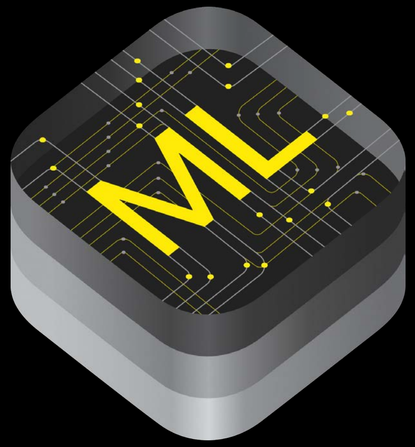
Core ML in Depth

Krishna Sridhar, Core ML
Zach Nation, Core ML

The easiest way to integrate machine learning models into your app.



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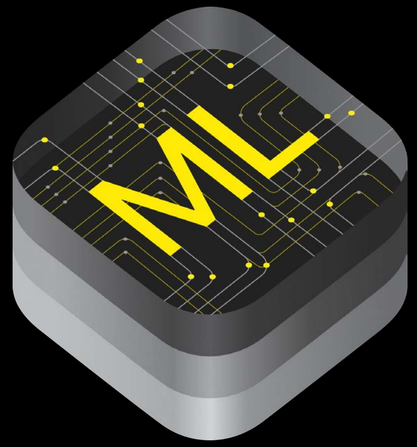
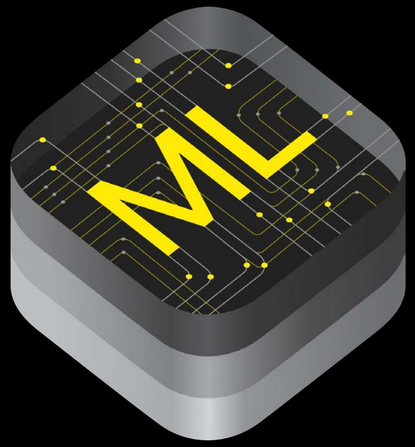


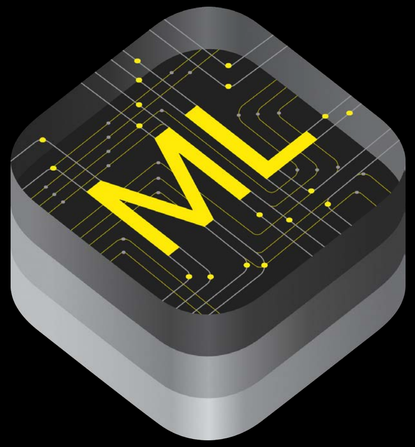
macOS

The easiest way to integrate machine learning models into your app.



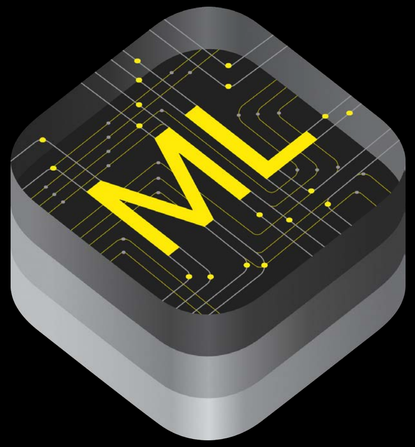
macOS iOS

The easiest way to integrate machine learning models into your app.



macOS iOS watchOS

The easiest way to integrate machine learning models into your app.

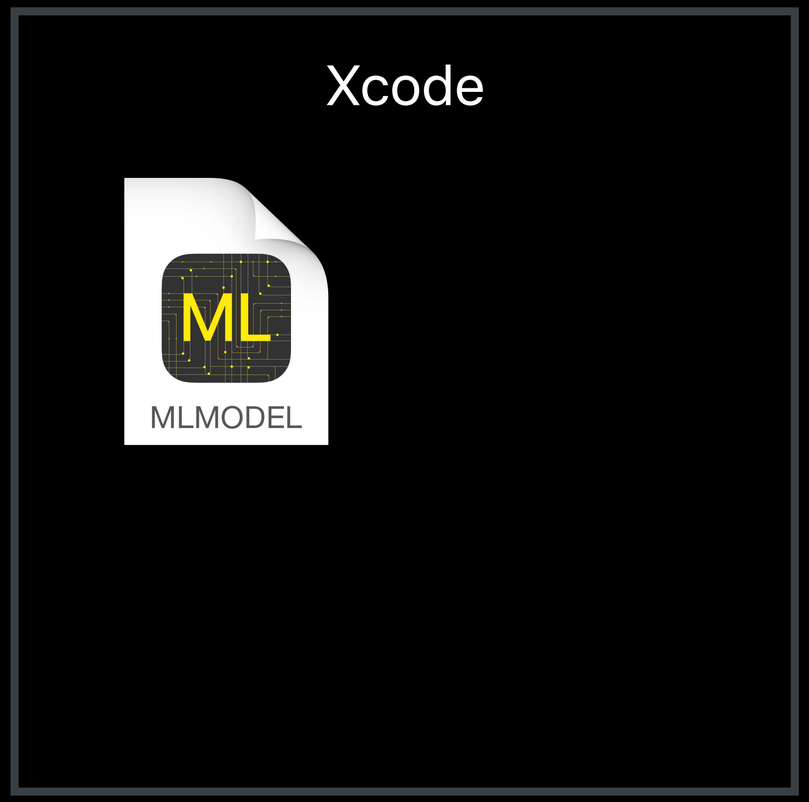


macOS iOS watchOS tvOS

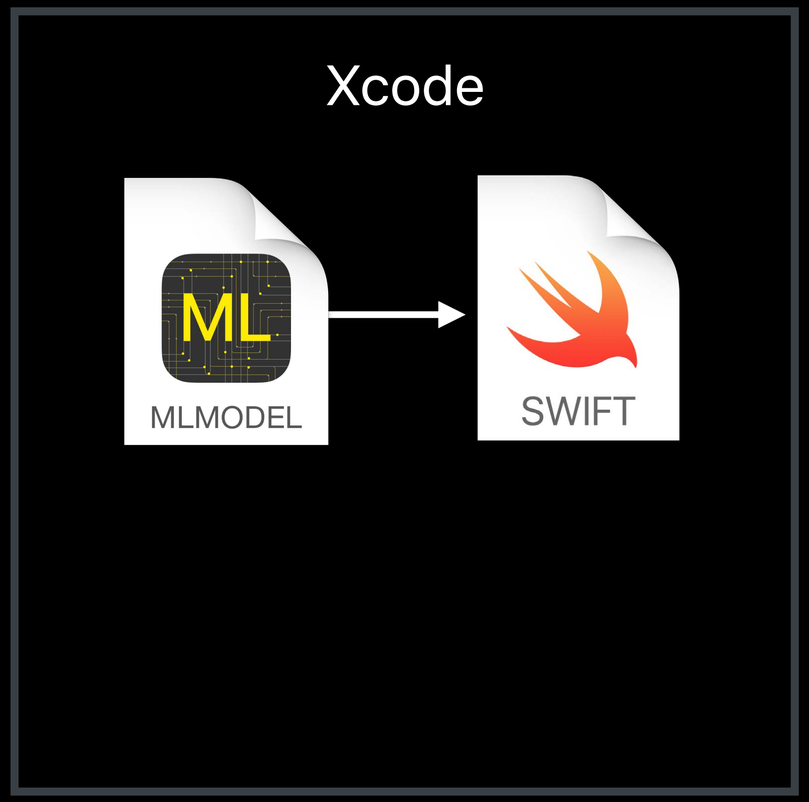
Think of models as code

Development Flow

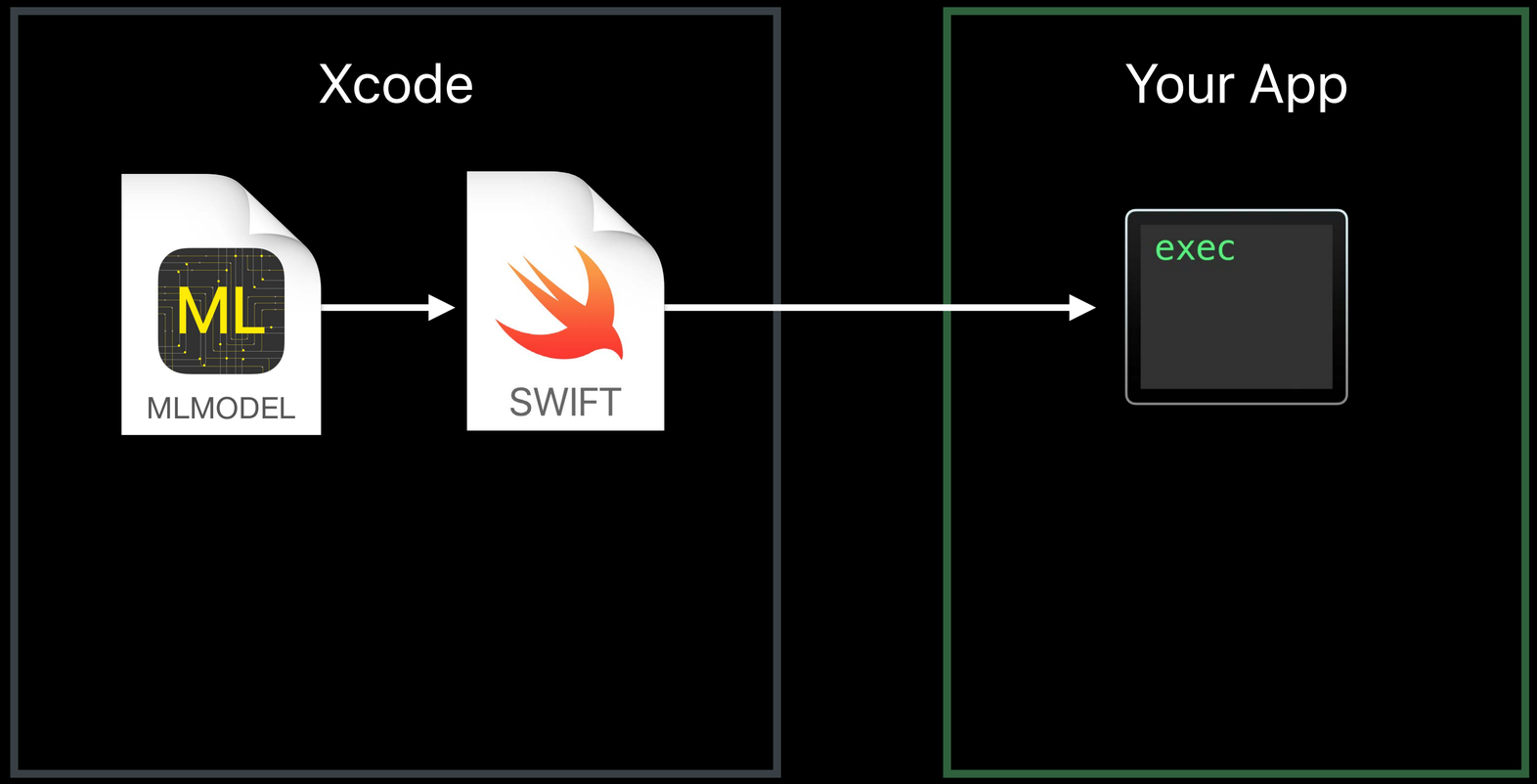
Development Flow



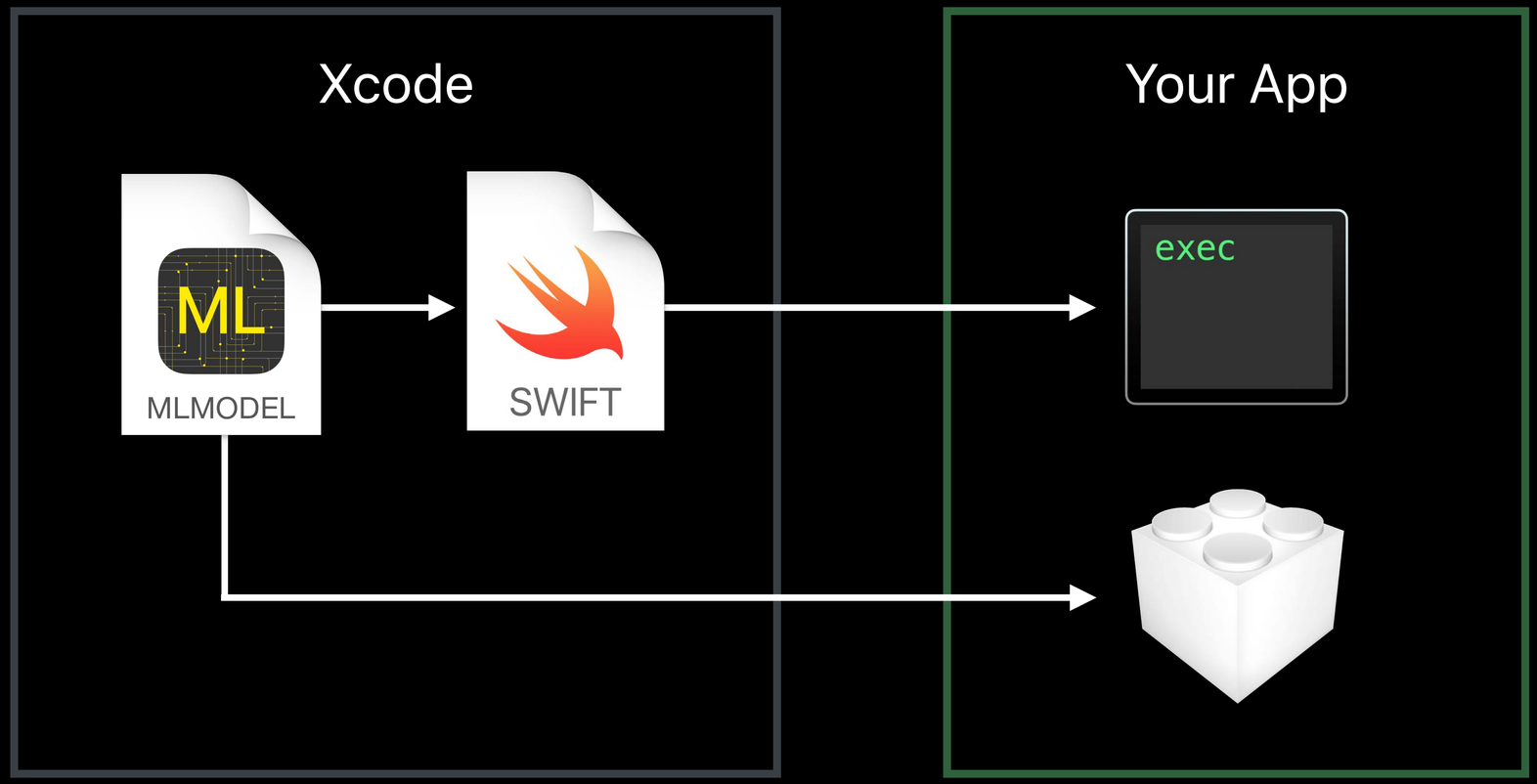
Development Flow



Development Flow



Development Flow



Rose

Confidence 95%

Rose

Confidence 95%

```
let model = FlowerClassifier()

if let prediction = try? model.prediction(image: image) {
    return prediction.flowerType
}
```

Rose

Confidence 95%

```
let model = FlowerClassifier()

if let prediction = try? model.prediction(image: image) {
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```
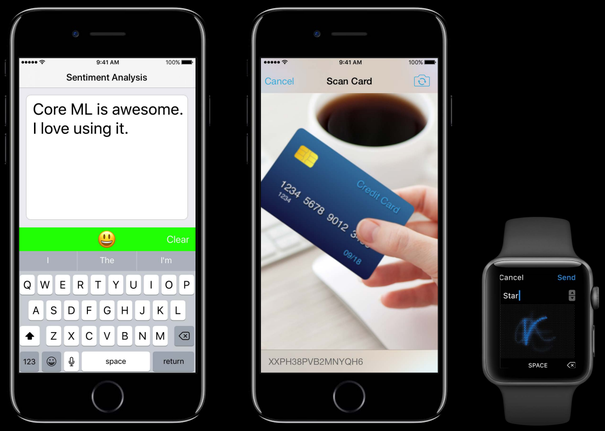
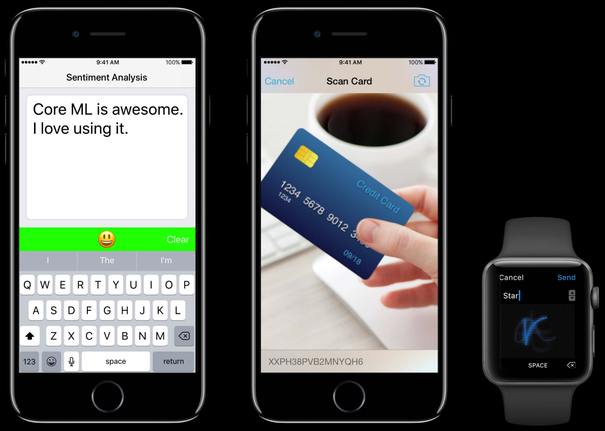

This Session

Use Cases

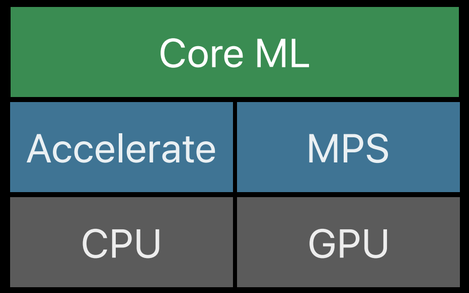


This Session

Use Cases

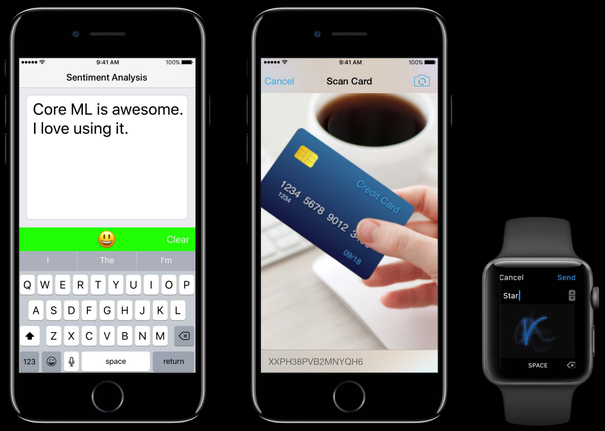


Hardware Optimized

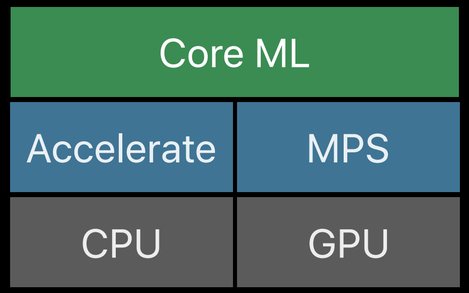


This Session

Use Cases



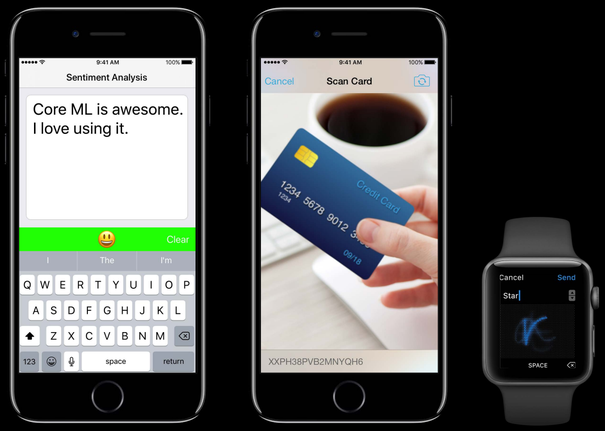
Hardware Optimized



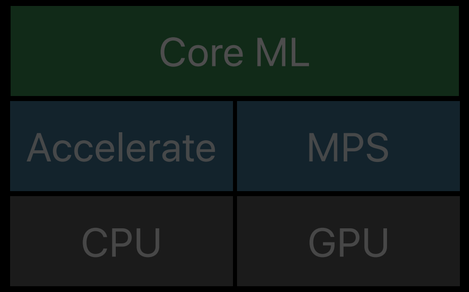
Obtaining Models

This Session

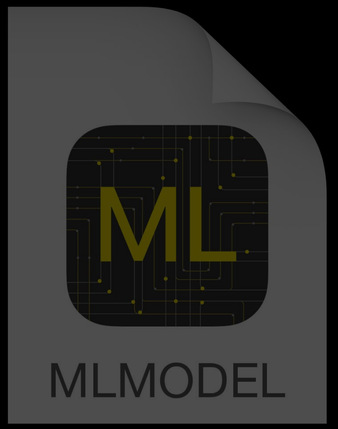
Use Cases



Hardware Optimized

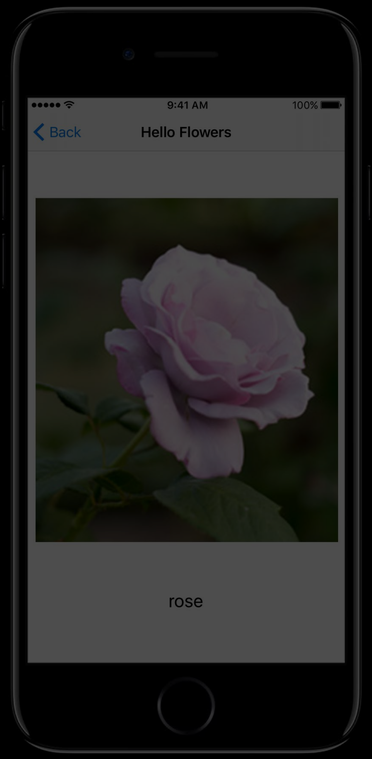


Obtaining Models



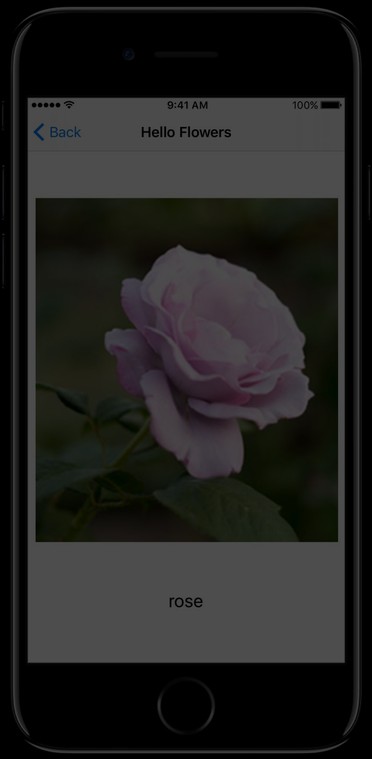

9:41 AM
100%
Back
Hello Flowers
rose


Cancel
Send
Star
SPACE


9:41 AM
100%
Back
Hello Flowers
rose


9:41 AM
100%
Cancel
Scan Card
Credit Card
1234 5678 9012
09/18
XXPH38PVB2MNYQH6

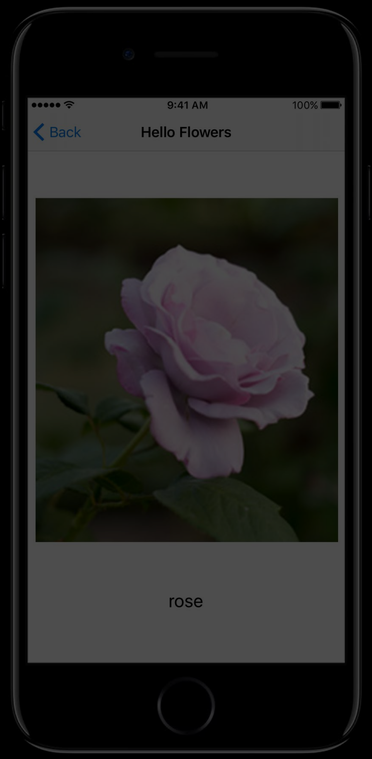

Cancel
Send
Star
SPACE


9:41 AM
100%
Back
Hello Flowers
rose


CLEAR
SYNC
128.05
FREEZE
BPM
FX
FX
SYNC
136.07
FREEZE
BPM


9:41 AM
100%
Cancel
Scan Card
Credit Card
1234 5678 9012
1234
09/18
XXPH38PVB2MNYQH6

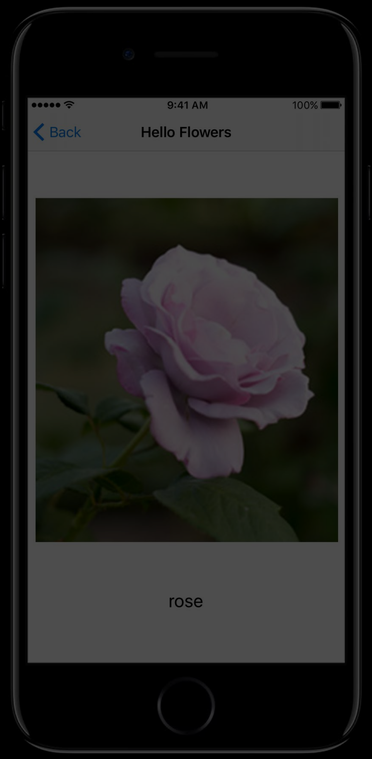

Cancel
Send
Star
SPACE

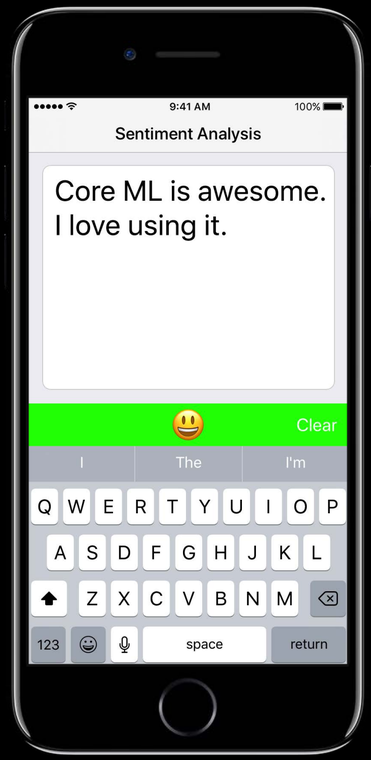

9:41 AM
100%
Back
Hello Flowers
rose


CLEAR
SYNC
128.05
FREEZE
BPM
FX
FX
SYNC
136.07
FREEZE
BPM


9:41 AM
100%
Cancel
Scan Card
Credit Card
1234 5678 9012
1234
09/18
XXPH38PVB2MNYQH6


Cancel
Send
Star
SPACE


9:41 AM
100%
Back
Hello Flowers
rose


9:41 AM
100%
Sentiment Analysis
Core ML is awesome.
I love using it.
Clear
I
The
I'm
Q W E R T Y U I O P
A S D F G H J K L
Z X C V B N M
123
space
return

Sentiment Analysis

Object Detection

Personalization

Style Transfer

Music Tagging

Gesture Recognition

Summarization

Sentiment Analysis

Object Detection

Personalization

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Music Tagging

Gesture Recognition

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Summarization

Generalized Linear Models

Tree Ensembles

Support Vector Machines

Feedforward Neural Networks

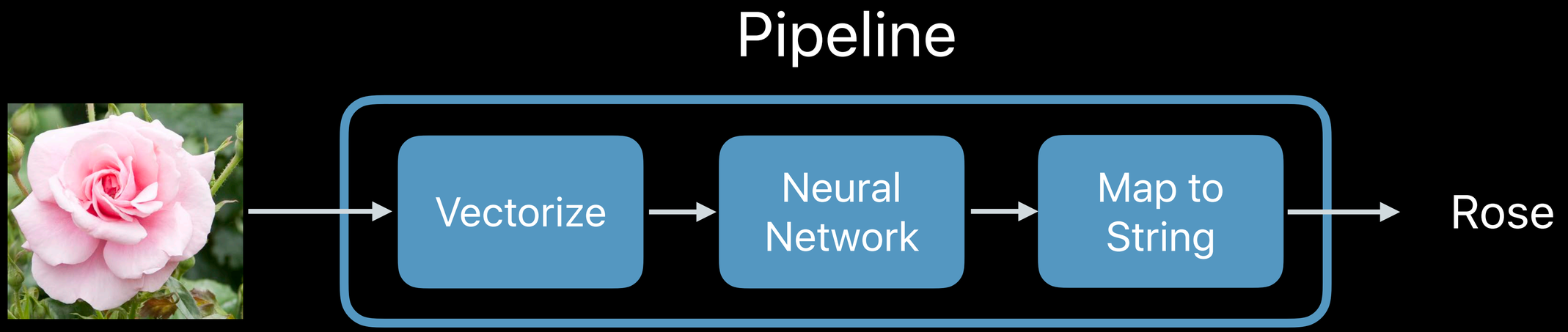
Convolution Neural Networks

Recurrent Neural Networks

Feedforward
Neural Networks

Convolution
Neural Networks

Recurrent
Neural Networks


Pipeline
Vectorize
Neural Network
Map to String
Rose

Sentiment Analysis

Object Detection

Personalization

Style Transfer

Music Tagging

Gesture Recognition

Summarization

Focus on code, not models!

Models as Functions

Numeric

Categories

Images

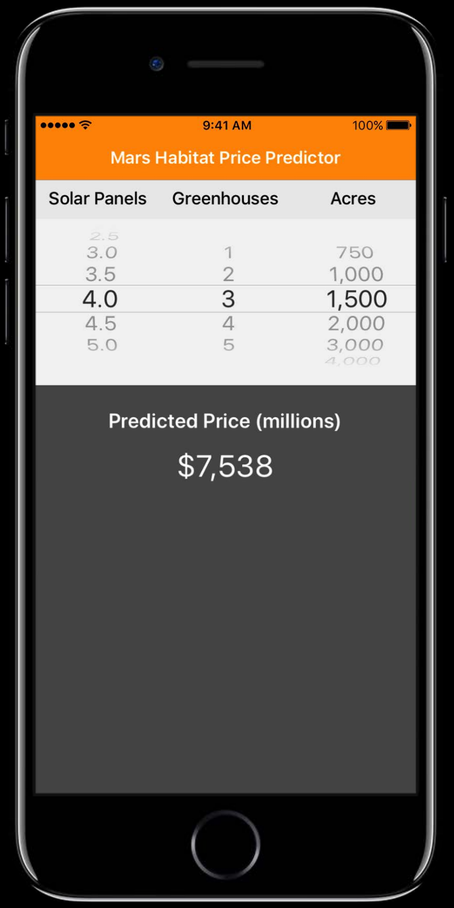
Arrays

Dictionaries

Numeric and Categories

developer.apple.com/machine-learning

Numeric	`Double, Int64`
Categories	`String, Int64`
Images	`CVPixelBuffer`
Arrays	`MLMultiArray`
Dictionaries	`[String : Double], [Int64 : Double]`



Images

Numeric

Categories

Images

Arrays

Dictionaries

```
Double, Int64

String, Int64

CVPixelBuffer

MLMultiArray

[String : Double], [Int64 : Double]
```

Multi-Dimensional Arrays

Numeric

Categories

Images

Arrays

Dictionaries

```
Double, Int64

String, Int64

CVPixelBuffer

MLMultiArray

[String : Double], [Int64 : Double]
```

Dictionaries

Numeric

Categories

Images

Arrays

Dictionaries

```
Double, Int64

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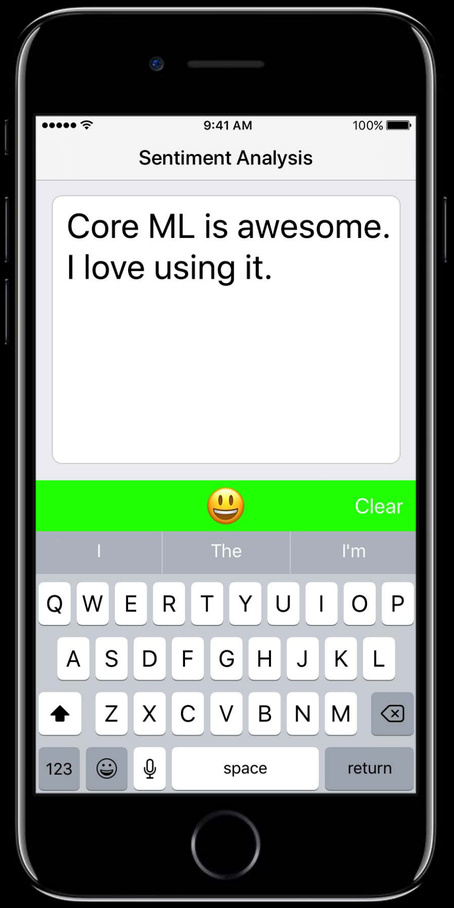
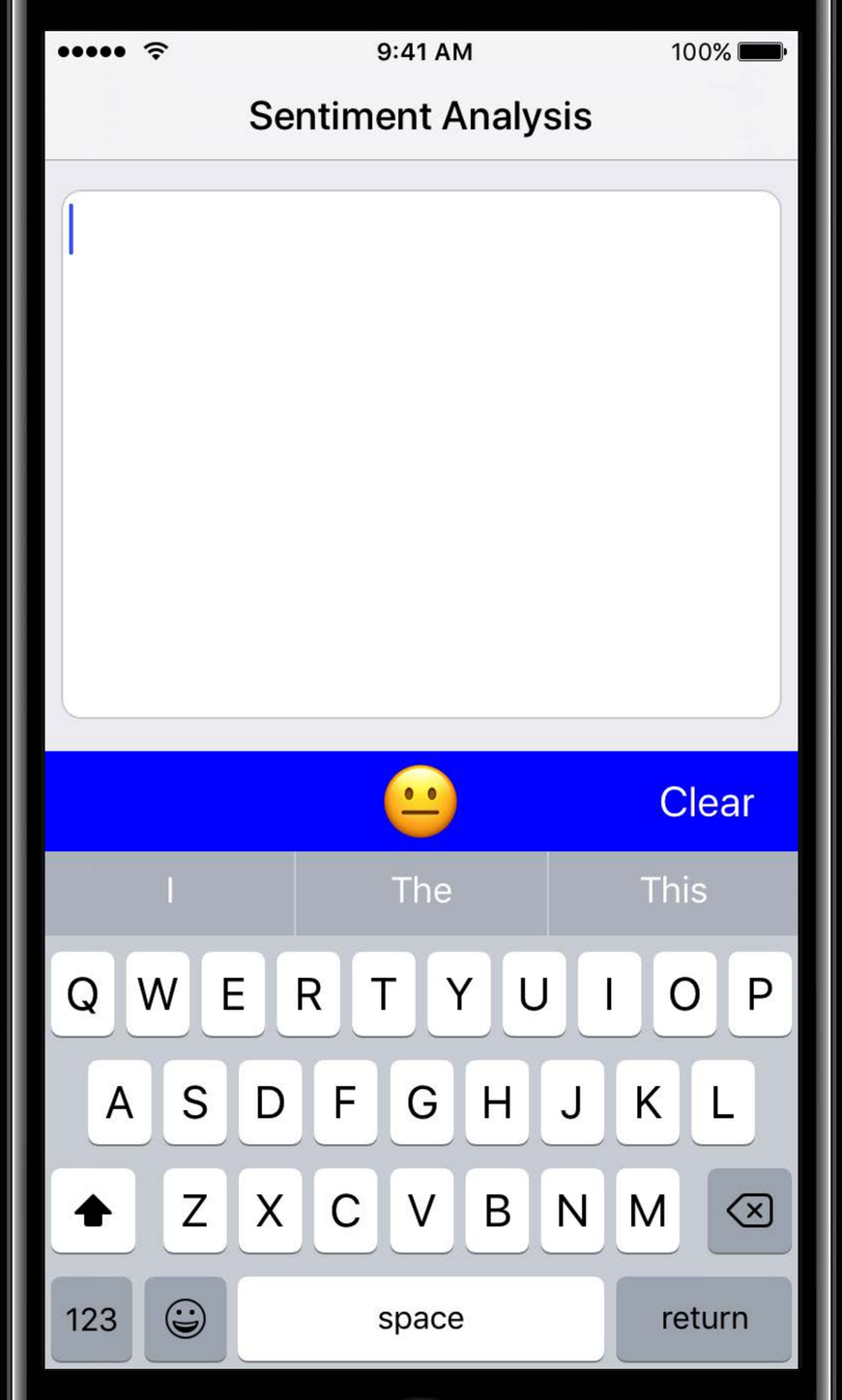
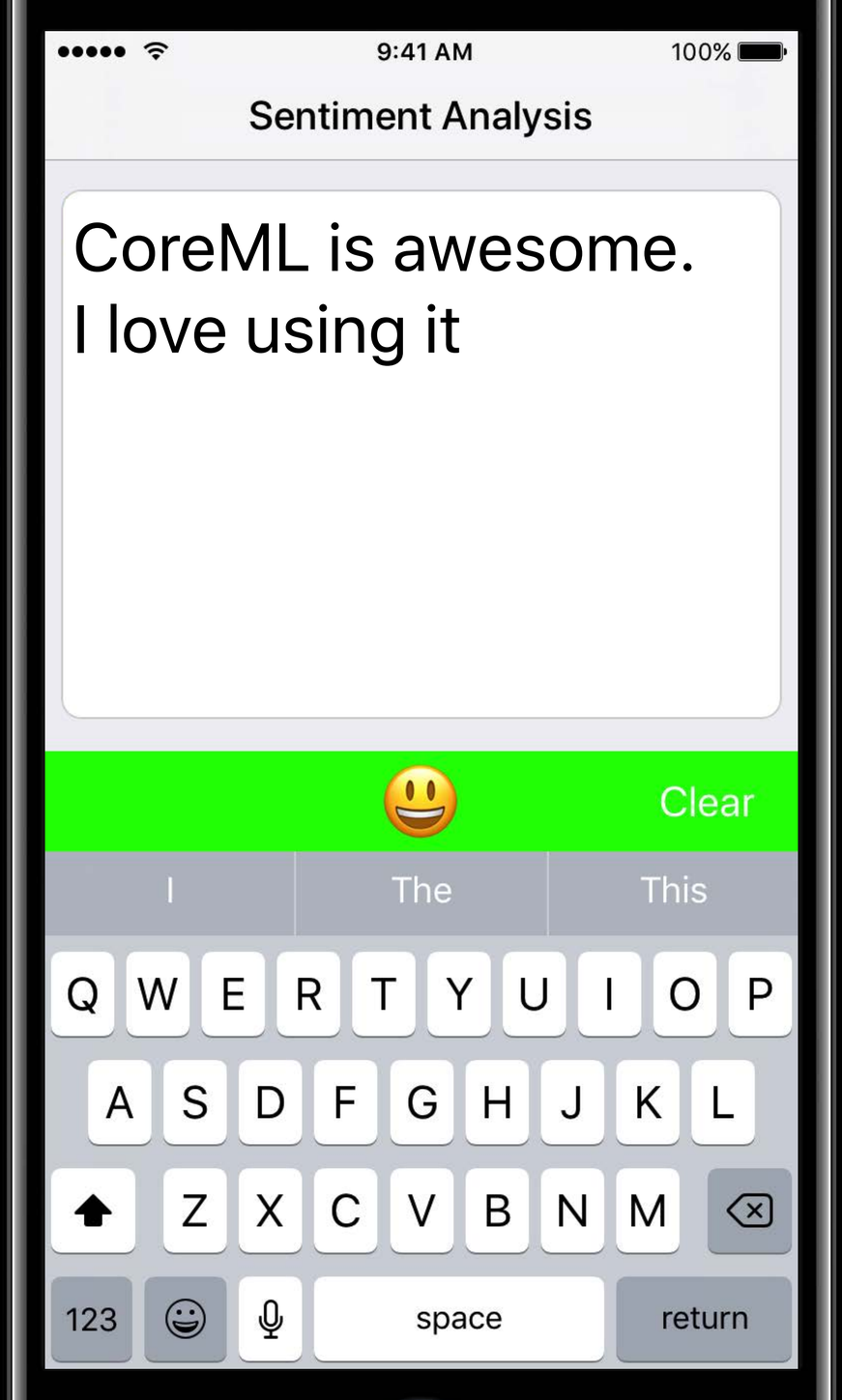


Working with Text


9:41 AM
100%
Sentiment Analysis
Clear
I
The
This
Q W E R T Y U I O P
A S D F G H J K L
Z X C V B N M
123
space
return


9:41 AM
100%
Sentiment Analysis
CoreML is awesome.
I love using it
Clear
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This
Q W E R T Y U I O P
A S D F G H J K L
Z X C V B N M
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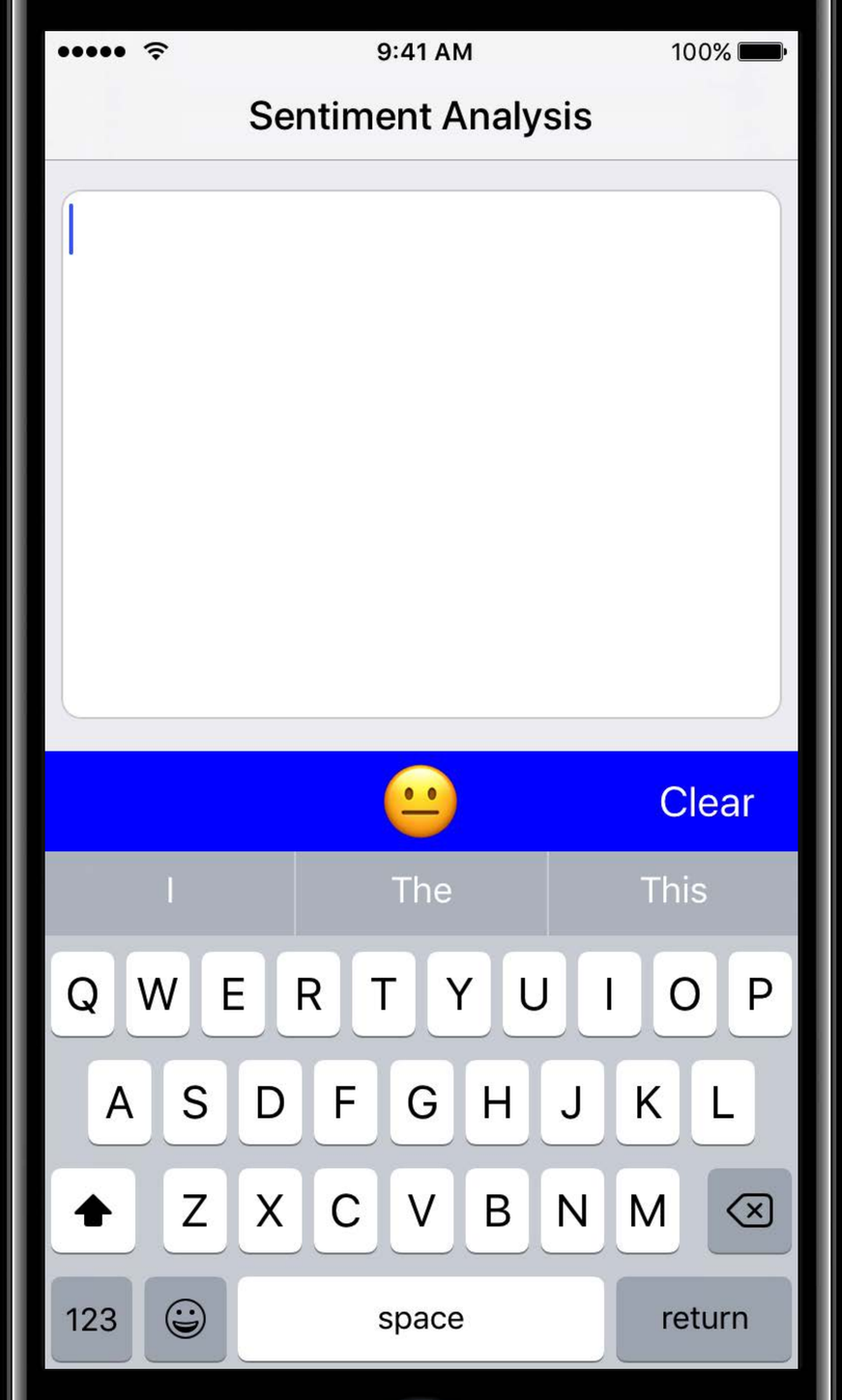
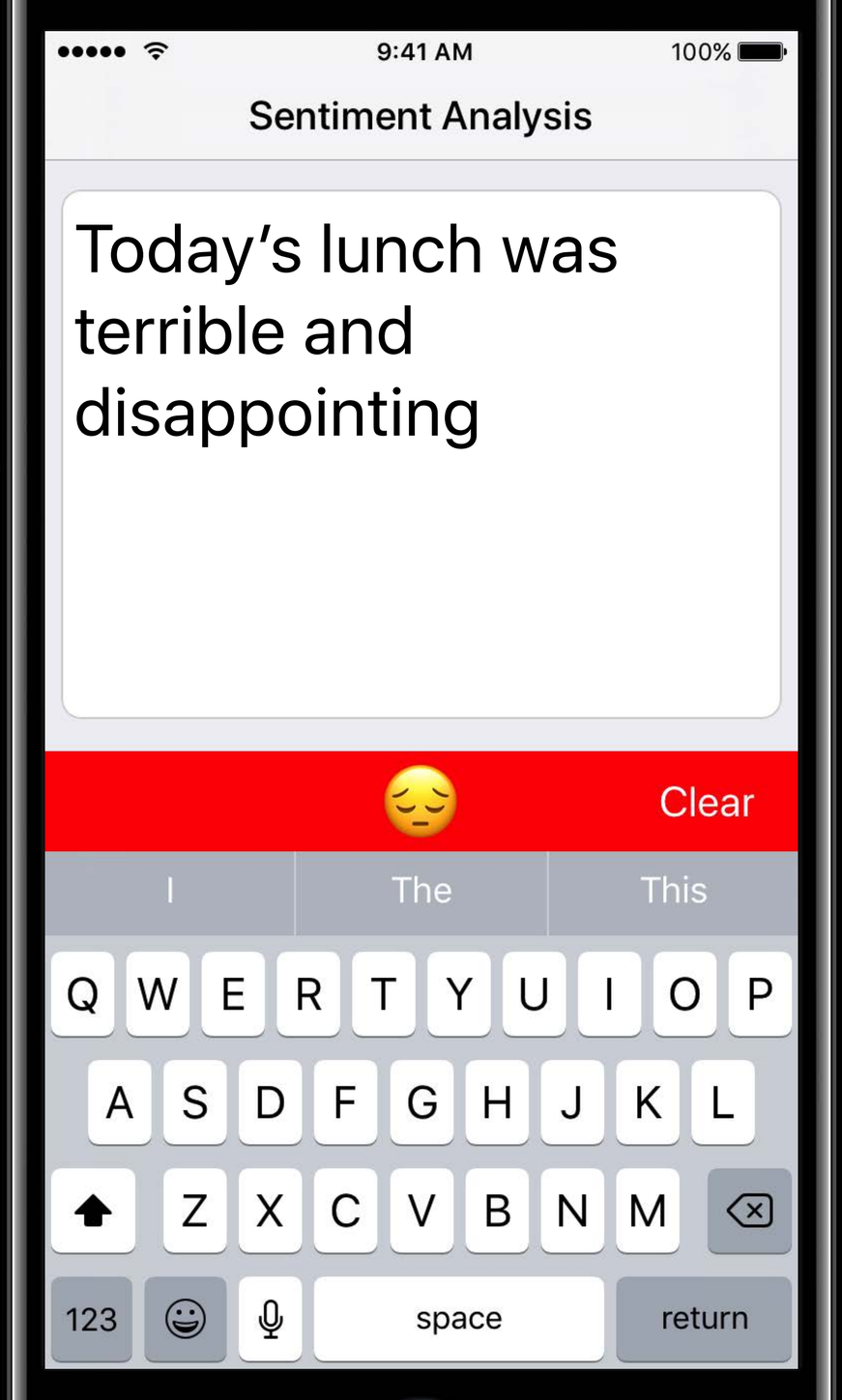
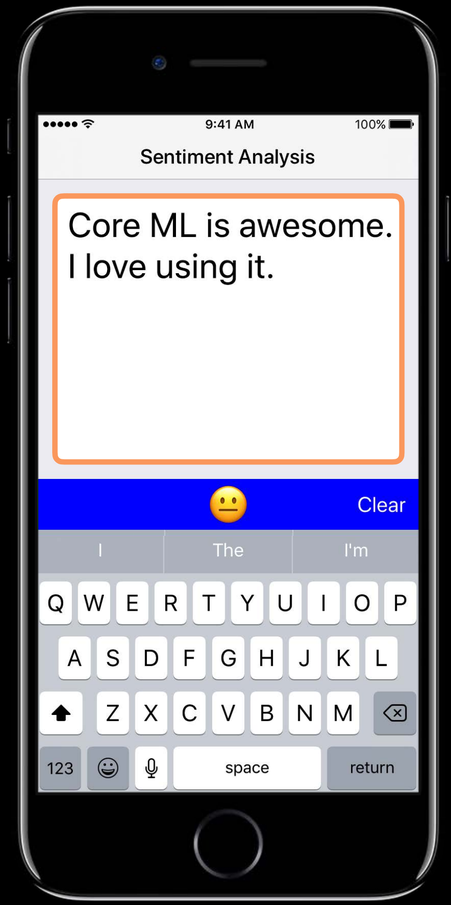
space
return


9:41 AM
100%
Sentiment Analysis
Clear
I
The
This
Q W E R T Y U I O P
A S D F G H J K L
Z X C V B N M
123
space
return

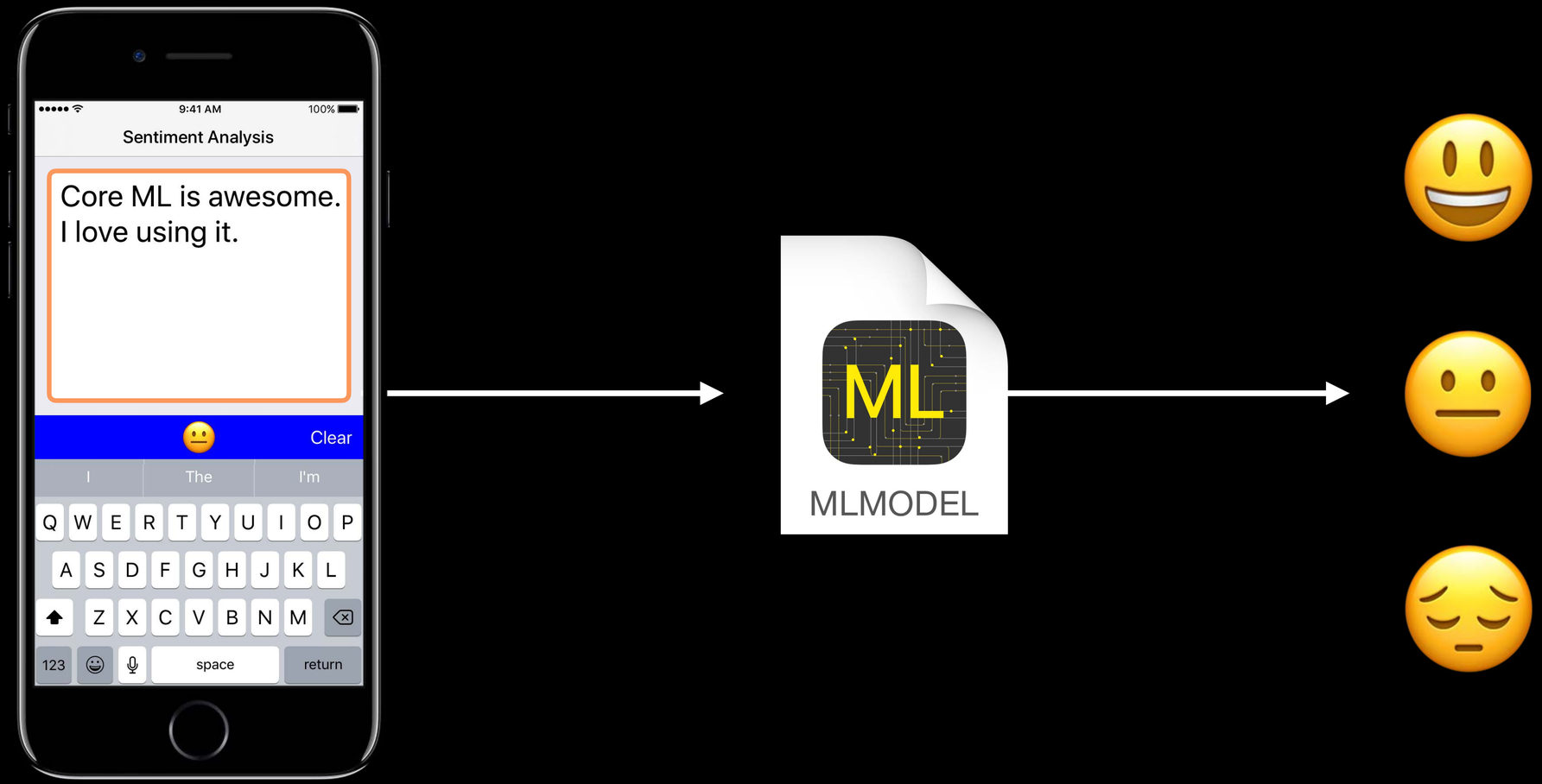

9:41 AM
100%
Sentiment Analysis
Today’s lunch was terrible and disappointing
Clear
I
The
This
Q W E R T Y U I O P
A S D F G H J K L
Z X C V B N M
123
space
return

Sentiment Analysis Application

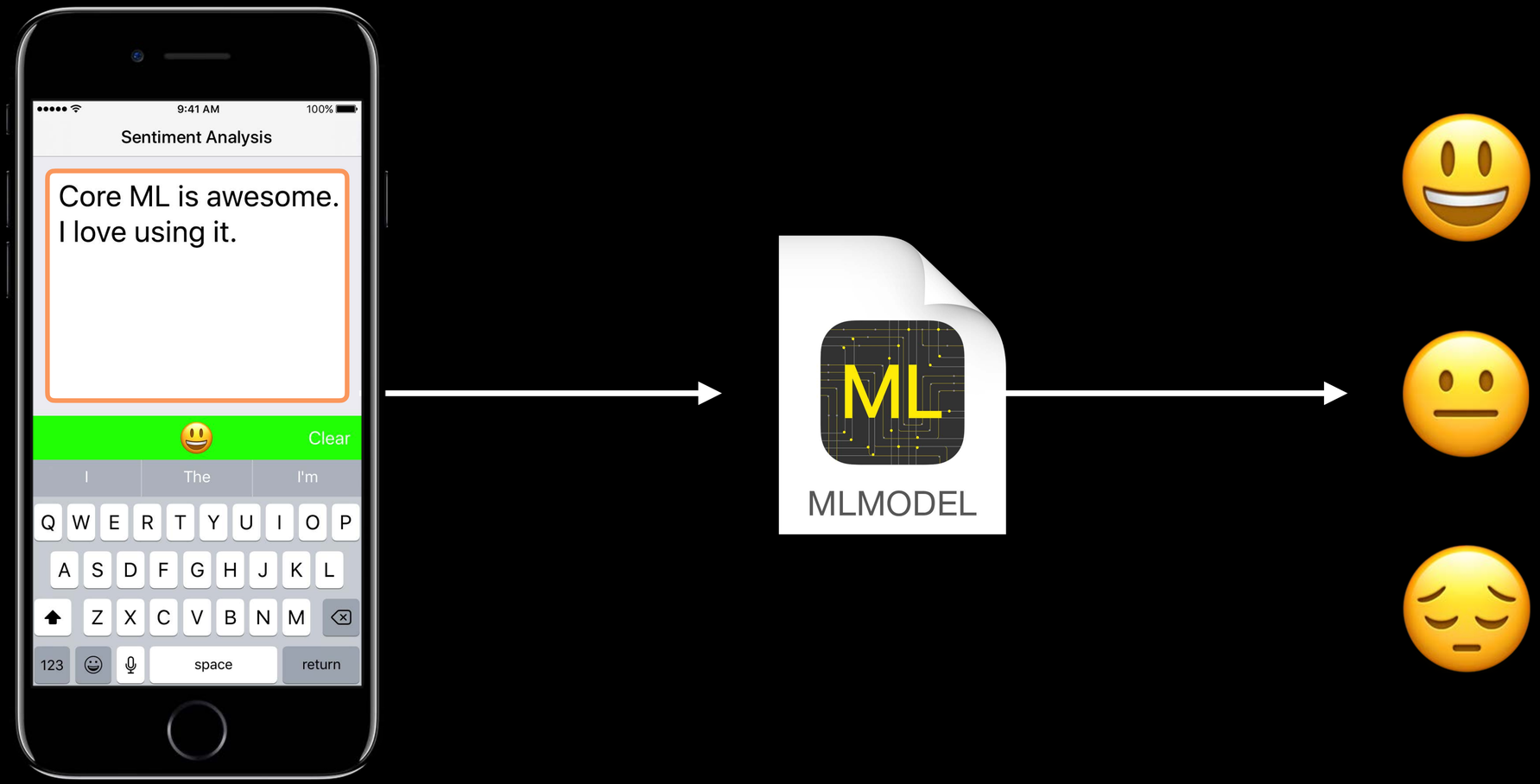


Sentiment Analysis Application

Sentiment Analysis Application



Sentiment Analysis Application



Using Other Formats

Word Counts

```
{
   "Core"    : 1,
   "ML"      : 1,
   "is"      : 1,
   "awesome" : 1,
   "I"       : 1,
   "love"    : 1,
   "using"   : 1,
   "it"      : 1,
}
```

Using Other Formats

Word Counts

```
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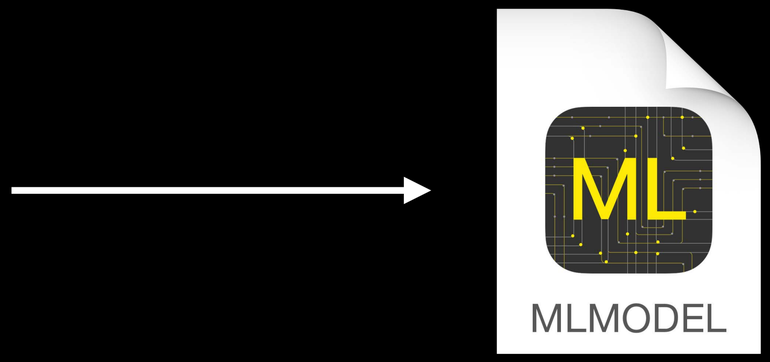
   "Core"    : 1,
   "ML"      : 1,
   "is"      : 1,
   "awesome" : 1,
   "I"       : 1,
   "love"    : 1,
   "using"   : 1,
   "it"      : 1,
}
```



Using Other Formats

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   "awesome" : 1,
   "I"       : 1,
   "love"    : 1,
   "using"   : 1,
   "it"      : 1,
}
```
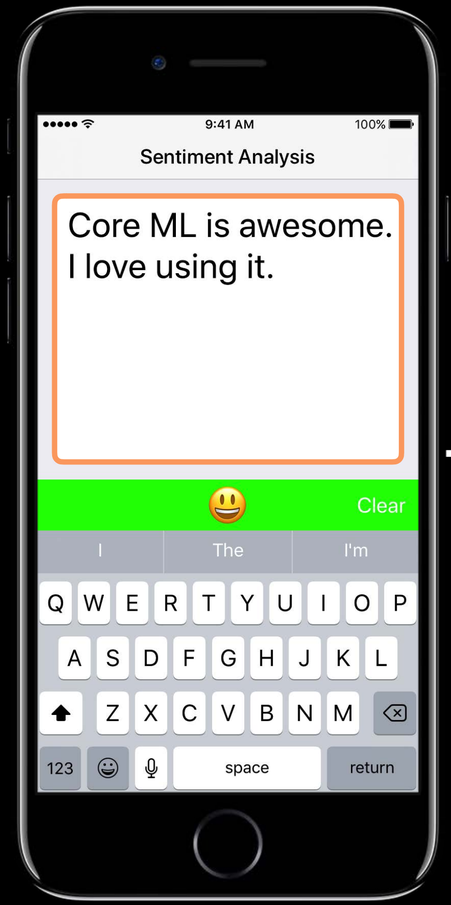
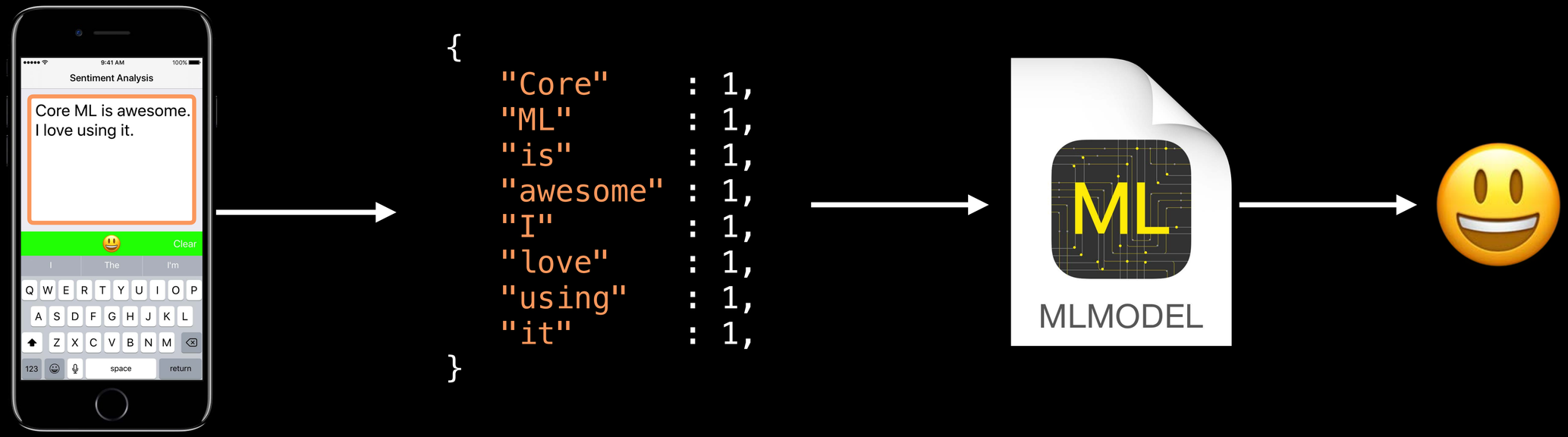

Use NLP to Process Text



Word Counts

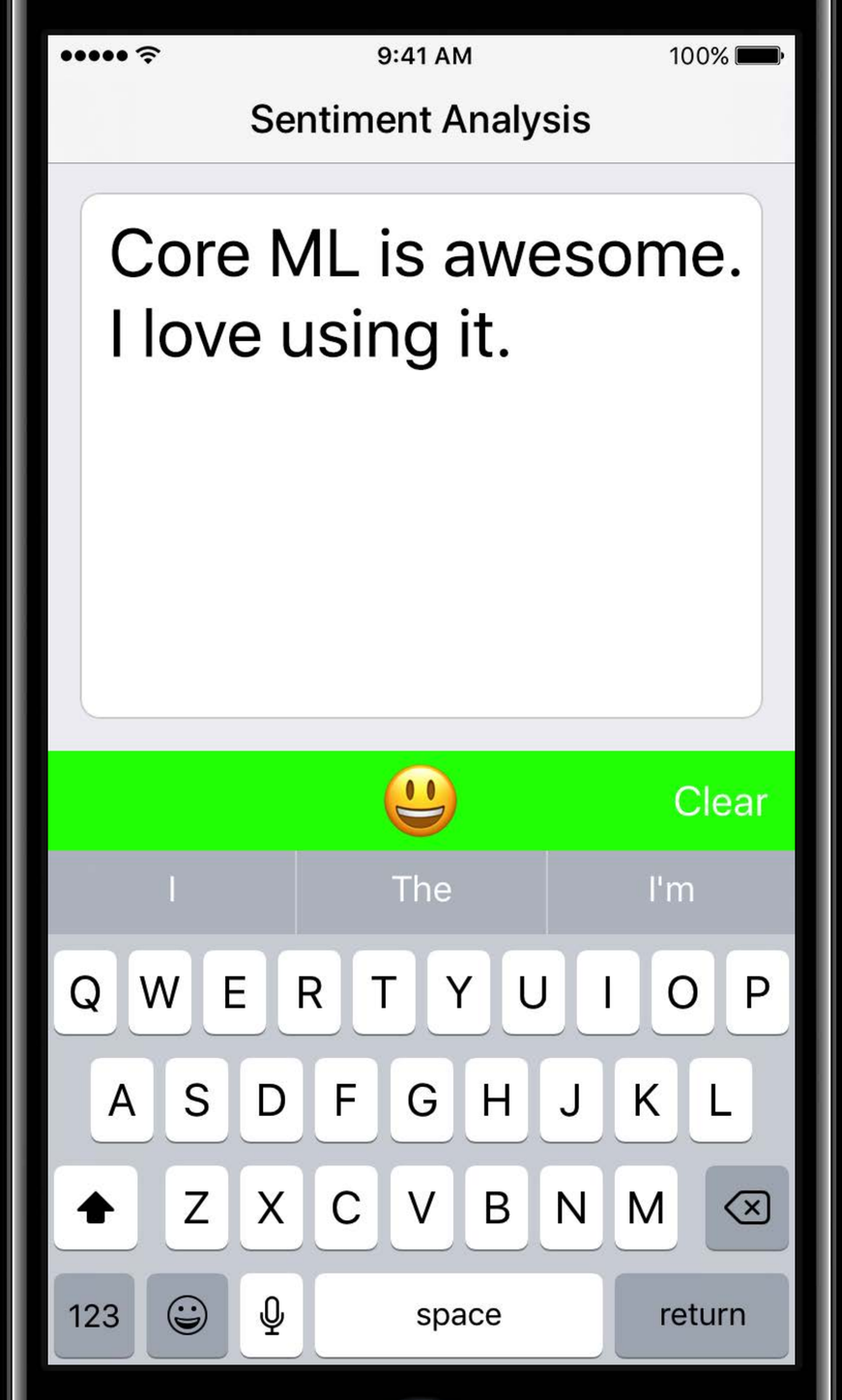
```
{
   "Core"    : 1,
   "ML"      : 1,
   "is"      : 1,
   "awesome" : 1,
   "I"       : 1,
   "love"    : 1,
   "using"   : 1,
   "it"      : 1,
}
```

Sentiment Analysis Application

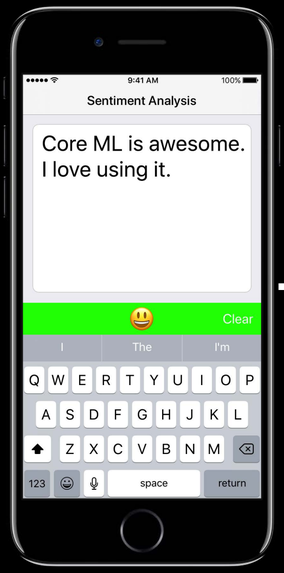


Use NLP (NSLinguisticTagger)

Use Core ML


9:41 AM
100%
Sentiment Analysis
Core ML is awesome.
I love using it.
Clear
I
The
I'm
Q W E R T Y U I O P
A S D F G H J K L
Z X C V B N M
123
space
return

Processing Text




```
{
    "Core"    : 1,
    "ML"      : 1,
    "is"      : 1,
    "awesome" : 1,
    "I"       : 1,
    "love"    : 1,
    "using"   : 1,
    "it"      : 1,
}
```

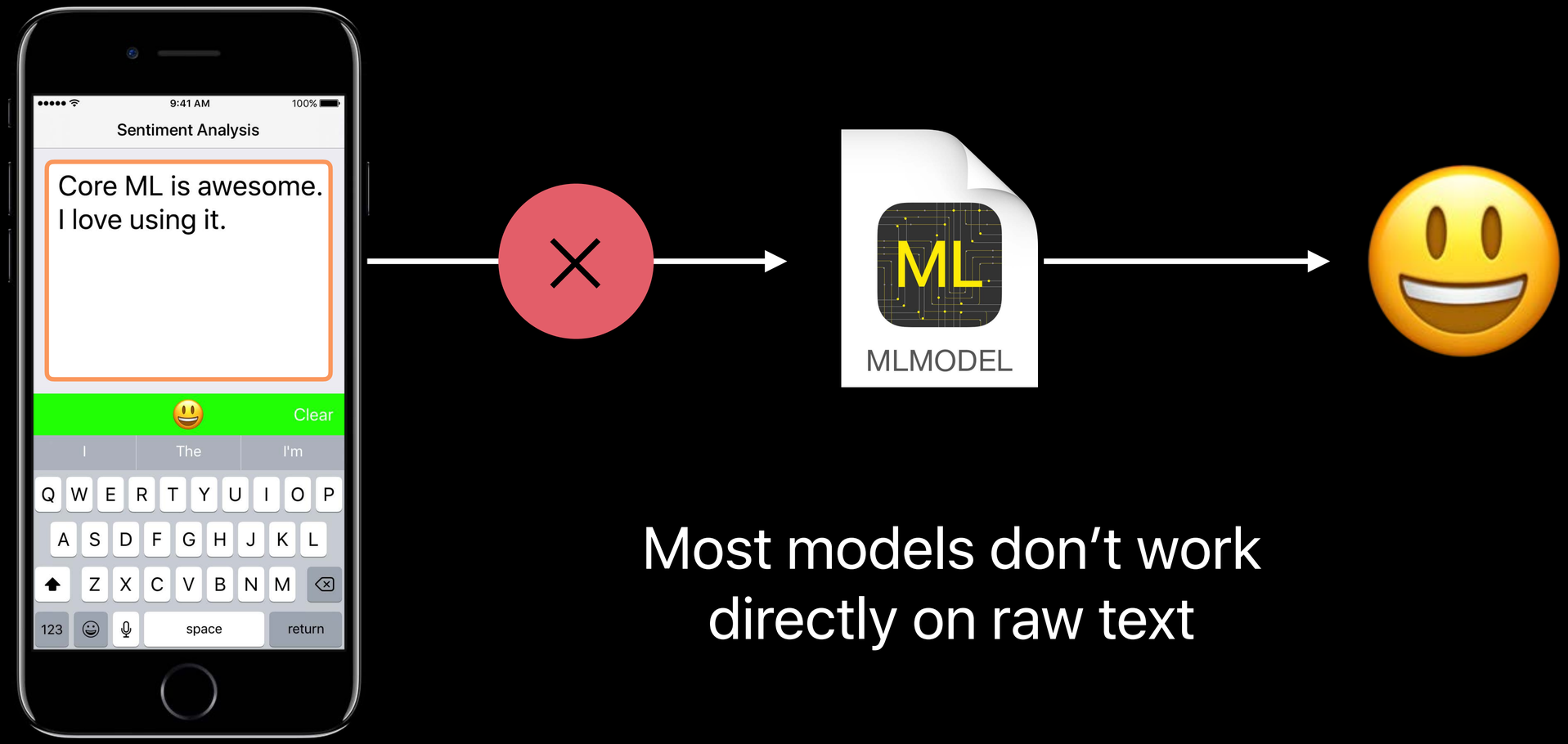
```
func tokenizeAndCountWords(rawTxt: String) -> [String : Double] {
    // Tokenize using NSLinguisticTagger
    ...

    // Count occurrences of each token
}
```

Making Predictions

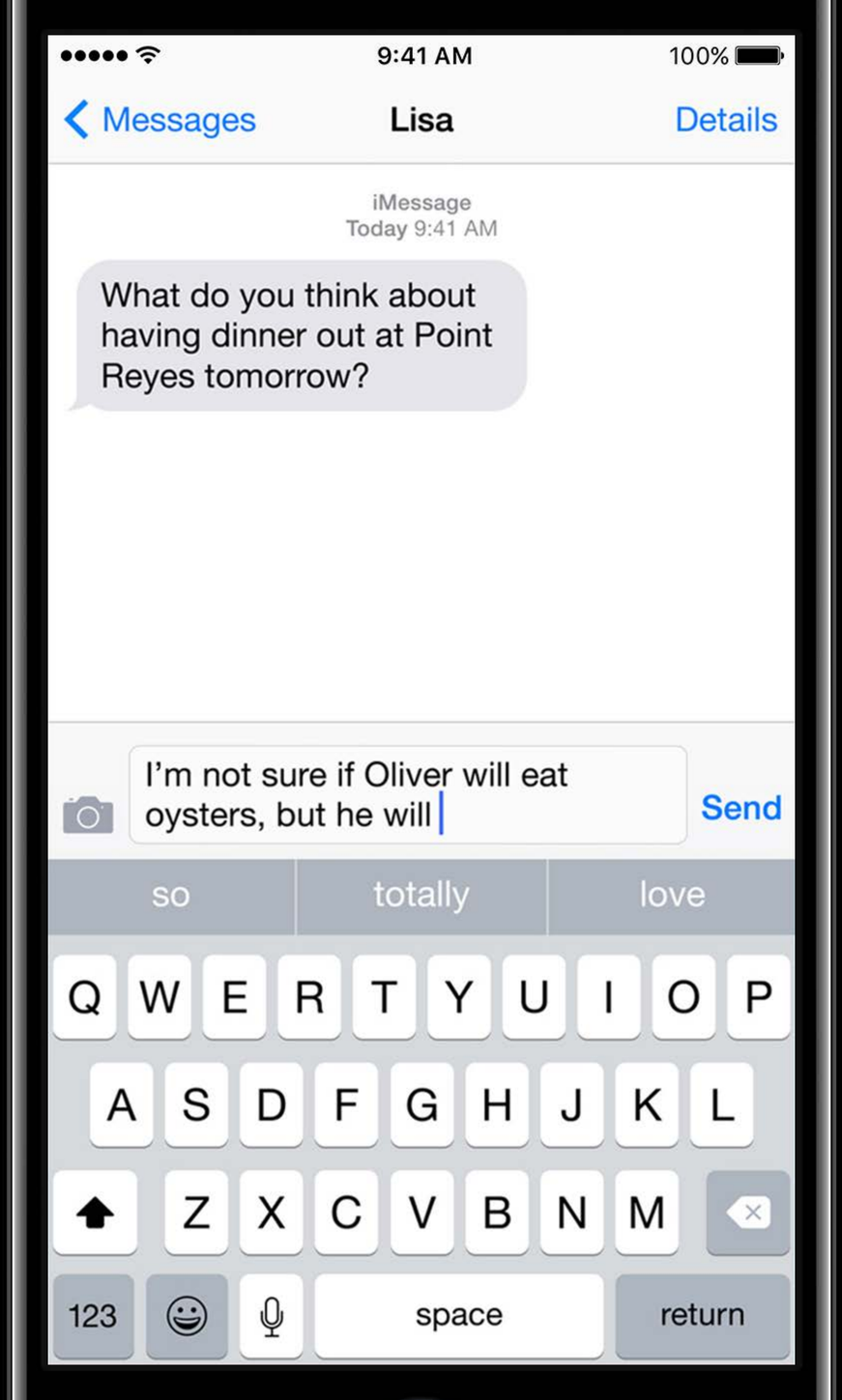
```
{
    "Core"    : 1,
    "ML"      : 1,
    "is"      : 1,
    "awesome" : 1,
    "I"       : 1,
    "love"    : 1,
    "using"   : 1,
    "it"      : 1,
}
```


```
let model = SentimentAnalysis()

if let prediction = try? model.prediction(wordCounts: counts) {
    print("Sentiment: \(prediction.sentiment)")
}
```

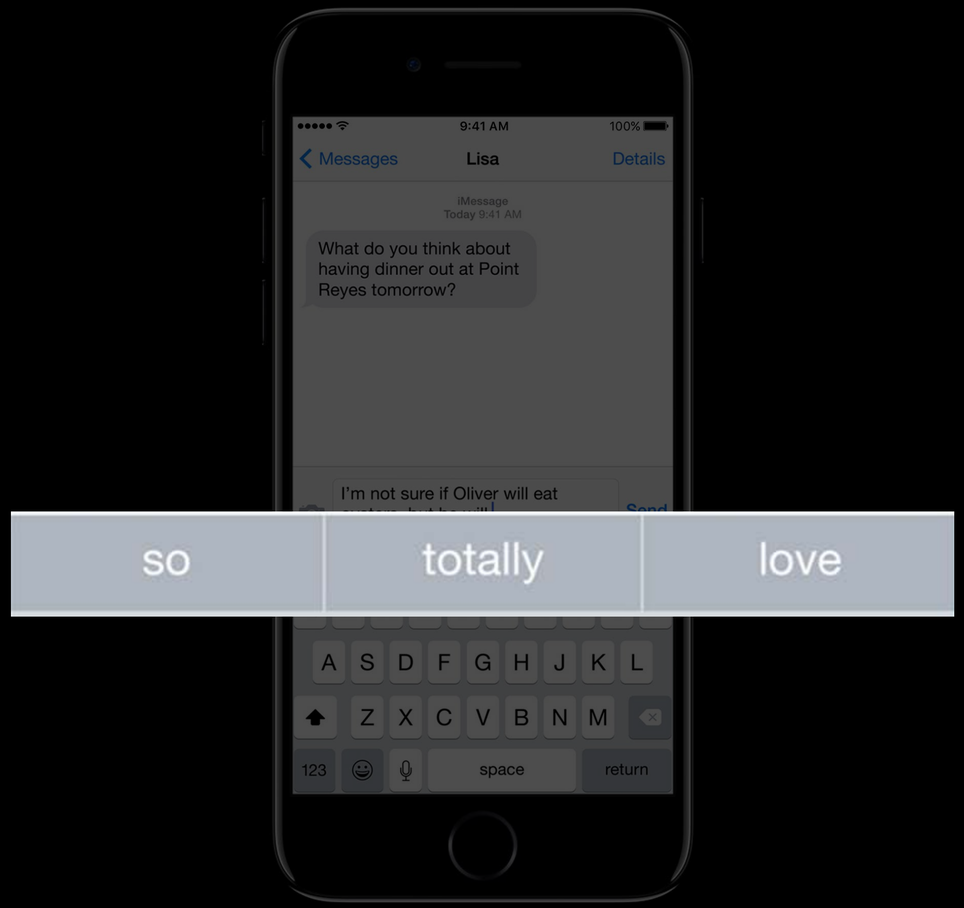
Text Gotchas



Most models don’t work directly on raw text


9:41 AM
100%
Messages
Lisa
Details
iMessage
Today 9:41 AM
What do you think about having dinner out at Point Reyes tomorrow?
I'm not sure if Oliver will eat oysters, but he will
Send
so
totally
love
Q W E R T Y U I O P
A S D F G H J K L
Z X C V B N M
123
space
return

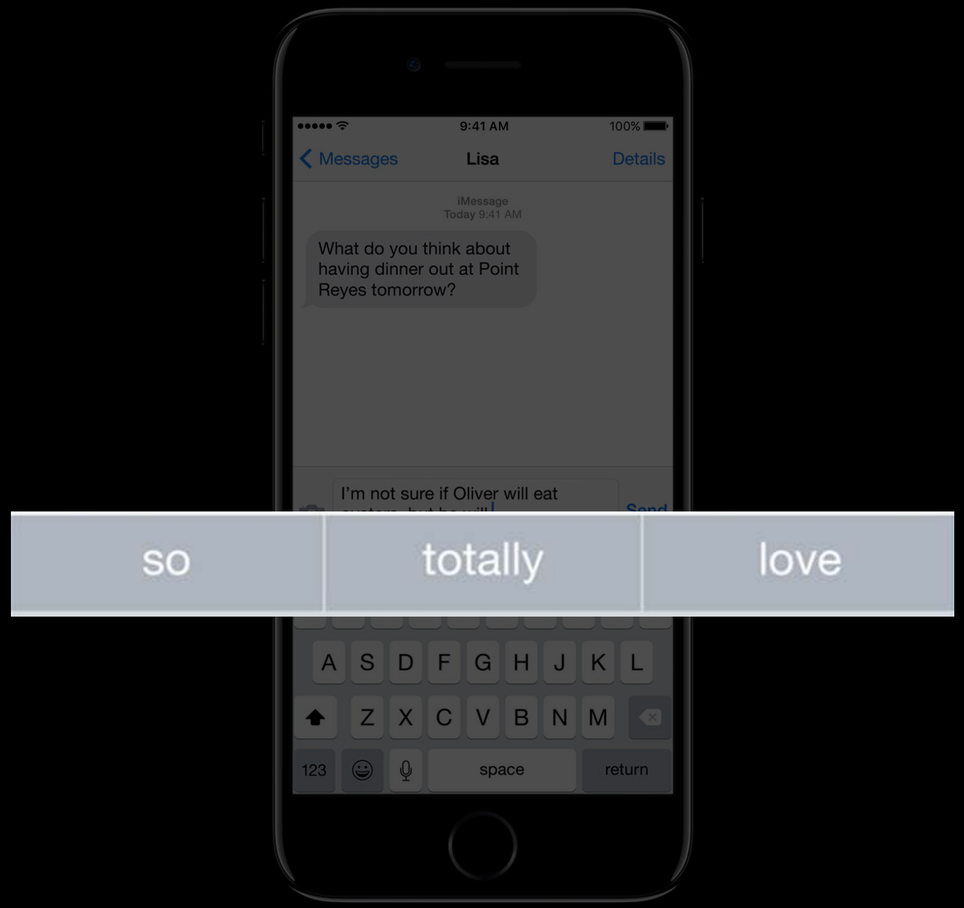
Predictive Keyboard



I'm not sure Oliver will eat oysters, but he will

Love

Predictive Keyboard



I'm not sure Oliver will eat oysters, but he will

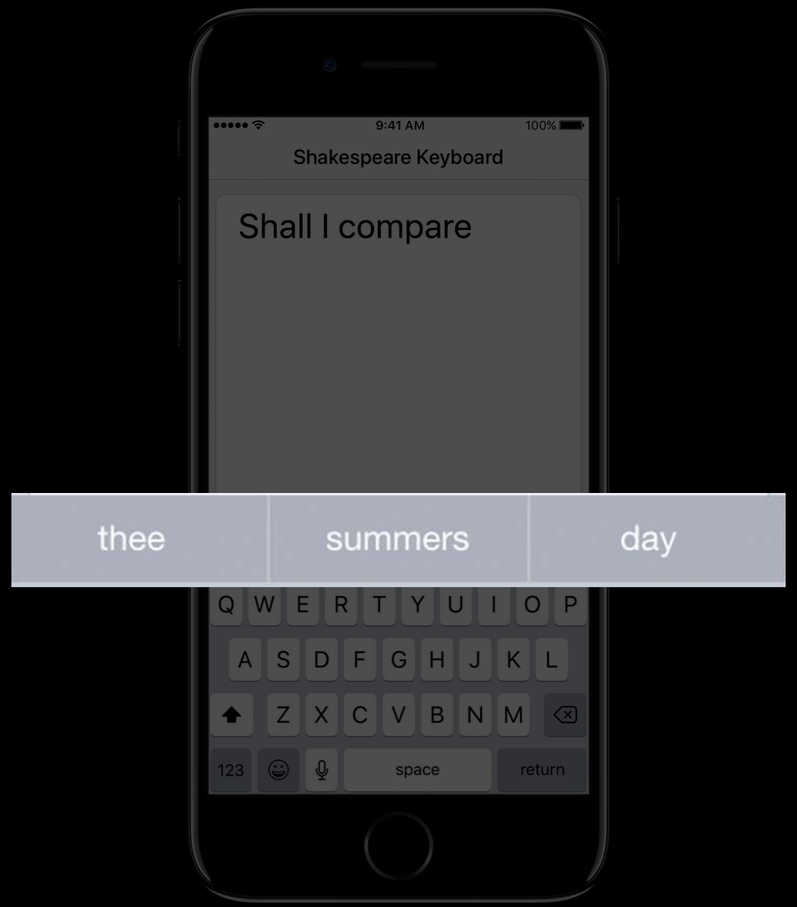
Love

Task - Next word prediction

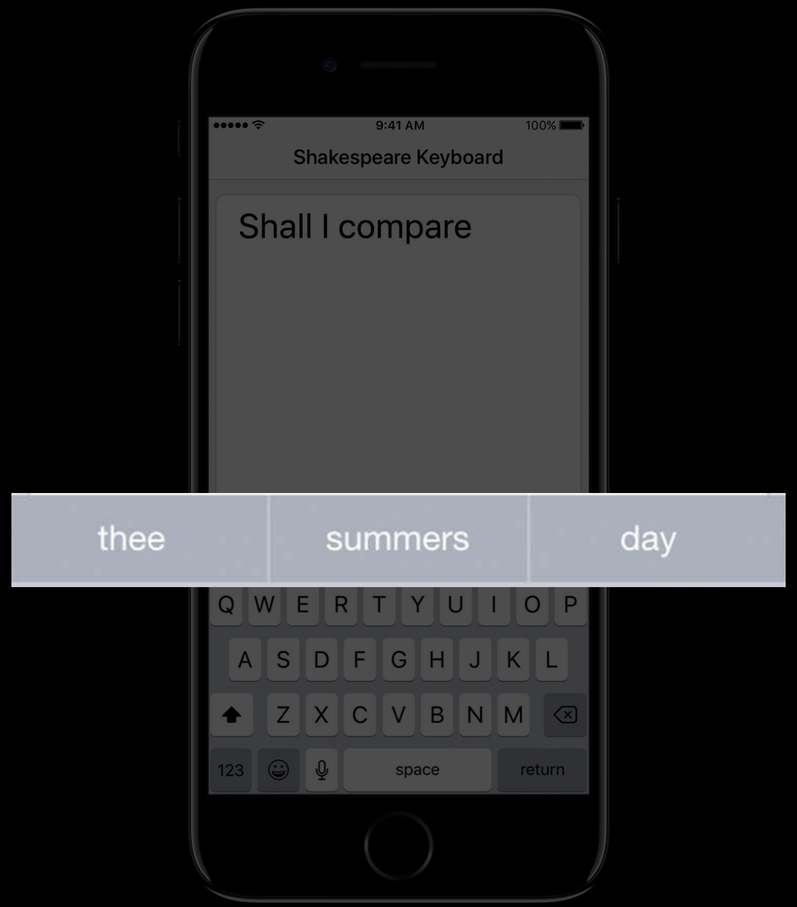

9:41 AM
100%
Shakespeare Keyboard
Shall I compare
thee
summers
day
Q W E R T Y U I O P
A S D F G H J K L
Z X C V B N M
123
space
return

Language Models

Shakespeare Keyboard

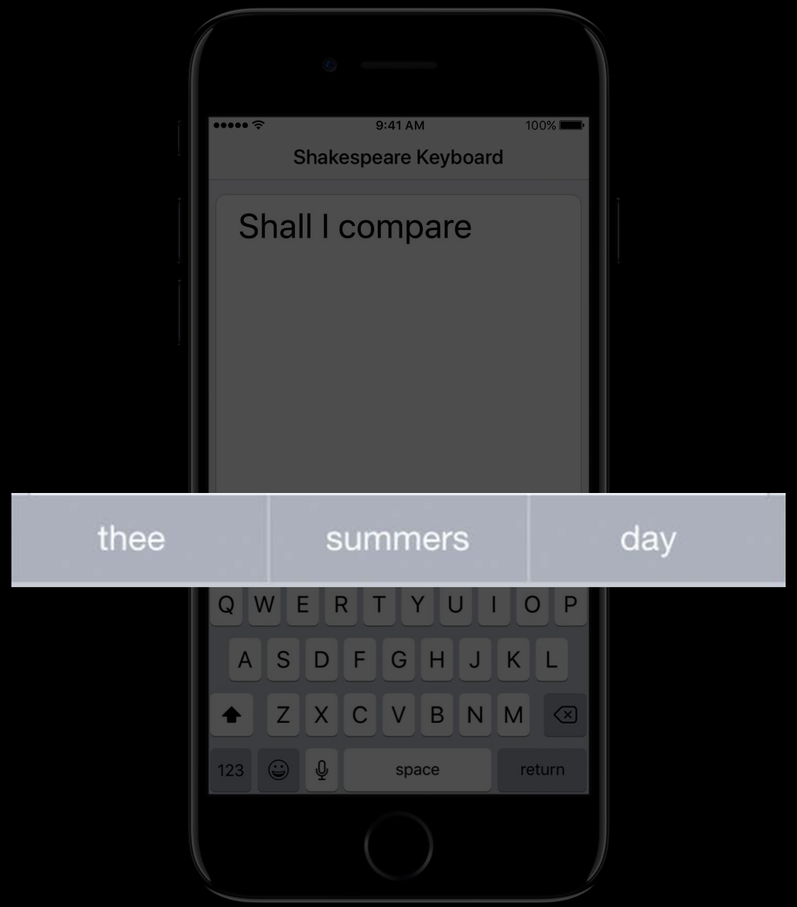


Shakespeare Keyboard

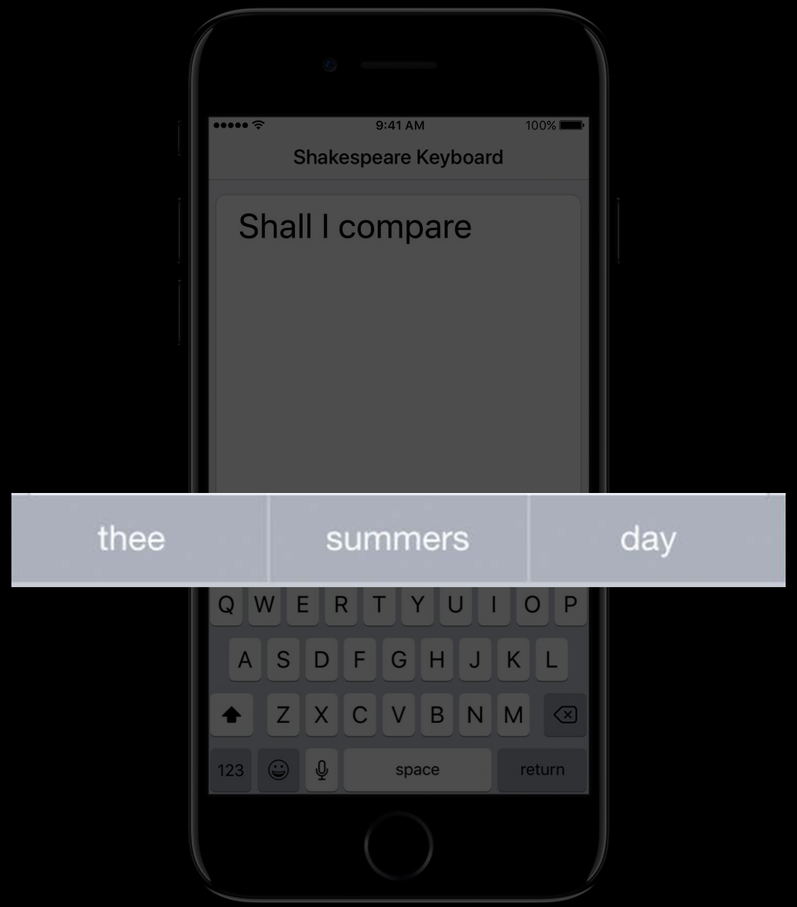


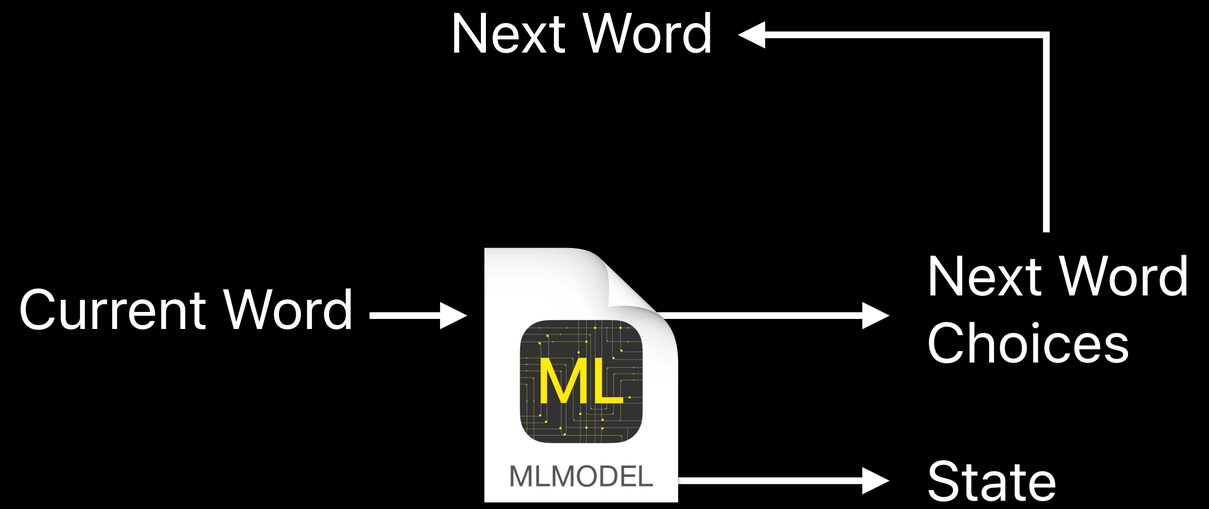
Current Word →

Shakespeare Keyboard

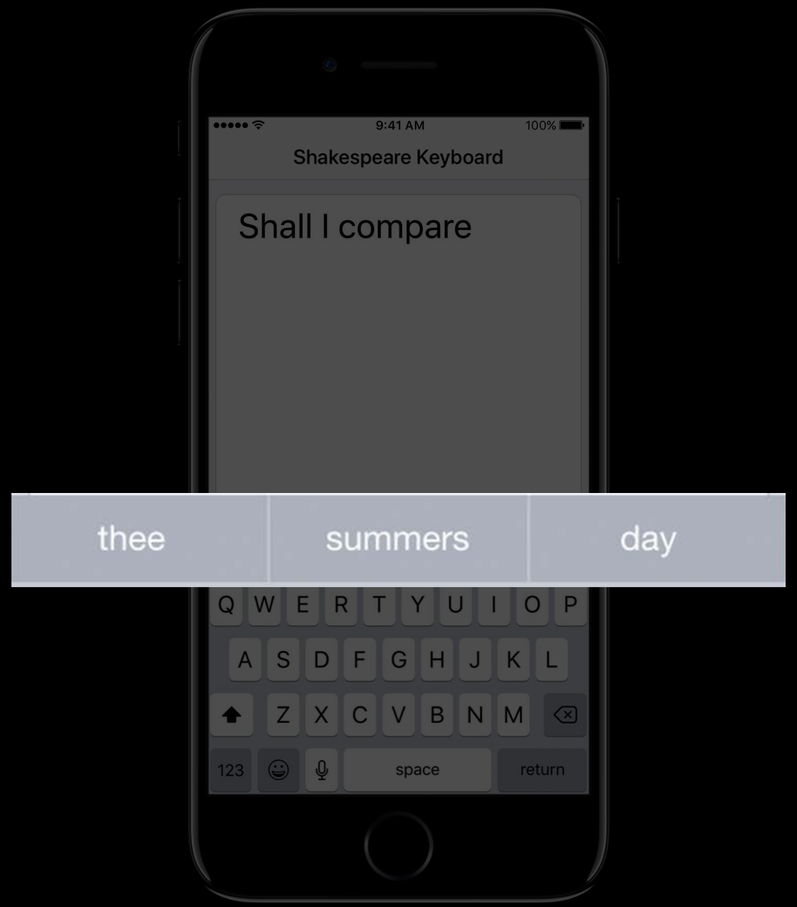


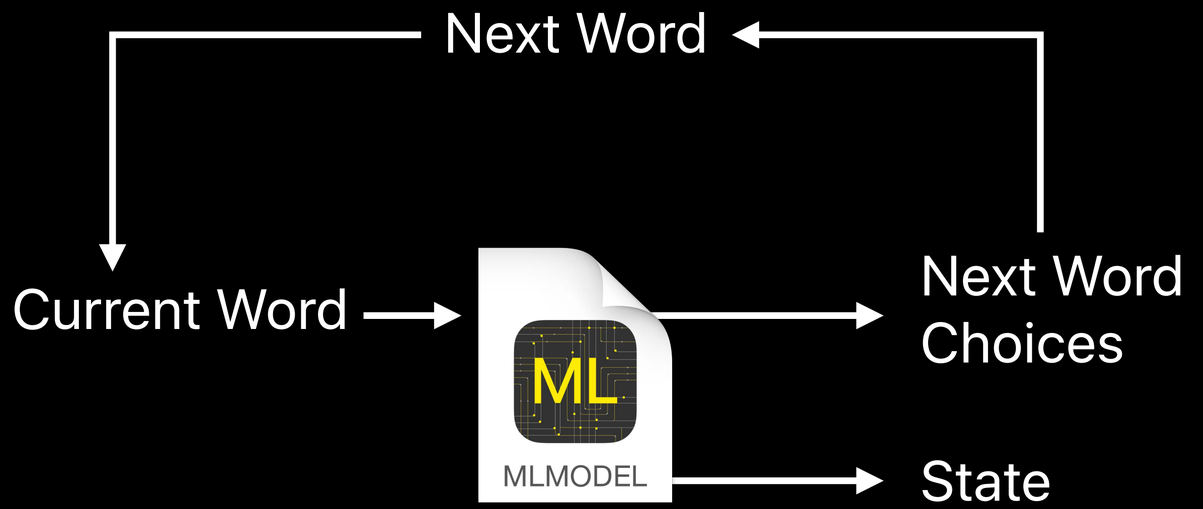
Shakespeare Keyboard



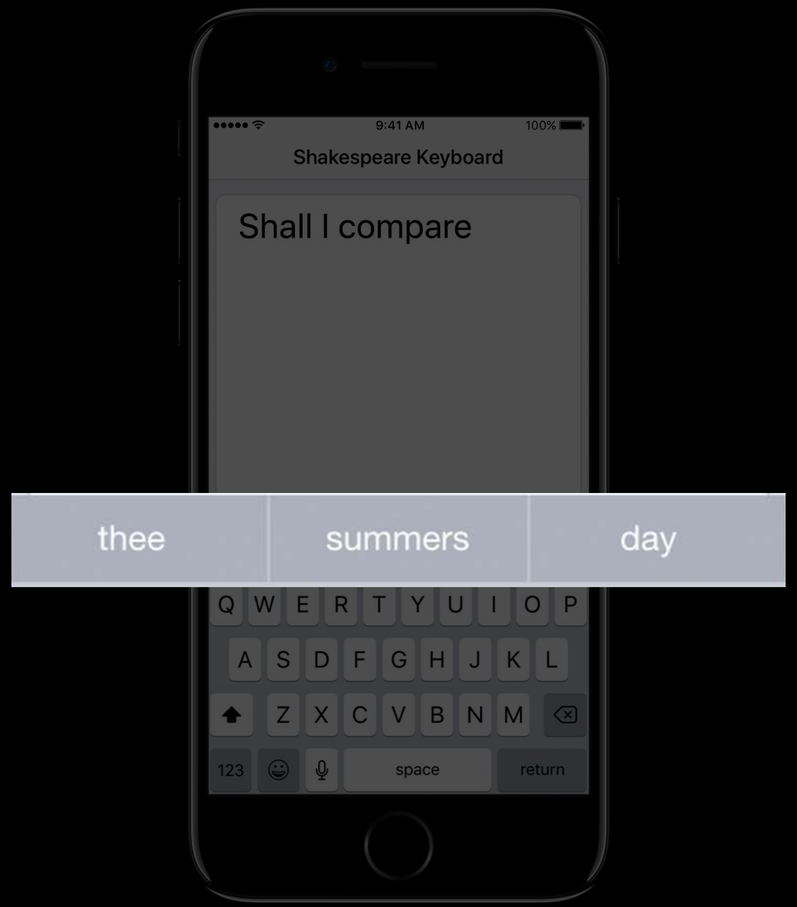


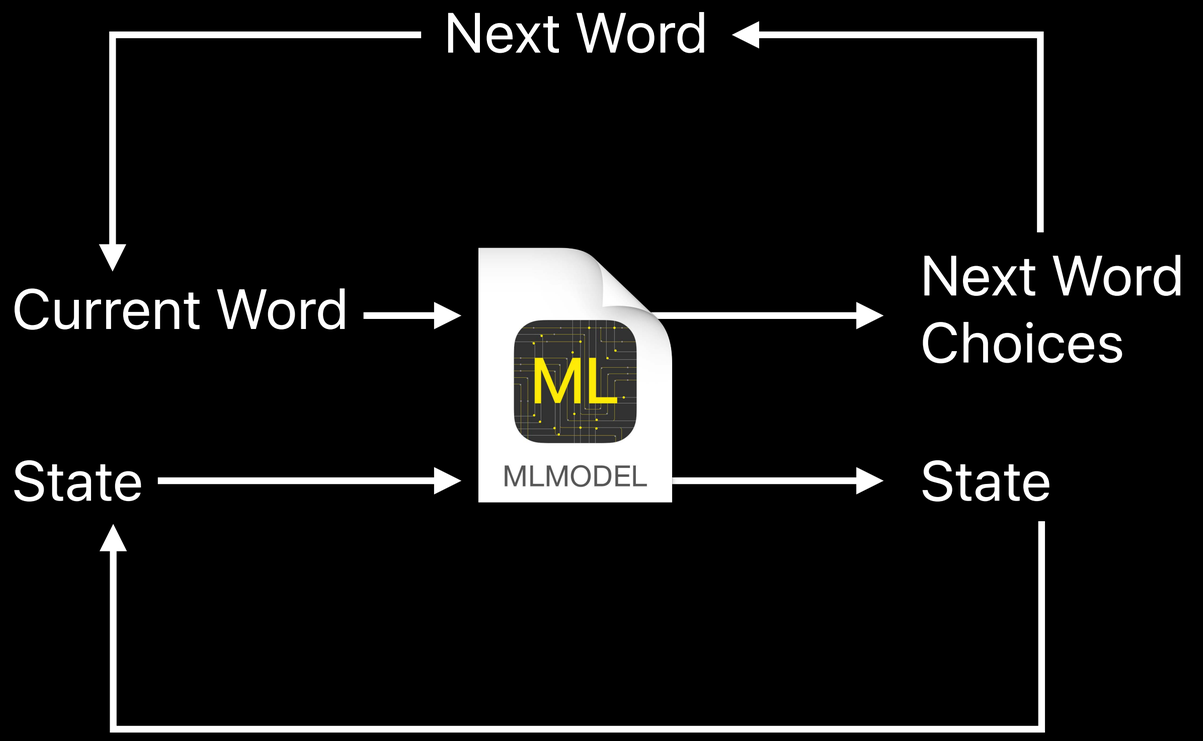
Shakespeare Keyboard



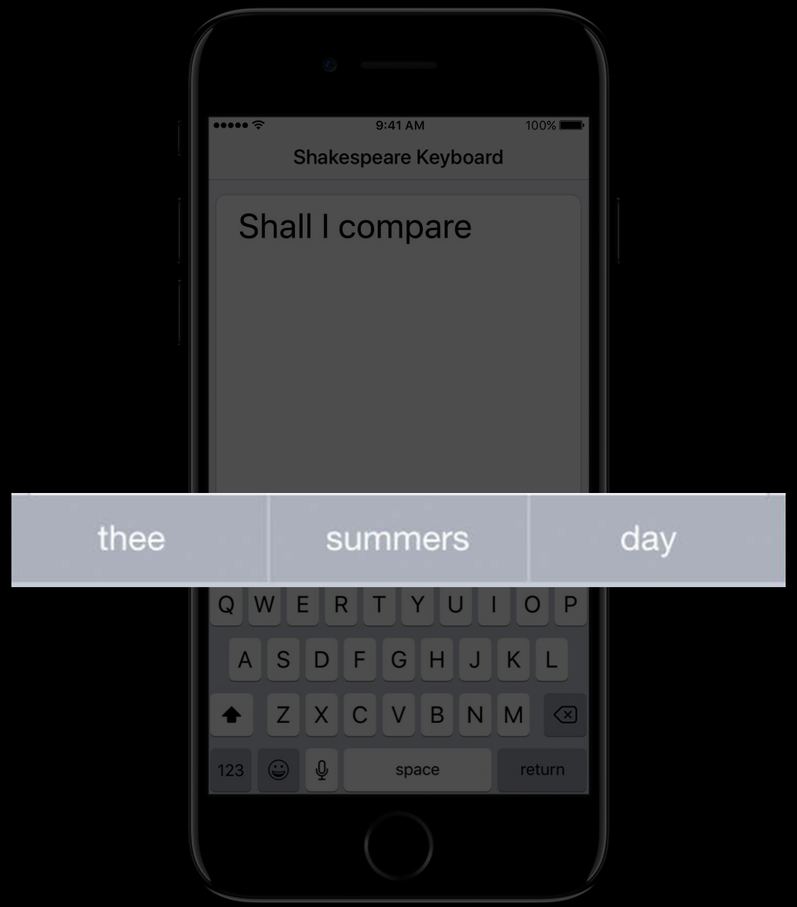


Shakespeare Keyboard



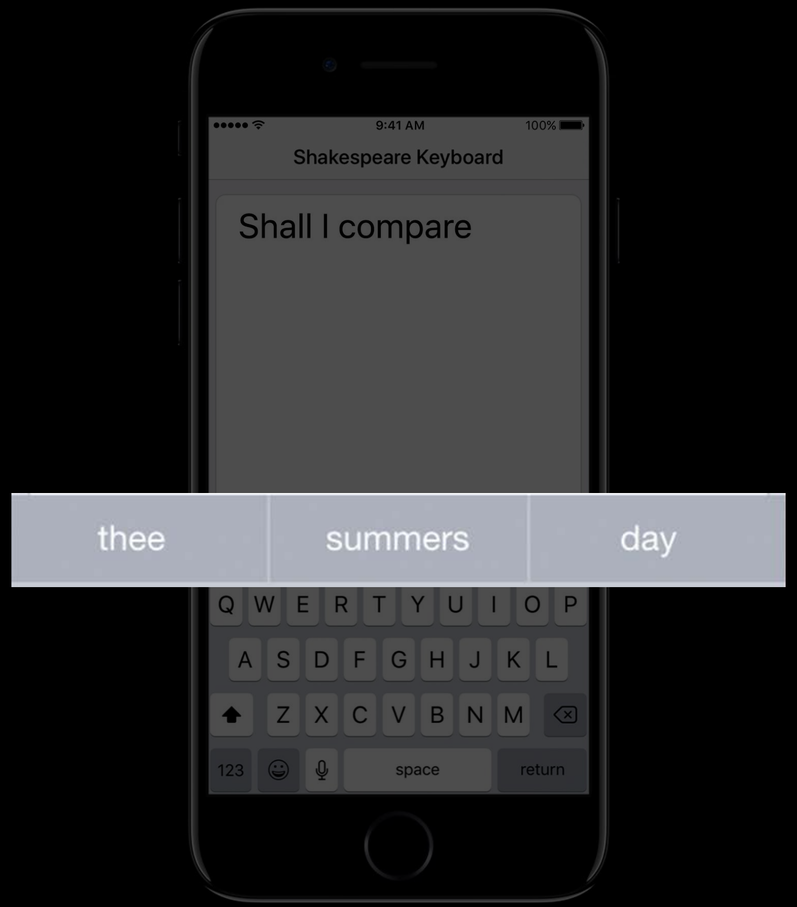


Sample Code




```
if let output = try? model.prediction(input: input) {

    // Send the best 3 words to the user
    displayTopPredictions(output.nextWordProb)

}

// Update state for next prediction
input.state = output.state
input.currentWord = getNextWordFromUser()
```

Sample Code

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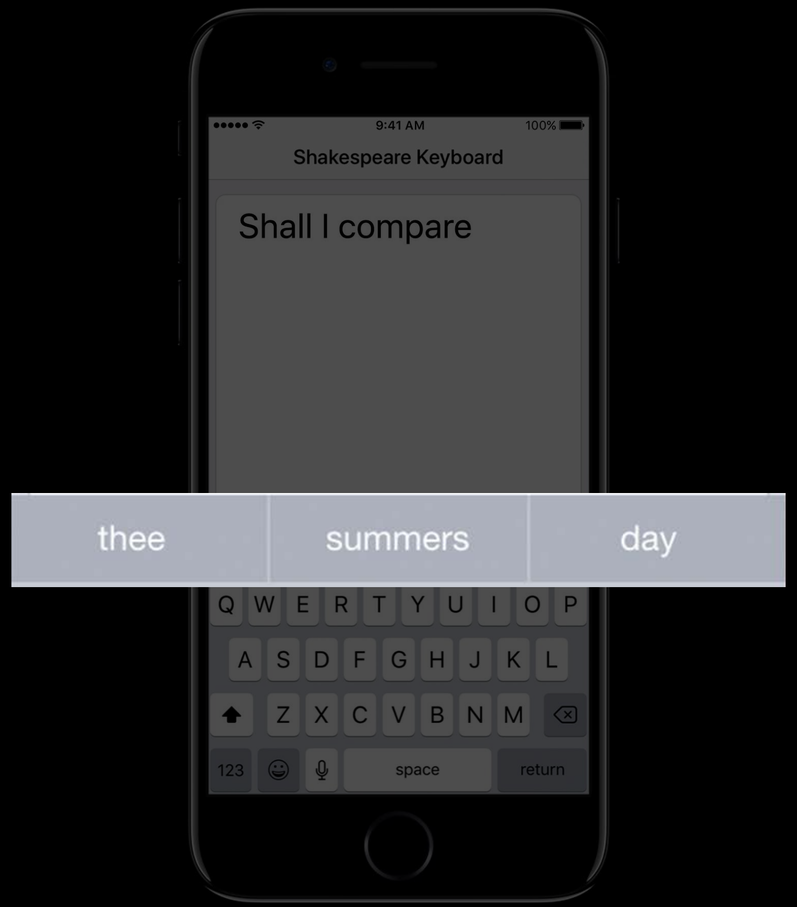


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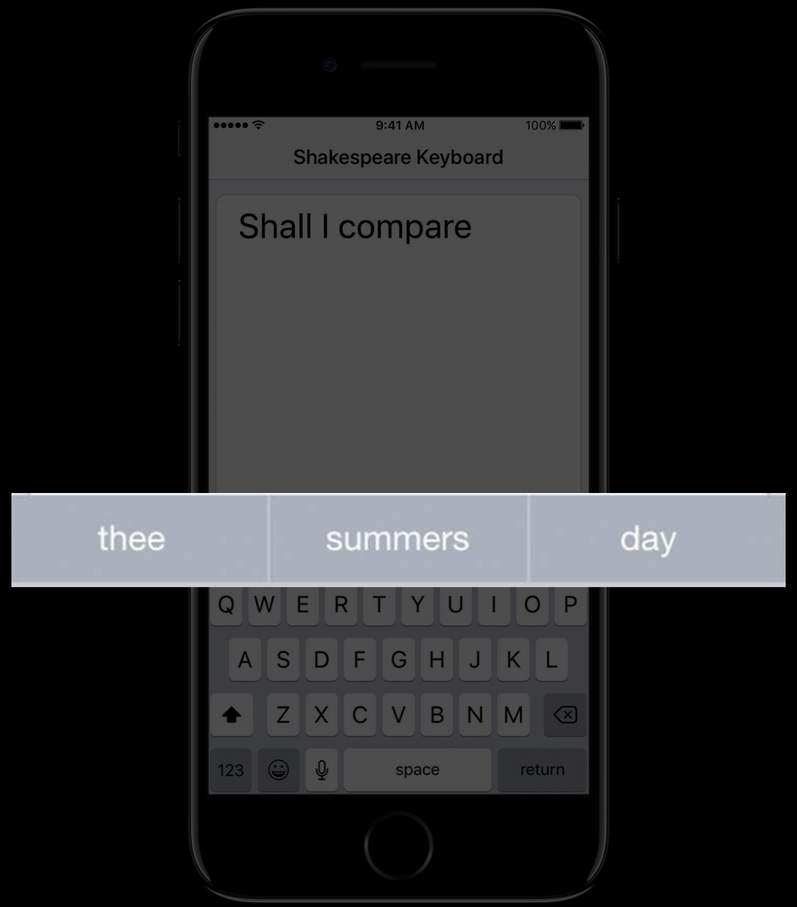


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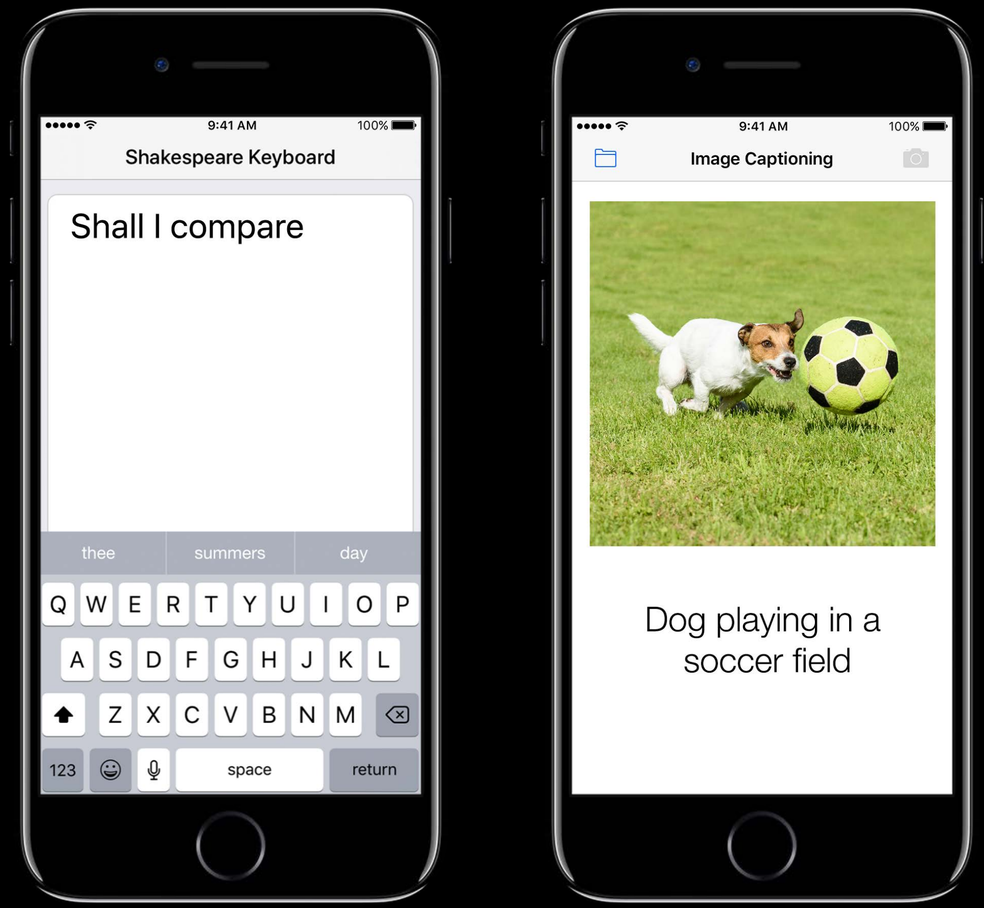
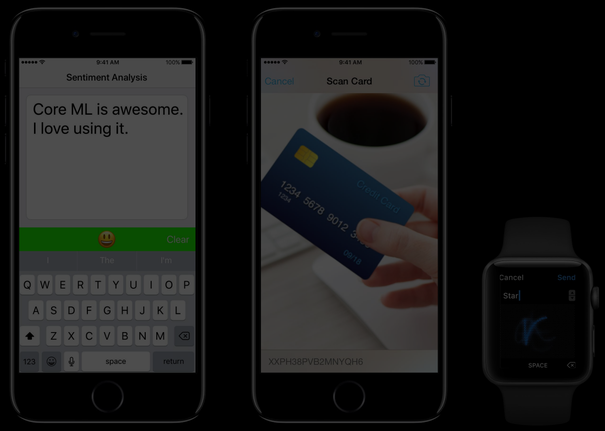
Come to the Labs



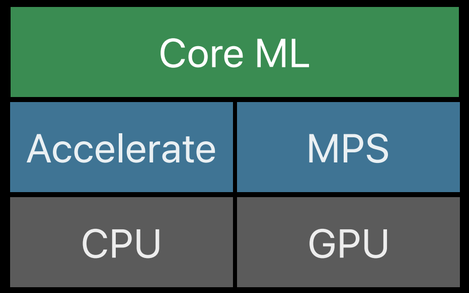
Thursday	11:00–3:30
Friday	1:30–4:00

This Session

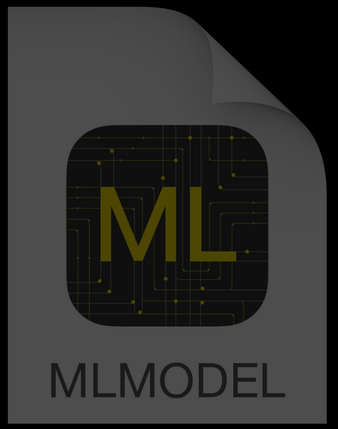
Use Cases



Hardware Optimized



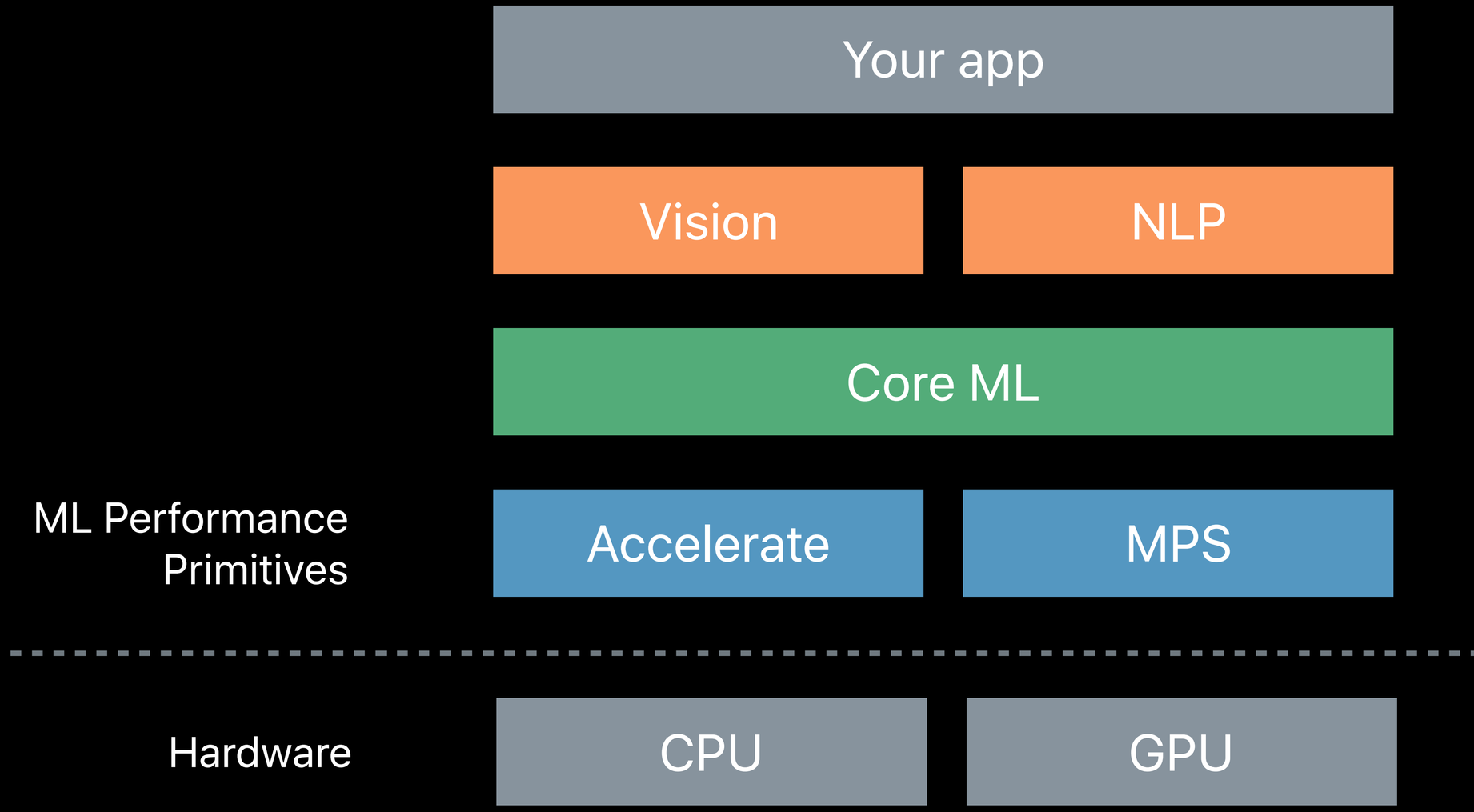
Obtaining Models



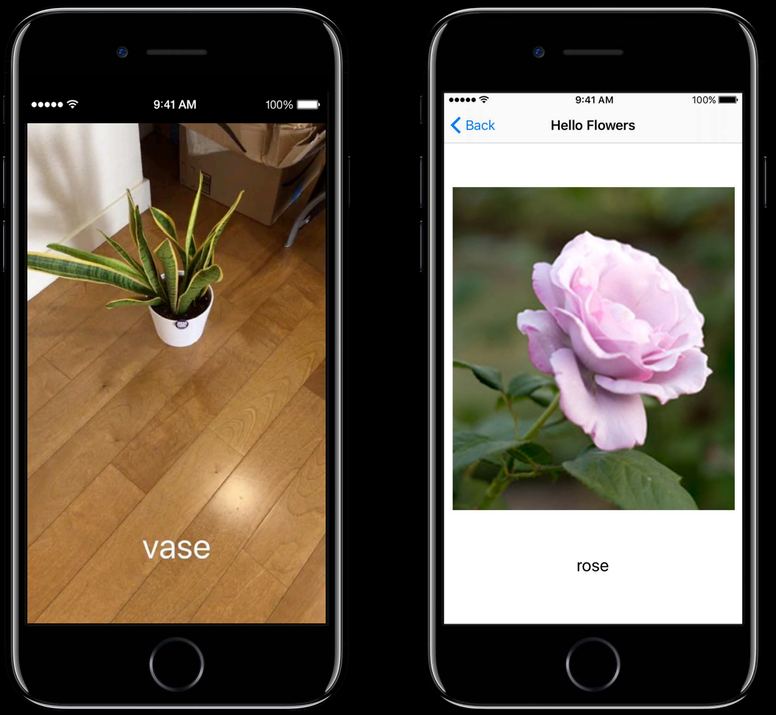

9:41 AM
100%
dining table
35.8 %


9:41 AM
100%
dining table
35.8 %

Built on Performance Primitives



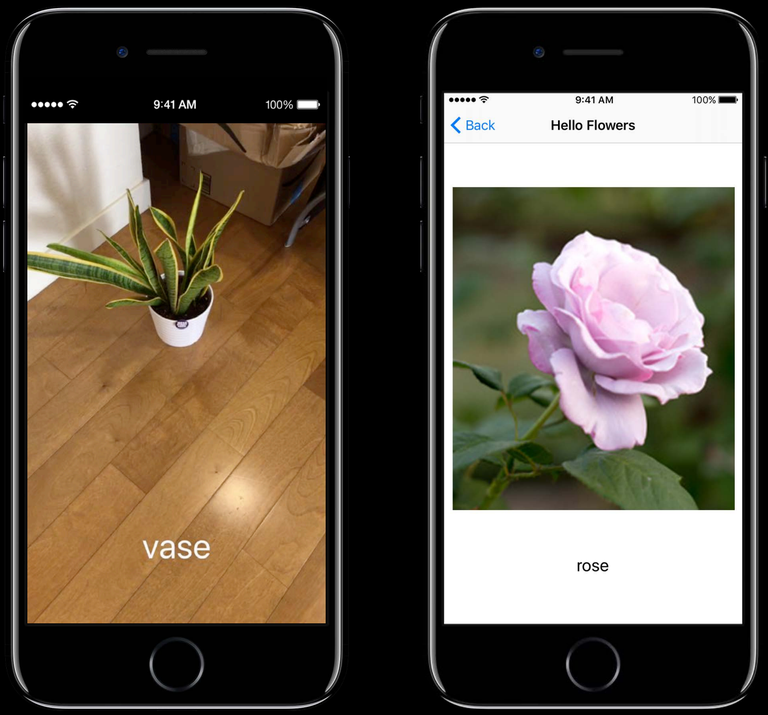
Optimized for Hardware



Runs on GPU

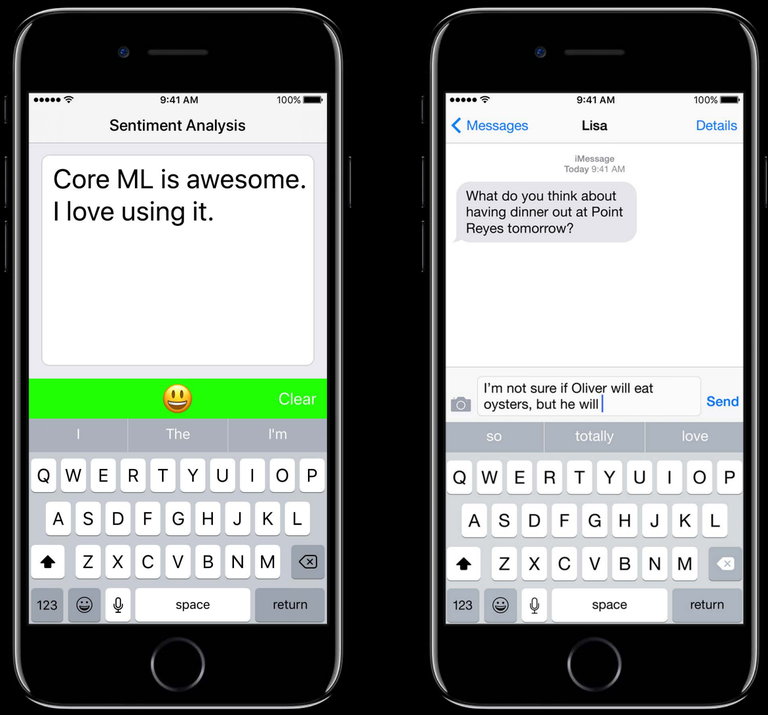
MPS

Optimized for Hardware



Runs on GPU

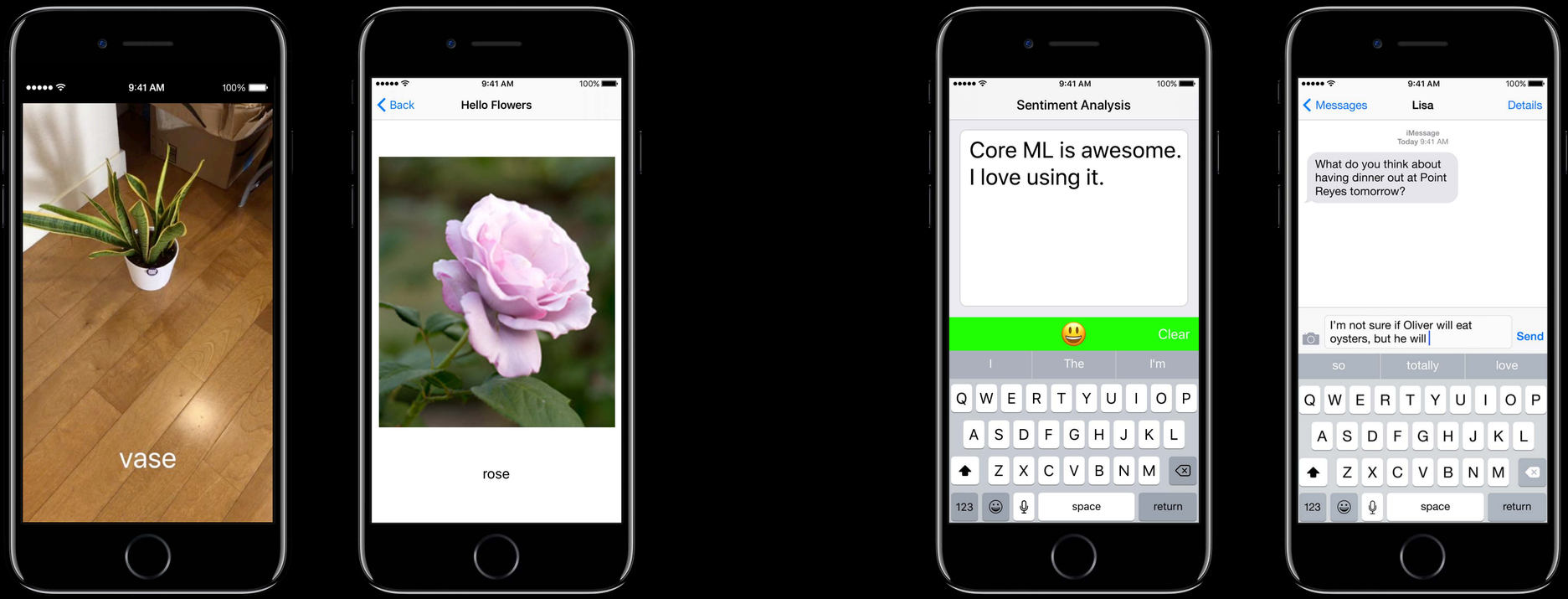
MPS



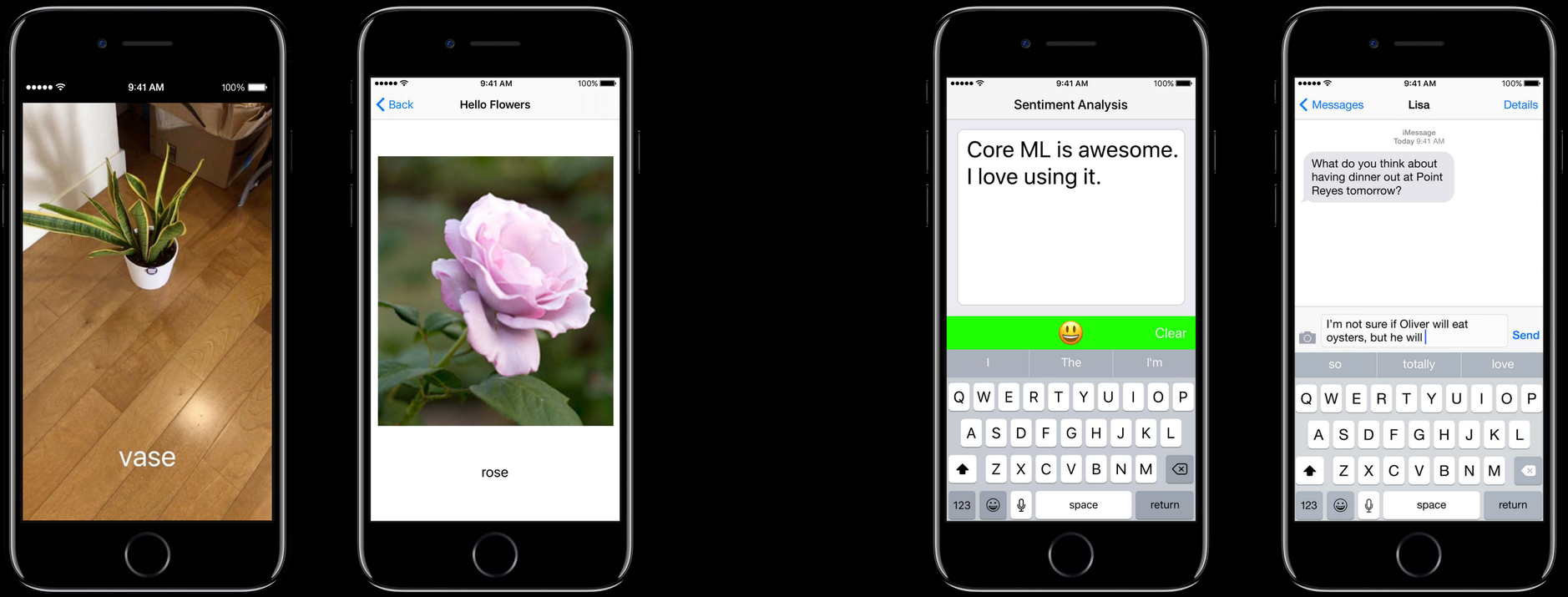
Runs on CPU

Accelerate

Optimized for Hardware

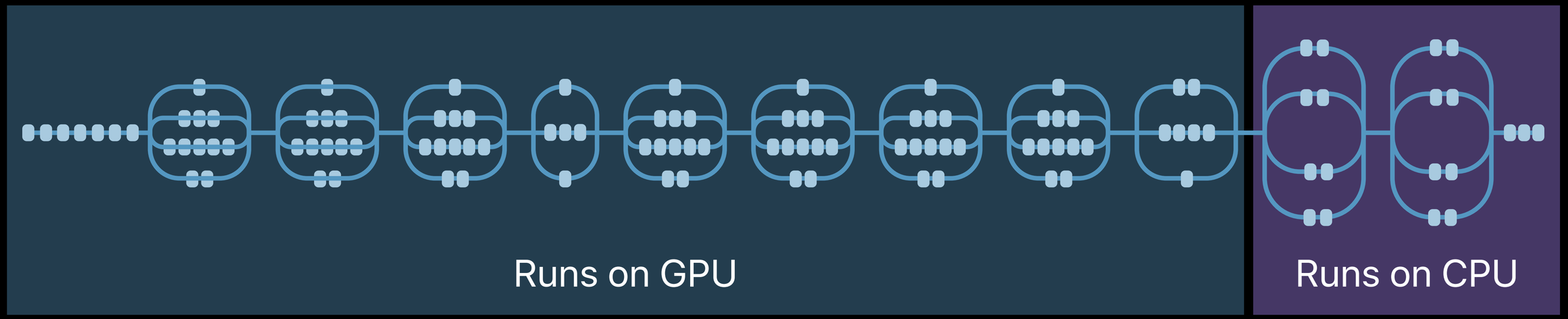


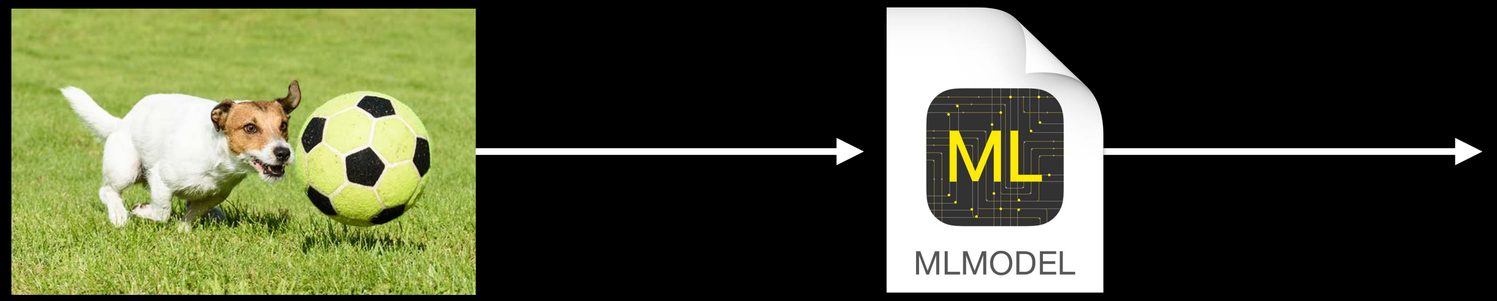
Optimized for Hardware



Runs on Core ML

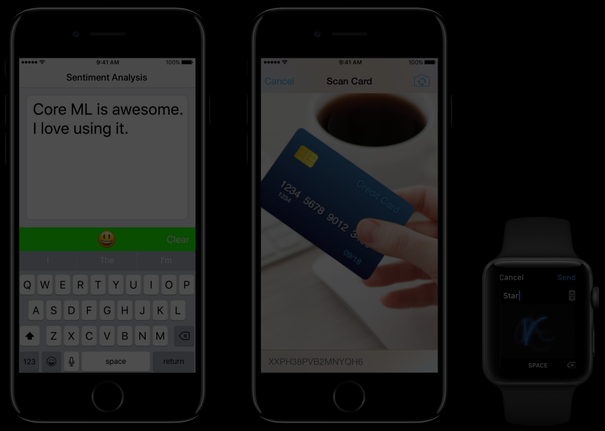
Context Switching



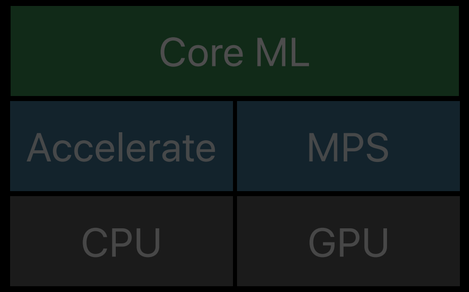


This Session

Use Cases

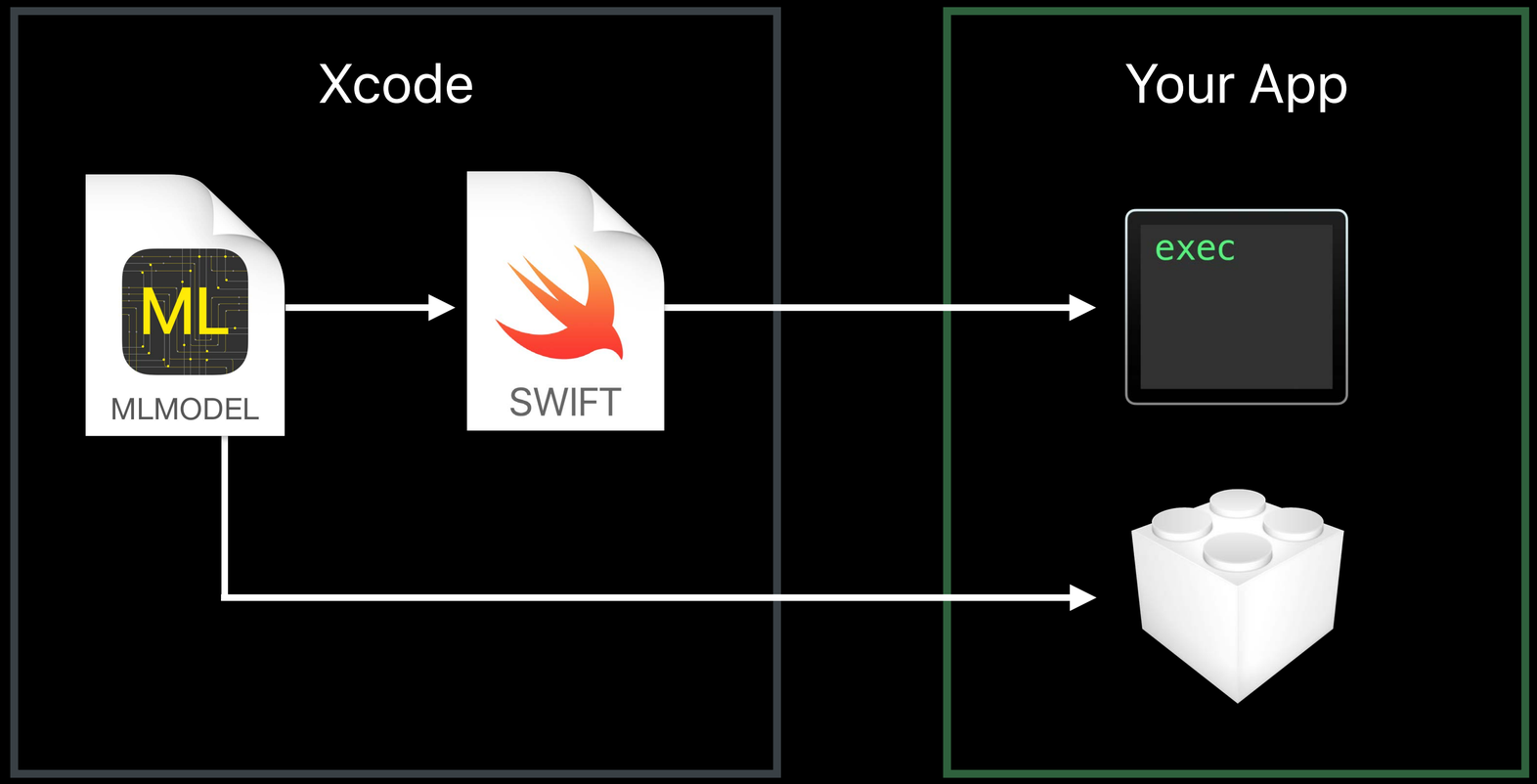


Hardware Optimized



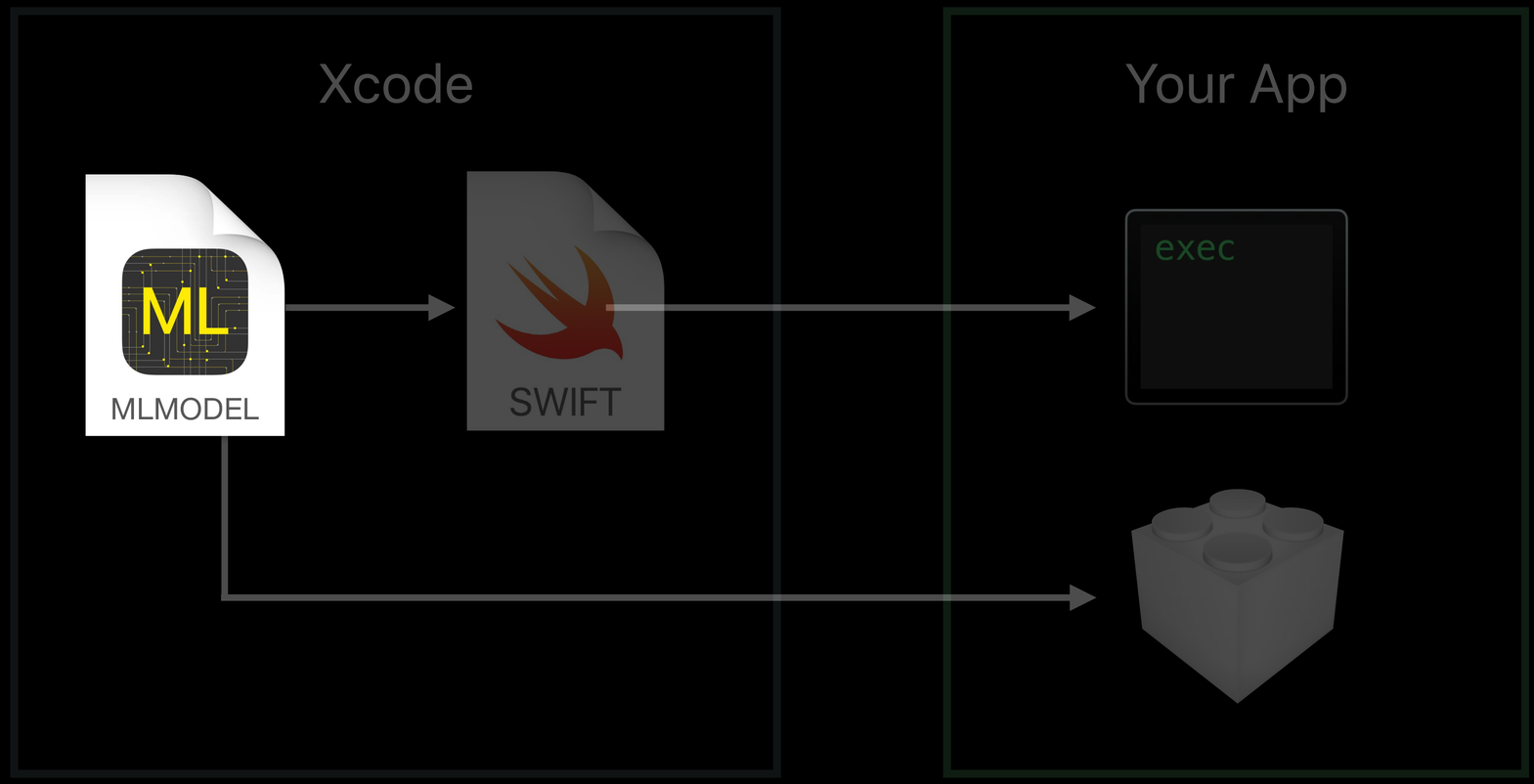
Obtaining Models

Deploying Core ML Models



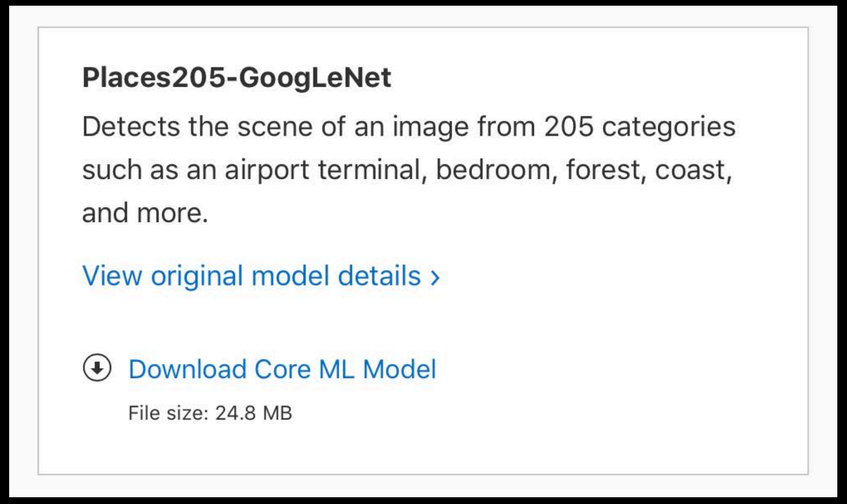
Deploying Core ML Models

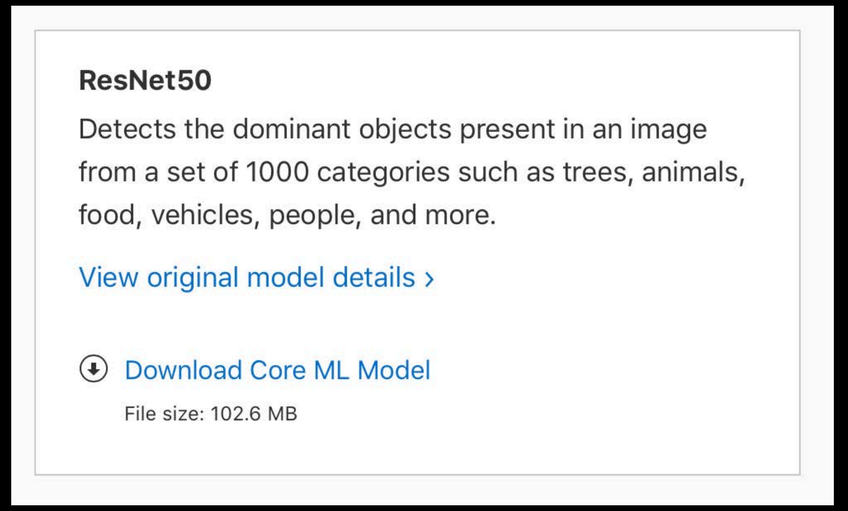
Where do models come from?



Example Models

Task specific Core ML models





developer.apple.com/machine-learning

Tap into ML Community

Popular ML libraries

Many models

Thriving communities

scikit learn

Caffe

Keras

dmlc XGBoost

LIBSVM

Tap into ML Community

Popular ML libraries

Many models

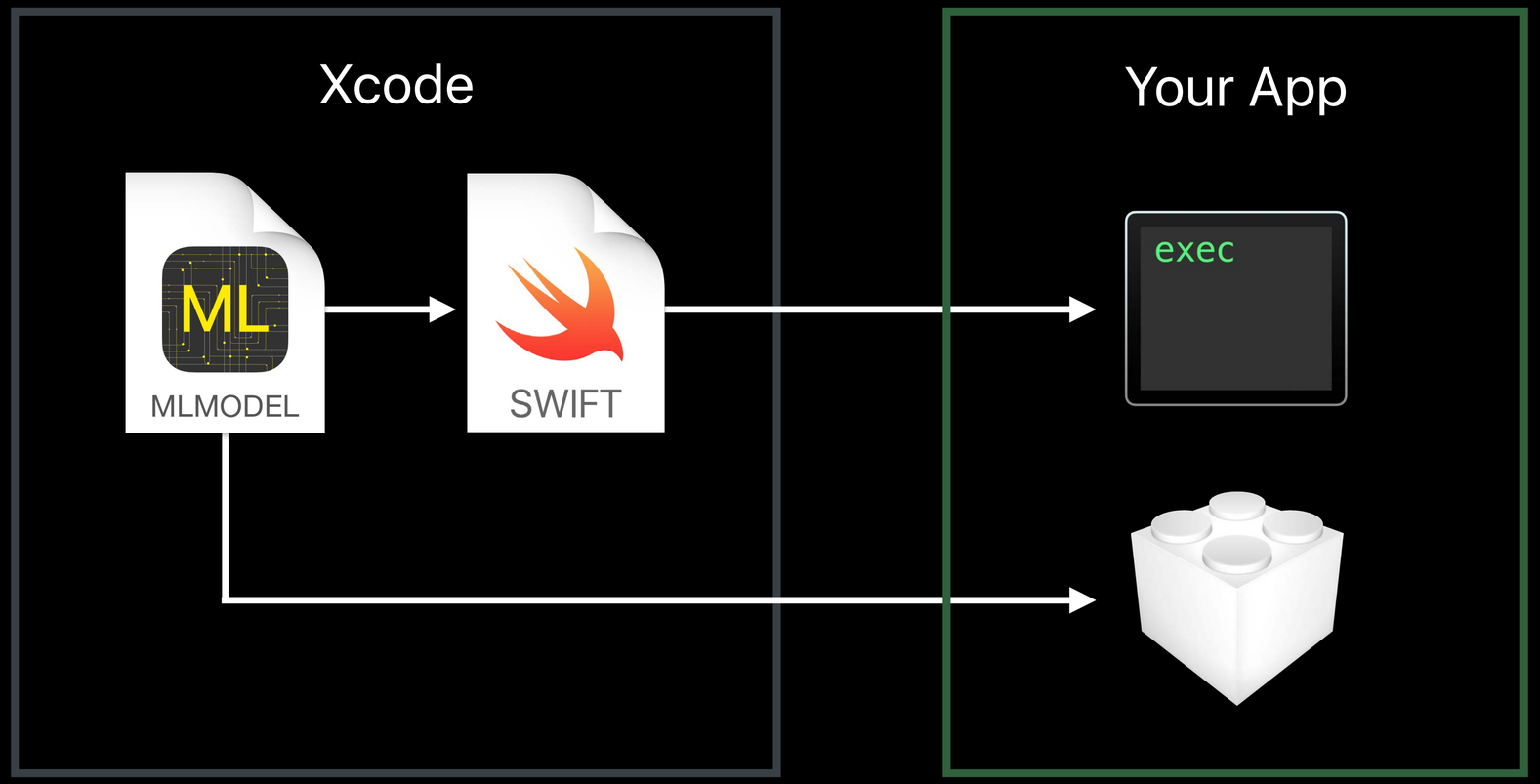
Thriving communities

Core ML Tools

Core ML Tools

Open Source

Conversion Workflow



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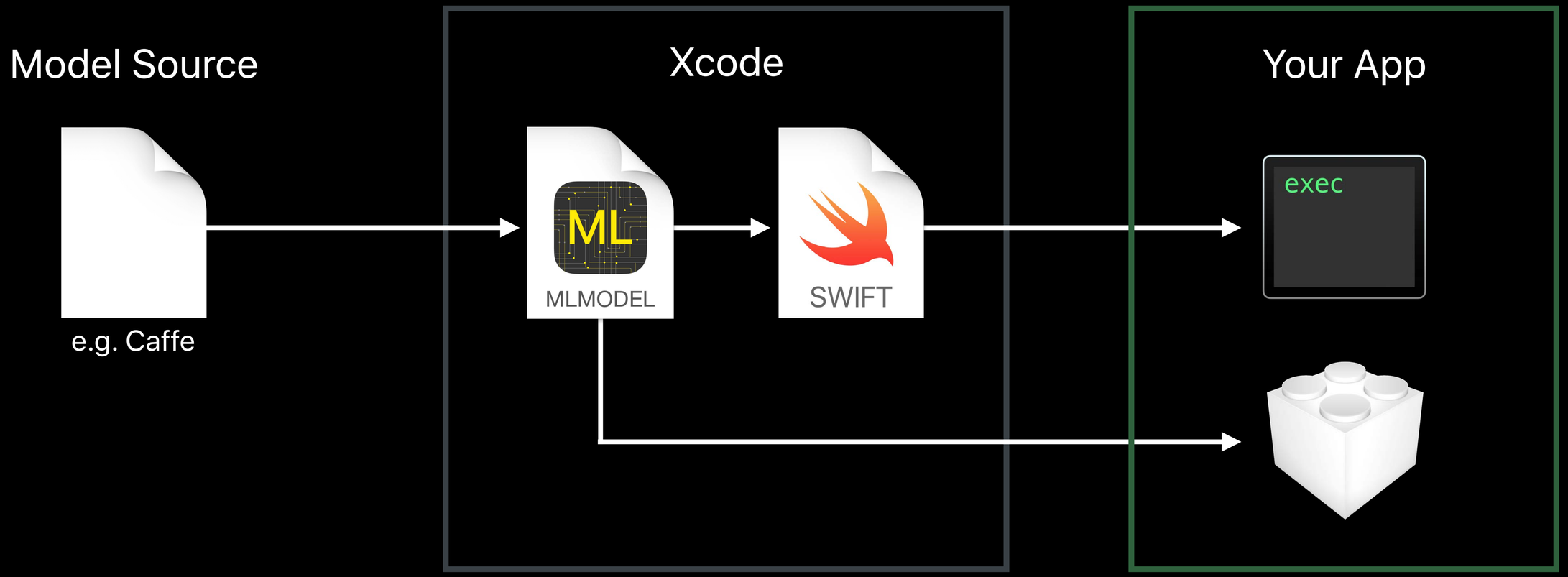

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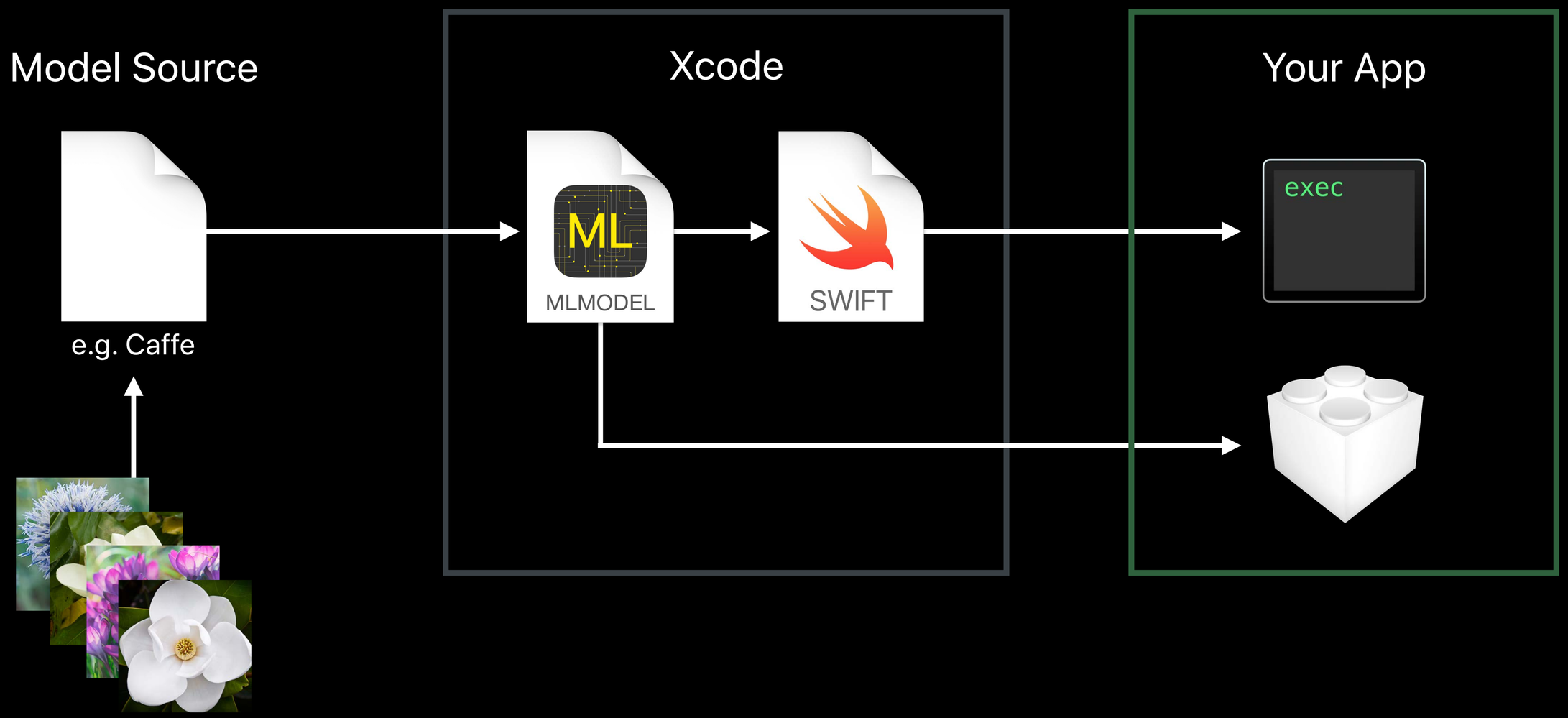
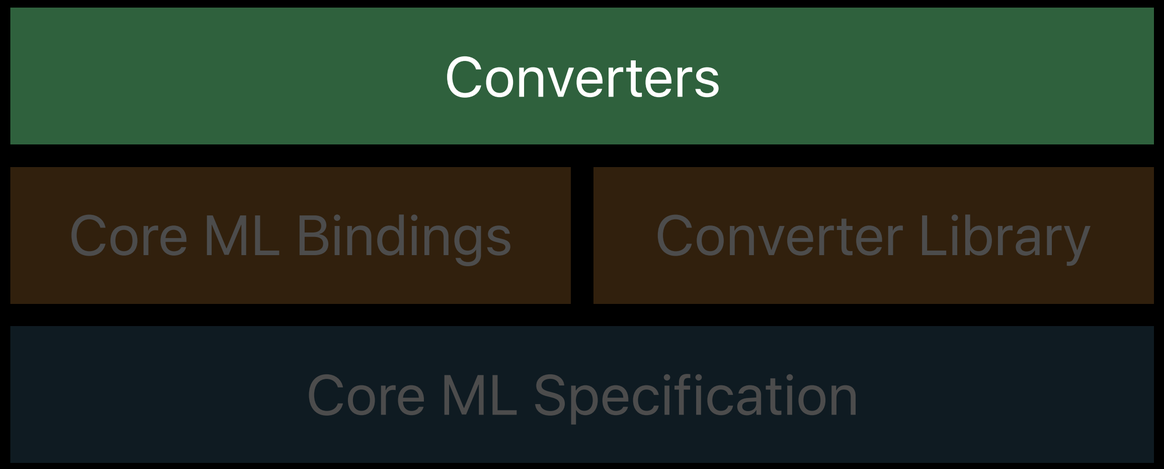


Getting Started

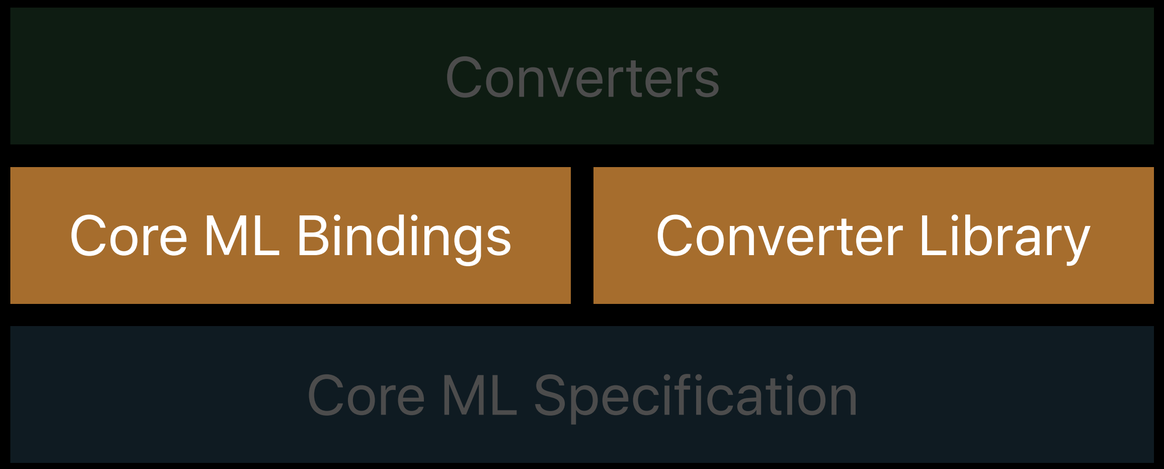
```
  ## Download and install python package
> pip install coremltools
```

What Is coremltools?



Convert from other formats

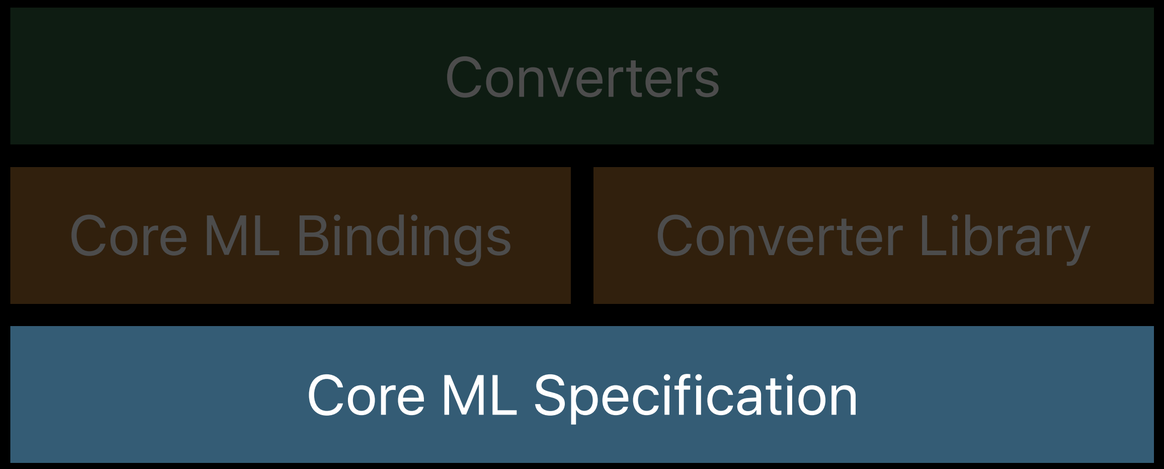
What Is coremltools?



Convert from other formats

Build your own converter

What Is coremltools?

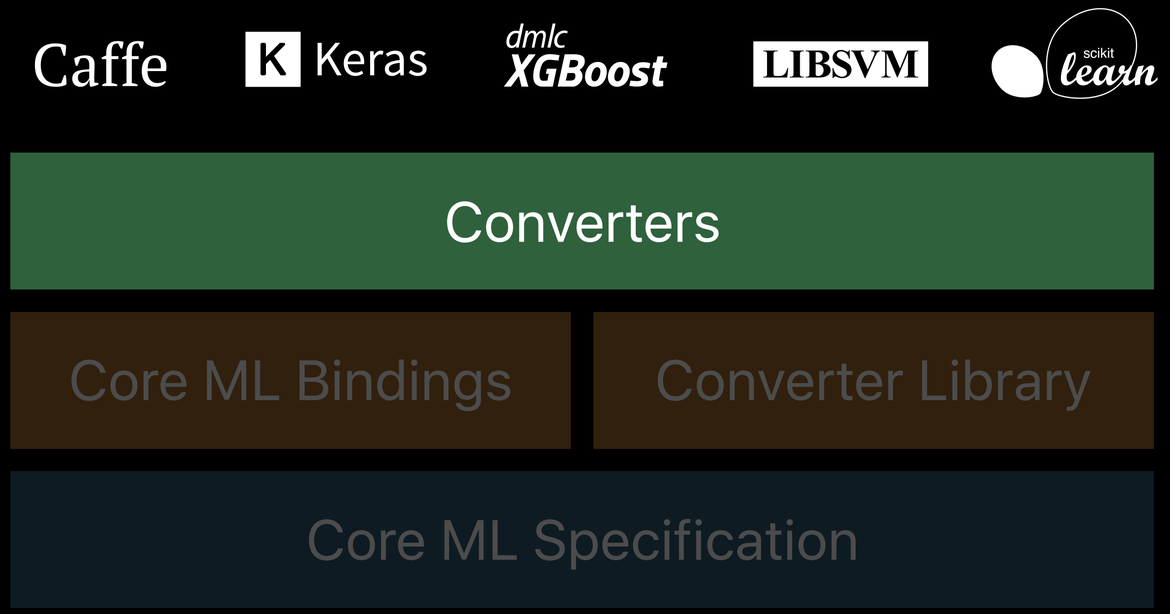


Convert from other formats

Build your own converter

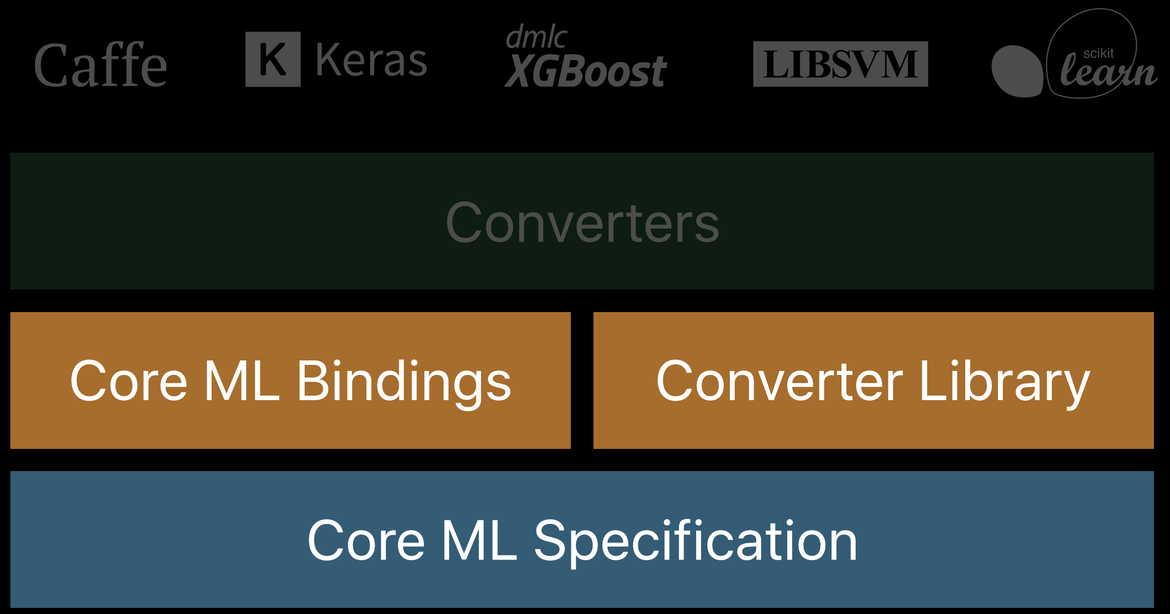
Write your own models

Compatible and Extensible



Compatible

Compatible and Extensible



Extensible

Core ML Model

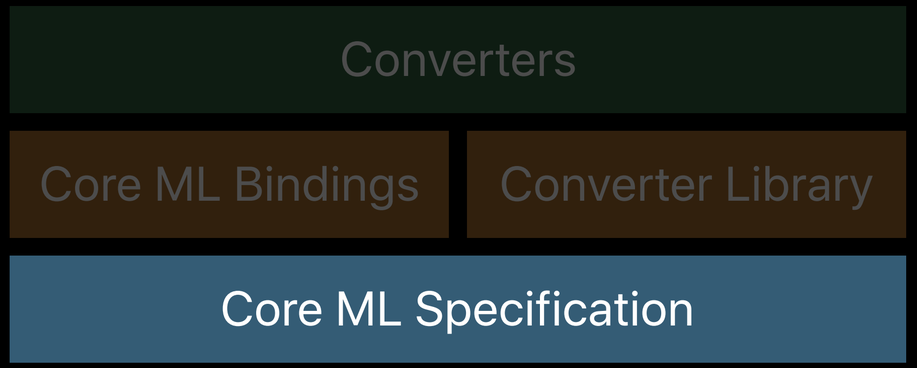
developer.apple.com/machine-learning

Single document

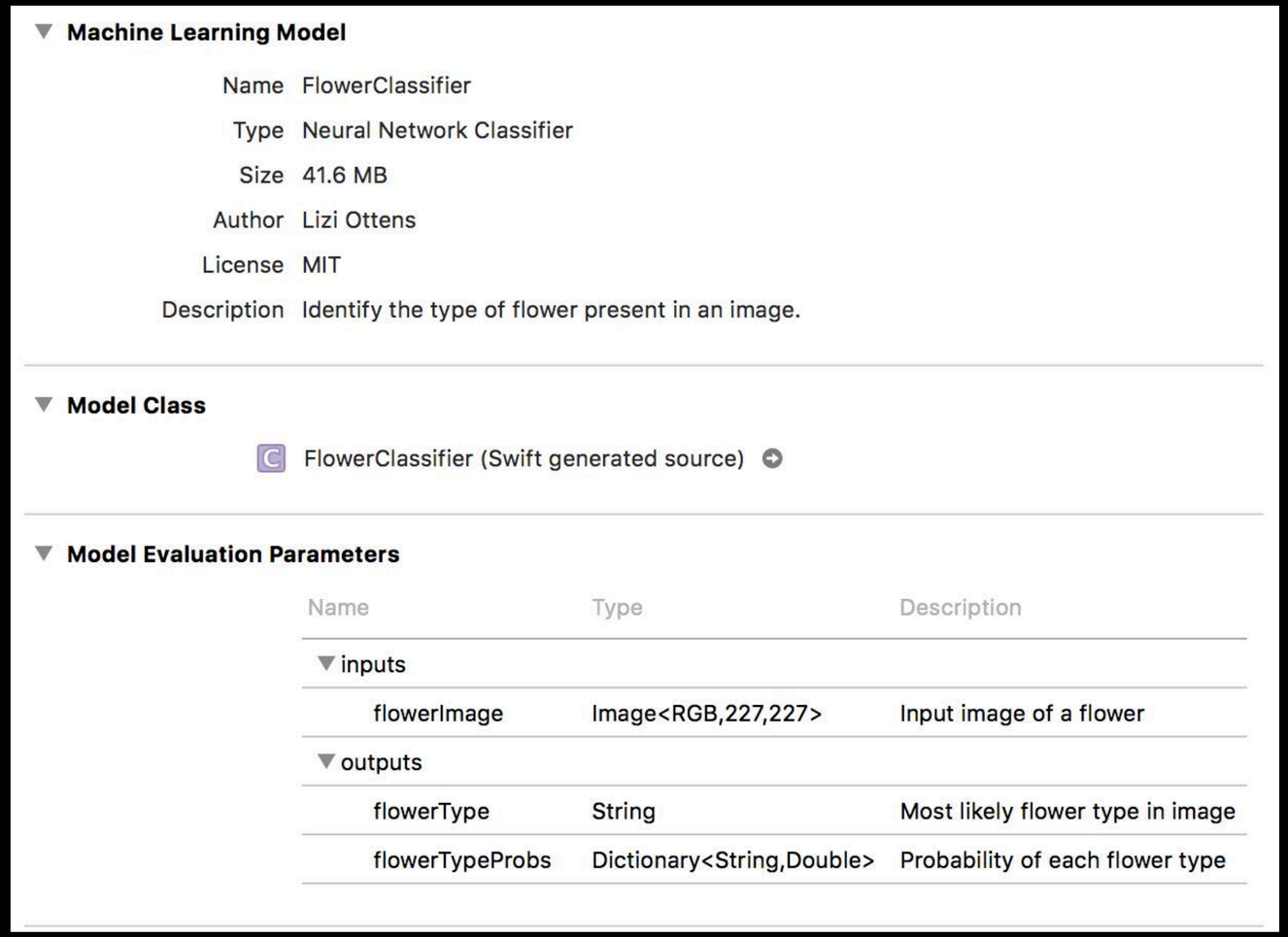
Encapsulates

- Functional description (inputs ⟶ outputs)
- Trained parameters

Public format



Xcode Model View



Xcode Model View

Machine Learning Model

Name	FlowerClassifier
Type	Neural Network Classifier
Size	41.6 MB
Author	Lizi Ottens
License	MIT
Description	Identify the type of flower present in an image.

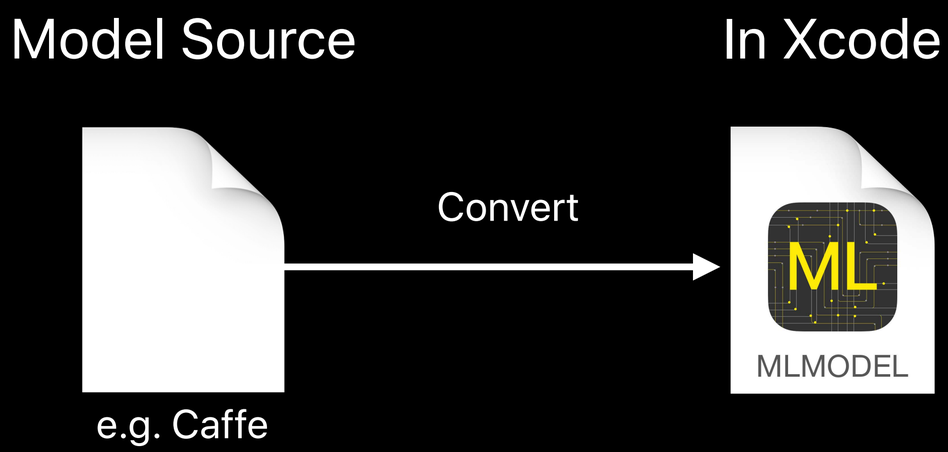
Model Class

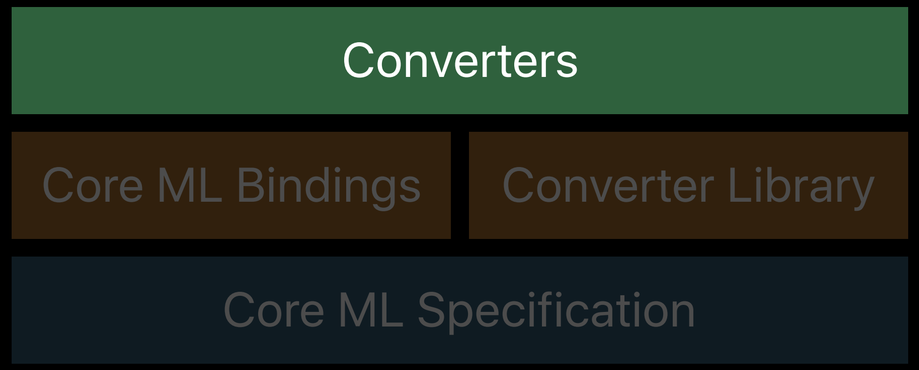
FlowerClassifier (Swift generated source)

Model Evaluation Parameters

Name	Type	Description
▼ inputs		
flowerImage	Image<RGB,227,227>	Input image of a flower
▼ outputs		
flowerType	String	Most likely flower type in image
flowerTypeProbs	Dictionary<String,Double>	Probability of each flower type

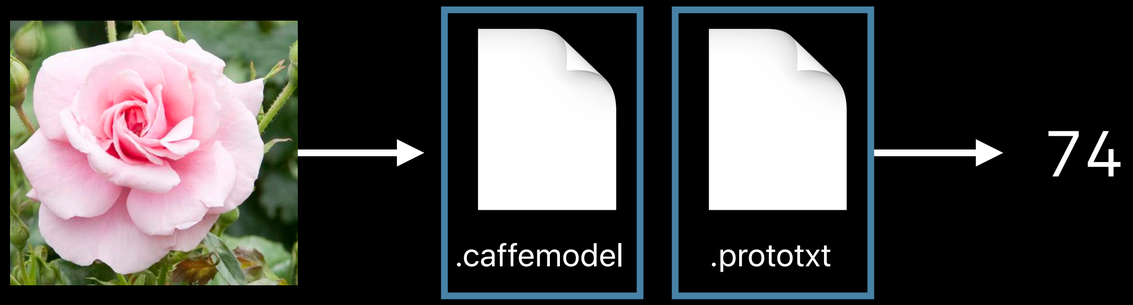
Core ML Converters



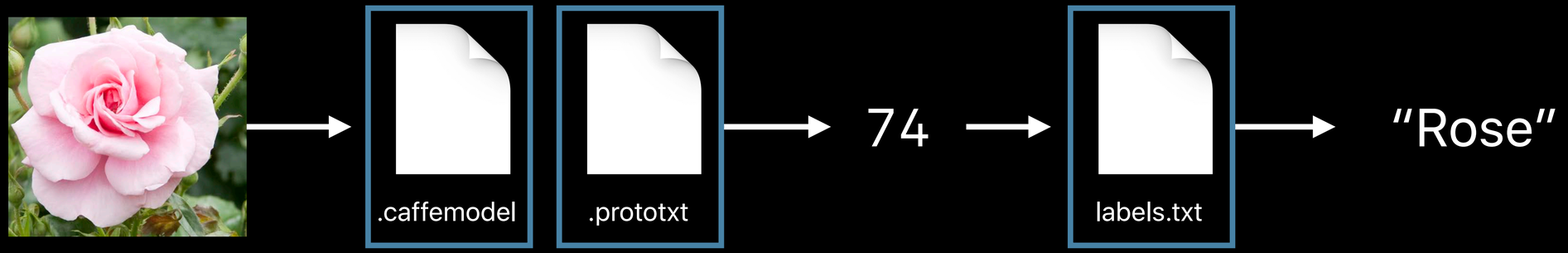


Unified APIs to convert models from various formats to Core ML

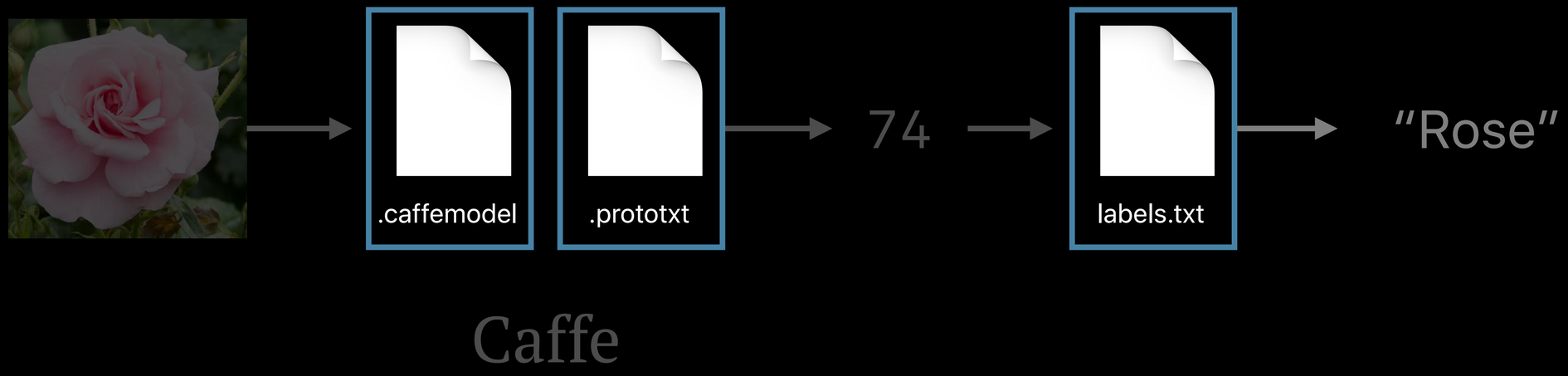
Flower Classification in Caffe



Flower Classification in Caffe



Flower Classification in Caffe



Needed for conversion to Core ML format

Demo

Demo Summary

```
import coremltools

caffe_model = ('flowers.caffemodel','flowers.prototxt')
model = coremltools.converters.caffe.convert(
                caffe_model,
                image_input_names = 'data',
                class_labels = 'labels.txt')

model.save('FlowerClassifier.mlmodel')
```

Demo Summary

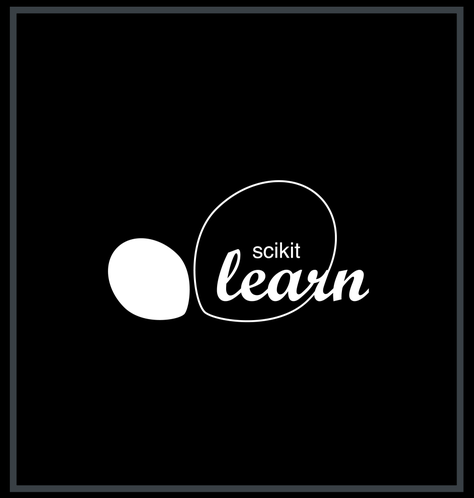
```
import coremltools

keras_model = 'flowers.h5'
model = coremltools.converters.keras.convert(
                  keras_model,
                  image_input_names = 'data',
                  class_labels = 'labels.txt')

model.save('FlowerClassifier.mlmodel')
```

Supported Packages

Neural Networks



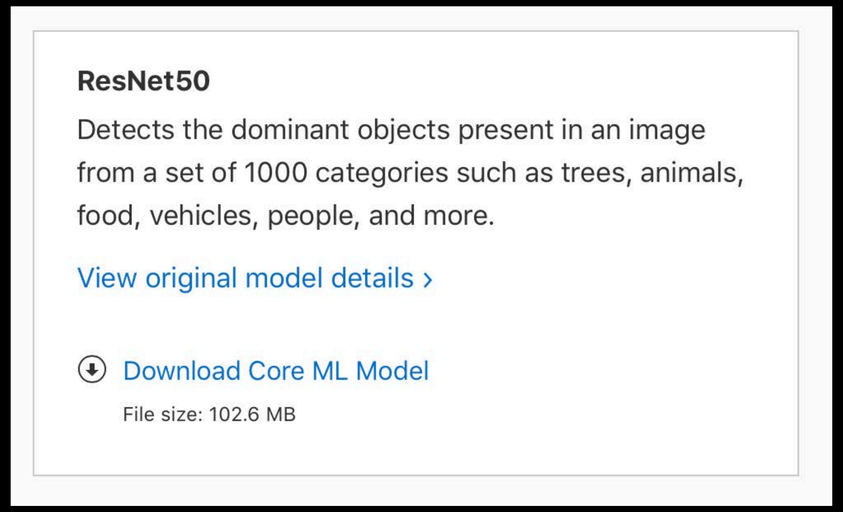
Pipelines

Tree Ensembles

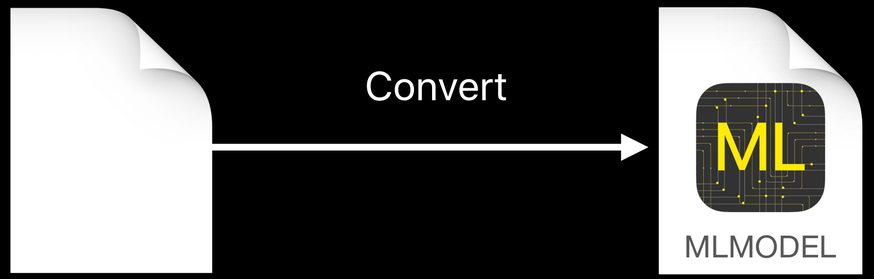
Linear Models
Support Vector Machines

Obtaining Models

Summary



developer.apple.com/machine-learning



Caffe

Keras

LIBSVM

dmlc XGBoost

scikit learn

Summary

Summary

Easy integration of ML models

Summary

Easy integration of ML models

Rich datatype support

Summary

Easy integration of ML models

Rich datatype support

Hardware optimized

Summary

Easy integration of ML models

Rich datatype support

Hardware optimized

Compatible with popular formats

More Information

https://developer.apple.com/wwdc17/710

Related Sessions

Introducing Core ML		WWDC 2017
Vision Framework: Building on Core ML		WWDC 2017
Natural Language Processing and your Apps		WWDC 2017
Accelerate and Sparse Solvers	Grand Ballroom A	Thursday 10:00AM
Using Metal 2 for Compute	Grand Ballroom A	Thursday 4:10PM

Labs

Core ML and Natural Language Processing Lab	Technology Lab D	Thu 11:00AM-3:30PM
Core ML and Natural Language Processing Lab	Technology Lab D	Fri 1:50PM-4:00PM


WWDC17