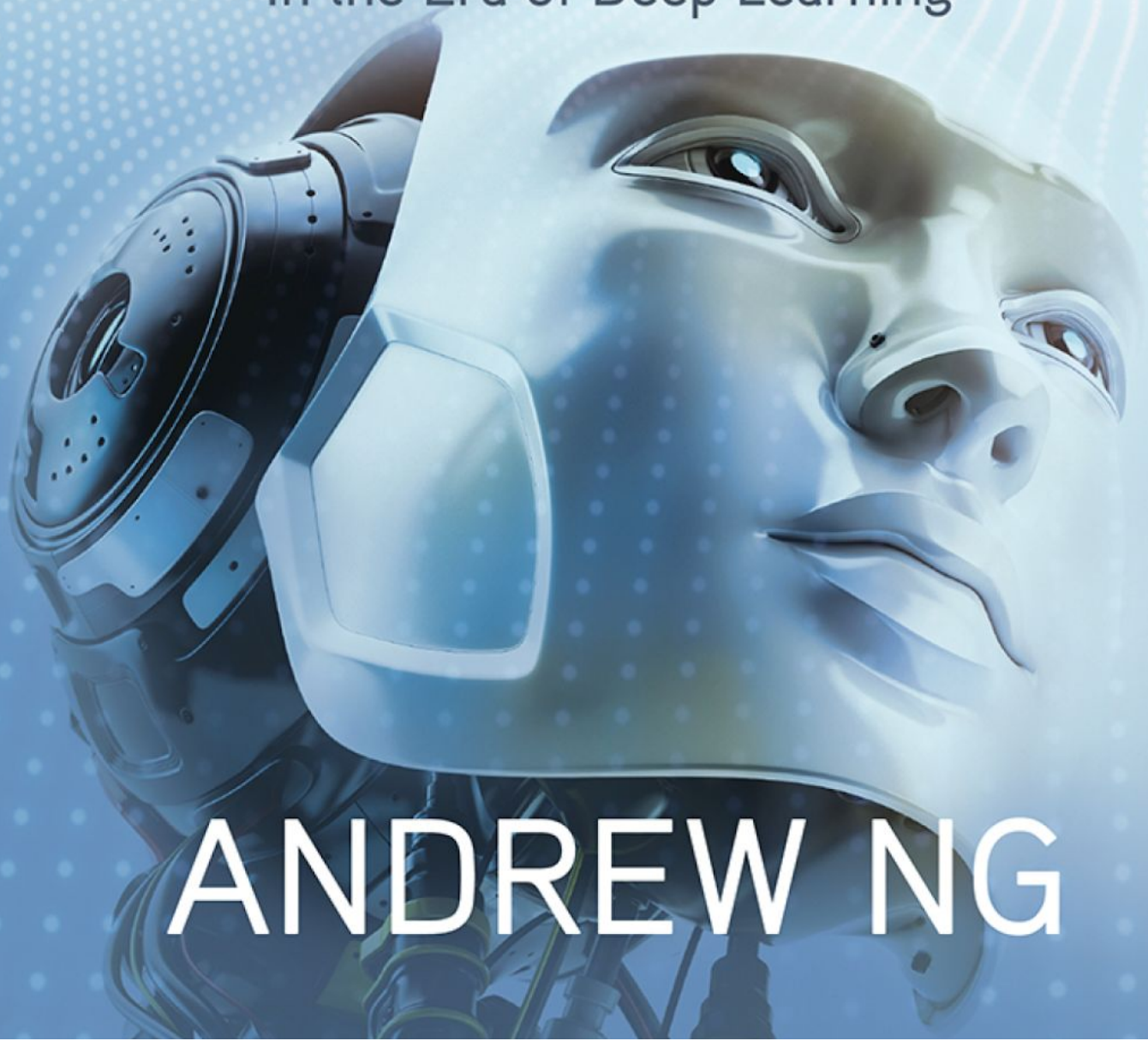


Draft Version

# MACHINE LEARNING YEARNING

Technical Strategy for AI Engineers,  
In the Era of Deep Learning



ANDREW NG



deeplearning.ai

Machine Learning Yearning is a  
deeplearning.ai project.

© 2018 Andrew Ng. All Rights Reserved.

## 23 Addressing Bias and Variance

Here is the simplest formula for addressing bias and variance issues:

- If you have high avoidable bias, increase the size of your model (for example, increase the size of your neural network by adding layers/neurons).
- If you have high variance, add data to your training set.

If you are able to increase the neural network size and increase training data without limit, it is possible to do very well on many learning problems.

In practice, increasing the size of your model will eventually cause you to run into computational problems because training very large models is slow. You might also exhaust your ability to acquire more training data. (Even on the internet, there is only a finite number of cat pictures!)

Different model architectures—for example, different neural network architectures—will have different amounts of bias/variance for your problem. A lot of recent deep learning research has developed many innovative model architectures. So if you are using neural networks, the academic literature can be a great source of inspiration. There are also many great open-source implementations on github. But the results of trying new architectures are less predictable than the simple formula of increasing the model size and adding data.

Increasing the model size generally reduces bias, but it might also increase variance and the risk of overfitting. However, this overfitting problem usually arises only when you are not using regularization. If you include a well-designed regularization method, then you can usually safely increase the size of the model without increasing overfitting.

Suppose you are applying deep learning, with L2 regularization or dropout, with the regularization parameter that performs best on the dev set. If you increase the model size, usually your performance will stay the same or improve; it is unlikely to worsen significantly. The only reason to avoid using a bigger model is the increased computational cost.

## 24 Bias vs. Variance tradeoff

You might have heard of the “Bias vs. Variance tradeoff.” Of the changes you could make to most learning algorithms, there are some that reduce bias errors but at the cost of increasing variance, and vice versa. This creates a “trade off” between bias and variance.

For example, increasing the size of your model—adding neurons/layers in a neural network, or adding input features—generally reduces bias but could increase variance. Alternatively, adding regularization generally increases bias but reduces variance.

In the modern era, we often have access to plentiful data and can use very large neural networks (deep learning). Therefore, there is less of a tradeoff, and there are now more options for reducing bias without hurting variance, and vice versa.

For example, you can usually increase a neural network size and tune the regularization method to reduce bias without noticeably increasing variance. By adding training data, you can also usually reduce variance without affecting bias.

If you select a model architecture that is well suited for your task, you might also reduce bias and variance simultaneously. Selecting such an architecture can be difficult.

In the next few chapters, we discuss additional specific techniques for addressing bias and variance.

## 25 Techniques for reducing avoidable bias

If your learning algorithm suffers from high avoidable bias, you might try the following techniques:

- **Increase the model size** (such as number of neurons/layers): This technique reduces bias, since it should allow you to fit the training set better. If you find that this increases variance, then use regularization, which will usually eliminate the increase in variance.
- **Modify input features based on insights from error analysis**: Say your error analysis inspires you to create additional features that help the algorithm eliminate a particular category of errors. (We discuss this further in the next chapter.) These new features could help with both bias and variance. In theory, adding more features could increase the variance; but if you find this to be the case, then use regularization, which will usually eliminate the increase in variance.
- **Reduce or eliminate regularization** (L2 regularization, L1 regularization, dropout): This will reduce avoidable bias, but increase variance.
- **Modify model architecture** (such as neural network architecture) so that it is more suitable for your problem: This technique can affect both bias and variance.

One method that is not helpful:

- **Add more training data**: This technique helps with variance problems, but it usually has no significant effect on bias.

## 26 Error analysis on the training set

Your algorithm must perform well on the training set before you can expect it to perform well on the dev/test sets.

In addition to the techniques described earlier to address high bias, I sometimes also carry out an error analysis on the *training data*, following a protocol similar to error analysis on the Eyeball dev set. This can be useful if your algorithm has high bias—i.e., if it is not fitting the training set well.

For example, suppose you are building a speech recognition system for an app and have collected a training set of audio clips from volunteers. If your system is not doing well on the training set, you might consider listening to a set of ~100 examples that the algorithm is doing poorly on to understand the major categories of training set errors. Similar to the dev set error analysis, you can count the errors in different categories:

Audio clip	Loud background noise	User spoke quickly	Far from microphone	Comments
1	✓			Car noise
2	✓		✓	Restaurant noise
3		✓	✓	User shouting across living room?
4	✓			Coffeeshop
% of total	75%	25%	50%	

In this example, you might realize that your algorithm is having a particularly hard time with training examples that have a lot of background noise. Thus, you might focus on techniques that allow it to better fit training examples with background noise.

You might also double-check whether it is possible for a person to transcribe these audio clips, given the same input audio as your learning algorithm. If there is so much background noise that it is simply impossible for anyone to make out what was said, then it might be unreasonable to expect any algorithm to correctly recognize such utterances. We will discuss the benefits of comparing your algorithm to human-level performance in a later section.

# 27 Techniques for reducing variance

If your learning algorithm suffers from high variance, you might try the following techniques:

- **Add more training data:** This is the simplest and most reliable way to address variance, so long as you have access to significantly more data and enough computational power to process the data.
- **Add regularization** (L2 regularization, L1 regularization, dropout): This technique reduces variance but increases bias.
- **Add early stopping** (i.e., stop gradient descent early, based on dev set error): This technique reduces variance but increases bias. Early stopping behaves a lot like regularization methods, and some authors call it a regularization technique.
- **Feature selection to decrease number/type of input features:** This technique might help with variance problems, but it might also increase bias. Reducing the number of features slightly (say going from 1,000 features to 900) is unlikely to have a huge effect on bias. Reducing it significantly (say going from 1,000 features to 100—a 10x reduction) is more likely to have a significant effect, so long as you are not excluding too many useful features. In modern deep learning, when data is plentiful, there has been a shift away from feature selection, and we are now more likely to give all the features we have to the algorithm and let the algorithm sort out which ones to use based on the data. But when your training set is small, feature selection can be very useful.
- **Decrease the model size** (such as number of neurons/layers): *Use with caution.* This technique could decrease variance, while possibly increasing bias. However, I don't recommend this technique for addressing variance. Adding regularization usually gives better classification performance. The advantage of reducing the model size is reducing your computational cost and thus speeding up how quickly you can train models. If speeding up model training is useful, then by all means consider decreasing the model size. But if your goal is to reduce variance, and you are not concerned about the computational cost, consider adding regularization instead.

Here are two additional tactics, repeated from the previous chapter on addressing bias:

- **Modify input features based on insights from error analysis:** Say your error analysis inspires you to create additional features that help the algorithm to eliminate a particular category of errors. These new features could help with both bias and variance. In

theory, adding more features could increase the variance; but if you find this to be the case, then use regularization, which will usually eliminate the increase in variance.

- **Modify model architecture** (such as neural network architecture) so that it is more suitable for your problem: This technique can affect both bias and variance.