

Imagine an airplane flying one millimetre above the ground and circling the Earth once every 25 seconds while counting every blade of grass.

Shrink all that down so that it fits in the palm of your hand, and you'd have something equivalent to a modern hard drive, an object that can likely hold more information than your local library.

So how does it store so much information in such a small space?

At the heart of every hard drive is a stack of high-speed spinning discs with a recording head flying over each surface.

Each disc is coated with a film of microscopic magnetised metal grains, and your data doesn't live there in a form you can recognize. Instead, it is recorded as a magnetic pattern formed by groups of those tiny grains. In each group, also known as a bit, all of the grains have their magnetizations aligned in one of two possible states, which correspond to zeroes and ones. Data is written onto the disc by converting strings of bits into electrical current fed through an electromagnet.

This magnet generates a field strong enough to change the direction of the metal grain's magnetization.

Once this information is written onto the disc, the drive uses a magnetic reader to turn it back into a useful form, much like a phonograph needle translates a record's grooves into music. But how can you get so much information out of just zeroes and ones?

Well, by putting lots of them together. For example, a letter is represented in one byte, or eight bits, and your average photo takes up several megabytes, each of which is 8 million bits. Because each bit must be written onto a physical area of the disc, we're always seeking to increase the disc's areal density, or how many bits can be squeezed into one square inch.

The areal density of a modern hard drive is about 600 gigabits per square inch, 300 million times greater than that of IBM's first hard drive from 1957. This amazing advance in storage capacity wasn't just a matter of making everything smaller, but involved multiple innovations. A technique called the thin film lithography process allowed engineers to shrink the reader and writer. And despite its size, the reader became more sensitive by taking advantage of new discoveries in magnetic and quantum properties of matter. Bits could also be packed closer together thanks to mathematical algorithms that filter out noise from magnetic interference, and find the most likely bit sequences from each chunk of read-back signal.

And thermal expansion control of the head, enabled by placing a heater under the magnetic writer, allowed it to fly less than five nanometres above the disc's surface, about the width of two strands of DNA. For the past several decades, the exponential growth in computer storage capacity and processing power has followed a pattern known as Moore's Law, which, in 1975, predicted that information density would double every two years. But at around 100 gigabits per square inch, shrinking the magnetic grains further or cramming them closer together posed a new risk called the superparamagnetic effect. When a magnetic grain volume is too small, its magnetization is easily disturbed by heat energy and can cause bits to switch unintentionally, leading to data loss.

Scientists resolved this limitation in a remarkably simple way: by changing the direction of recording from longitudinal to perpendicular, allowing areal density to approach one terabit per square inch. Recently, the potential limit has been increased yet again through heat assisted magnetic recording. This uses an even more thermally stable recording medium, whose magnetic resistance is momentarily reduced by heating up a particular spot with a laser and allowing data to be written. And while those drives are currently in the prototype stage, scientists already have the next potential trick up their sleeves: bit-patterned media, where bit locations are arranged in separate, nano-sized structures, potentially allowing for areal densities of twenty terabits per square inch or more. So, it's thanks to the combined efforts of generations of engineers, material scientists, and quantum physicists that this tool of incredible power and precision can spin in the palm of your hand.

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