MACHINE LEARNING WITH TENSORFLOW.JS

FROM FUNDAMENTALS TO PRODUCTION
IN JAVASCRIPT AND TYPESCRIPT

TRAIN AND DEPLOY
MODELS IN THE BROWSER AND NODE.JS

REAL-WORLD ML
PRACTICAL EXAMPLES FOR MODERN APPLICATIONS

BUILT WITH
JAVASCRIPT AND TYPESCRIPT

FROM EXPERIMENTS TO PRODUCTION
SCALABLE, RELIABLE, PRODUCTION-READY ML

```
import * as tf from '@tensorflow/tfjs';

const model = tf.sequential({
  layers: [
    tf.layers.dense({ units: 128,
                      activation: 'relu ',
                      inputShape: [784]  }),
    tf.layers.dense({{ units: 10},
                      activation: 'softmax' })
  ]
});

await model.compile({
 optimizer: 'adam',
 loss: 'sparseCategoricalCrossentropy',
 metrics: ['accuracy']
});
```

TENSORFLOW.JS
LATEST APIs

NODE.JS
SERVER-SIDE ML

BROWSER
REAL-TIME INFERENCE

ADVANCED TOPICS
ATTENTION, TRANSFORMERS AND MORE

LUKAS MORRISON

Machine Learning with TensorFlow.js

From Fundamentals to Production in JavaScript and TypeScript

Steve Publications

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Contents

From Fundamentals to Production in JavaScript and TypeScript

TensorFlow.js has evolved into a complete, production-ready machine learning platform for the JavaScript ecosystem. This book takes you from foundational concepts through advanced techniques, showing you how to build, train and deploy machine learning models directly in the browser and Node.js. Whether you are adding real-time object detection to a web application, running server-side inference at scale, or experimenting with cutting-edge architectures like attention mechanisms, this book provides the practical knowledge and architectural guidance you need. Every chapter includes complete, runnable code examples using modern TensorFlow.js APIs and current JavaScript practices, with clear explanations of not just how things work but why they work and when to use each approach.

Introduction: Why Machine Learning in JavaScript?

In 2018, Google introduced TensorFlow.js at the TensorFlow Developer Summit. It was a bold proposition: bring machine learning to the browser. Developers could train models directly on users devices, run inference without sending data to a server, and integrate AI features into web applications using the same language they already knew.

Six years later, that proposition has not only proven viable but has become essential infrastructure for modern web development.

Consider these real-world scenarios:

A fashion retailer wants customers to see how clothing looks on their own bodies in real-time. They deploy a body segmentation model running entirely in the browser using TensorFlow.js and WebGPU, achieving 30 frames per second on modern devices without streaming video to any server. The latency is near-zero, the privacy is preserved, and the infrastructure costs are negligible because all computation happens client-side.

A financial services company needs to detect fraudulent transactions as they happen. They train a model in Python using TensorFlow, convert it to TensorFlow.js format, and deploy it on their Node.js inference servers. The same model architecture that powers their data science team now runs in production alongside their existing Express API, with sub-millisecond predictions and seamless integration into their JavaScript stack.

An educational platform wants students to build interactive machine learning experiments without installing Python or configuring development environments. They embed a TensorFlow.js playground directly in the browser where students can train neural networks on live data, visualize loss curves, and experiment with architectures, all from a single HTML file.

These are not hypothetical examples. They represent actual use cases that developers are solving today with TensorFlow.js.

What This Book Covers

This book is structured to take you through the complete journey of machine learning development with TensorFlow.js, organized into five progressive parts:

Part I: Foundations establishes the mental models and technical fundamentals you need. You will learn what tensors are, how TensorFlow.js manages memory (a critical difference from server-side ML frameworks), and how neural networks transform data through layers. By the end of this part, you will have trained your first model from scratch and understand the mechanics behind every operation.

Part II: Building Models covers the full spectrum of model construction, from simple sequential networks to complex architectures using the Functional API. You will learn about training loops, loss functions, optimizers, callbacks, evaluation metrics, and how to diagnose and fix common training problems like overfitting and underfitting. This part also explores advanced topics including recurrent neural networks, attention mechanisms, custom layers, and hyperparameter tuning strategies.

Part III: Data and Preprocessing addresses the often-overlooked reality that most machine learning work is data work. You will learn how to build efficient data pipelines using tf.data, handle different data types (images, text, structured data), apply normalization and augmentation techniques, and transform raw inputs into formats your models can consume.

Part IV: Specialized Applications dives deep into three major domains where TensorFlow.js excels: computer vision (image classification, object detection, pose estimation), natural language processing (sentiment analysis, text classification, embeddings), and time-series forecasting (LSTM-based prediction for sequential data). Each chapter includes practical examples using both pretrained models and custom training.

Part V: Deployment and Production tackles the realities of shipping machine learning to production. You will learn about model formats, saving and loading strategies, converting Python models, GPU acceleration with WebGL and WebGPU backends, server-side deployment with Node.js, performance optimization, security considerations, privacy-preserving techniques like federated learning, and interoperability with other ML ecosystems including ONNX and PyTorch.

Who Should Read This Book

This book assumes you are comfortable with JavaScript and have experience building web applications or Node.js services. You do not need prior machine learning experience. Concepts are introduced progressively, starting from first principles. If you understand arrays, functions and basic mathematics (linear algebra concepts are explained as needed), you can follow along.

If you are a data scientist or ML engineer looking to deploy models in JavaScript environments, this book will give you the framework-specific knowledge to integrate TensorFlow.js into your workflow effectively.

How to Use the Code Examples

Every code example in this book is designed to be runnable with minimal modification. Browser examples use ES modules and can be tested directly in modern browsers or simple HTML files. Node.js examples include clear dependency information. TypeScript types are shown where they add clarity, but JavaScript remains the primary language for accessibility.

All examples prioritize current TensorFlow.js APIs (version 4.x) and modern JavaScript practices. Deprecated patterns are explicitly flagged when discussed for historical context.

The book does not include exercises or quizzes. Instead, each chapter builds on previous material through progressively more complex examples, so working through the code sequentially is the best way to learn.

A Note on Versions and Changes

Machine learning frameworks evolve rapidly. TensorFlow.js version 4.x represents a mature, stable API with strong backward compatibility. However, new features like WebGPU backend support continue to emerge. Where APIs or recommendations have changed over time, this book prioritizes current official documentation while noting version-specific considerations. If you encounter discrepancies between this book and the latest TensorFlow.js release notes, trust the official documentation for breaking changes but treat the architectural principles and patterns described here as enduring guidance.

Let us begin.

Chapter 1: Machine Learning Meets JavaScript

The story of TensorFlow.js begins with a simple observation: JavaScript has become the universal language of interactive computation. It runs in every modern browser, powers server-side applications through Node.js, drives mobile apps via React Native and Ionic, and even controls embedded devices. Yet for years, machine learning development lived almost entirely in Python. Data scientists trained models using TensorFlow or PyTorch, exported them to specialized formats, and engineers deployed them behind API endpoints.

TensorFlow.js changed that paradigm by bringing the full power of TensorFlow directly into JavaScript environments. This chapter sets the stage for everything that follows: why TensorFlow.js matters, how it fits into the broader ML landscape, and getting you running your first prediction in under a minute.

Why Machine Learning in JavaScript?

Before diving into code, let us understand the fundamental motivations for doing machine learning in JavaScript rather than relying solely on Python-based backends. There are five compelling reasons:

1. Client-side intelligence and reduced latency. When inference happens directly in the browser, there is no network round-trip to a server. A real-time object detection model analyzing webcam video can run at 30+ frames per second locally, whereas sending each frame to a server would introduce unacceptable latency even on fast connections. This matters for applications like augmented reality overlays, interactive image filters, gesture-based controls, and any experience where responsiveness is critical.

2. Privacy-preserving computation. When models run in the browser, user data never leaves their device. A healthcare application analyzing medical images can perform inference locally without transmitting sensitive patient data to a server. A productivity tool can analyze writing patterns or document

content without sending it to external APIs. This is not just a technical advantage but increasingly a regulatory and ethical requirement under frameworks like GDPR and HIPAA.

3. Offline capability. Browser-based machine learning works without an internet connection once the model is loaded. Progressive web apps can provide AI-powered features that function reliably in airplane mode, in areas with poor connectivity, or when backend services are temporarily unavailable. This resilience matters for field applications, educational tools used in low-connectivity regions, and any product where reliability cannot depend on network conditions.

4. Cost efficiency at scale. Every inference request to a server costs money: compute resources, bandwidth, infrastructure maintenance. When you move inference to the client, each additional user brings their own compute capacity. A product serving millions of users can offload massive computational workloads to browsers without proportionally increasing server costs. The trade-off is that clients have more constrained hardware than servers, which means models must be optimized for size and efficiency, a constraint TensorFlow.js addresses directly through quantization, model compression, and efficient backends.

5. Full-stack JavaScript integration. For teams already working in JavaScript, TensorFlow.js eliminates the need to maintain separate Python services for ML functionality. The same developers building your React frontend or Express backend can integrate machine learning features directly into their existing codebase using familiar tools, patterns and deployment pipelines. This reduces organizational complexity and accelerates iteration.

None of these reasons means you should never use server-side ML. Large models, complex training jobs, and batch processing still belong on powerful servers with dedicated GPUs. TensorFlow.js is not a replacement for Python-based ML infrastructure but a complementary tool that extends what is possible within the JavaScript ecosystem.

How TensorFlow.js Fits Into the ML Landscape

To understand where TensorFlow.js belongs, let us map the broader machine learning ecosystem:

Training vs inference. Machine learning has two distinct phases. Training involves feeding large datasets to a model and iteratively adjusting its parameters (weights) to minimize prediction errors. This is computationally intensive, often requiring powerful GPUs, distributed systems, and specialized tooling. Inference (also called prediction or serving) involves using a trained model to make predictions on new data. Inference is typically less computationally demanding than training and can run efficiently on consumer hardware.

TensorFlow.js excels at inference in JavaScript environments. It also supports training in the browser and Node.js, but practical constraints apply: browser tabs have limited memory (often 1-4 GB), GPUs are shared with graphics rendering, and training large models can freeze the UI or exhaust resources. The common pattern is to train models in Python using TensorFlow or Keras on powerful hardware, convert them to TensorFlow.js format, and deploy for inference in browsers or Node.js. For smaller models and datasets, browser-based training is perfectly viable and offers unique advantages like interactive experimentation and federated learning scenarios where each client trains locally.

TensorFlow.js vs other JavaScript ML libraries. Several alternatives exist:

- **ONNX Runtime Web:** Runs ONNX-format models (exported from PyTorch, TensorFlow, or other frameworks) in browsers with WebAssembly acceleration. Strong for teams already using ONNX as an interchange format.
- **Transformers.js:** Specialized library for running large language models and transformers in browsers using WebGPU. Built by Hugging Face, optimized specifically for NLP tasks.
- **ml5.js:** A higher-level abstraction over TensorFlow.js designed for creative coding and education. Simplifies APIs further but offers less control.
- **Brain.js:** A lightweight neural network library focused on simplicity rather than performance or feature completeness.

TensorFlow.js remains the most mature, full-featured option with the broadest ecosystem: official pretrained models, comprehensive documentation, active Google backing, and seamless interoperability with Python TensorFlow through model conversion tools.

The TensorFlow.js ecosystem. TensorFlow.js is not a single package but a collection of coordinated libraries:

- **@tensorflow/tfjs-core:** The foundational library providing tensor operations, automatic differentiation, and backend abstraction. This is the low-level engine everything else builds on.
- **@tensorflow/tfjs-layers:** A high-level API similar to Keras for building models using layers. Most developers interact with this layer of the API.
- **@tensorflow/tfjs-data:** Utilities for loading and preprocessing data from various sources (CSV files, images, JSON).
- **@tensorflow/tfjs-converter:** Tools for converting Python TensorFlow/Keras models to TensorFlow.js format.
- **@tensorflow/tfjs-vis:** Visualization tools for monitoring training progress, displaying tensors, and building interactive ML interfaces.
- **@tensorflow/tfjs-node:** Node.js bindings that connect to the TensorFlow C++ backend for accelerated computation on servers.
- **@tensorflow-models/*:** A family of pretrained model packages (MobileNet, Coco SSD, PoseNet, etc.) ready to use out of the box.

The main @tensorflow/tfjs package re-exports most of these components for convenience, making it easy to get started without managing multiple dependencies.

Your First Prediction in 30 Seconds

Let us skip theory and see TensorFlow.js in action immediately. Open a modern browser console (Chrome, Firefox, or Edge all work) and paste this code:

```
// Load TensorFlow.js from CDN
import * as tf from
↪  'https://cdn.jsdelivr.net/npm/@tensorflow/tfjs@4.22.0/+esm';

console.log('TensorFlow.js version:', tf.version_core);
console.log('Backend:', tf.getBackend());
```

You should see output like:

```
TensorFlow.js version: 4.22.0
Backend: webgl
```

The backend tells you how TensorFlow.js will execute computations. WebGL is the default in browsers and uses your GPU for acceleration. If WebGL is unavailable, it falls back to CPU execution.

Now let us create a simple model that learns to predict house prices based on square footage. This is a classic linear regression problem: given input features (size), predict a continuous output (price). Our model will learn the relationship from example data.

```
// Create training data: house sizes in hundreds of square feet
const xs = tf.tensor2d([1.0, 2.0, 3.0, 4.0, 5.0], [5, 1]);

// Corresponding prices in hundreds of thousands of dollars
const ys = tf.tensor2d([1.5, 2.5, 3.5, 4.5, 5.5], [5, 1]);

// Build a simple linear model: one neuron with no activation function
const model = tf.sequential();
model.add(tf.layers.dense({units: 1, inputShape: [1]}));

// Prepare the model for training
model.compile({
  optimizer: 'adam',
  loss: 'meanSquaredError'
});

// Train the model for 50 epochs
await model.fit(xs, ys, {epochs: 50});

// Make predictions on new data
const predictions = model.predict(tf.tensor2d([6.0], [1, 1]));
console.log('Predicted price for 600 sq ft:', (await predictions.data())[0]);

// Clean up tensors to free memory
xs.dispose();
ys.dispose();
predictions.dispose();
```

The predicted price should be approximately 650 thousand dollars, which is exactly what the linear pattern in our data suggests. The model learned that each additional hundred square feet adds roughly 100 thousand dollars.

What just happened? Let us break it down briefly:

- **tf.tensor2d()** created two-dimensional tensors (arrays) to hold our input features and target values. Tensors are the fundamental data structure in

TensorFlow.js: multidimensional arrays that can be processed efficiently on GPUs.

- **tf.sequential()** created a model consisting of layers stacked linearly, one after another.
- **tf.layers.dense()** added a fully connected layer with one output unit (neuron). This is the simplest possible neural network: a single linear transformation.
- **model.compile()** configured how the model learns: using the Adam optimizer (an adaptive learning algorithm) and mean squared error as the loss function (a measure of prediction accuracy).
- **model.fit()** trained the model by showing it our five examples repeatedly for 50 epochs, gradually adjusting its internal weights to minimize the difference between predictions and actual values.
- **model.predict()** used the trained model to make a prediction on new data the model had never seen before.

This example is deliberately simple. Real machine learning involves more complex models, larger datasets, careful validation, and attention to many practical details. But the fundamental pattern (create tensors, build a model, compile it, train it, predict with it) remains the same regardless of complexity.

Browser vs Node.js: Two Environments, One API

TensorFlow.js runs in two primary environments with important differences:

In the browser:

- Uses WebGL for GPU acceleration by default (or WASM/WebGPU as alternatives)
- Memory is constrained: modern browsers typically limit each tab to 1-4 GB of RAM and a portion of GPU memory
- Execution must be non-blocking: long-running operations should use async patterns or tf.nextFrame() to avoid freezing the UI
- Models are loaded over HTTP, which means initial load time matters for user experience
- Privacy advantage: user data stays local
- Ideal for: real-time inference on user-generated content (images, audio, text), interactive ML demos, offline-capable features

In Node.js:

- Can use @tensorflow/tfjs-node or @tensorflow/tfjs-node-gpu for native TensorFlow C++ backend with CPU/GPU acceleration
- Access to full system memory and GPU resources (when using GPU backend)
- Execution is synchronous by default: operations block the main thread, so production servers should use worker threads or job queues
- Models can be loaded from local filesystem
- Ideal for: high-throughput inference APIs, batch processing, training on larger datasets, server-side ML features

The API itself is nearly identical between environments. The same model-building code, training loops, and prediction calls work in both contexts. This portability is one of TensorFlow.js's strongest advantages: you can prototype in the browser with instant visual feedback, then deploy the same logic to Node.js servers without rewriting your ML code.

Setting Up Your Development Environment

You have three main options for working with TensorFlow.js, depending on your project needs:

Option 1: Direct browser usage via CDN (quickest start)

For experimentation and simple demos, you can load TensorFlow.js directly from a CDN in an HTML file without any build tools:

```
<!DOCTYPE html>
<html>
<head>
  <script src=
  ↪  "https://cdn.jsdelivr.net/npm/@tensorflow/tfjs@4.22.0/dist/tf.min.js"><
  ↪  /script>
</head>
<body>
  <script>
    // TensorFlow.js is available as tf
    console.log('TensorFlow.js loaded, version:', tf.version_core);

    // Your ML code here
```

```
    const tensor = tf.tensor2d([1, 2, 3, 4], [2, 2]);
    console.log(tensor.print());
  </script>
</body>
</html>
```

This approach requires no installation and works immediately. It is ideal for learning, prototyping and simple applications. For production use, consider bundling to avoid CDN dependencies and reduce load times.

Option 2: ES modules with a build tool (recommended for most projects)

For serious development, install TensorFlow.js as an npm package and use it with your preferred build system (Vite, Webpack, Parcel, or plain Node.js):

```
npm install @tensorflow/tfjs
```

Then import it in your JavaScript or TypeScript code:

```
import * as tf from '@tensorflow/tfjs';

async function main() {
  console.log('TensorFlow.js version:', tf.version_core);

  const model = tf.sequential();
  model.add(tf.layers.dense({units: 10, inputShape: [5]}));
  // ... rest of your code
}

main();
```

With a bundler like Vite or Webpack, you can also use tree-shaking to include only the parts of TensorFlow.js your application actually uses, significantly reducing bundle size. TensorFlow.js provides configuration options for generating size-optimized bundles when bandwidth is a concern.

Option 3: Node.js with native backend (for server-side ML)

For Node.js applications that need maximum performance, use the native backend:

```
npm install @tensorflow/tfjs-node
# Or for GPU acceleration on Linux:
npm install @tensorflow/tfjs-node-gpu
```

Then import instead of the standard package:

```
import * as tf from '@tensorflow/tfjs-node';

console.log('Backend:', tf.getBackend()); // Should show 'tensorflow'
```

The native backend connects directly to the TensorFlow C++ library, providing significantly faster execution than pure JavaScript for most operations. GPU acceleration via CUDA is available on Linux with @tensorflow/tfjs-node-gpu.

TypeScript support. TensorFlow.js is written in TypeScript and publishes type definitions automatically. If you are using TypeScript, imports work seamlessly with full IntelliSense support:

```
import * as tf from '@tensorflow/tfjs';

const model: tf.LayersModel = tf.sequential();
model.add(tf.layers.dense({units: 16, activation: 'relu', inputShape: [8]}));
```

TypeScript integration is one of the practical advantages of TensorFlow.js over many ML libraries: you get compile-time checking for method signatures, tensor shapes, and configuration options.

Summary

TensorFlow.js brings machine learning directly into JavaScript environments, enabling client-side inference with low latency and strong privacy guarantees, server-side deployment alongside existing Node.js infrastructure, and full-stack integration for teams working in JavaScript. The library supports both browser and Node.js execution with a consistent API, multiple backends for different performance needs, and extensive tooling for model conversion from Python TensorFlow.

In the next chapter, we dive into the fundamental building block of all machine learning computation: tensors. Understanding tensors deeply is essential because every operation in TensorFlow.js (from simple arithmetic to complex neural network inference) works with tensors.

Chapter 2: Tensors, the Building Blocks

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What Is a Tensor?

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Creating Tensors in TensorFlow.js

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Tensor Shapes, Ranks, and Dimensions

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Chapter 6: Evaluation, Prediction, and Debugging

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Chapter 9: Computer Vision with TensorFlow.js

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