MACHINE LEARNING

WHAT IS MACHINE LEARNING?

Machine Learning (ML) is a sub-field of Artificial Intelligence (AI) which concerns with developing computational theories of learning and building learning machines. The goal of machine learning, closely coupled with the goal of AI, is to achieve a thorough understanding about the nature of learning process (both human learning and other forms of learning), about the computational aspects of learning behaviors, and to implant the learning capability in computer systems. Machine learning has been recognized as central to the success of Artificial Intelligence, and it has applications in various areas of science, engineering and society.

Before we talk about *machine* learning, it would be useful to discuss the issue "what is learning". Learning is a phenomenon and process which has manifestations of various aspects. Roughly speaking, learning process includes (one or more of) the following:

(1) Acquisition of new (symbolic) knowledge. For example, learning mathematics is this kind of learning. When we say someone has learned math, we mean that the learner obtained descriptions of the mathematical concepts, understood their meaning and their relationship with each other. The effect of learning is that the learner has acquired knowledge of mathematical systems and their properties, and that the learner can use this knowledge to solve math problems. Thus this kind of learning is characterized as obtaining new symbolic information plus the ability to apply that information effectively.

(2) Development of motor or cognitive skills through instruction and practice. Examples of this kind of learning are learning to ride a bicycle, to swim, to play piano, etc. This kind of learning is also called *skill refinement*. In this case, just acquiring a symbolic description of the rules to perform the task is not sufficient, repeated practice is needed for the learner to obtain the skill. Skill refinement takes place at the subconscious level.

(3) Refinement and organization of knowledge into more effective representations or more useful form. One example of this kind of learning can be reorganization of the rules in a knowledge base such that more important rules are given higher priorities so that they can be used more easily and conveniently.

(4) Discovery of new facts and theories through observation and experiment. For example, the discovery of physics and chemistry laws.

The general effect of learning in a system is the improvement of the system's capability to solve problems. It is hard to imagine a system capable of learning cannot improve its problem-solving performance. A system with learning capability should be able to do self-changing in order to perform better in its future problem-solving.

We also note that **learning can not take place in isolation**: We typically learn something (knowledge K) to perform some tasks (T), through some experience E, and whether we have learned well or not will be judged by some performance criteria P at the task T. For example, as Tom Mitchell put it in his ML book, for the "checkers learning problem", the task T is to play the game of checkers, the performance criteria P could be the percentage of games won against opponents, and the experience E could be in the form playing practice games with a teacher (or self). For learning to take place, we do need a learning algorithm A for self-changing, which allows the learner to get experience E in the task T, and acquire knowledge K (thus change the learner's knowledge set) to improve the learner's performance at task T.

Learning = Improving performance P at task T by acquiring knowledge K using self-changing algorithm A through experience E in an environment for task T.

$$Learning involves \begin{cases} T: \ Task\ in\ an\ environment \\ E: Experience\ in\ T \\ P: performance\ criteria \\ K: Knowledge\ acquired \\ A: Algorithm \text{ for } self - changing \end{cases}$$

There are various forms of improvement of a system's problem-solving ability:

(1) To solve wider range of problems than before - perform generalization.
(2) To solve the same problem more effectively - give better quality solutions.
(3) To solve the same problem more efficiently - faster.

There are other view points as to what constitutes the notion of learning. For example, Minsky gives a more general definition,

"Learning is making useful changes in our minds".

And McCarthy suggests,

"Learning is constructing or modifying representations of what is being experienced."

From this perspective, the central aspect of learning is acquisition of certain forms of representation of some reality, rather than the improvement of performance. However, since it is in general much easier to observe a system's performance behavior than its internal representation of reality, we usually link the learning behavior with the improvement of the the system's performance.

Now that we have a basic discussion of what is learning, we can proceed to consider the notion of *machine learning.* What is the main focus of machine learning research versus the general study of learning behavior? What are the goals of machine learning research? These are the questions we will try to answer now.

The main focus of machine learning is to study the *computational aspect* of learning process and to construct machines that are capable of learning (via computation). We need not only to build computational models of learning, but also design and implement efficient learning algorithms according to such computational models. Of course the study of cognitive aspect of learning is important to machine learning, however, the computational aspect of learning is of central significance.

WHY MACHINE LEARNING?

To answer this question, we should look at two issues:

(1). What are the goals of machine learning;

(2). Why these goals are important and desirable.

The Goals of Machine Learning.

The goal of ML, in simples words, is to understand the nature of (human and other forms of) learning, and to build learning capability in computers. To be more specific, there are three aspects of the goals of ML.

(1) To make the computers smarter, more intelligent. The more direct objective in this aspect is to develop systems (programs) for specific practical learning tasks in application domains.

(2) To develop computational models of human learning process and perform computer simulations. The study in this aspect is also called *cognitive modeling*.

(3) To explore new learning methods and develop general learning algorithms independent of applications.

Why the goals of ML are important and desirable.

It is self-evident that the goals of ML are important and desirable. However, we still give some more supporting argument to this issue. First of all, implanting learning ability in computers is practically necessary. Present day computer applications require the representation of huge amount of complex knowledge and data in programs and thus require tremendous amount of work. Our ability to code the computers falls short of the demand for applications. If the computers are endowed with the learning ability, then our burden of coding the machine is eased (or at least reduced). This is particularly true for developing expert systems where the "bottle-neck" is to extract the expert's knowledge and feed the knowledge to computers. The present day computer programs in general (with the exception of some ML programs) cannot correct their own errors or improve from past mistakes, or learn to perform a new task by analogy to a previously seen task. In contrast, human beings are capable of all the above. ML will produce smarter computers capable of all the above intelligent behavior.

Second, the understanding of human learning and its computational aspect is a worthy scientific goal. We human beings have long been fascinated by our capabilities of intelligent behaviors and have been trying to understand the nature of intelligence. It is clear that central to our intelligence is our ability to learn. Thus a thorough understanding of human learning process is crucial to understand human intelligence. ML will gain us the insight into the underlying principles of human learning and that may lead to the discovery of more effective education techniques. It will also contribute to the design of machine learning systems.

Finally, it is desirable to explore alternative learning mechanisms in the space of all possible learning methods. There is no reason to believe that the way human being learns is the only possible mechanism of learning. It is worthy exploring other methods of learning which may be more efficient, effective than human learning.

We remark that Machine Learning has become feasible in many important applications (and hence the popularity of the field) partly because the recent progress in learning algorithms and theory, the rapidly increase of computational power, the great availability of huge amount of data, and interests in commercial ML application development.

Moreover we note that ML is inherently a multi-disciplinary subject area.

We compare the human learning with machine learning along the dimensions of speed, ability to transfer, and others. which shows that machine learning is both an opportunity and challenge, in the sense that we can hope to discover ways for machine to learn which are better than ways human learn (the opportunity), and that there are amply amount of difficulties to be overcome in order to make machines learn (the challenge).

Dimension	Human Learning	Machine Learning
Speed	Slow	Slow - hope to find tricks for machine to learn fast
Ability to transfer	No copy mechanism	Easy to copy
Require repetition	Yes	Yes/No
Error-prone	Yes	Yes
Noise-tolerant	Yes	No