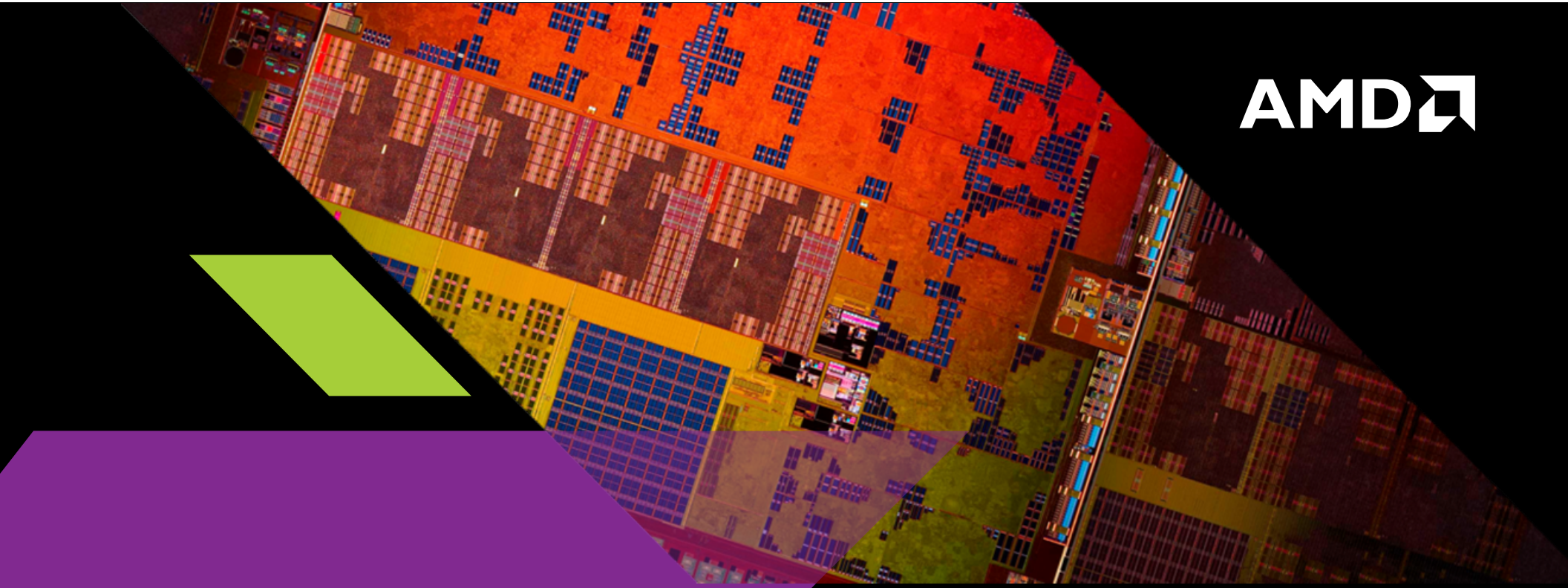


EXPLORATION OF NUMERICAL PRECISION IN DEEP NEURAL NETWORKS

NICHOLAS MALAYA AND ALLEN RUSH

6/19/17

ADVANCED MICRO DEVICES

SNAPSHOT OF THE SEMICONDUCTOR COMPANY

- CPUs [Ryzen]
  - One of two x86 suppliers
- GPUs [Radeon]
- Gaming Consoles:
  - Xbox One / Project Scorpio
  - PS4
  - WiiU
- APUs, Servers [EPYC], Supercomputers, etc.

Blue Waters Supercomputer

You have probably used our products

WHY IS AMD INTERESTED IN MACHINE LEARNING?

GPUS “KILLER APPLICATION”

- Simple Answer: interested in all computation

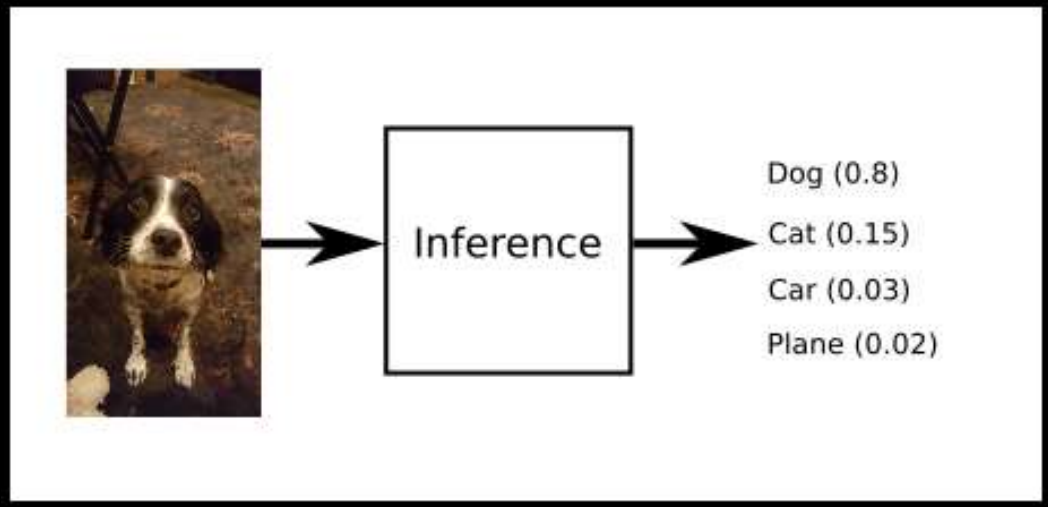
- Machine Learning is particularly interesting
  - Potential to impact nearly all software, industries
    - NLP, autonomous cars, image classification, etc.
    - “Software is eating the world, AI is eating software”
  - Compute intensive (rare)
  - Known to be extremely amenable to acceleration

WHAT IS MACHINE LEARNING?

THE ROAD TO DEEP NEURAL NETWORKS

AMD

- AI / Machine Learning:
  - Systems designed to acquire their own knowledge
  - Typically: gradient-based optimization (SGD) minimizes residual between data and model
- Rough definition of supervised learning:
  - Given a set of **data** (e.g. labelled images of dogs)
    Train a model to
    Infer properties of new data instances
    (e.g. label new images that contain dogs)
- **Training**: select parameters of model (weights)
  - Model already provided concept (feature) of dog
- **Inference**: prediction using the trained model

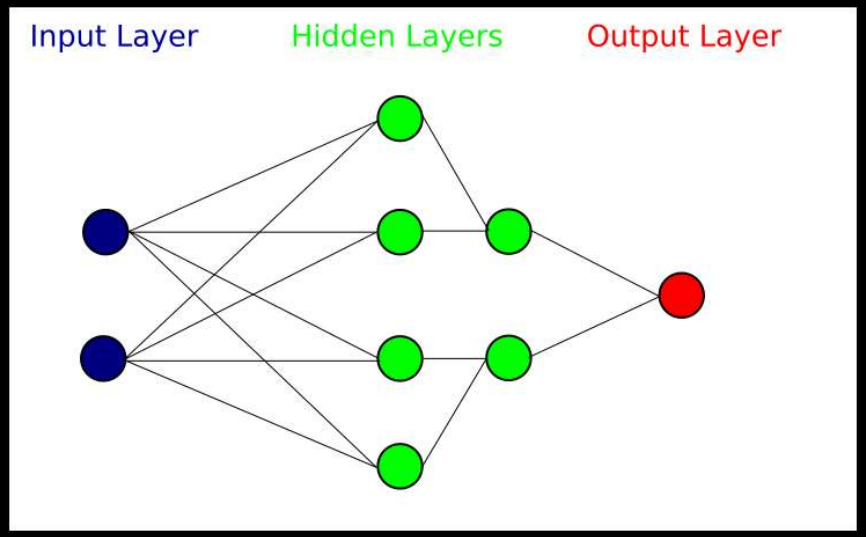


NEURAL NETWORKS

THE ROAD TO DEEP NEURAL NETWORKS

AMD

- Multilayer Perceptron / Feed-forward Neural Networks:
  - Neurons connected by synapses (weights)
  - **Input layer** (visible layer): observable variables
  - **Hidden layers**: extract increasingly abstract features from data
  - **Output**: prediction / classification of network
  - Many parameters, non-trivial to train
- Characterized by non-linear “activation function”:
  - Sigmoid, ReLU, etc.
  - Very high order basis functions
- **Hungry**
  - “Big Data”
- **Key Observation: Deeper Networks more accurate**
  - **ANN doubled in size roughly every 2.4 years**
  - **Growth driven by faster computers with larger memory**
  - GPUs achieve 95% of peak compute



WHAT ARE THE MEANS TO SUPERIOR PERFORMANCE?

REPRESENTATIVE APPROACHES

AMD

- Algorithmic:
  - FFT:
    - FFT, multiplication, iFFT
  - Strassen-Wenograd:
    - "Trades" multiplications for addition operations
- Sparse Weights:
  - Identify weights that are zero, "Prune"
  - Reduces computation, energy cost, introduces sparsity
- Reduced Precision of operations:
  - Reduced bit-width: fp16, fp8, binary, ternary
  - Reduces computation
  - Observation: inference less sensitive than training
  - Can be supported directly in hardware!

THE PROBLEM

WHAT ARE WE TRYING TO SOLVE

AMD

- No *a-priori* results capable of predicting sensitivity to precision

- Every problem must be evaluated individually
  - Requires human intervention
    - Expensive
    - Slow
    - Error-prone
    - Philosophically unappealing: autonomous algorithms should not require human intervention
  - **Mathematicians**: The solution may be unstable!
    - Could be sensitive to data, hyper-parameters, etc.
  - Objective: produce method capable of predicting numerical precision requirements for any problem
    - Heuristic?
    - Formal proof?
    - Scaling argument?

THE TEAM

IN ORDER OF IMPORTANCE

AMD

- Students (the folks actually doing the work):
  - Zhaoqi Li
  - Yu Ma
  - Catalina Vajiac
  - Yunkai Zhang
- Academic Mentor:
  - Hangjie Ji, PhD
    - Department of Mathematics, Duke University
- Industry Mentors:
  - Nicholas Malaya, PhD
  - Allen Rush, AMD Fellow
  - Alan Lee, CVP AMD, IPAM Board Member

GOALS

EASY AND MEDIUM OBJECTIVES

AMD

- **Estimate→ Easy: 100%, Medium: 50%, Hard < 32%, Stretch < 5%**
  - **Bonus:** *Where did these numbers come from?*

- **Easy:**
  - Machine Learning Frameworks (Tensorflow, Caffe, etc.) installed
  - Familiarity with core ML concepts and terminology
  - Hardware implications of mixed/reduced precision

- **Medium:**
  - Implement mixed/half/single/double precision on toy problem
  - Characterization of solution stability on toy problem

- This is research! These goals will evolve.

GOALS

HARD AND STRETCH GOALS

AMD

- **Reminder: Hard < 32%, Stretch < 5%**
- **Hard:**
  - **Stability Analysis of inference (and then, backpropagation)**
  - Can we demonstrate why inference is less sensitive to precision?
    - Likely, fewer gradients and fewer accumulated operations
    - This would be a significant result
  - **Pivot: develop statistical estimator of *a posteriori* error**
    - Likely, using Bayesian Inference
  - Scaling arguments for hyper-parameter impact on precision?
    - E.g. Neural network connectivity, depth and number of neurons
- **Stretch:**
  - Submission of results to ICML / NIPS 2018

- This is research! These goals will evolve.

FINIS

AMD

Thank you!

Questions / Comments?

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