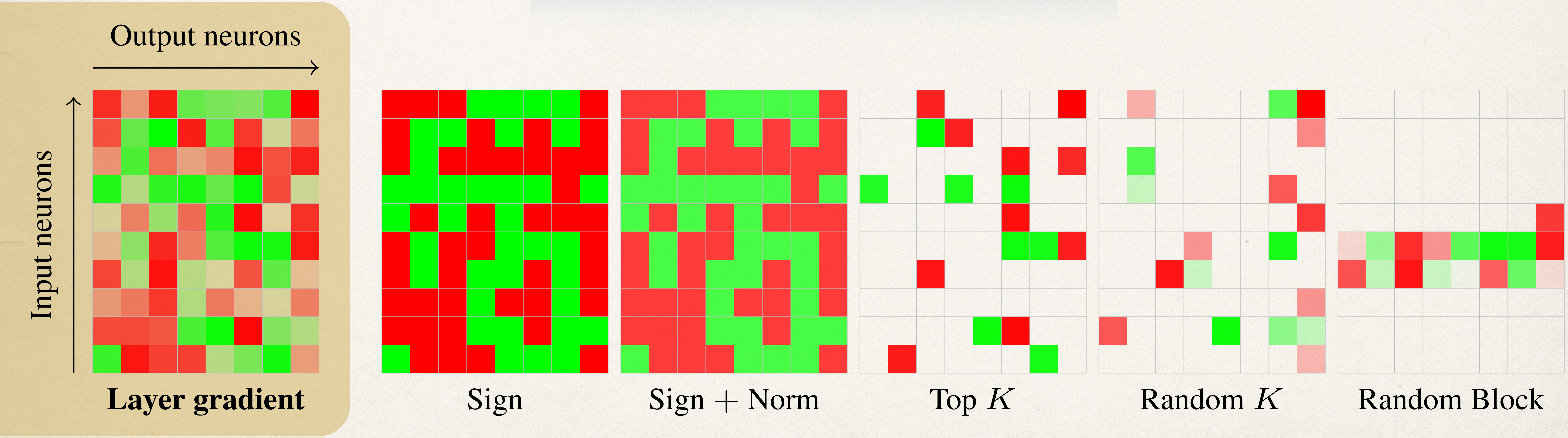


A compressed version of model updates?

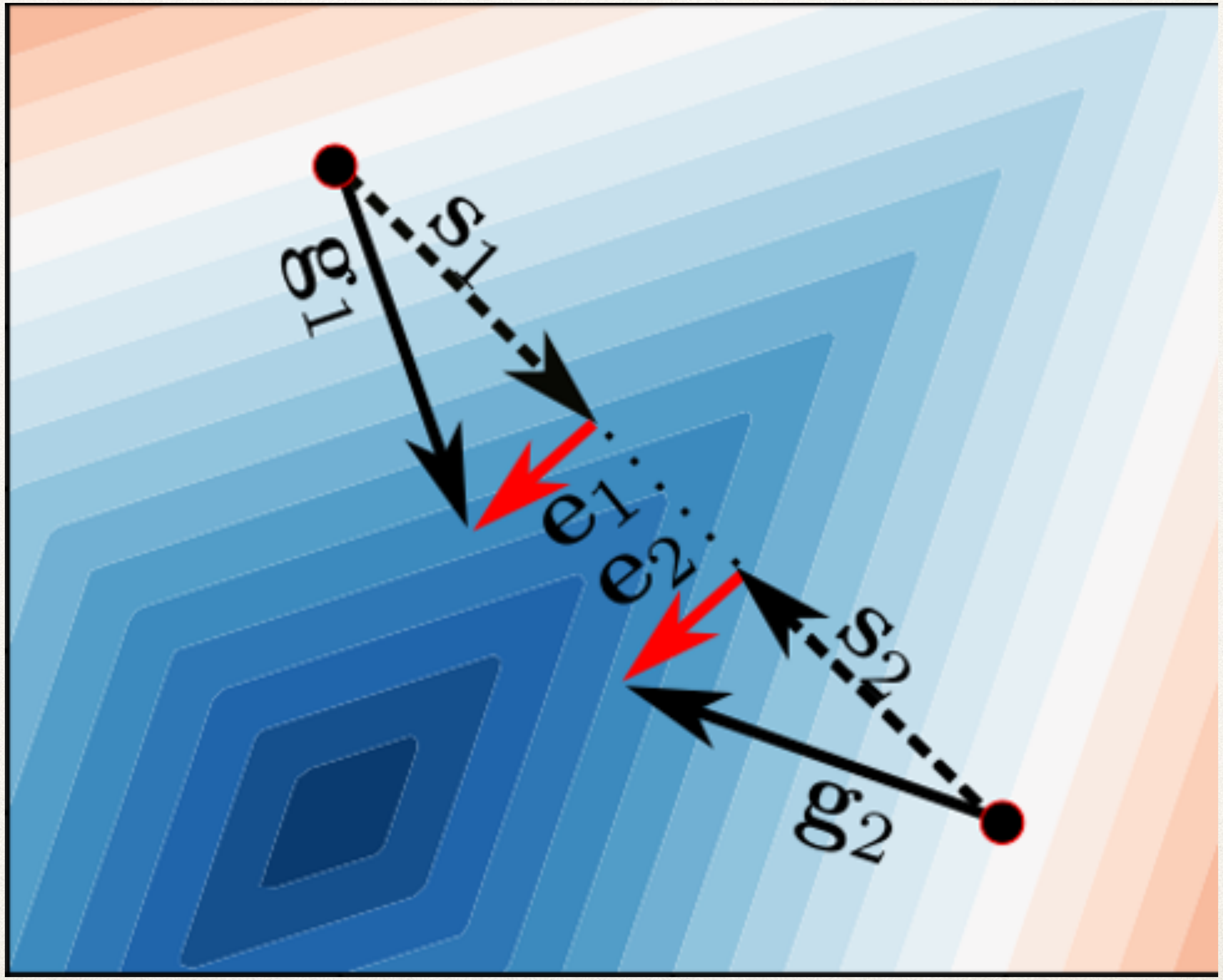
Examples:	**Communication Reduction**
✤ quantization (e.g. 1-bit SGD)	**32x**
✤ top k=1% of all the entries	**100x**
✤ rank-1 approximation	**>100x**

Gradient Compression

A compressed version of model updates?

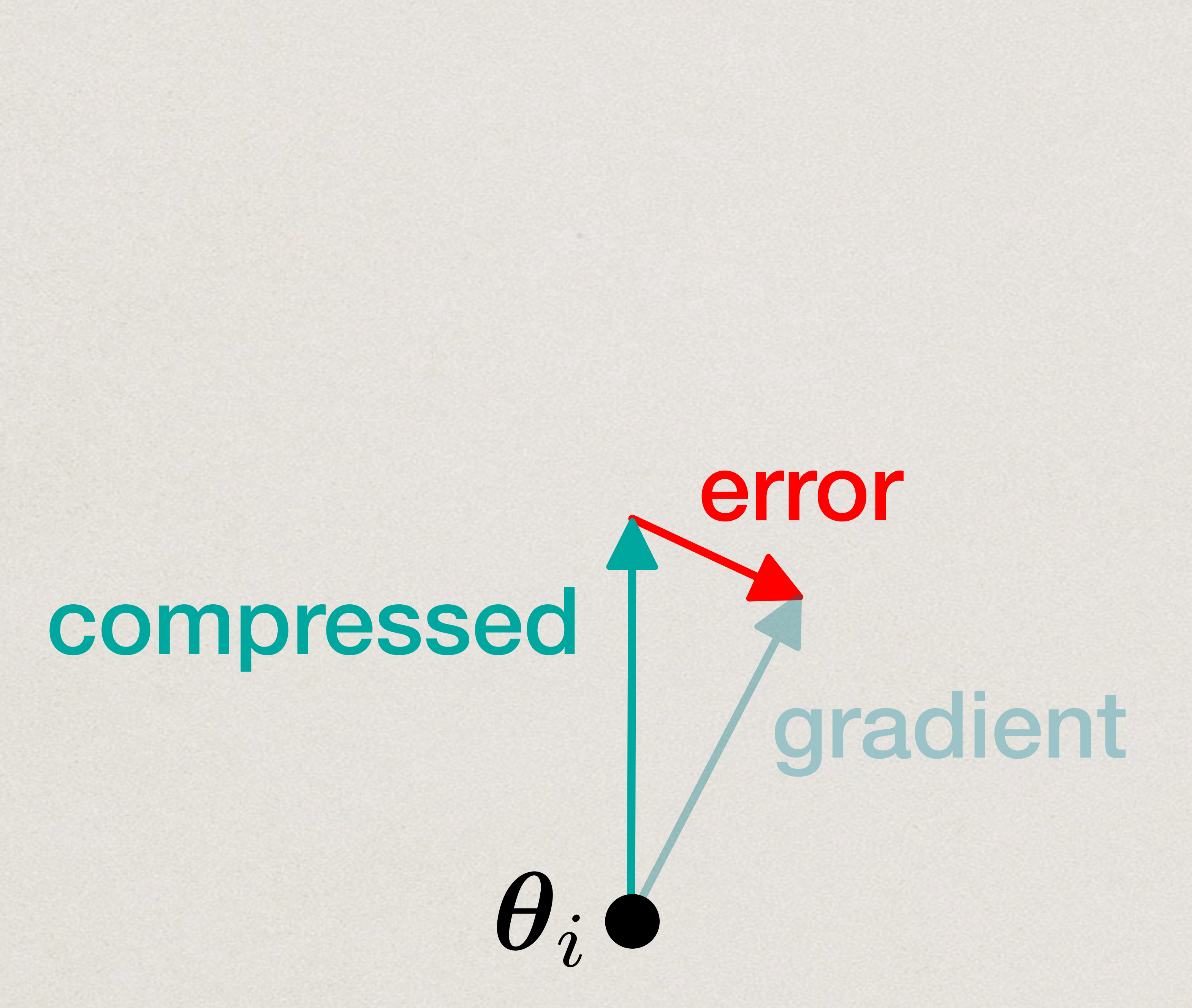


SGD fails with naive/biased compressors

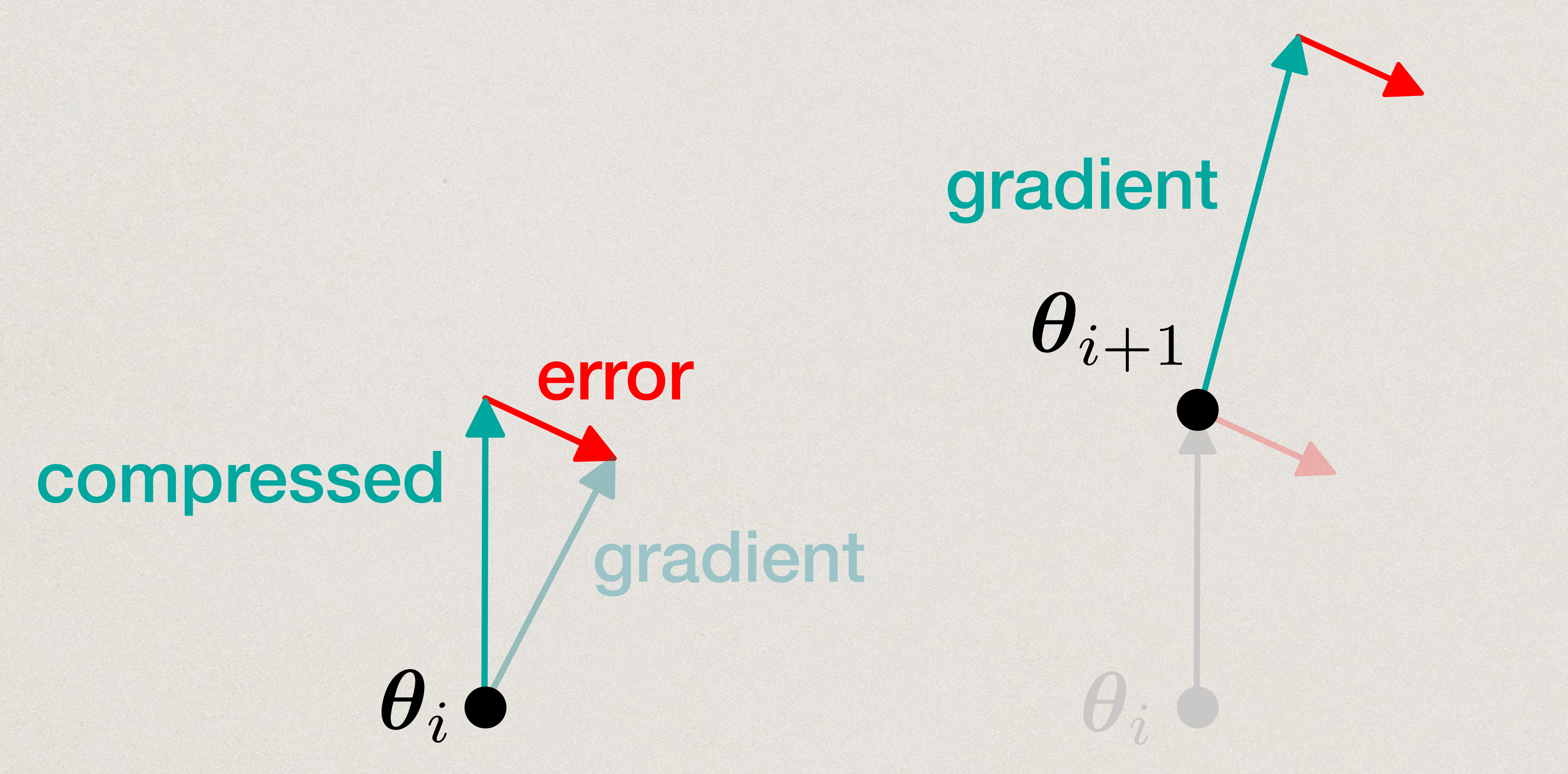


$$\min_{x\in\mathbb{R}^2} \ |x_1 + x_2| + 2\,|x_1 - x_2|$$

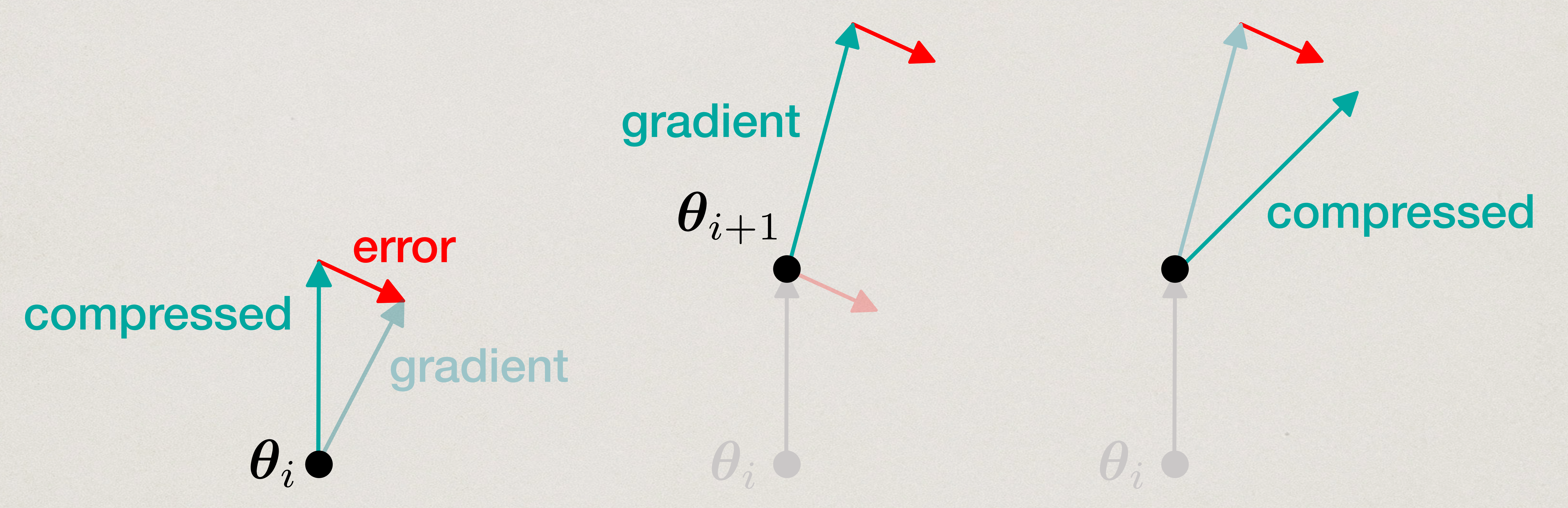
Error Feedback



Error Feedback



Error Feedback



Error Feedback: Convergence Rate

δ: compression ratio

$$\|\mathcal{C}(\mathbf{x}) - \mathbf{x}\|_2^2 \leq (1-\delta)\|\mathbf{x}\|_2^2$$

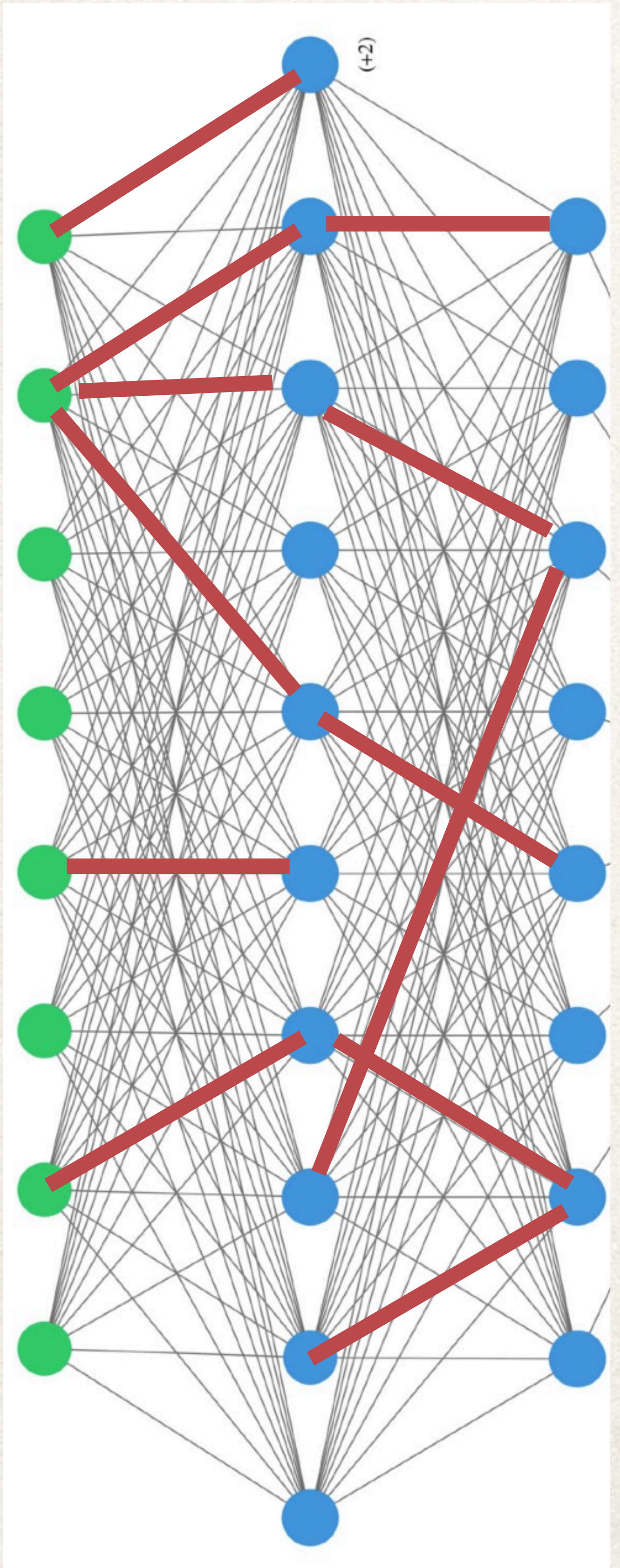
SGD on smooth non-convex objectives (w/ central coordinator)

$$\mathbb{E}\|\nabla f(\bar{x}_t)\|^2 \leq \mathcal{O}\left(\frac{1}{\sqrt{nT}} + \frac{1}{\delta^2 T}\right)$$

Can we also save Compute and Memory?

e.g. for deployment on low-resource devices

Model Compression with Error Feedback

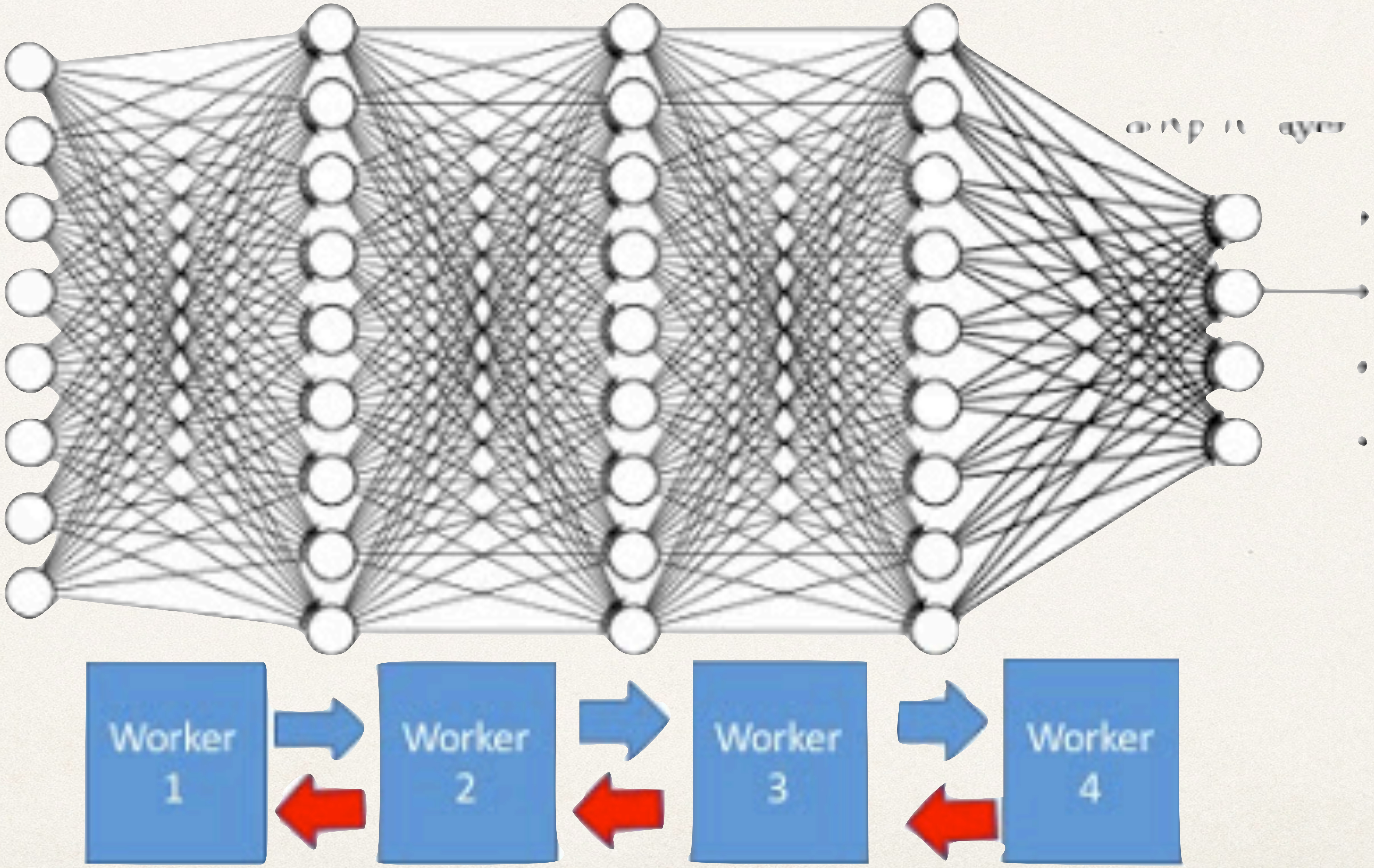


Prune most weights (set to zero)

set to limited precision

interactive while training

Model-Parallel DL

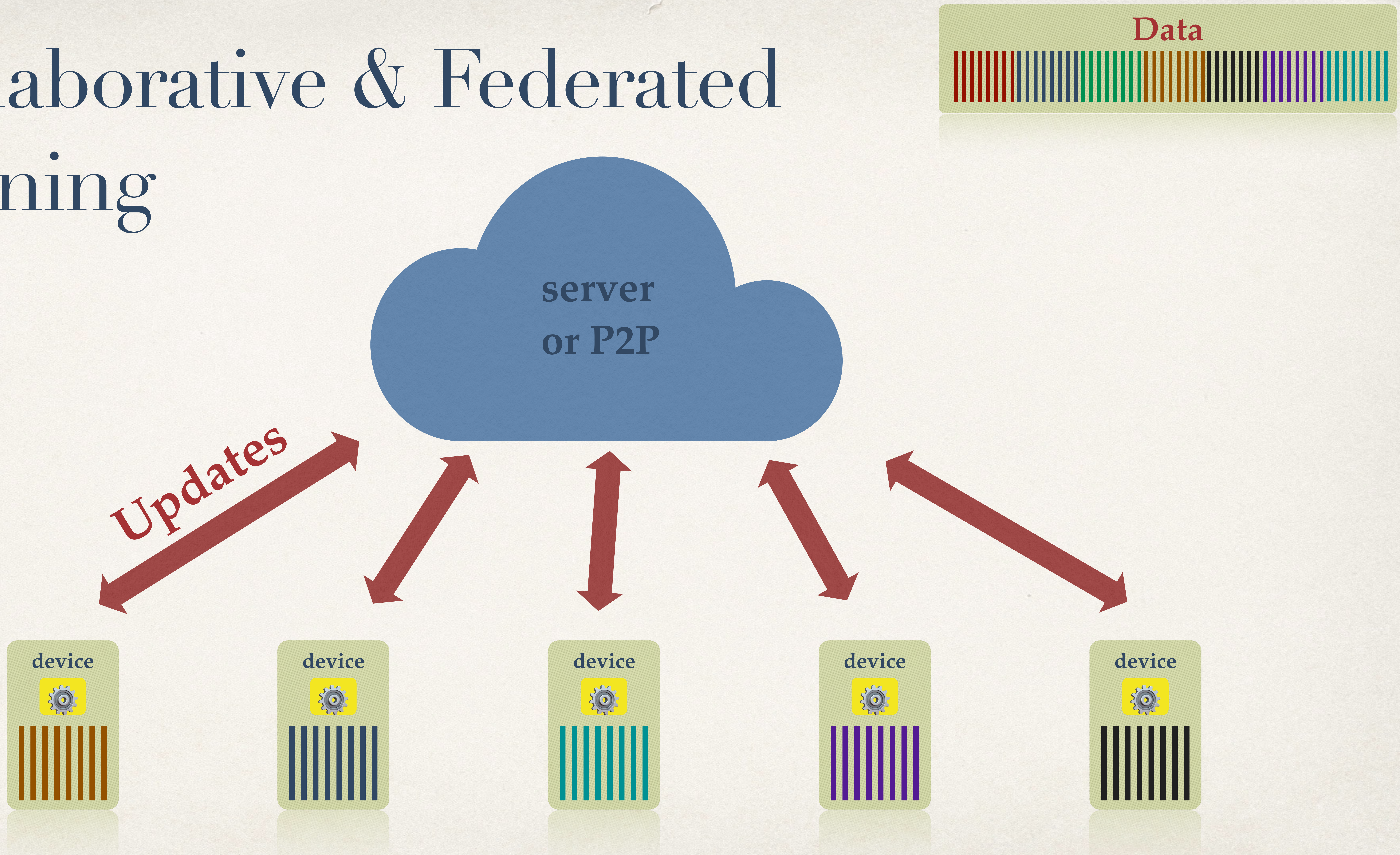


http://kuozhangub.blogspot.com/2017/08/data-parallel-and-model-parallel.html

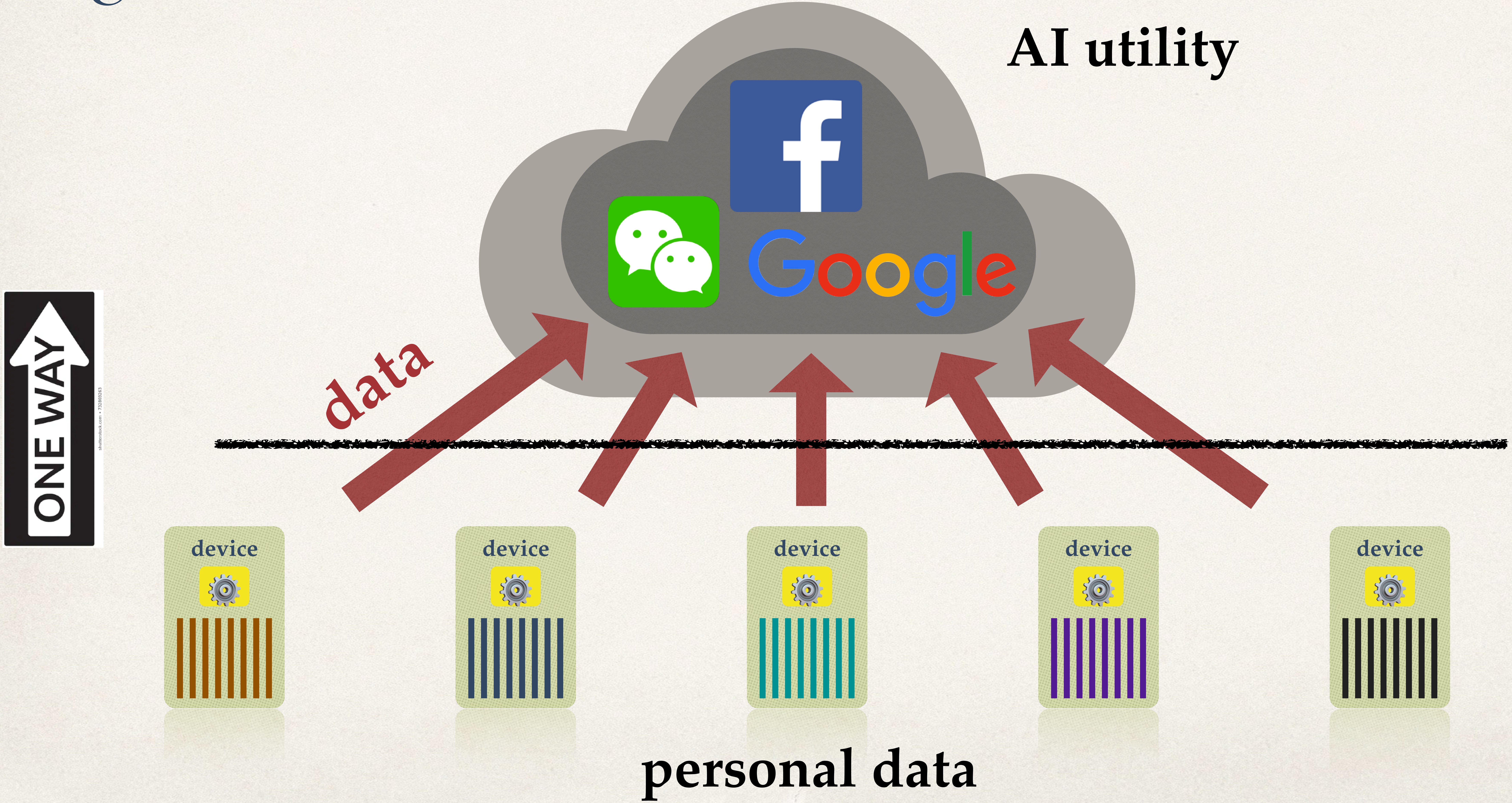
2

Gradients from collaborators:
- Federated Learning

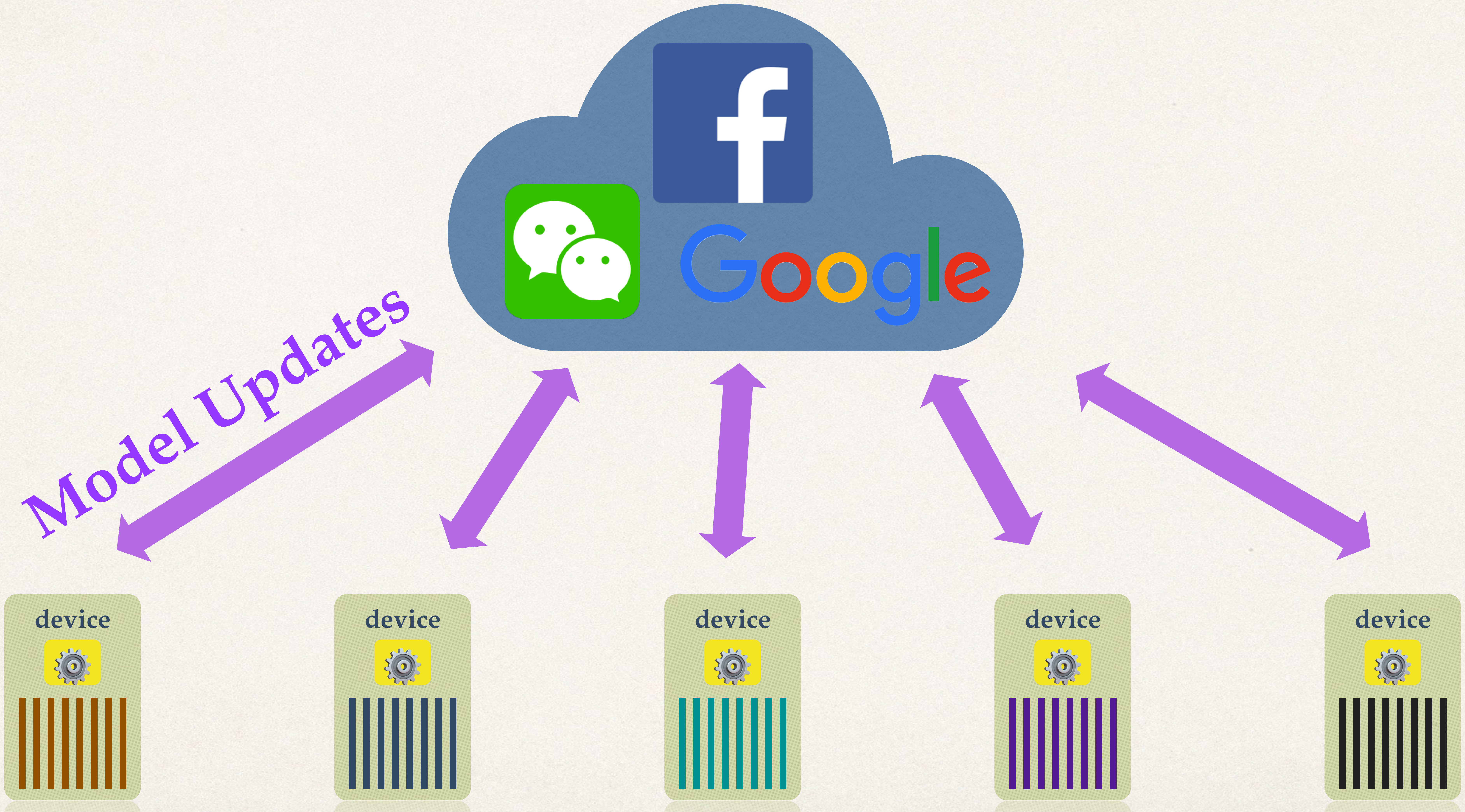
Collaborative & Federated Training



Big Picture

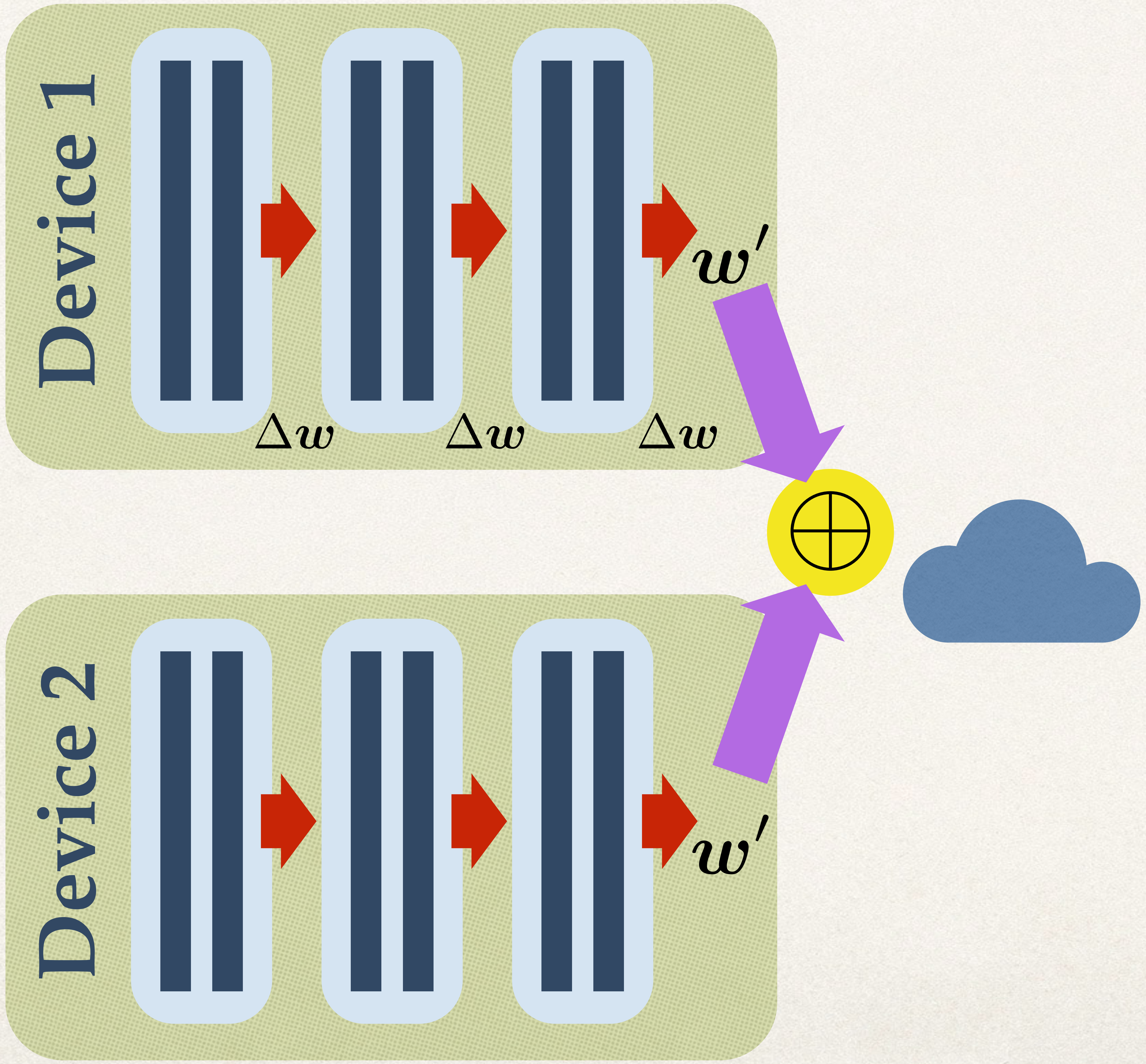

AI utility
Google
data
ONE WAY
device
device
device
device
device
personal data

2a Federated Learning



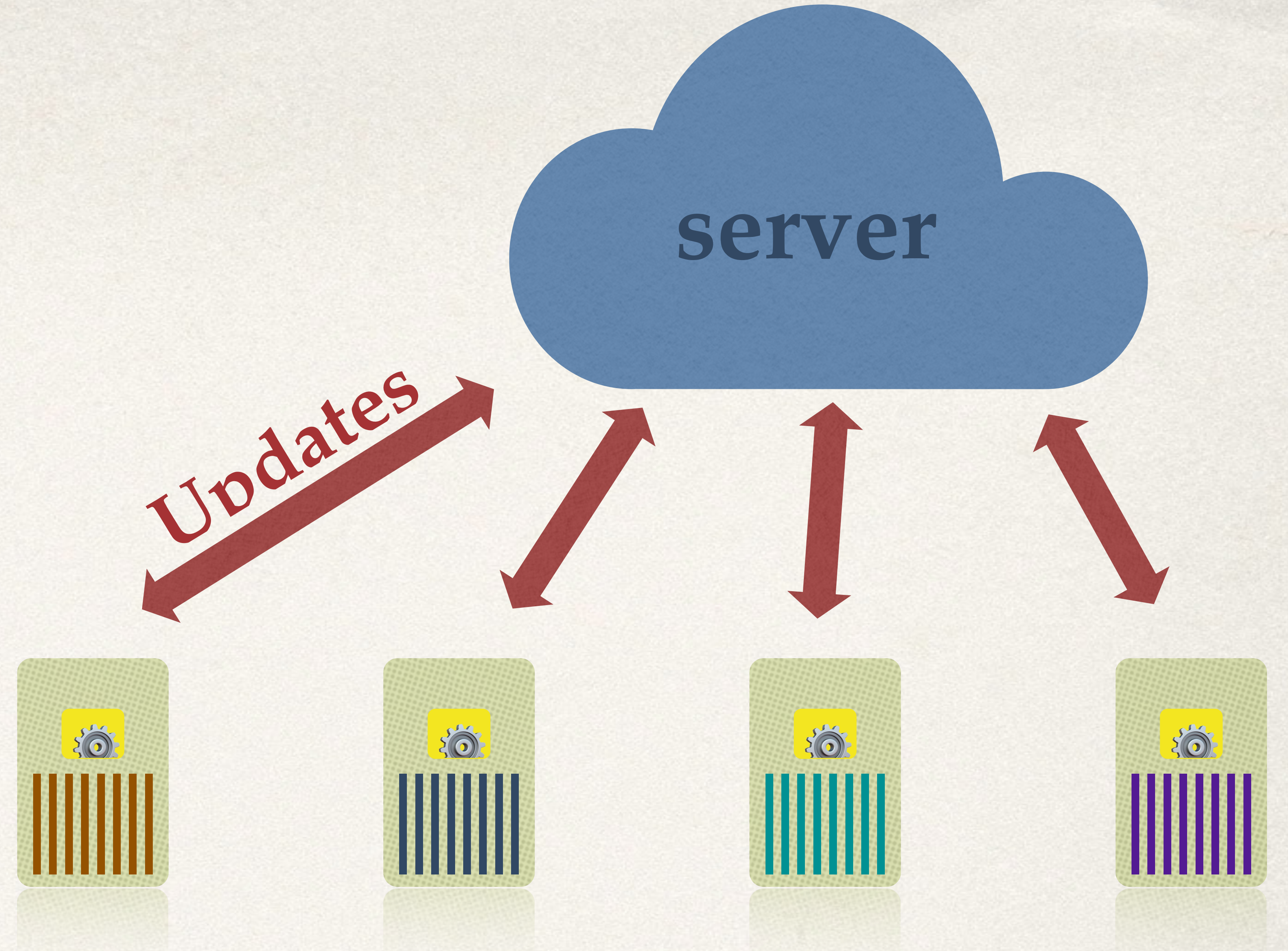
data never leaves device

2a Federated Learning



- Local SGD steps = "Federated averaging"
- Google Android Keyboard

Client drift



- **Federated Learning**

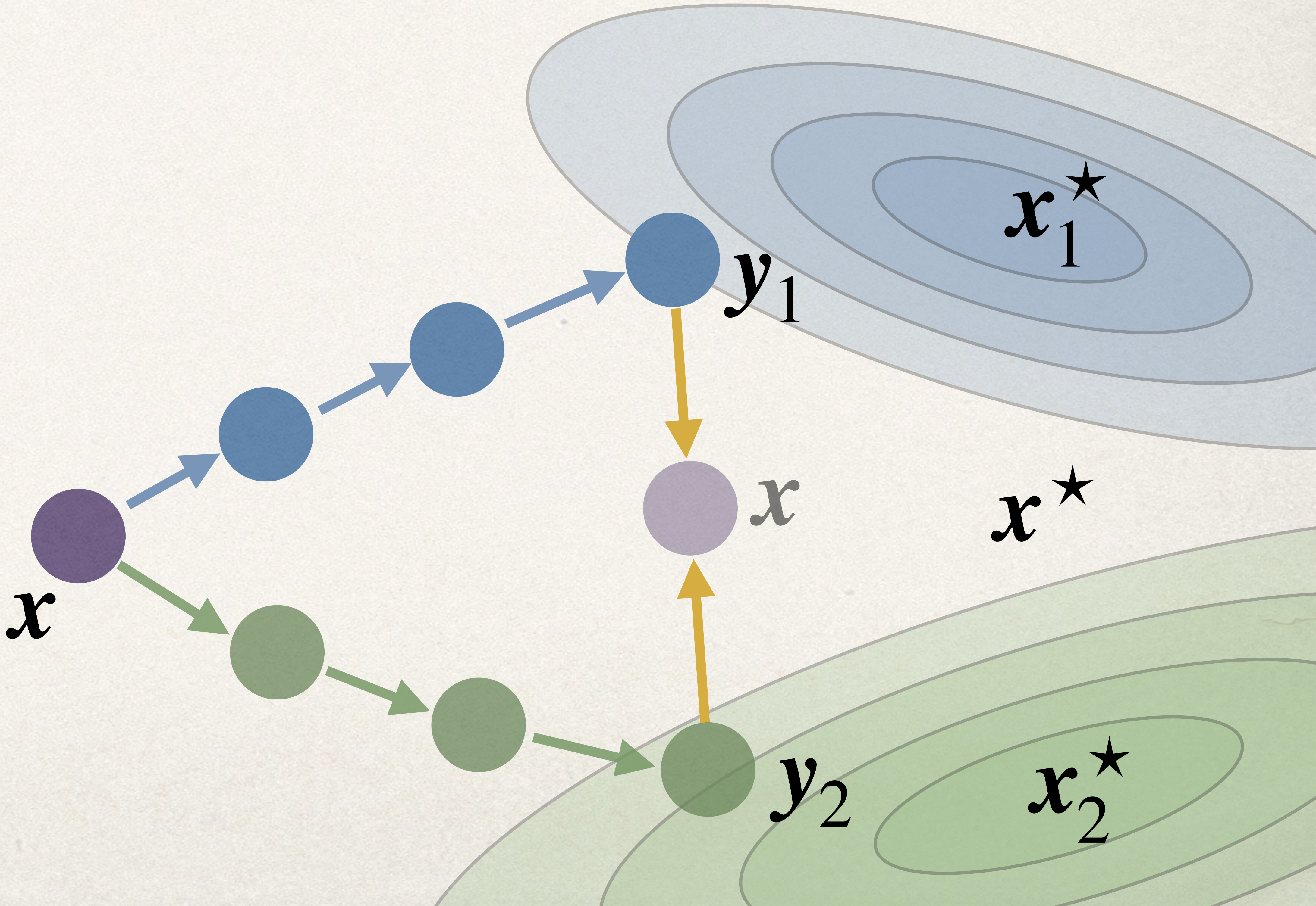
$$\min_{\boldsymbol{x}} \frac{1}{n} \sum_{i}^{n} f_i(\boldsymbol{x})$$

- **Fed Avg / Local SGD**

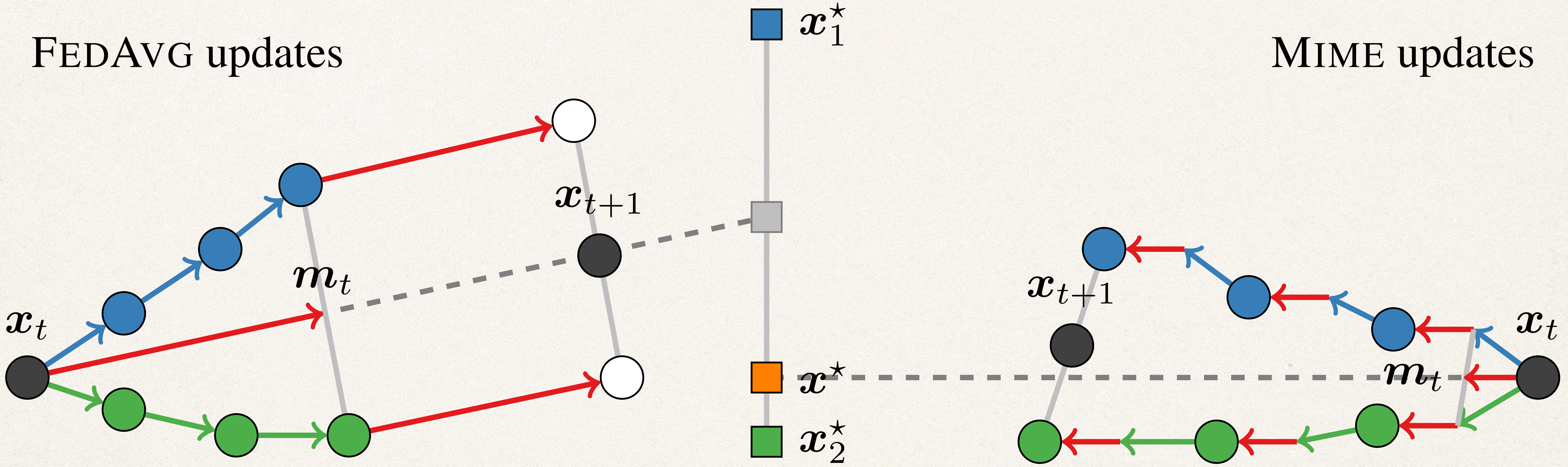
for some local steps

$$\boldsymbol{y}_i := \boldsymbol{y}_i - \eta \nabla f_i(\boldsymbol{y}_i)$$

$$\boldsymbol{x} := \frac{1}{n} \sum_{i=1}^{n} \boldsymbol{y}_i \qquad \textit{(aggregation)}$$



Client drift



Mime algorithm framework

***for** some local steps*

$$\boldsymbol{y}_i := \boldsymbol{y}_i - \eta\Big((1-\beta)\,\nabla f_i(\boldsymbol{y}_i) + \beta\boldsymbol{m}\Big)$$

$$\boldsymbol{m} := (1-\beta)\,\nabla f_i(\boldsymbol{x}) + \beta\boldsymbol{m}$$

aggregated on server after each round

Thanks!

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