Twitter Thread by foone

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A fun fact on the wikipedia page for the metal–oxide–semiconductor field-effect transistor:
it is the most frequently manufactured device in history, and the total number manufactured from 1960-2018 is 13 sextillion.

That's 13,000,000,000,000,000,000,000.

Though this picture is a bit misleading.

Even with devices this small, we couldn't make 13 sextillion of them in 60 years.

So imagine a chip like this. It's the 555 timer, which is one of the most popular integrated circuits ever made.

In 2017, it was estimated a billion are made every year.

And at the heart of it is the die, which looks like this:
(from Ken Shirriff's blog)
https://t.co/mz5PQDjYqF

And that's fundamentally a bunch of CMOS transistors (along with some diodes and resistors), which are a type of MOSFET. How many of them are on a 555?

about 25. Not many, but it's a very simple chip.

so that's a 25 billion mosfets a year right there, on one very simple chip designed back in 1971.

So how do you get to 13 sextillion?
Simple: Modern CPUs have a fuckton of these.

Like... The Nintendo Switch! It's powered by a Nvidia Tegra X1.
There's no specs on that specific chip that I can see, but the Tegra Xavier (Which is effectively the Tegra X3) has 7 billion

transistors.

And Nintendo has sold something like 70 million Switches.
So even if the X1 only has 1/7th as many transistors as the Xavier, that's still 70 quadrillion transistors.

And you wanna know the funny part?

That's a rounding error. The CPU/GPU chip is only a small percentage of the number of transistors in the Switch.

and you might think AHA! THE SCREEN!

One way to make LCDs is with Thin-film transistors, where there's actually a transparent MOSFET layer which each individual subpixel has a transistors.

and with 1280x720 pixels and 3 colors, that's... only about 3 million transistors.

So it's not the screen.

So one of the most important developments in electronics was the floating-gate MOSFET, discovered in the late 60s.
This is where you build a MOSFET where instead of acting like a switch, the gate electrically isolated, and doesn't easily change.

You use the lovely sounding "hot-carrier injection" to charge up the gate. This is where you basically overpower insulation around the gate, allowing some electrons to force their way through.

Then you use a quantum-mechanical effect called field electron emission to read the data back out.

Basically you can run a current through the mosfet, and based on if it was charged or not, it'll have a different threshold voltage.

The problem is that to write back to this floating-gate MOSFET, you need a lot more electricity to cause it to breakdown the isolation temporarily and let the charge leak out. This damages it over time and results in a limited lifespan...

But the effect where you run a lot of current through it and it reaches a level that causes the isolation to break down and suddenly the charge all leaks out at once... it reminded someone of a camera flash.

So this type of data storage was called "Flash memory".

And it's taken over the world in the 41 years since it was invented.

But here's the thing about flash memory:
You need at minimum one MOSFET for every single bit you store, plus a bunch more to handle addressing and writing and erasing and controlling.

And back to the Nintendo Switch: It's got 32 gigabytes of built in storage.
That's not a lot. Your computer or phone probably has at least 4 times that much.

But how many transistors is 32gb of flash?

Somewhere around 35 billion.

It's also got 4 gigabytes of (D)RAM.

So that's another 4 billion transistors.

But yeah, add all those together, plus any secondary chips on the Switch, and it's gonna be something like 50-100 billion transistors.
And Nintendo has sold 70 million of those.

So now think about how many desktop computers there are, and how many phones, and how many smart devices (anything smarter than a toaster)...

So you may now see how we have made 13 SEXTILLION MOSFETS

(BTW my explanation for how flash works is overly simplified: modern flash uses MLC tech, where instead of just storing one bit per MOSFET, multiple bits can be encoded by using different levels of charge)