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Optimizing Deep Learning Systems for Hardware

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Part II : Hardware & Memory Hierarchy

- PII.a : Existing Solution: CPU, GPU, TPU, FPGA, ASIC basics
- PII.b : Memory hierarchy, bandwidth bottlenecks, movement costs
- PII.c : Precision

Numerical Precision

- Numerical precision refers to the number of bits used to represent a number in computation.
- Common formats in deep learning: FP32 → FP16/BF16 → INT8.
- Precision affects:

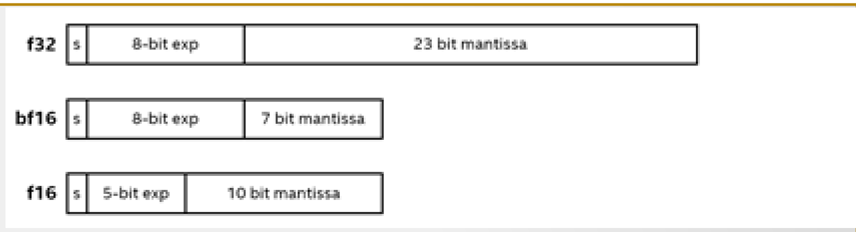
  ↑ Memory footprint

  ↑ Computation cost

  ↑ Energy consumption

  ↓ Accuracy of the model

Numerical Precision



Format	Bits	Use Case	Pros	Cons
FP32	32	Standard training	High accuracy	High memory & energy cost
FP16 / BF16	16	Mixed-precision training	Reduced memory & energy, higher throughput	Slight accuracy degradation
INT8	8	Inference	Minimal memory & energy, very high throughput	Needs quantization, may lose accuracy

Why change precision?

- Scientific computing and HPC often require FP64 (double precision):
  - e.g.: Climate simulations, fluid dynamics, molecular modeling
- Sensitive numerical operations where rounding errors accumulate

- However, Training of DL models usually requires FP32 for gradients,
  - **but** forward pass may allow lower precision.

Quantization

- Lower precision increases throughput and reduces memory pressure.
- But lowes accuracy
- May require **quantization-aware training** to preserve accuracy.
- Hardware-aware design:
    - Use FP32 for sensitive computations (gradients)
    - FP16/INT8 for forward pass and inference
    - Goal: balance accuracy, energy, and speed.

Precision choice

- Precision choice is workload- and hardware-dependent.
- Lower precision improves energy efficiency, throughput, and memory usage.
- High precision is critical for scientific accuracy.
- Mixed strategies are often the optimal compromise.
  - A quantization research.

Next: Part III

- Part I : Fundamentals
- Part II : Hardware Types & Memory Hierarchy
- **Part III : Model-Level Optimizations**
- Part IV : System-Level Optimizations
- Part V : Introduction to Scaling Deep Learning in HPC

Thanks!

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