Mobile ML Workshop

ML@B · Spring 2018

Installation and Setup

- `pip install numpy keras tensorflow`
- Download Xcode from the Mac App Store
- `git clone https://github.com/mlberkeley/mobile_ml_workshop`
- **Sign In Here**: www.tinyurl.com/mobile-ml

Who We Are

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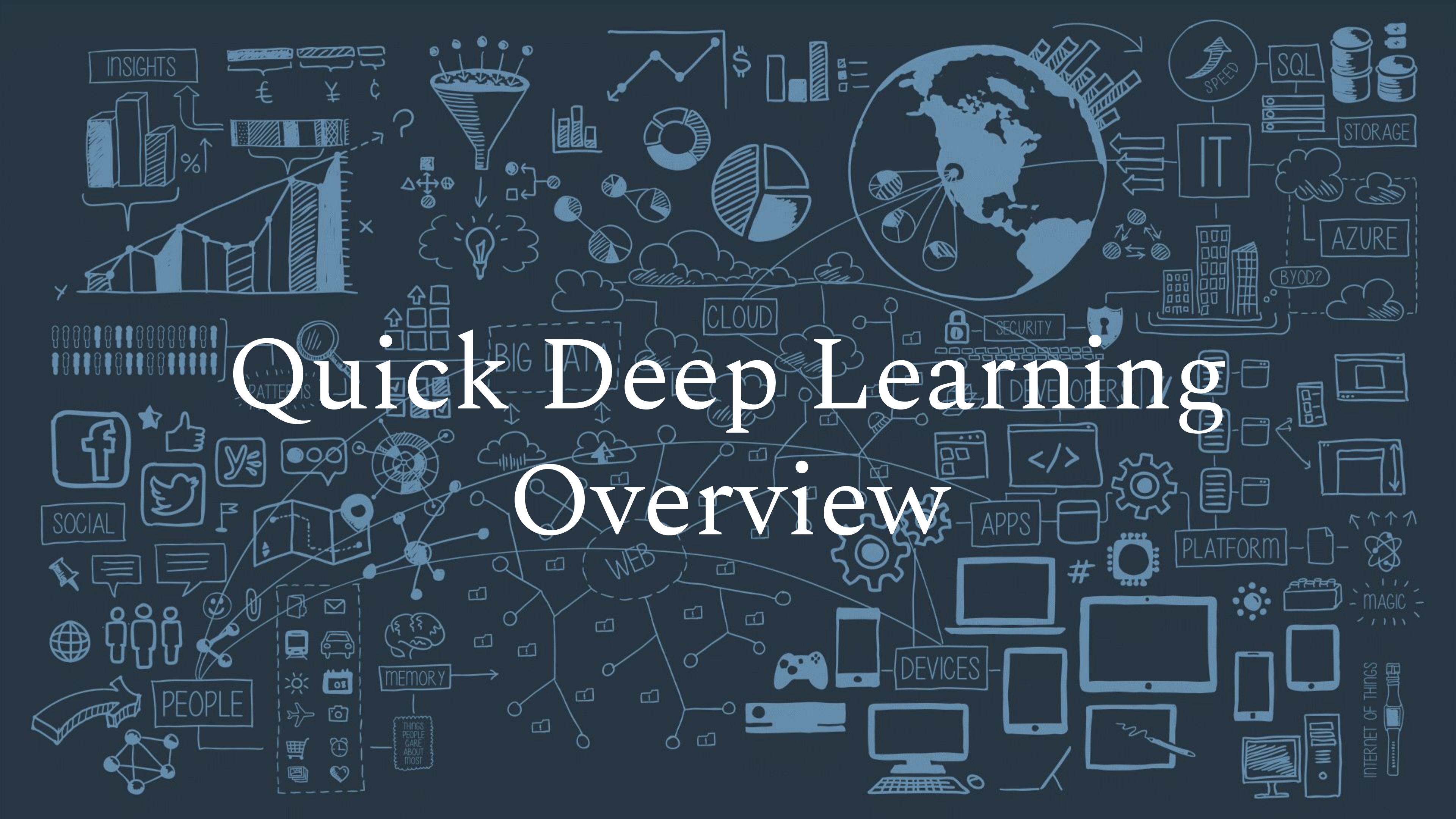
What we will be building

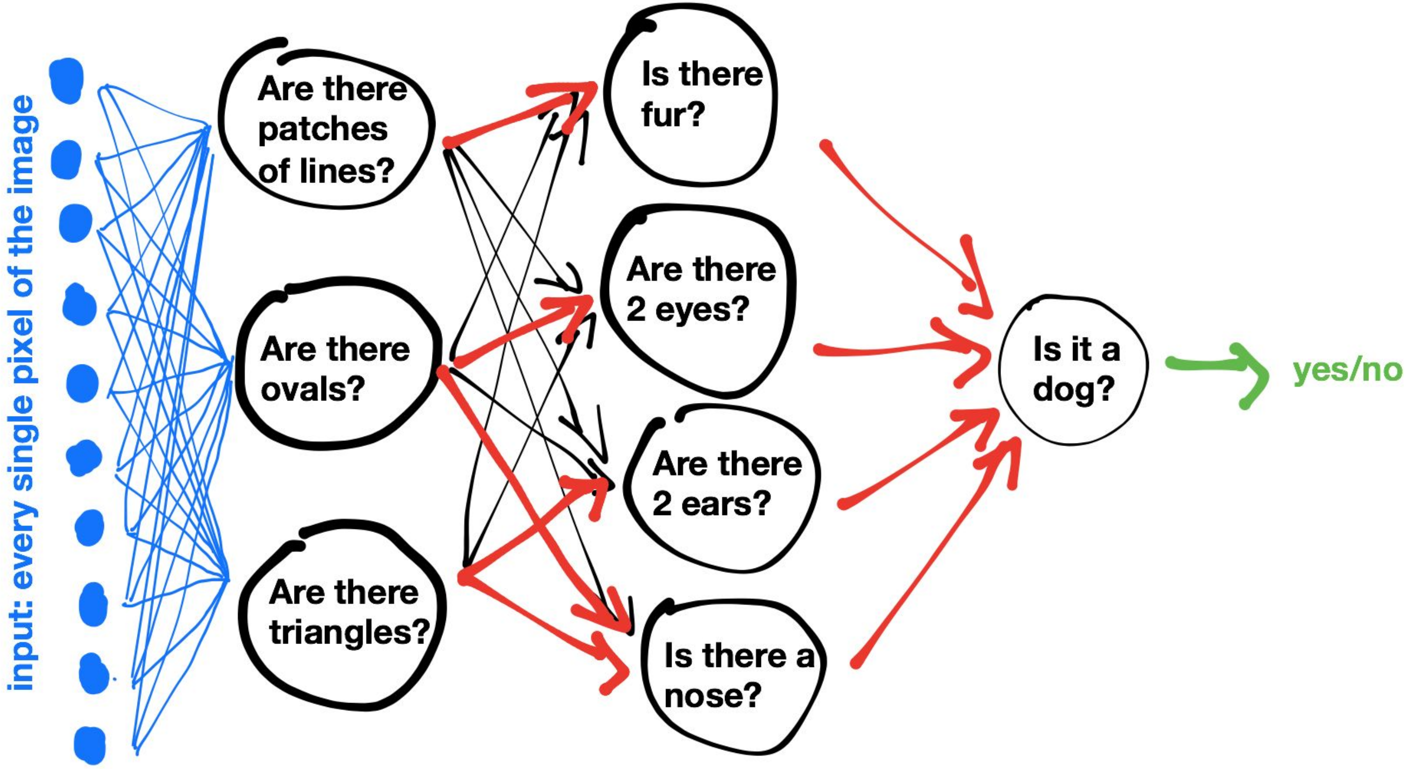
Agenda

- Deep Learning Overview
- Principles of Mobile ML
- Swift Overview
- CoreML
- Building a Mobile ML System

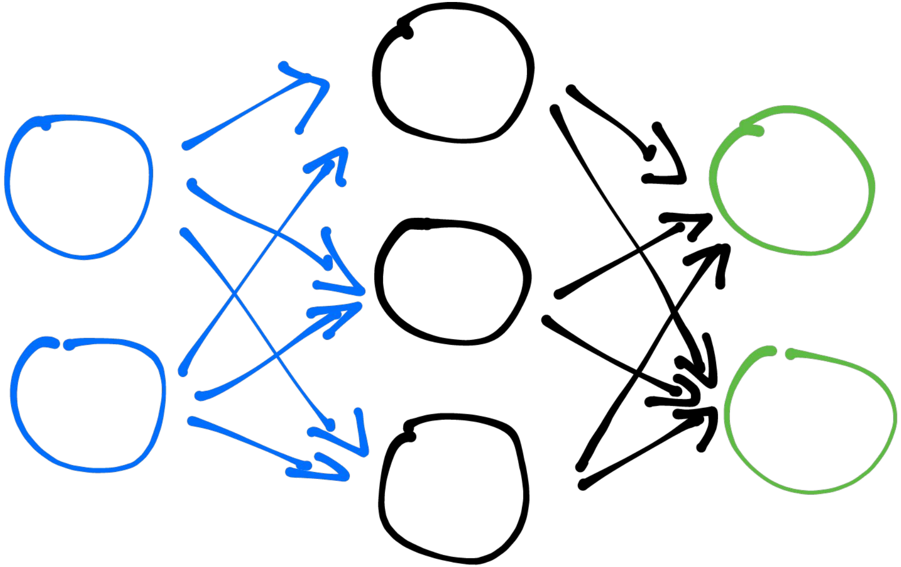


Quick Deep Learning Overview

Why are Neural Nets so Powerful?



Structure of Basic Feedforward Network

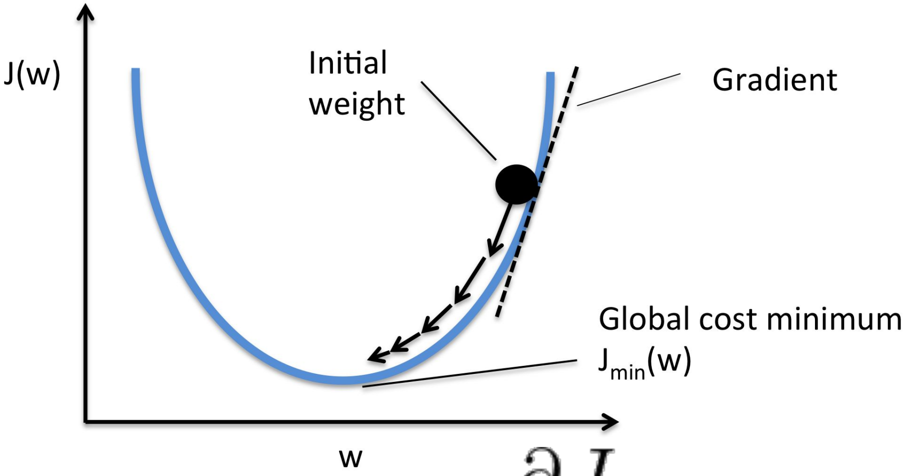


Input layer Hidden layer Output layer

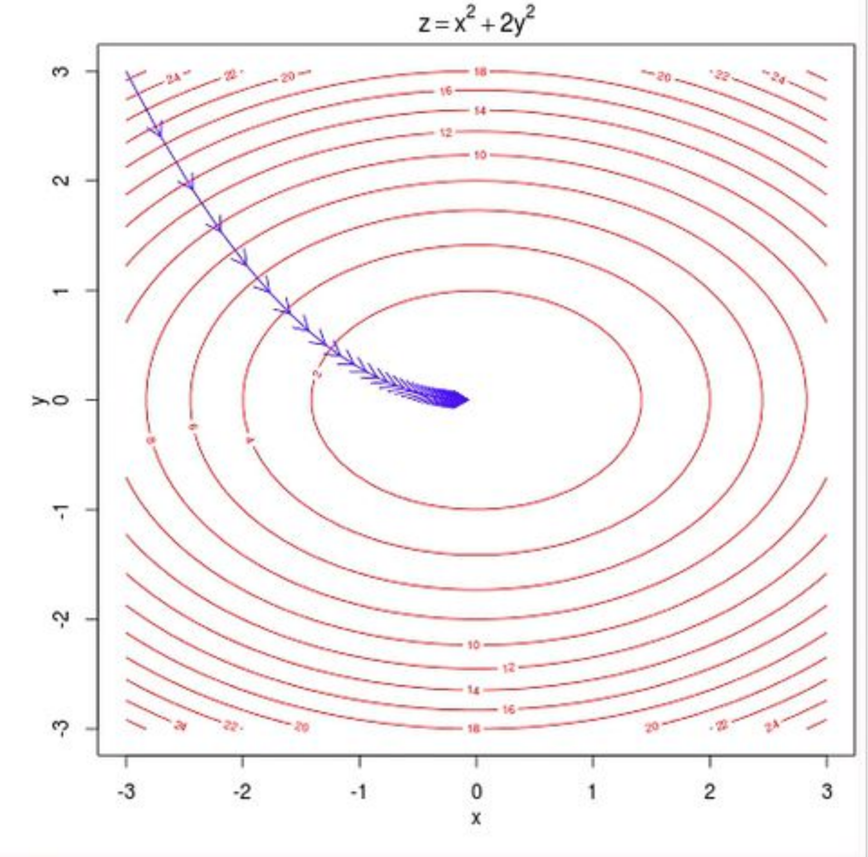
$$\hat{y} = f(\vec{x}) = \sigma\left(W^{(2)}\sigma\left(W^{(1)}\vec{x} + \beta^{(1))}\right) + \beta^{(2))}\right)$$

Gradient Descent

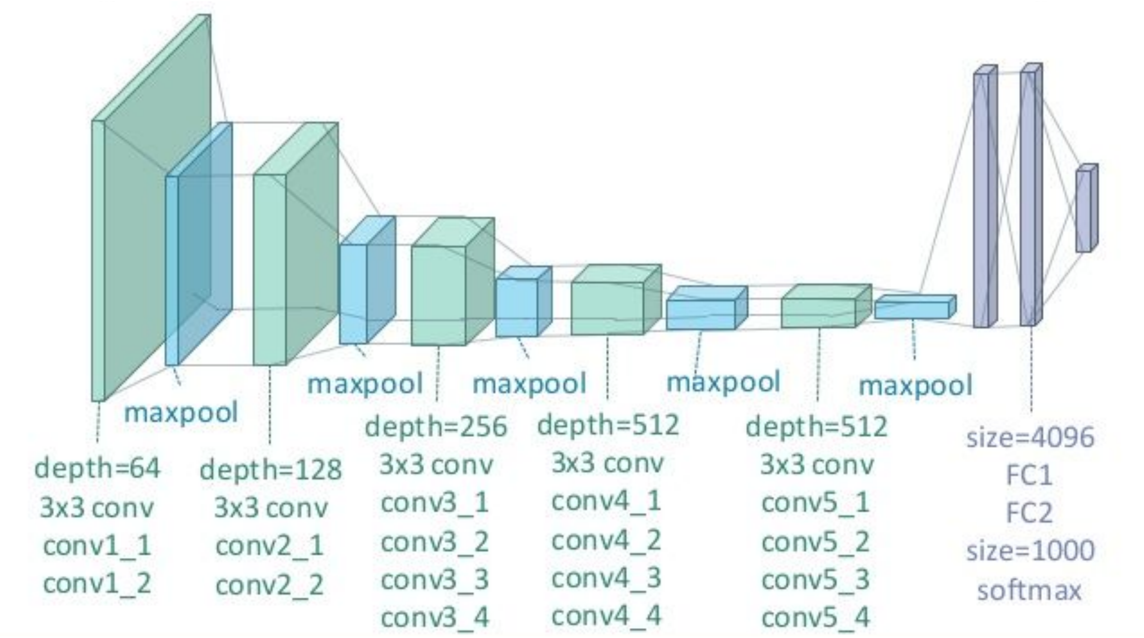
Define the cost function J(w) to be the average of the L(f(x), y) over all the training examples x. Note that the cost function J(w) is a function of the weights of the network.



$$\vec{w} \leftarrow \vec{w} - \eta \frac{\partial J}{\partial \vec{w}}$$



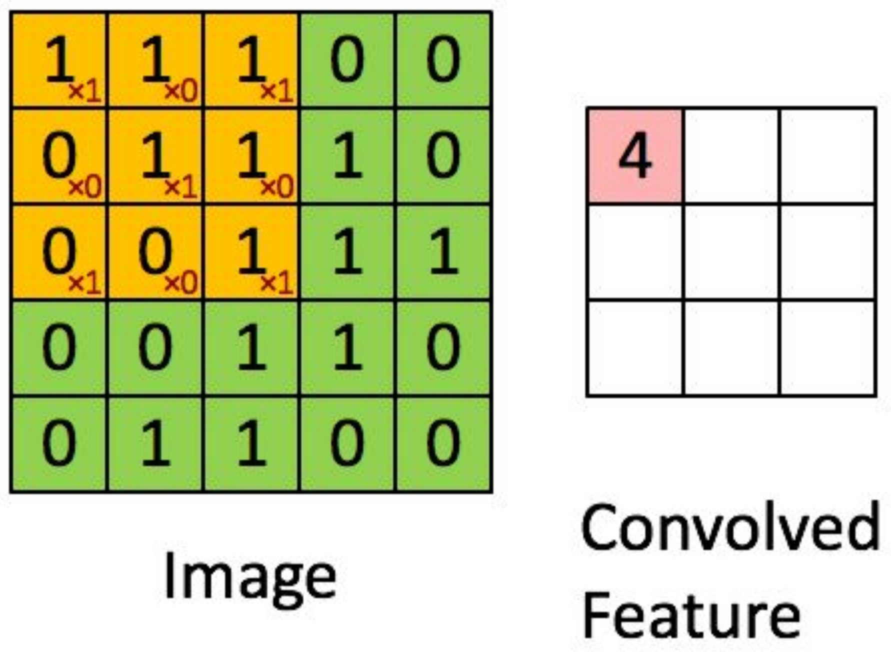
Convolutional Neural Networks



Convolutions

Weight Filter

1	0	1
0	1	0
1	0	1



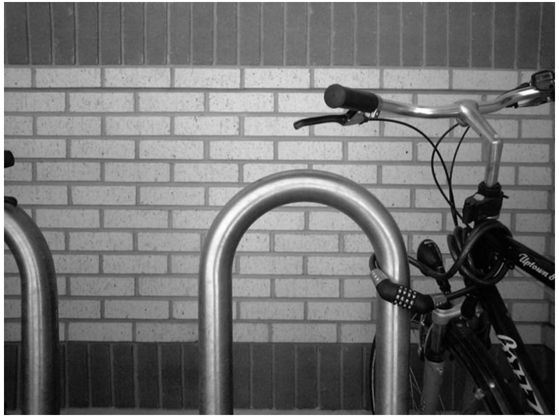
1 ×1	1 ×0	1 ×1	0	0
0 ×0	1 ×1	1 ×0	1	0
0 ×1	0 ×0	1 ×1	1	1
0	0	1	1	0
0	1	1	0	0

Image

4		

Convolved Feature

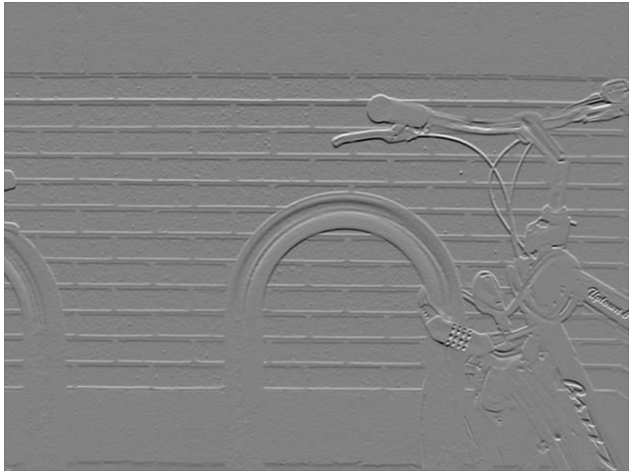
Convolutions



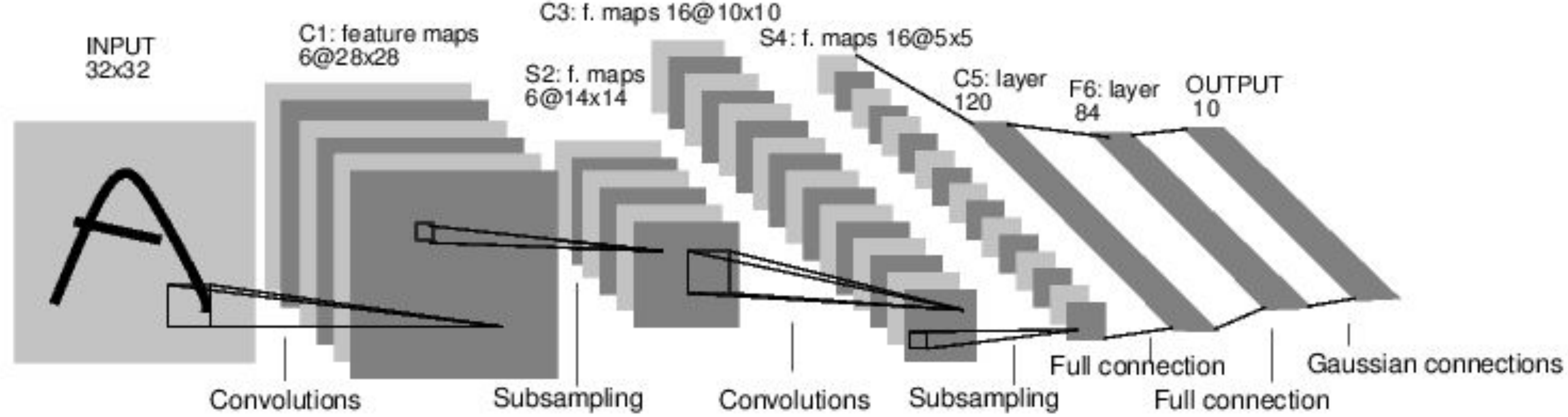
*

1	2	1
0	0	0
-1	-2	-1

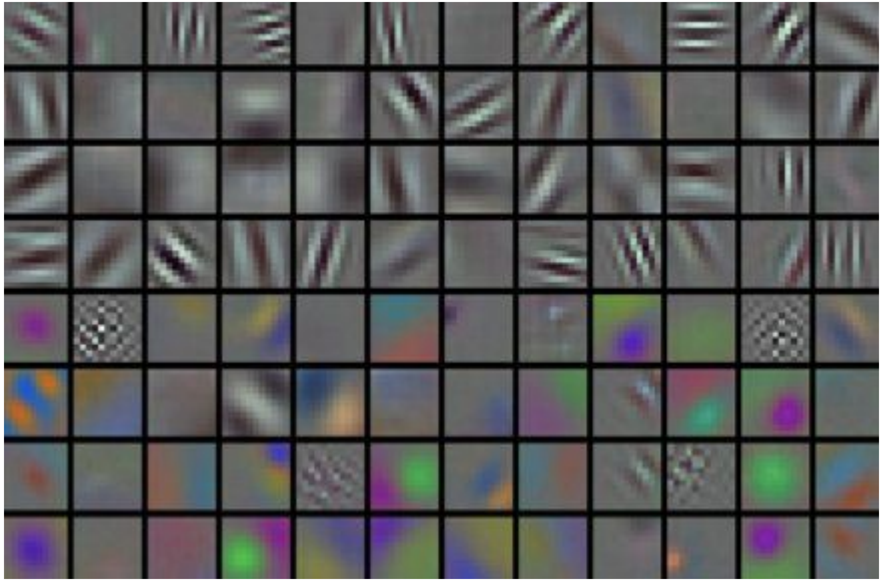
—



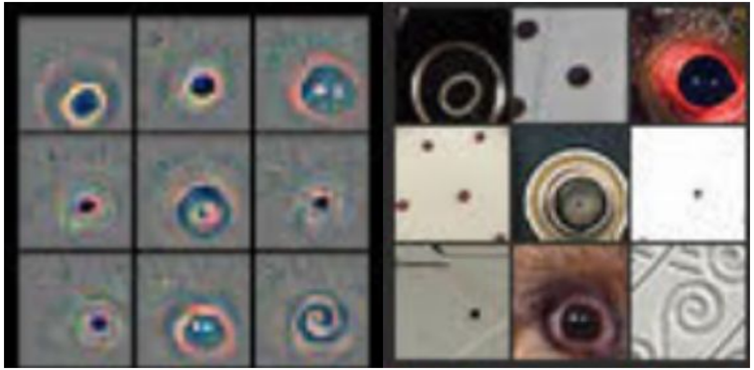
Convolutional Neural Networks



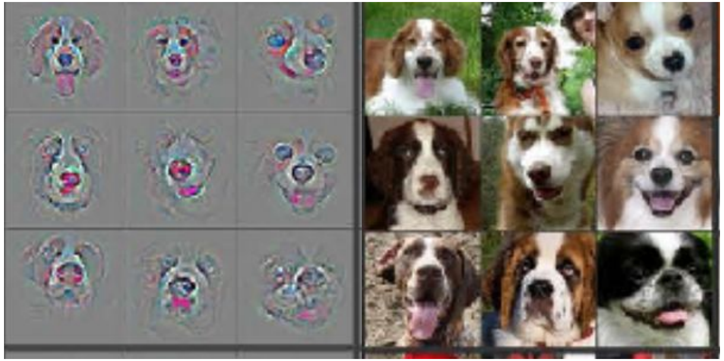
Early Layers Learn Edge Detectors



Later Layers Build Interesting Abstractions

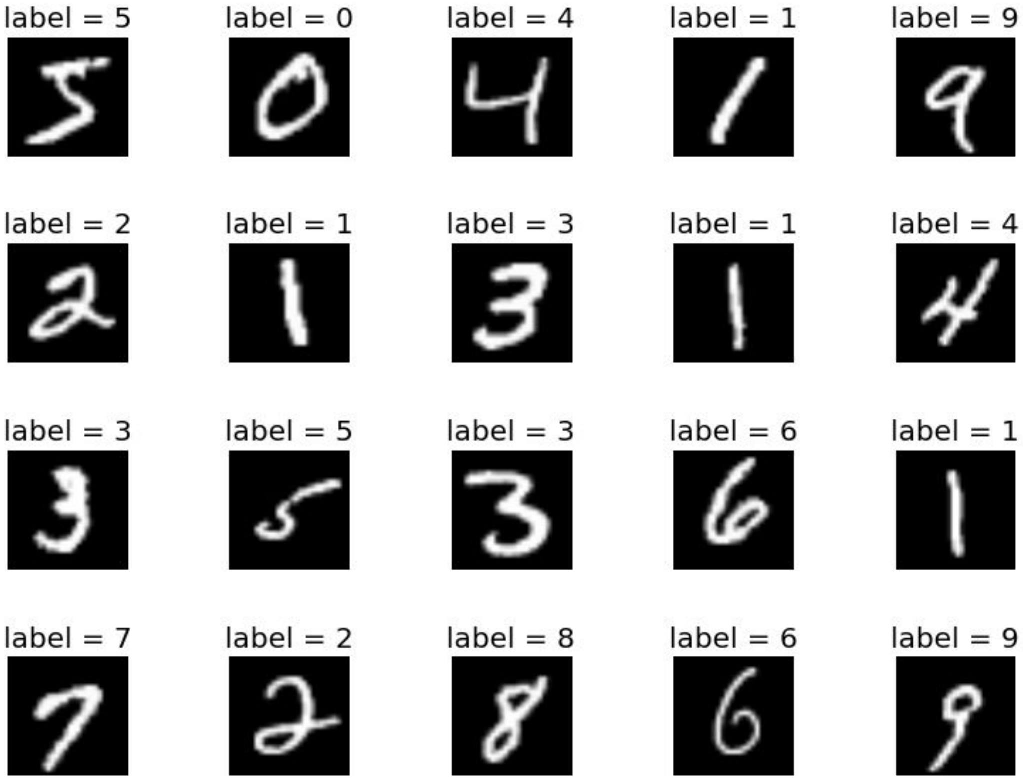


Layer 2 of AlexNet



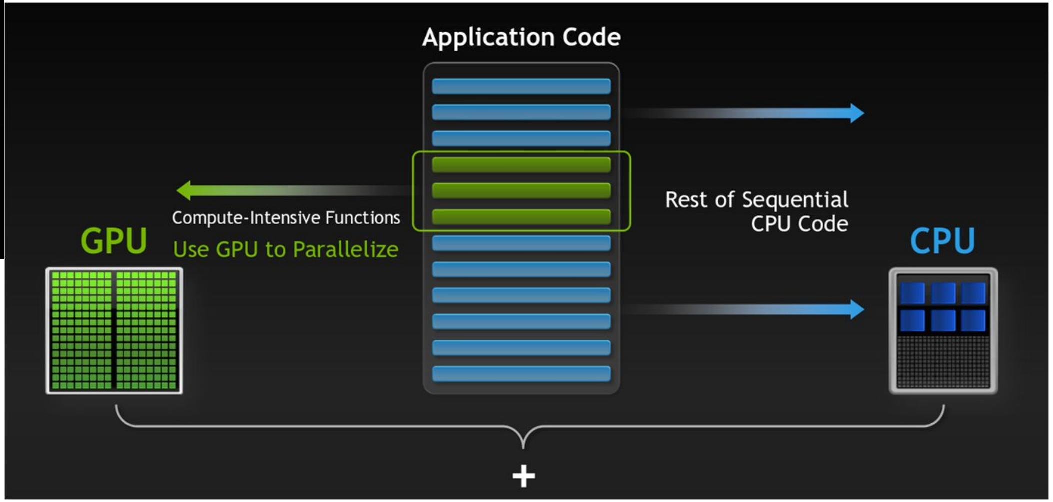
Layer 4 of AlexNet

Deep Learning for MNIST Digit Classification



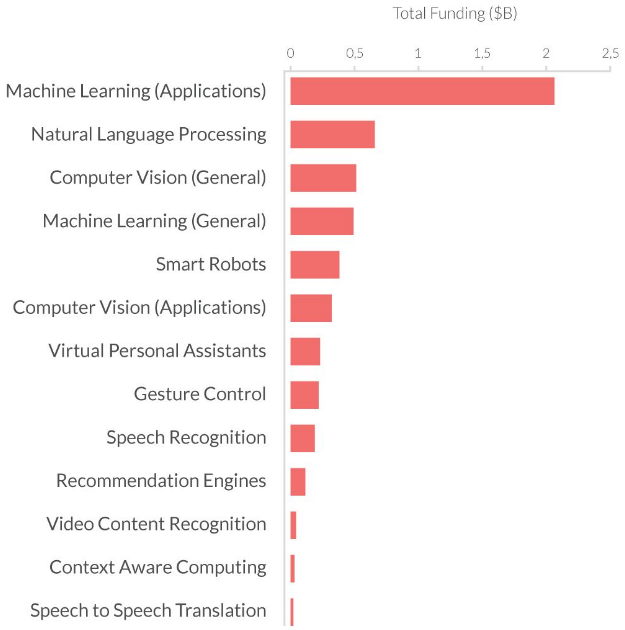
High Level Mobile Principles

How does Deep Learning leverage computational resources?



Why Mobile?

FUNDING BY ARTIFICIAL INTELLIGENCE CATEGORY

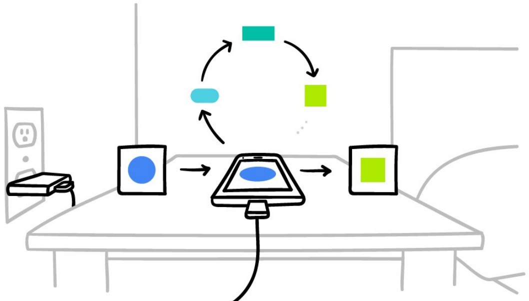


Challenges for Mobile ML

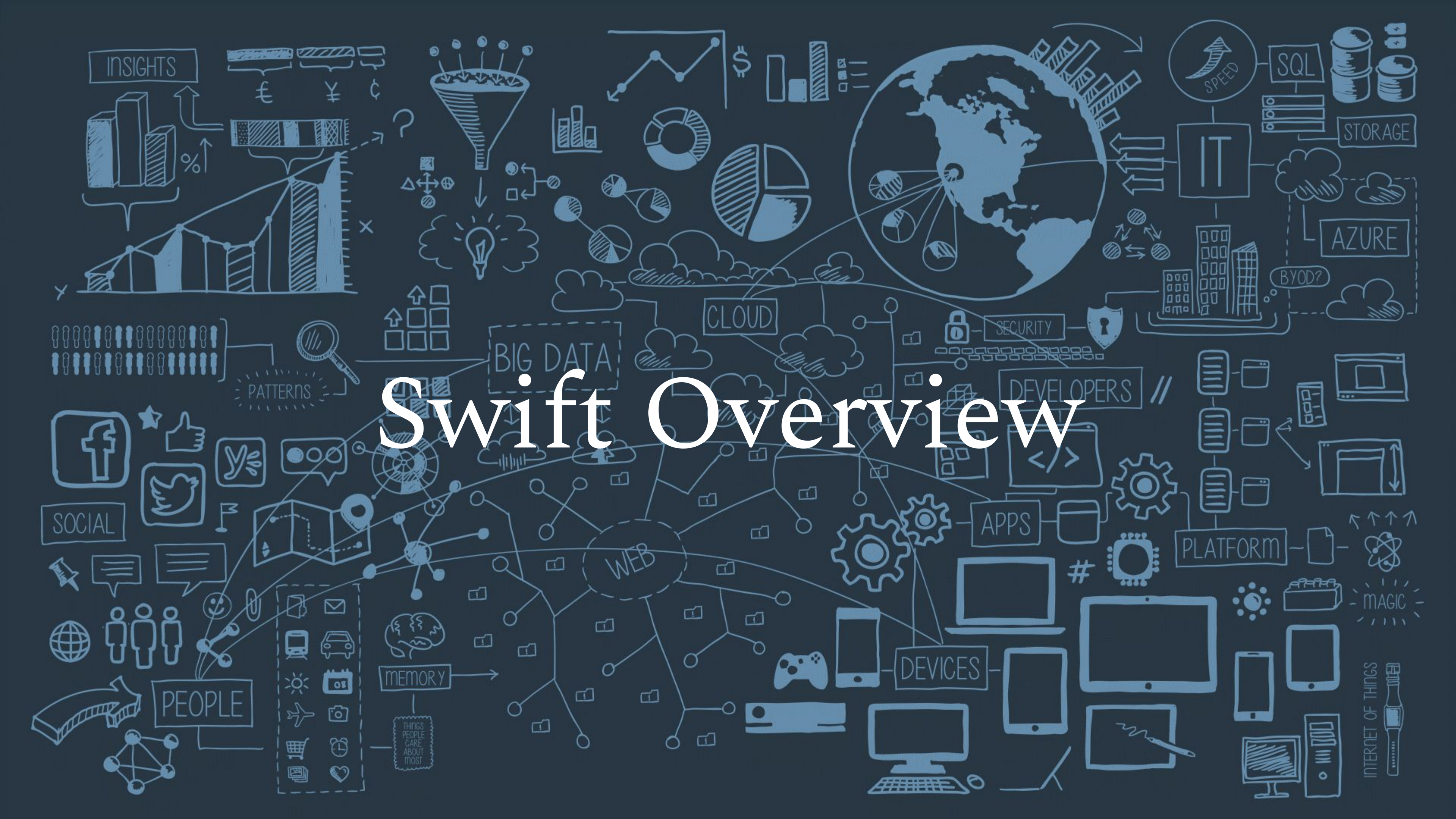
- Computational resource-limited environment
- Restrictions on amount of power we can consume
- Cannot assume connectivity to the internet or power source
- Very sensitive and personal data on people’s phones.
- Data is not i.i.d (different amounts and sources of data)

Strategies to Deal With Challenges

- Balance between training on device (better for privacy) and training on a server (better for aggregation and compute resources)
- If training on device, be sure to only do it when user has enough battery and computational resources (for example, plugged in overnight)
- If training on server, be sure to anonymize data in some way (look into differential privacy if curious) and not wait on disconnected users to deliver data
- Federated Learning: Training on mobile and using a weighted average to update model on server



Swift Overview



What is Swift?

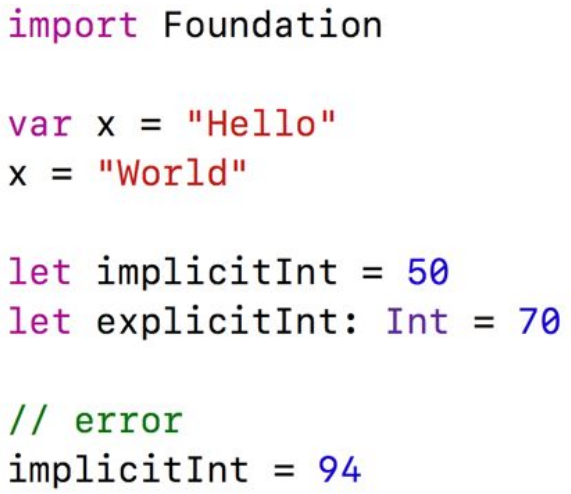
- Swift is the language currently used to develop iOS Apps
- ~10th most popular programming language
- Created by Apple, open-sourced
- Built on top of speedy LLVM (low-level virtual machine) compiler
- Supports Python-like REPL and runs on Linux

Constants/Variables

- Use **let** to declare a constant, **var** to declare a variable

- // to comment a line

- Swift will infer a type but you can explicitly define a type with a colon following the variable name



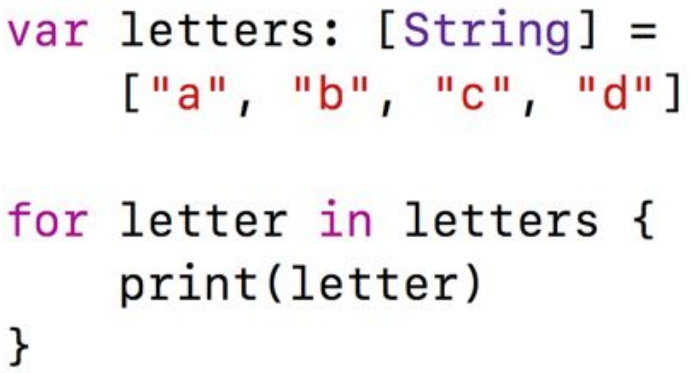
```
import Foundation

var x = "Hello"
x = "World"

let implicitInt = 50
let explicitInt: Int = 70

// error
implicitInt = 94
```

Arrays

- Specified using square brackets around type

- Do not have a fixed size

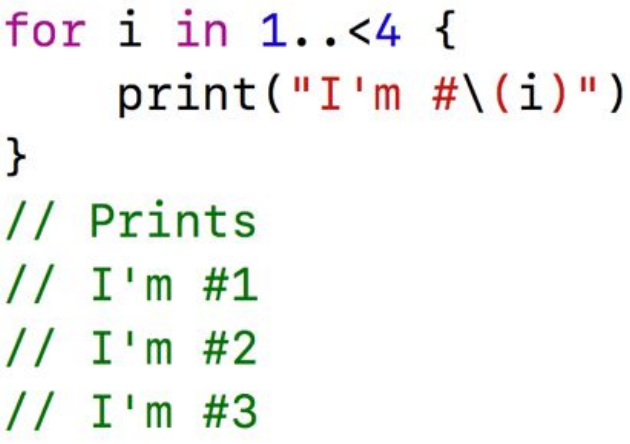
- Use .**append** or **+=** to add elements
  Use .**count** to get size of array
  Swift supports enhanced for loops



```
var letters: [String] =
    ["a", "b", "c", "d"]

for letter in letters {
    print(letter)
}
```

Control Flow

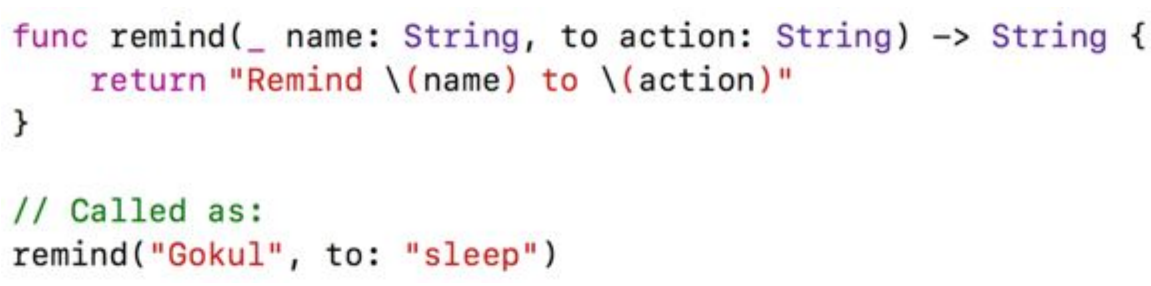
- Use **…** to specify an inclusive interval
- Use **..<** to specify an upper-bound exclusive interval
- Also, "…**\(var_name)**…" inserts variable into string



```
for i in 1..<4 {
    print("I'm #\(i)")
}
// Prints
// I'm #1
// I'm #2
// I'm #3
```

Functions

- Explicit parameter and return types
- Interior and exterior parameter names

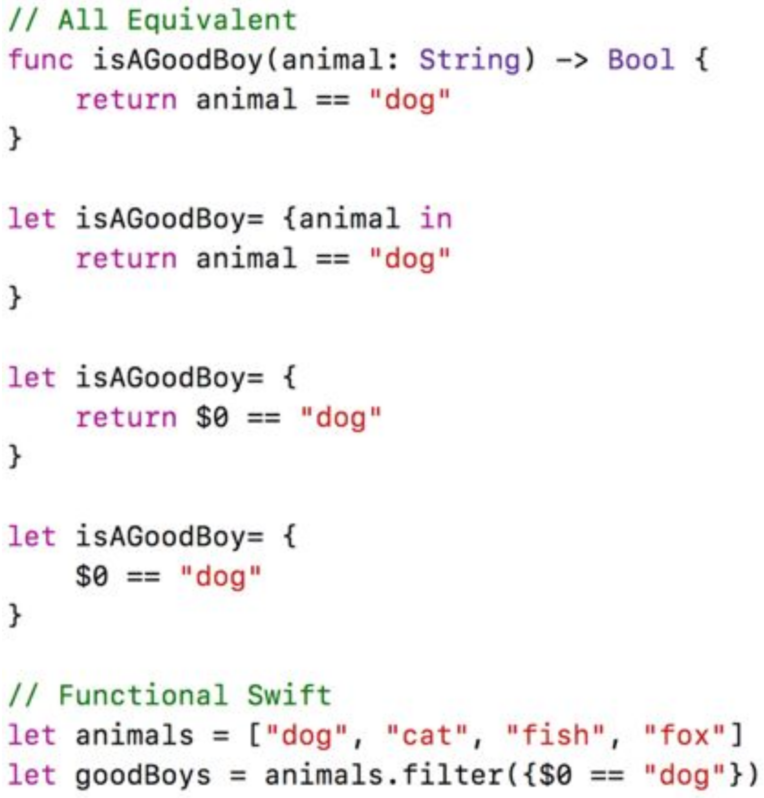


```swift
func remind(_ name: String, to action: String) -> String {
    return "Remind \(name) to \(action)"
}

// Called as:
remind("Gokul", to: "sleep")
```

Closures

- Unnamed functions that can be passed as arguments to other functions
- Used for functional programming



```
// All Equivalent
func isAGoodBoy(animal: String) -> Bool {
    return animal == "dog"
}

let isAGoodBoy= {animal in
    return animal == "dog"
}

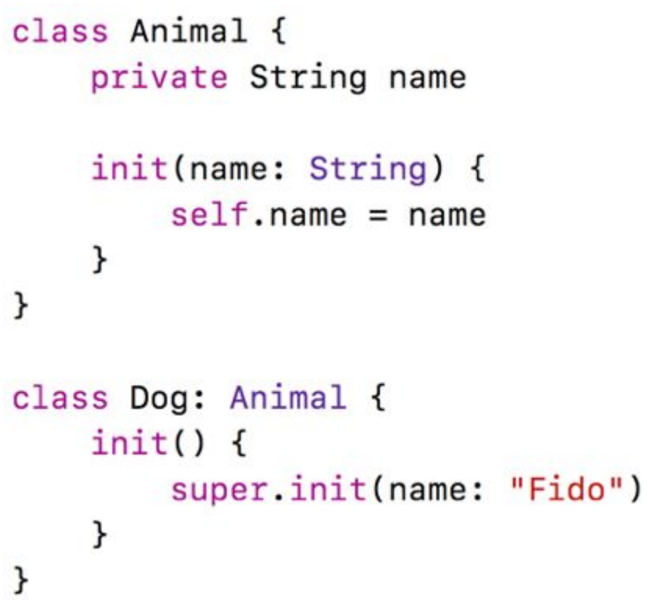
let isAGoodBoy= {
    return $0 == "dog"
}

let isAGoodBoy= {
    $0 == "dog"
}

// Functional Swift
let animals = ["dog", "cat", "fish", "fox"]
let goodBoys = animals.filter({$0 == "dog"})
```

Classes

- Use **self** to refer to current object
- Use **super** to reference superclass
- Use a colon to specify subclassing



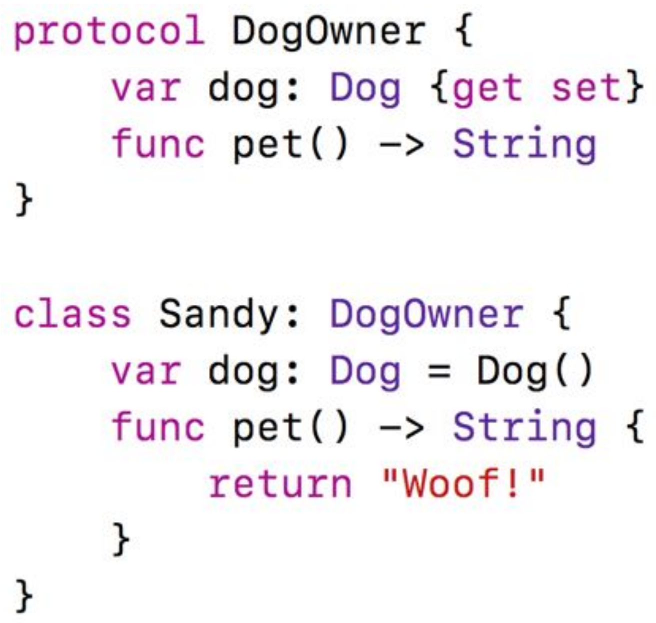
```
class Animal {
    private String name

    init(name: String) {
        self.name = name
    }
}

class Dog: Animal {
    init() {
        super.init(name: "Fido")
    }
}
```

Protocols

- Similar to interfaces in other languages
- Can specify variables and functions
- Can specify whether variable should be gettable or settable
- Same colon syntax as subclassing



```
protocol DogOwner {
    var dog: Dog {get set}
    func pet() -> String
}

class Sandy: DogOwner {
    var dog: Dog = Dog()
    func pet() -> String {
        return "Woof!"
    }
}
```

Protocols

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- Can specify variables and functions

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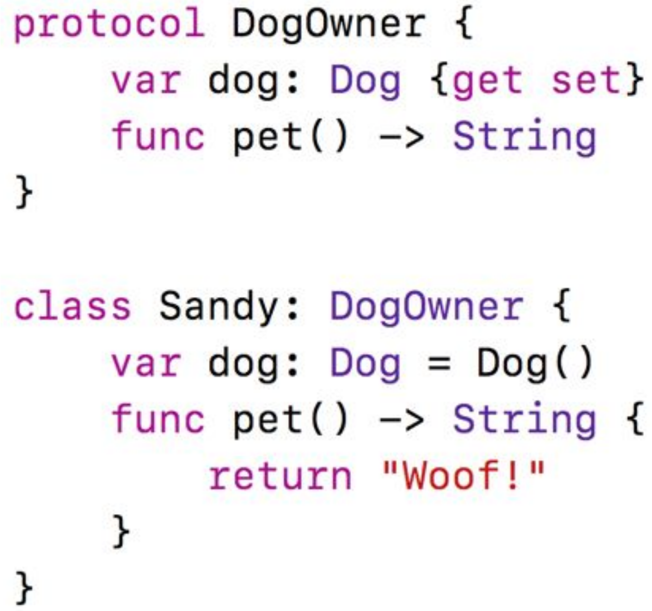

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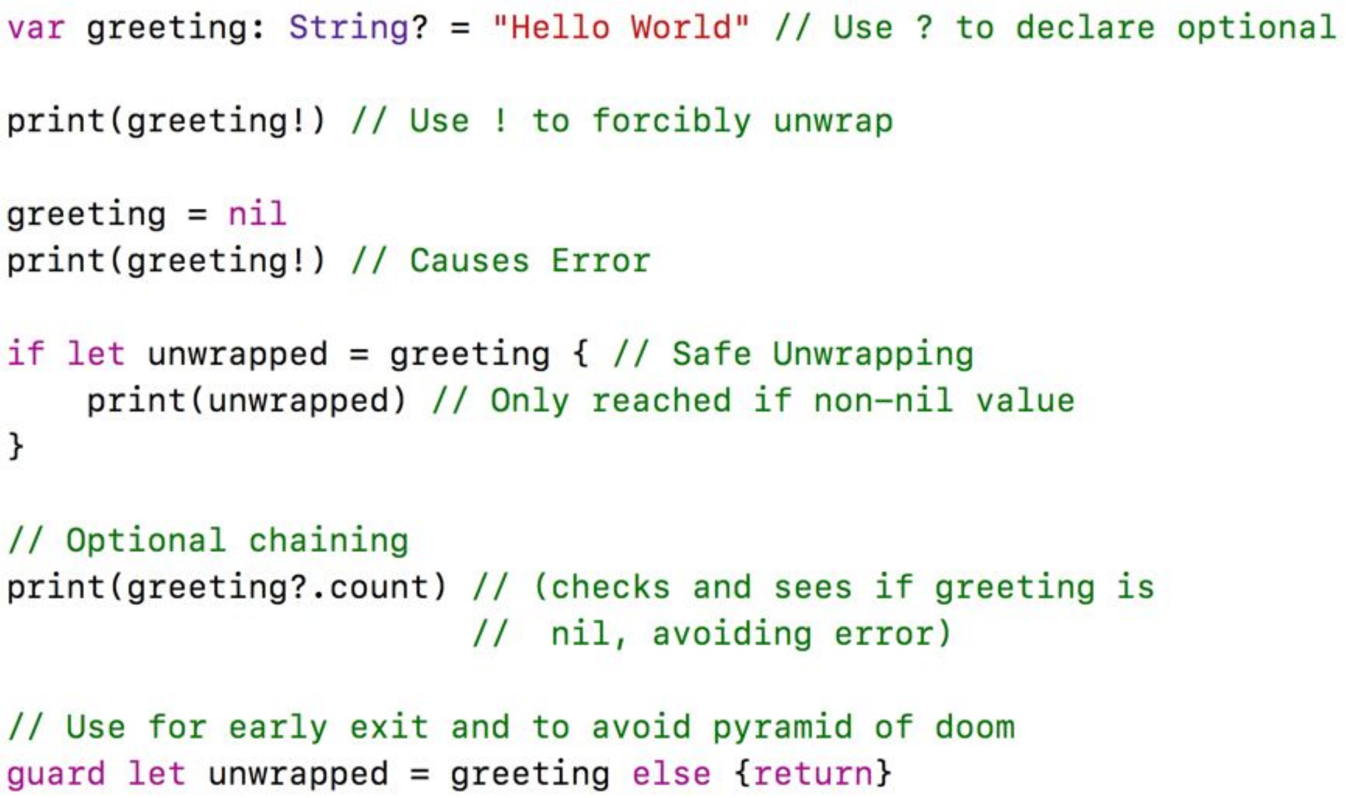
protocol DogOwner {
    var dog: Dog {get set}
    func pet() -> String
}

class Sandy: DogOwner {
    var dog: Dog = Dog()
    func pet() -> String {
        return "Woof!"
    }
}
```

Optionals

- One of the signature features (and sometimes headaches) of Swift
- A type that indicates that an object of another (non-optional) type exists or a nil value
- Unwrap to get at data that is potentially contained

Optionals: Syntax



```
var greeting: String? = "Hello World" // Use ? to declare optional

print(greeting!) // Use ! to forcibly unwrap

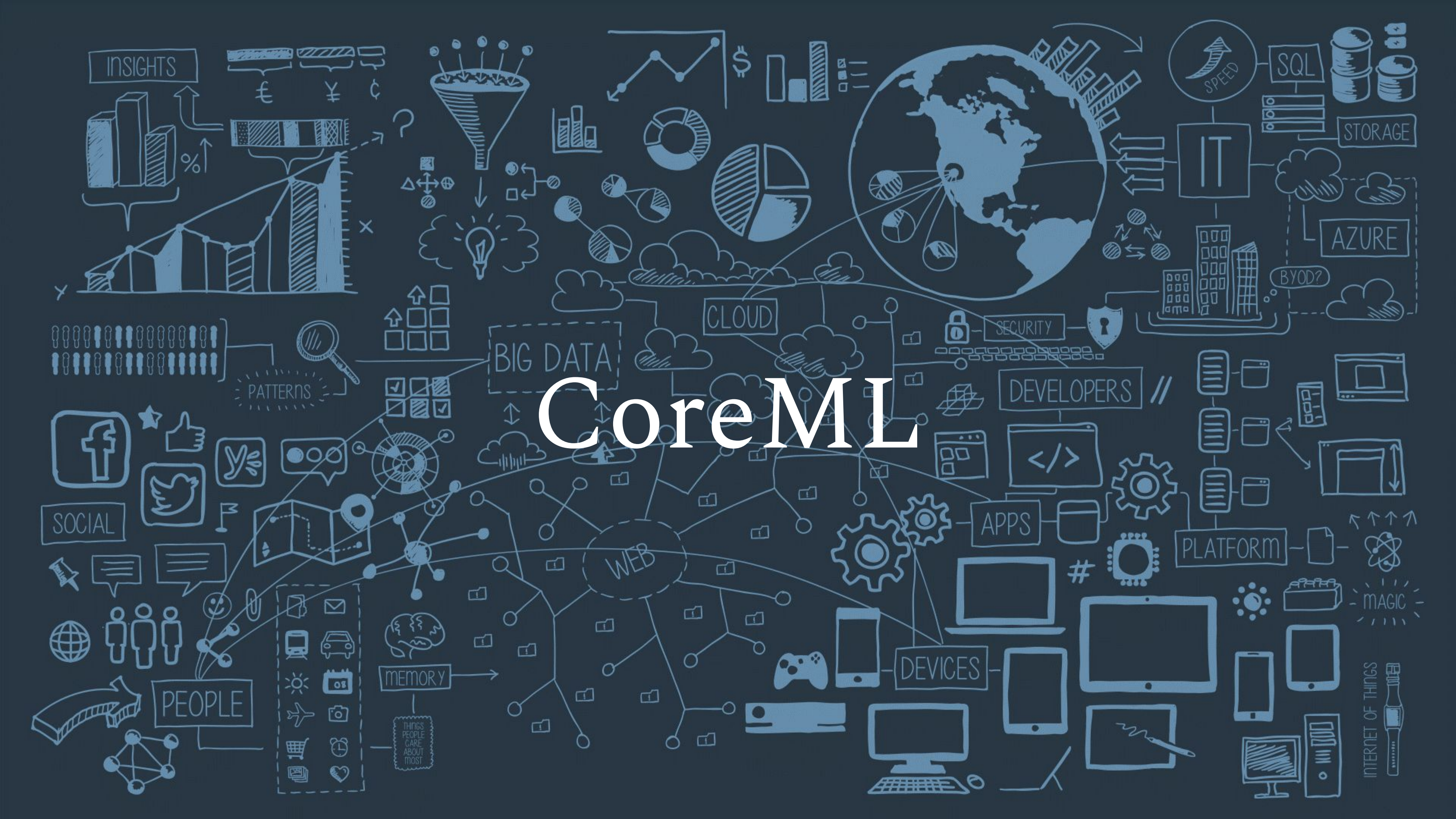
greeting = nil
print(greeting!) // Causes Error

if let unwrapped = greeting { // Safe Unwrapping
    print(unwrapped) // Only reached if non-nil value
}

// Optional chaining
print(greeting?.count) // (checks and sees if greeting is
                       //  nil, avoiding error)

// Use for early exit and to avoid pyramid of doom
guard let unwrapped = greeting else {return}
```

CoreML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DEVELOPERS
SOCIAL
APPS
PLATFORM
WEB
MAGIC
MEMORY
THINGS PEOPLE CARE ABOUT MOST
PEOPLE
DEVICES
INTERNET OF THINGS

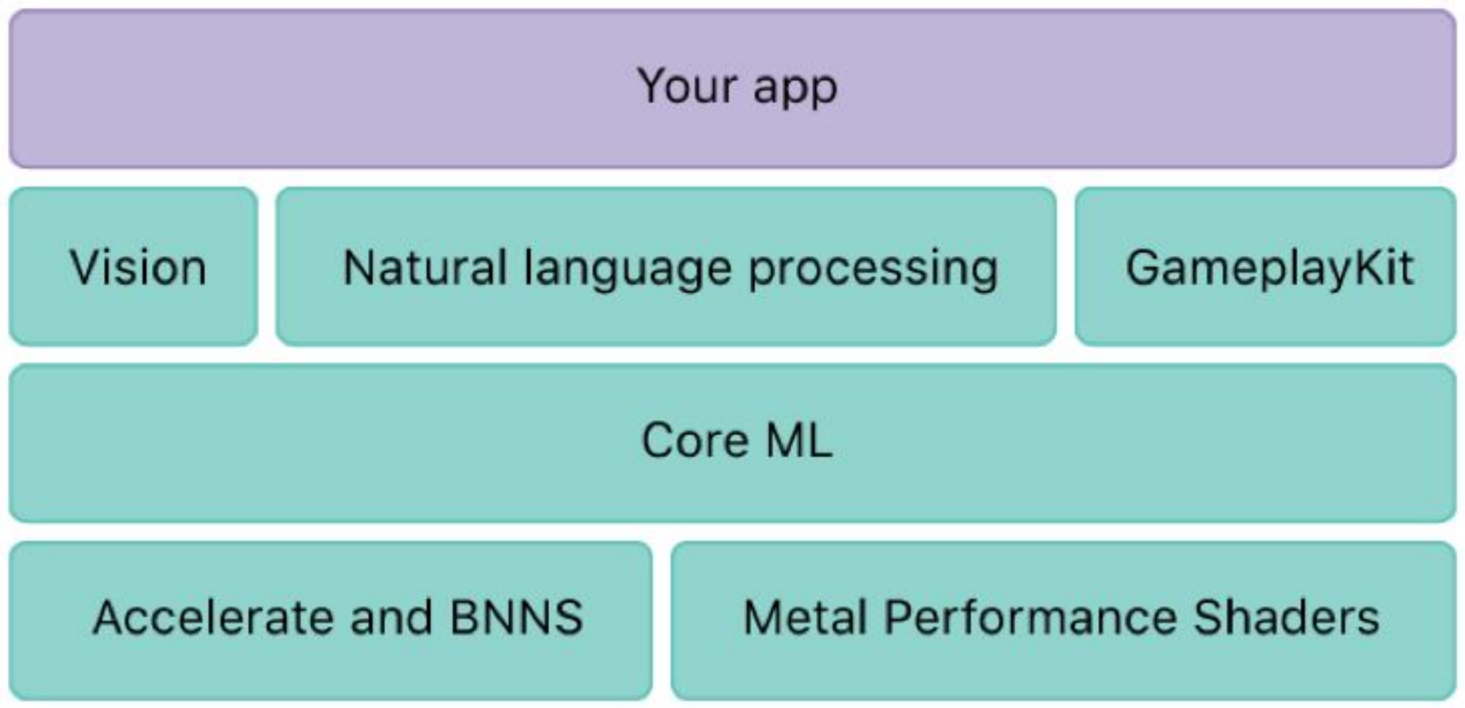
What is CoreML?

- CoreML released at WWDC 2017
- Represents a shift in traditional developer model
    - Researcher creates model
    - Apple takes care of hard part of implementation
    - You just have to connect the above

CoreML

- Lets you convert ML code written in Python into a **.mlmodel** file can be dropped directly into your app
- Hard part: optimizes code for iOS devices
- Some helpful preprocessing included
- Does not currently support on-device training

Architecture



Your app

Vision

Natural language processing

GameplayKit

Core ML

Accelerate and BNNS

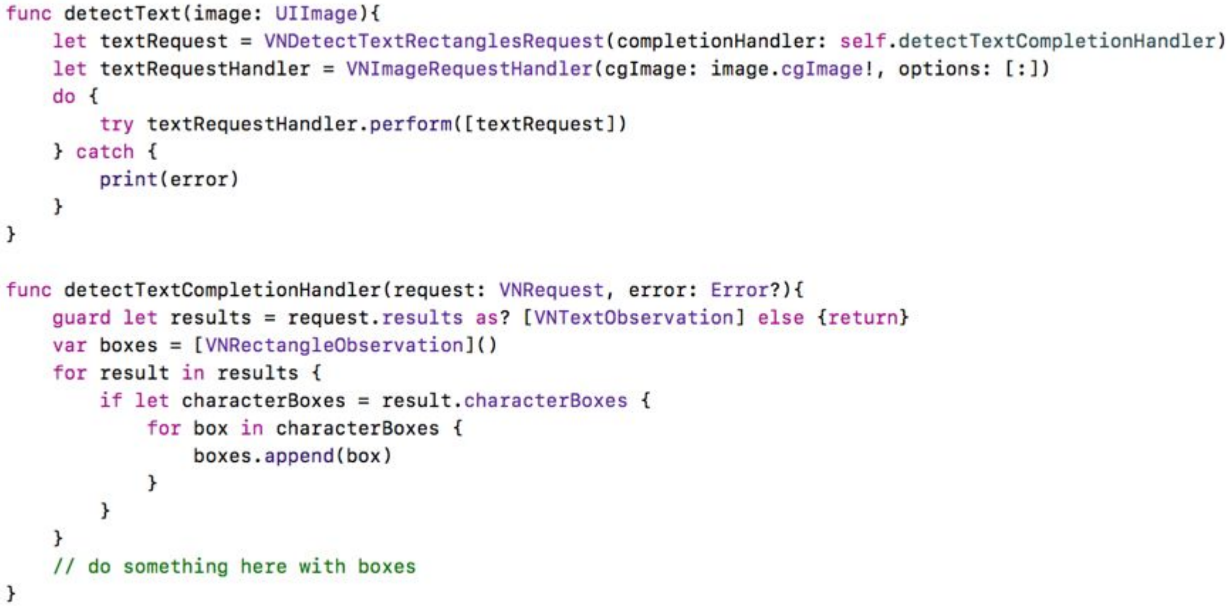
Metal Performance Shaders

Vision

- Allows you to detect face landmarks, perform OCR, scan barcodes, perform optical flow
- Slower but more accurate than CoreImage and AVFoundation
- Three Steps
  1. Call **VNRequestHandler**
  2. Which executes a **VNRequest**
  3. And returns some **VNObservation** for you to process

Vision: Code

- Be sure to add Camera Usage Description to Info.plist and import Vision



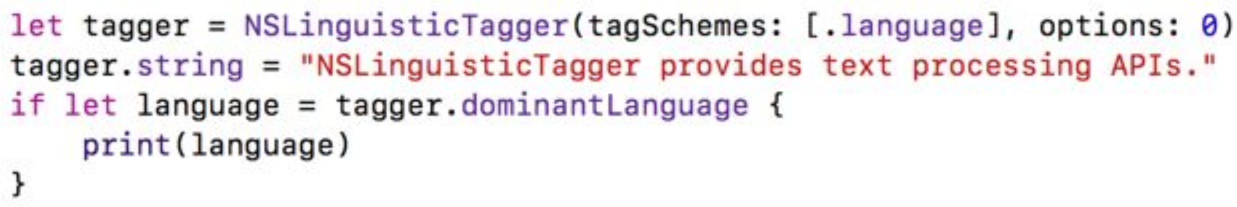
```swift
func detectText(image: UIImage){
    let textRequest = VNDetectTextRectanglesRequest(completionHandler: self.detectTextCompletionHandler)
    let textRequestHandler = VNImageRequestHandler(cgImage: image.cgImage!, options: [:])
    do {
        try textRequestHandler.perform([textRequest])
    } catch {
        print(error)
    }
}

func detectTextCompletionHandler(request: VNRequest, error: Error?){
    guard let results = request.results as? [VNTextObservation] else {return}
    var boxes = [VNRectangleObservation]()
    for result in results {
        if let characterBoxes = result.characterBoxes {
            for box in characterBoxes {
                boxes.append(box)
            }
        }
    }
    // do something here with boxes
}
```

NSLinguisticTagger

- Part of NS but revamped with deep learning for 2017
- On device processing so no privacy worries
- Can identify language, tokenize (split up into chunks), lemmatize (give root form of word), and detect named entities (rigid designators of concepts that may be important)
- Two Steps
  - Create **NSLinguisticTagger** with tagSchemes set to application
  - Set **tagger.string** to the text to be analyzed.

NSLinguisticTagger: Code

- For example, to detect dominant language:



```
let tagger = NSLinguisticTagger(tagSchemes: [.language], options: 0)
tagger.string = "NSLinguisticTagger provides text processing APIs."
if let language = tagger.dominantLanguage {
    print(language)
}
```

- For all use case sample code, check out this link

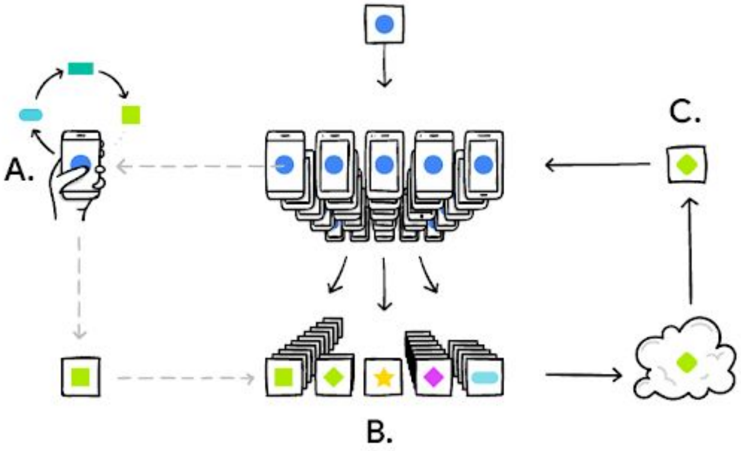
Building a Mobile ML System

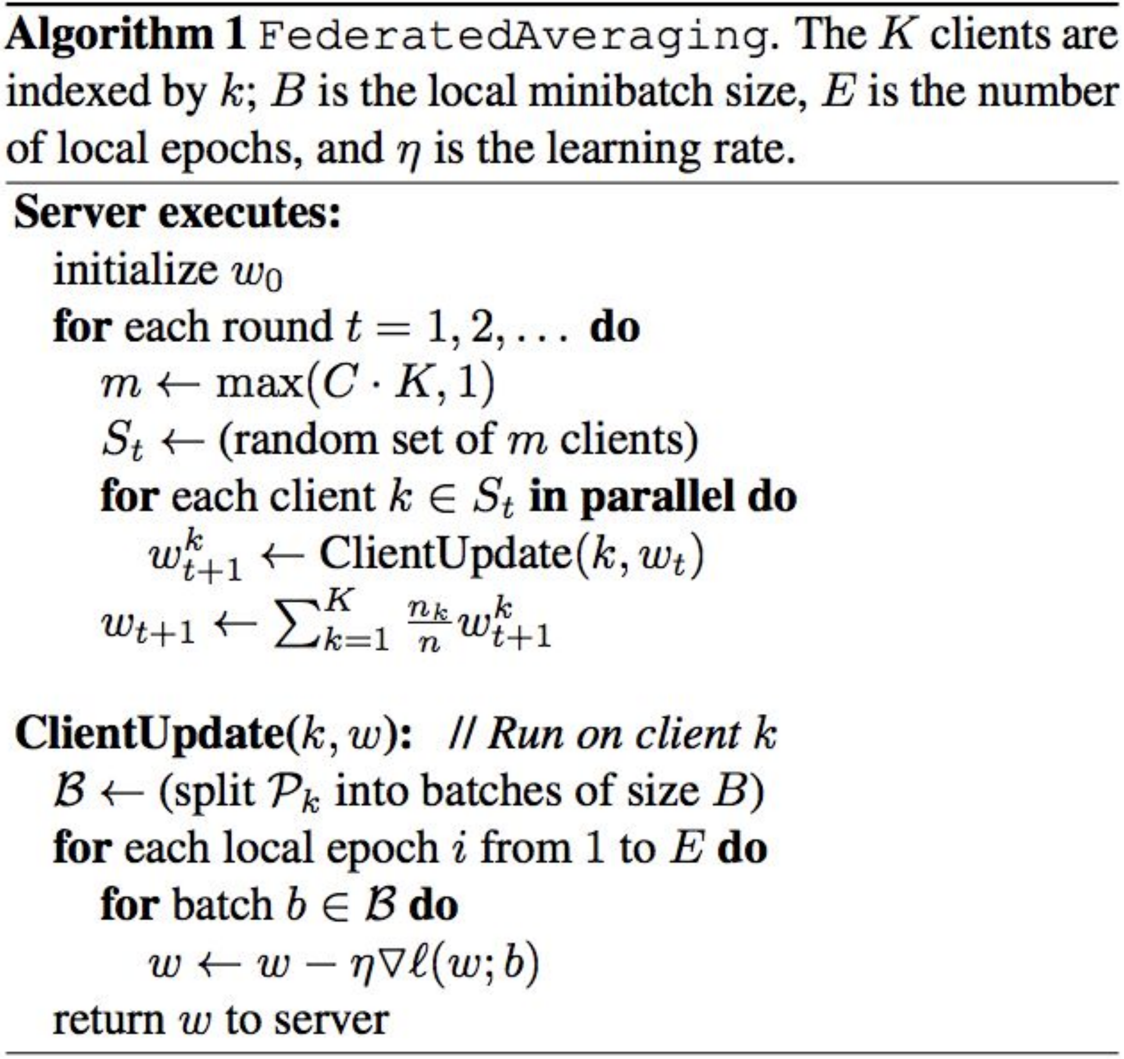
Setup

- We’ll be using Python 3.5
- `git clone https://github.com/mlberkeley/mobile_ml_workshop`
- `pip install numpy keras tensorflow`
- Download Xcode from the Mac App Store
- `pip install h5py coremltools`
- `xcode-select --install`

Federated Learning

- Compute gradients based on individual user data
- Send gradients to server and update model by averaging gradients across users
- Maintains user data privacy

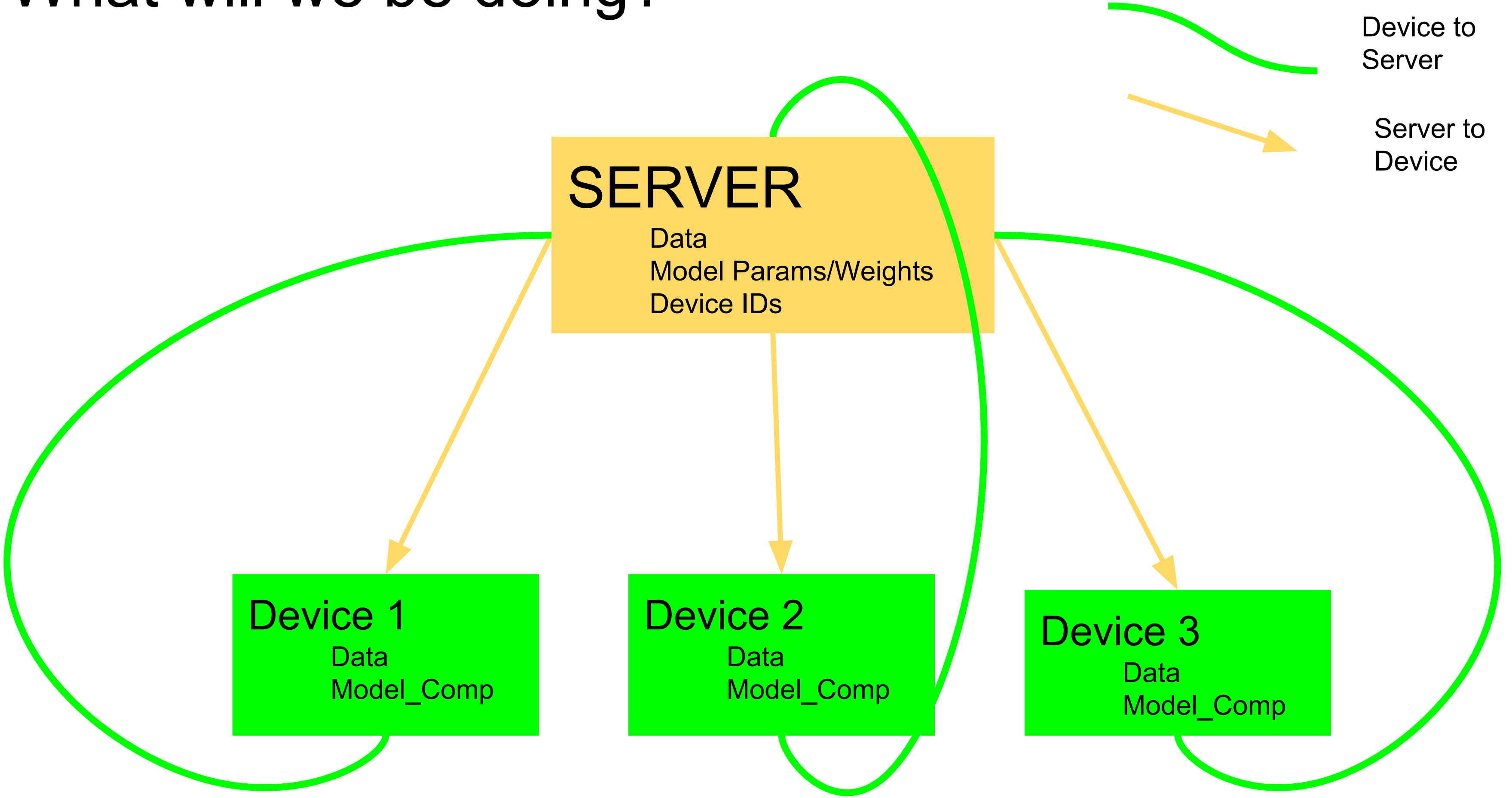




Algorithm 1 `FederatedAveraging`. The K clients are indexed by k; B is the local minibatch size, E is the number of local epochs, and η is the learning rate.

```
Server executes:
  initialize $w_0$
  for each round $t = 1, 2, \dots$ do
    $m \leftarrow \max(C \cdot K, 1)$
    $S_t \leftarrow$ (random set of $m$ clients)
    for each client $k \in S_t$ in parallel do
      $w_{t+1}^k \leftarrow \text{ClientUpdate}(k, w_t)$
    $w_{t+1} \leftarrow \sum_{k=1}^{K} \frac{n_k}{n} w_{t+1}^k$

ClientUpdate$(k, w)$:   // Run on client k
  $\mathcal{B} \leftarrow$ (split $\mathcal{P}_k$ into batches of size $B$)
  for each local epoch $i$ from 1 to $E$ do
    for batch $b \in \mathcal{B}$ do
      $w \leftarrow w - \eta \nabla \ell(w; b)$
  return $w$ to server
```

What will we be doing?



Device to Server

Server to Device

SERVER

Data

Model Params/Weights

Device IDs

Device 1

Data

Model_Comp

Device 2

Data

Model_Comp

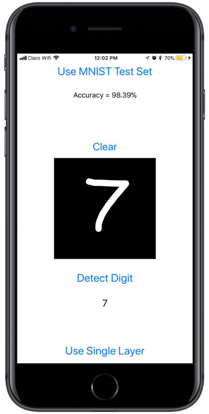
Device 3

Data

Model_Comp

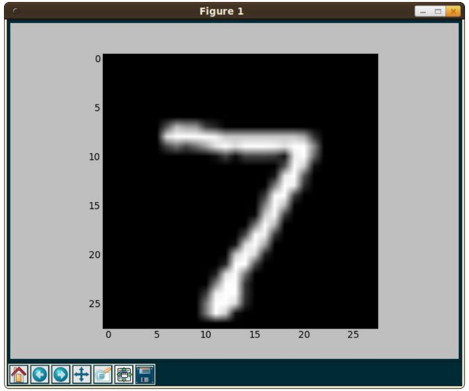
How can we make our model more accurate?

- Do preprocessing on MNIST images to make sure no pixels have gray values
    - Similar format as inputs from phone
- Change pen style on phone to sense pressure when writing
    - Makes digits written on phone more similar to MNIST images



Accuracy = 98.39%

7



Extra Resources

How to Deep Learn at Home

Run on CPU (really slow)

Buy a GPU (more expensive option)

Use AWS! - Here’s a Guide

(Jan. 2018) OR

Use Google Colab! (GPU guide)

Deep Learning Resources

ML@B’s Machine Learning Crash Course: Part 3

Stanford’s CS231n Convolutional Networks for Visual Recognition

Deep Learning Textbook by Goodfellow et. al.

ML@B’s Deep Learning Decal

Neural Networks and Deep Learning (Backprop section)