Semiconductors and Intel

An introduction

intel®

Semiconductors and Intel

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What is a semiconductor?

Semiconductors are essential for the operation of all modern electronic devices

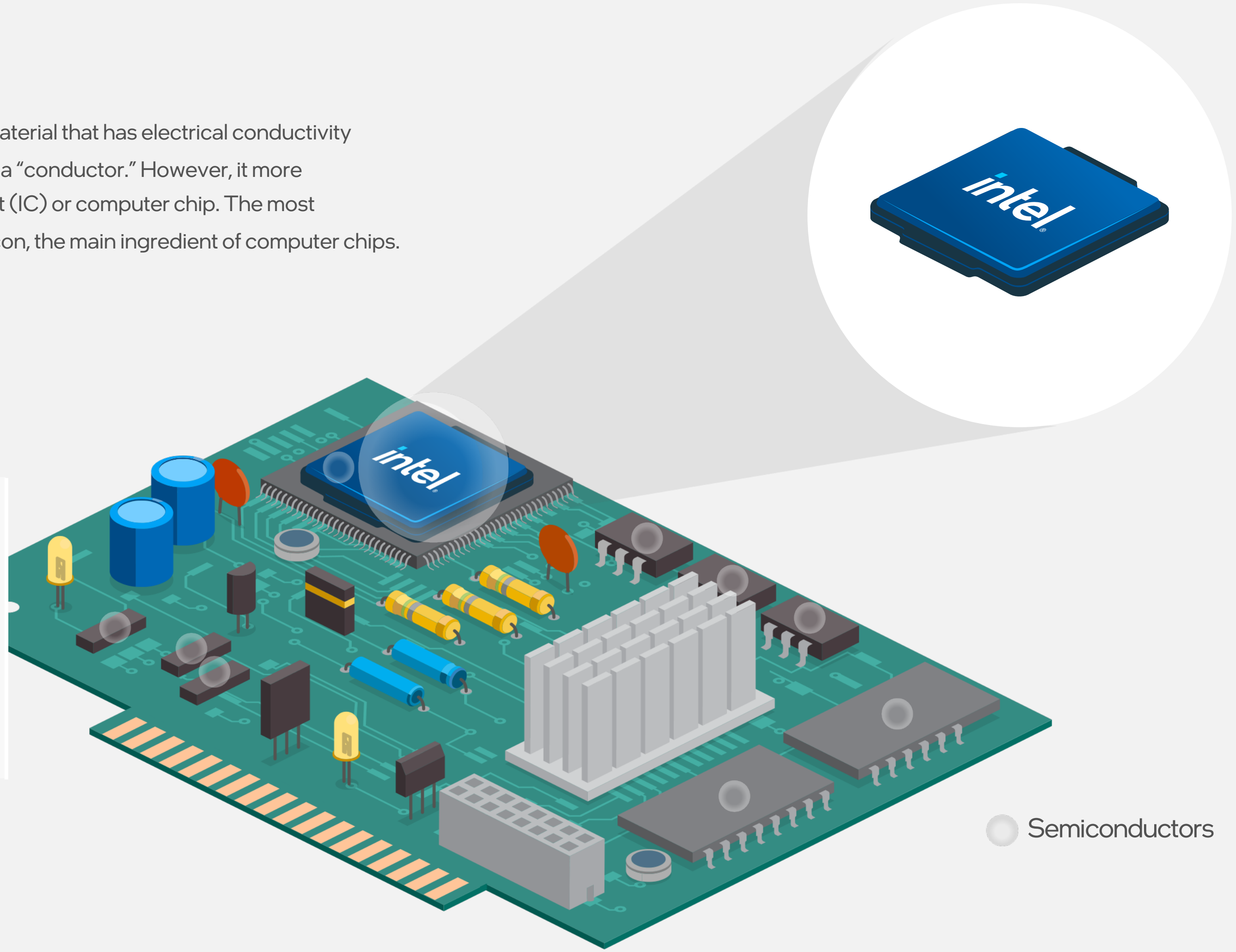
The semiconductor

The term "semiconductor" refers to a material that has electrical conductivity greater than an "insulator" but less than a "conductor." However, it more commonly refers to an integrated circuit (IC) or computer chip. The most common semiconductor material is silicon, the main ingredient of computer chips.

Did you know?

Semiconductors are the critical ingredient of computer chips, which are built for many functions. **This motherboard is showing at least eight of them** (the CPU, chipset, memory, storage, BIOS, and input/output chips).

Functions of semiconductors might include the amplification of signals, switching and energy conversion.



Semiconductors are everywhere

Quick **tip**

Semiconductors are the foundation of modern technology. Billions of connected devices on the planet would not function without them. Semiconductors are probably **the most complex products manufactured in the world,** yet they're often as small as a fingernail. They are packed with billions of microscopic switches, called "transistors," that make them work.

Communications

- Digital cameras
- Radios
- Scanners
- Smartphones
- Televisions
- Watches/clocks

Computing

- Computers/laptops
- XPUs
- Diodes
- Microcontrollers
- RF Transmitters
- Wireless HD video

Consumer/IoT

- ATMs
- Smoke detectors
- Internet
- Refrigerators
- Coffee makers
- Video games
- Washing machines

Healthcare

- Blood-pressure sensors
- Hearing aids
- MRIs
- Pacemakers
- Ultrasound modules
- Wireless patient monitors

Smart Energy

- A/C temp sensors
- Efficient logistics systems
- LED light bulbs
- Monitoring systems
- Security devices
- Smart home systems
- Solar panels

Transportation

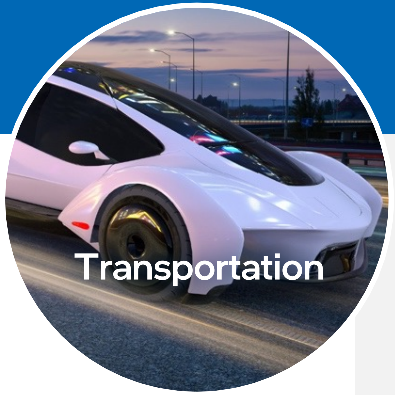
- Advanced driver assistance systems
- Diagnostic equipment
- Mapping/Sensing
- Navigation systems

1. http://www.semismatter.com/

Why are semiconductors so important?

Quick tip

The average American adult spends **over 12 hours a day** on electronics, such as computers, mobile devices, TVs and cars. Those devices are **all powered by semiconductors**, which improve our lives, increase productivity and drive economic growth.



$10-15B

The approximate cost to build a new semiconductor factory or "fab"

>6 AMERICAN FOOTBALL FIELDS

Nearly the size of the world's largest semiconductor fab

12K

The number of construction, high-tech & support jobs a semiconductor fab typically creates

+$440B

2020 revenue from the global semiconductor industry

The exponential computer

From a few in the world to many per person

1960s Mainframe Era
1 computer
1000s of users

1980s Desktop/PC Era
1 computer
1 user

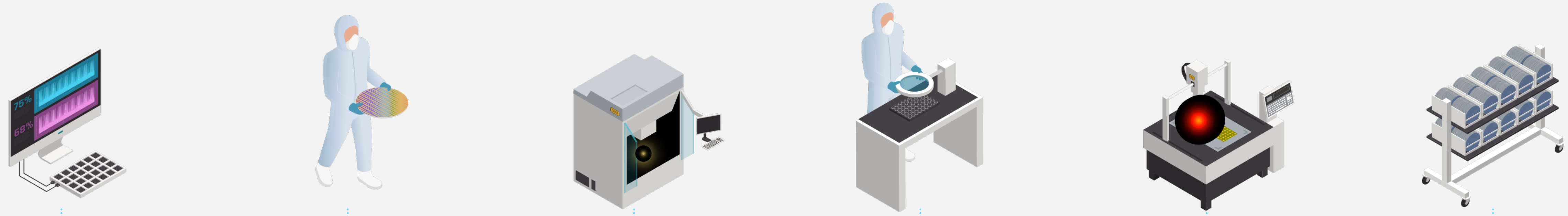
2000s Mobility Era
Several computers
1 user

2020s Ubiquity Era
1000s of computers
1 user

How chips are made

A computer chip's journey begins with research

Engineers and scientists from companies and academia develop revolutionary processing and packaging technologies



1

Design

Chip architects, logic designers and circuit designers create computerized drawings (blueprints).

2

Mask Ops

Engineers take the digital blueprints and convert them into glass templates, called masks, which are used in fabrication for photolithography, or "printing with light."

3

Fabrication

Technicians in bunny suits use a multitude of machines to create layers of circuits and devices on silicon wafers. Each wafer will contain hundreds of chips.

4

Die & Sort

Finished wafers get cut into dies (or computer chips) and placed on reels.

5

Test & Assembly

Technicians test each die one last time, then mount them between a heat spreader and a substrate to form a sleek, enclosed package.

6

Warehousing

Logistics professionals ship out chips to customers or global distribution hubs to be sent to manufacturers or boxed up for retail.

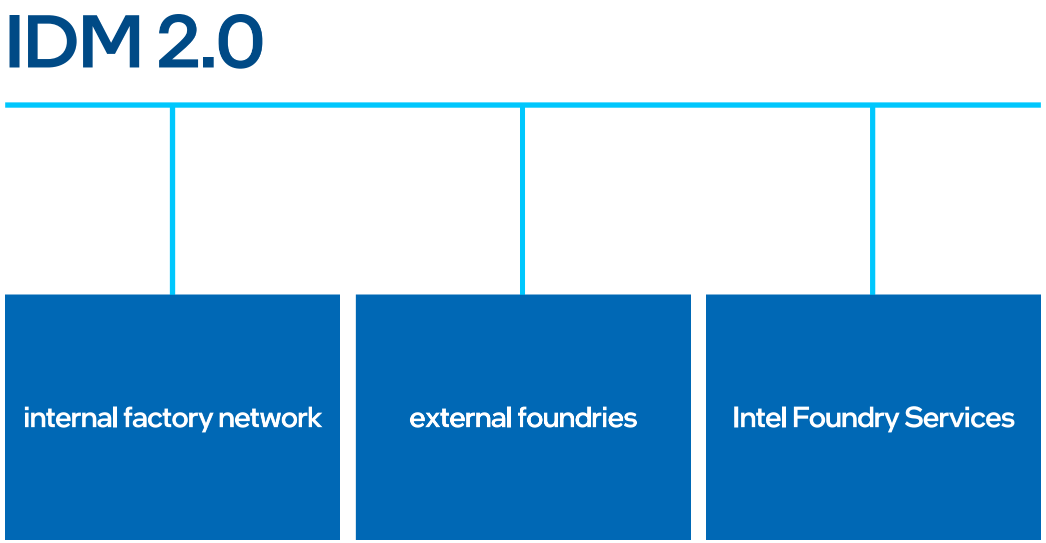
Foundries, Intel and IDM 2.0

Typically, semiconductor manufacturers are either:

- **Integrated device manufacturers (IDM)** that design, build and sell their own chips; or
- **Foundries** that build chips for "fabless" customers that design, brand and sell them

Intel is different. Its **IDM 2.0 strategy** combines:

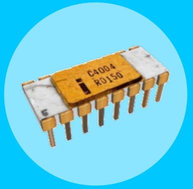
- Intel's **internal factory network** to build most of its products
- The use of **external foundries** for flexibility, scale and cost
- **Intel Foundry Services,** a new group dedicated to manufacturing for customers



Quick **tip**

Intel's first microprocessor, the 4004, had 2,300 transistors in 1971.

Today's have billions. Every process "node" (e.g., 22nm, 14 nm, Intel 7, Intel 4) means improvements in power, performance, area and/or other features.

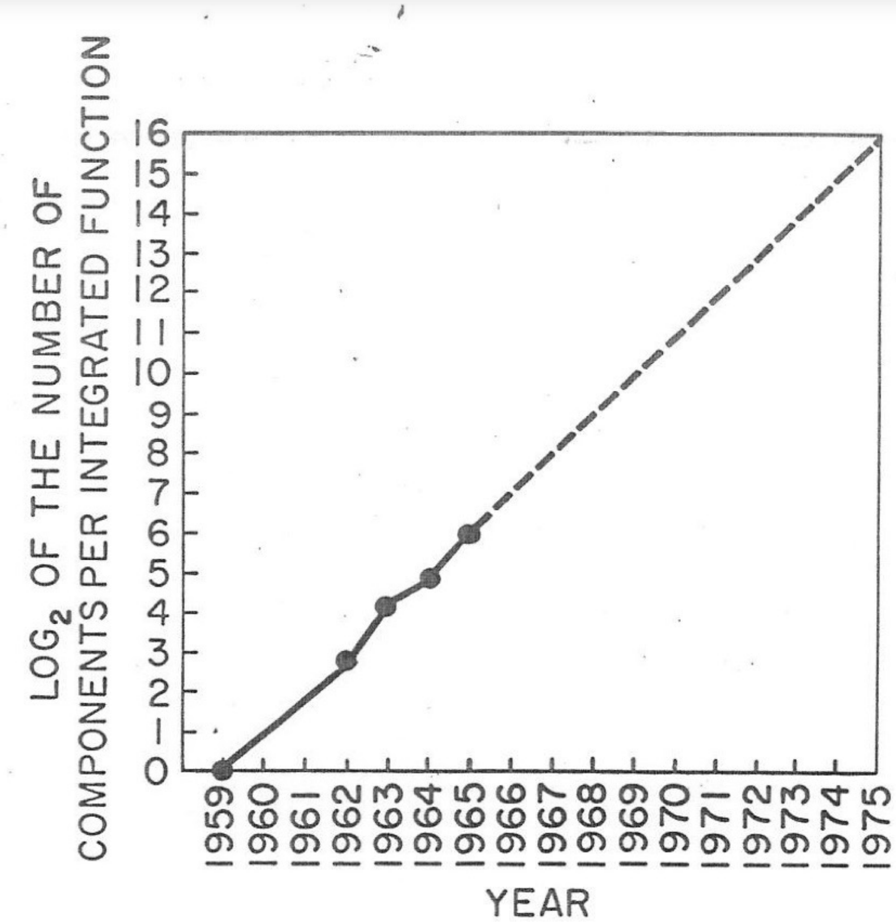


Moore's Law and what it means

Moore's Law was an observation of increasing economic efficiency

In 1965, Gordon Moore made what he later called **"a wild extrapolation of very little data"** that the number of components per integrated circuit would keep doubling annually (revised later to biannually).

Intel co-founder **Gordon Moore**



Why are process nodes important?

The result of each new process node can include:

Quick **tip**

A note on node names: Intel introduced a simple and clear naming structure for its process nodes in 2021, one that no longer refers to nanometers. New names include Intel 7, Intel 4, Intel 3, and Intel 20A, ushering in the angstrom era of semiconductors.

1

Denser components

Existing functional blocks (IPs) use less silicon area

Many options for better chips:

- **Multiply IPs** (more throughput)
- **Add new IPs** (new features and capabilities)
- **A smaller overall chip** (lower cost)

2

More power-efficient and quicker operation, and/or

3

More dynamic range (efficient at idle, faster at full throttle)

Packaging: protect, connect and re-architect

This Intel processor shows the silicon die at center, which would be attached to the substrate (left) and covered with a heatspreader (right). The combined enclosure is called the "package." It connects micron-sized features on the die to millimeter-sized features on a computer's motherboard, protects the die from contaminants, cools it, powers it, and increasingly, allows multiple die to be combined in novel ways.

The package

Packaging: protect, connect and re-architect

New packaging technologies allow the combination of myriad die into “systems in packages,” enabling more design and performance flexibility — leading to entirely new kinds of chips, like the powerful Ponte Vecchio GPU.

Intel is a world leader in advanced packaging development and manufacturing.

Quick **tip**

Intel EMIB very efficiently connects two die sitting side-by-side. Intel’s **Foveros technology** allows vertical stacking of processor die for the first time.

Advanced packaging enables new era of chip design

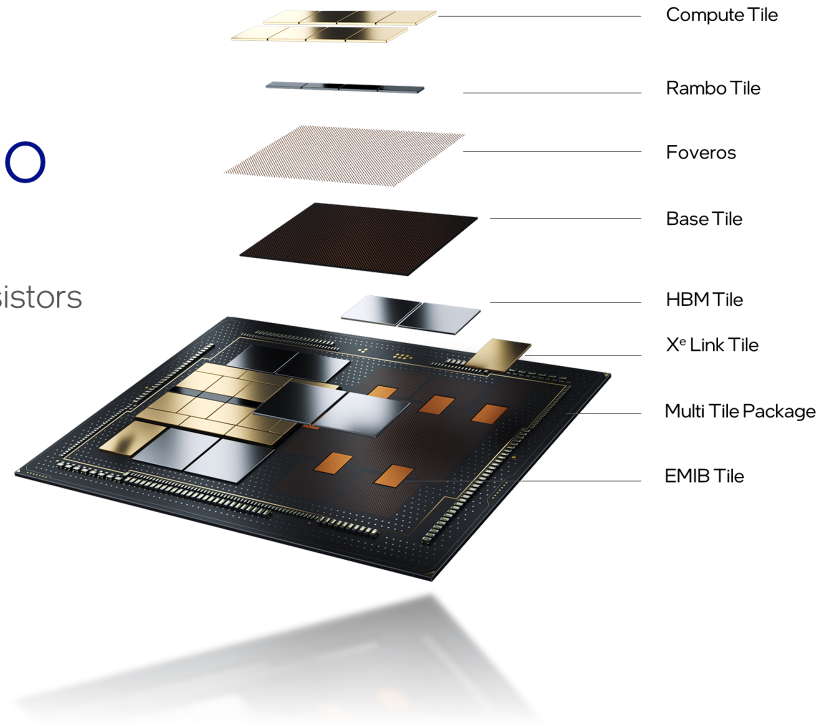
Ponte Vecchio

SOC

>100 Billion Transistors

47 Active Tiles

5 Process Nodes



Process versus microarchitecture

Think of a chip as a multistory urban building

Quick **tip**

Chip as tiny skyscraper: A common chip the size of your smallest fingernail is only around 1 millimeter thick but contains roughly 30 different layers of components and wires (called interconnects) that make up its complex circuitry.

Microarchitectures are blueprints; they convey what to build

- A **microarchitecture** represents a specific design, a single, unique building. An **architecture** comprises a family of buildings based on a unifying theme.
- Example: **Willow Cove** and **Goldmont** are CPU **microarchitectures**; both use Intel Architecture.

Process technologies are construction techniques

- How you take raw materials and create a building.
- Each new **node** is a refinement in process technology — new and better ways to build new and better buildings.

Major processor architectures

What Intel defines as XPUs

Quick **tip**

CPU architectures

X86: mobile device to supercomputer cores from Intel and AMD

ARM: a large span of processors for license or customization

RISC-V: open-source processor design

CPU

Central processing unit
(the brain of the computer)

What do they do:
Run the computer and all its programs

Major suppliers:
Intel, AMD, ARM
(Apple, Qualcomm, Samsung)

GPU

Graphics processing unit

What do they do:
Make images; accelerate highly parallel operations

Major suppliers:
Intel, AMD, Nvidia, ARM, Imagination

FPGA

Field-programmable gate array; software-configurable circuits

What do they do:
Acceleration, communications, circuit design, applications that change often

Major suppliers:
Intel, Xilinx

ASIC

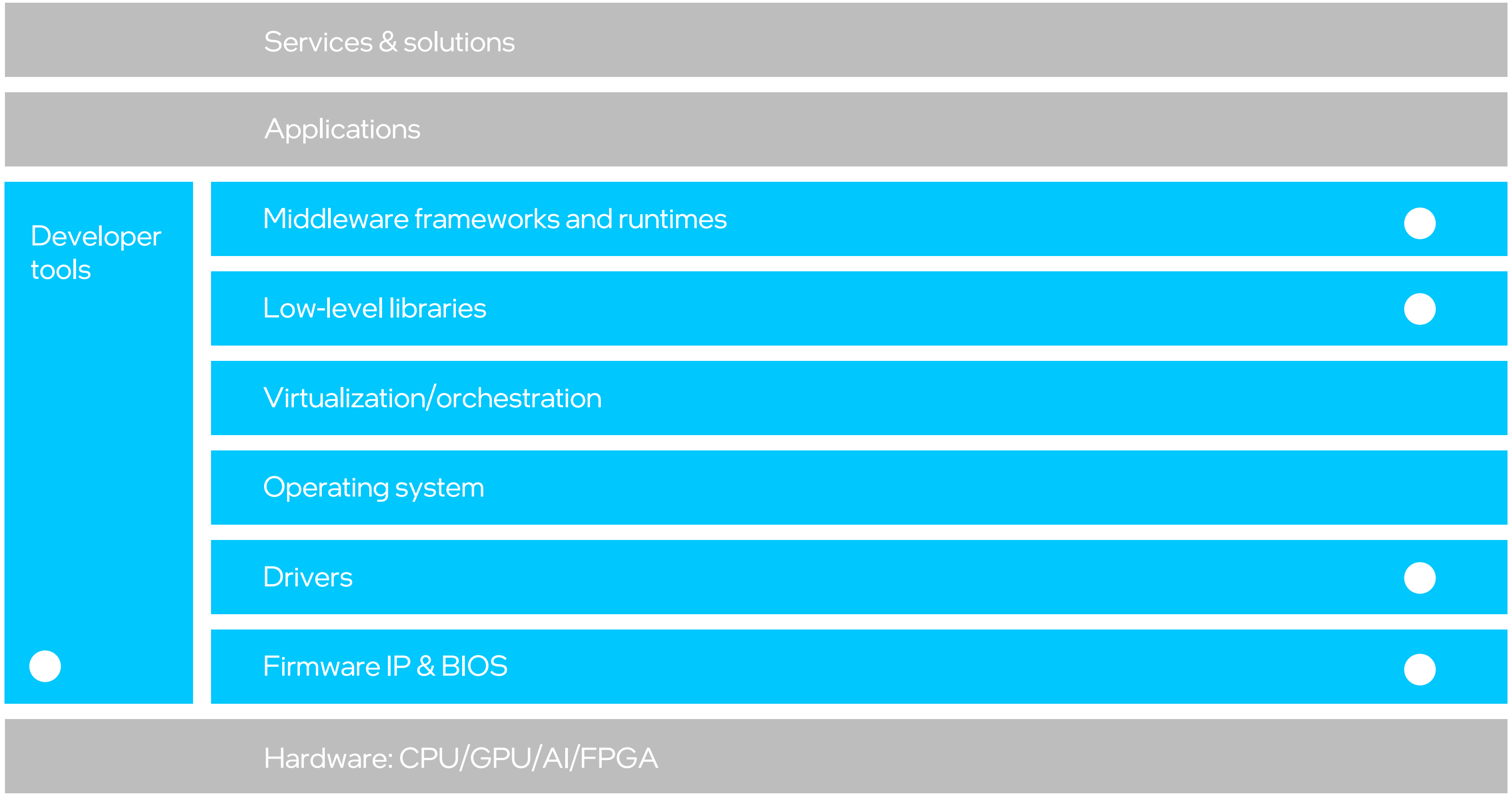
Application-specific integrated circuit

What do they do:
Do one thing, very quickly: deep learning, encryption, network processing

Major suppliers:
Many and varied (including Intel)

Modern chips require a lot of software

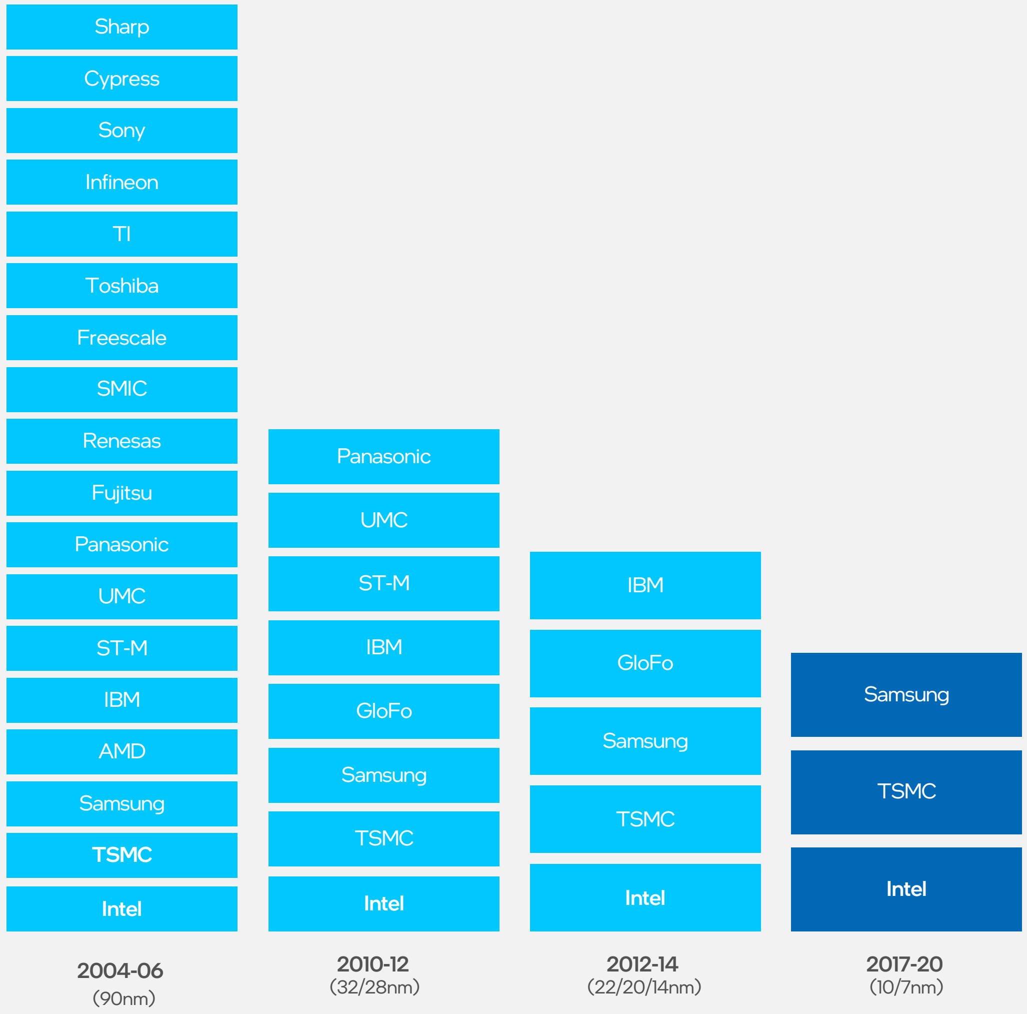
"For every order of magnitude performance potential from new hardware architecture, there is often more than 2 orders of magnitude unlocked by software." – Raja Koduri, Accelerated Computing Systems and Graphics (AXG) Group at Intel

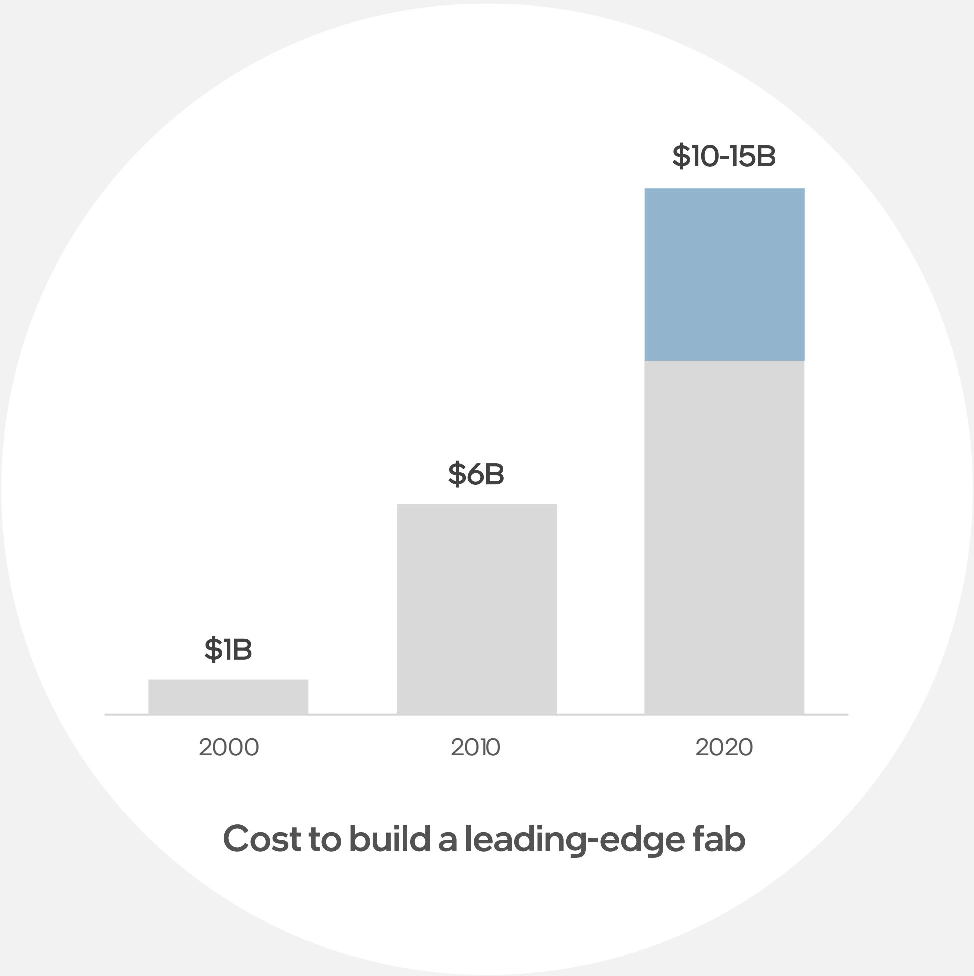


○ Software supplied by Intel for developers and customers

The high cost of manufacturing drives industry consolidation

Staying on the leading edge became unaffordable for all but the three largest companies





Semiconductors take a global path to production

And a lot of partnership

Quick tip

As the complexity and number of components in leading-edge chips have increased, so has the amount of time it takes to make them — **in some cases more than 3 months.**

Conceptual map flow:
(for illustrative purposes only)

Intel partners with thousands of innovative companies around the world to bring semiconductors to market, from raw materials to logistics and construction, including:

Front-end equipment		Front-end materials		Back end			Design		Other partners	
Process equipment	Process control	Materials	Silicon	Assembly equipment	Test equipment	Substrates	EDA/IP	Contract workers	Memory	Factory construction

Intel's history in 4 fast eras

1968-1984

The definitive Silicon Valley startup

1968: Intel founded with $3M

1969: First product, first customer

1971: Microprocessor invented

1976: Microcontroller invented

1981: IBM puts Intel 8088 in first PC

1983: Intel reaches $1B revenue

1984: First CHMOS DRAM, up to 64K

1985-1995

A logical exit from memory

1985: Intel exits DRAM, debuts 386 processor

1988: Intel enters flash memory

1991: Intel Inside logos appear worldwide; Intel breaks supercomputing record

1992: Intel becomes world's largest semiconductor company

1993: Pentium processor

1995: Pentium Pro launched for servers

1996-2014

One billion computers

1997: Iconic bunny people debut in ads

1998: Intel Celeron debuts

2000: Pentium 4; revenue surpasses $30B

2001: First Xeon chips for servers

2002: Hyperthreading introduced

2003: Intel Centrino makes Wi-Fi common; Intel ships billionth processor

2005: Multicore processors

2008: Intel Atom processor

2011: First 3-D transistor; Thunderbolt introduced

2013: Intel NUC mini PCs debut

2015-

XPUs and a new era of data

2015: $300M diversity and inclusion initiative; Intel acquires Altera

2016: Silicon photonics ship

2017: Intel acquires Mobileye; first product with EMIB packaging ships

2018: Employees contribute 1.5M volunteer hours for 50th anniversary; revenue crosses $70B

2020: Xe discrete graphics; first 3-D stacked processor

2021: Intel introduces IDM 2.0

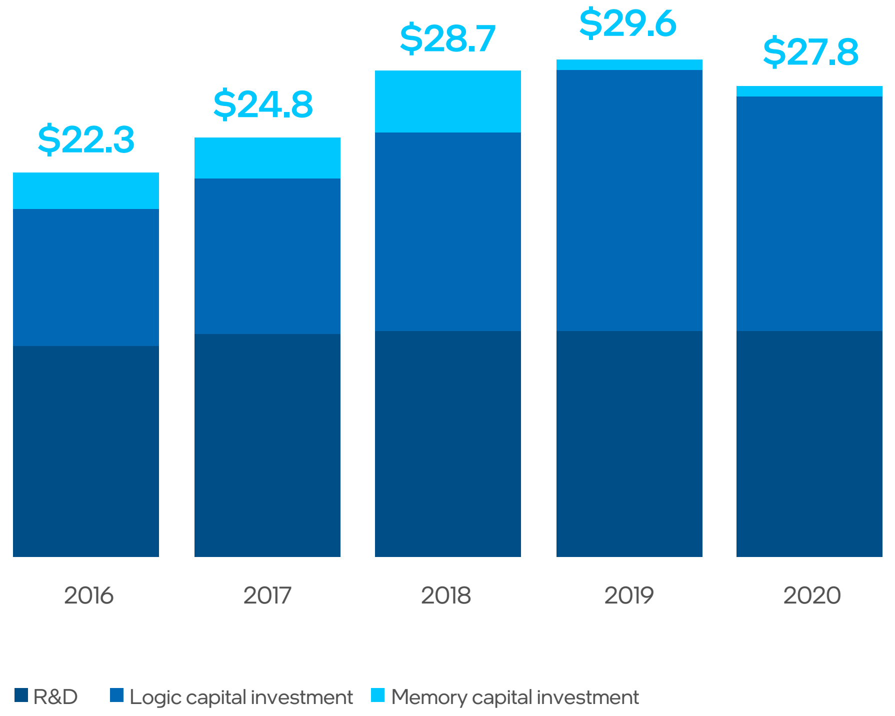
Intel invests in future technology and factories to build it

Intel invests in research and development primarily for future process technologies and the PC and data-centric businesses, while also making capital investments in manufacturing and wafer capacity.

Quick **tip**

In the U.S., only the biotech and pharma industry spends more on R&D as a percent of sales than the semiconductor industry.

R&D and capital investments
(in billions)

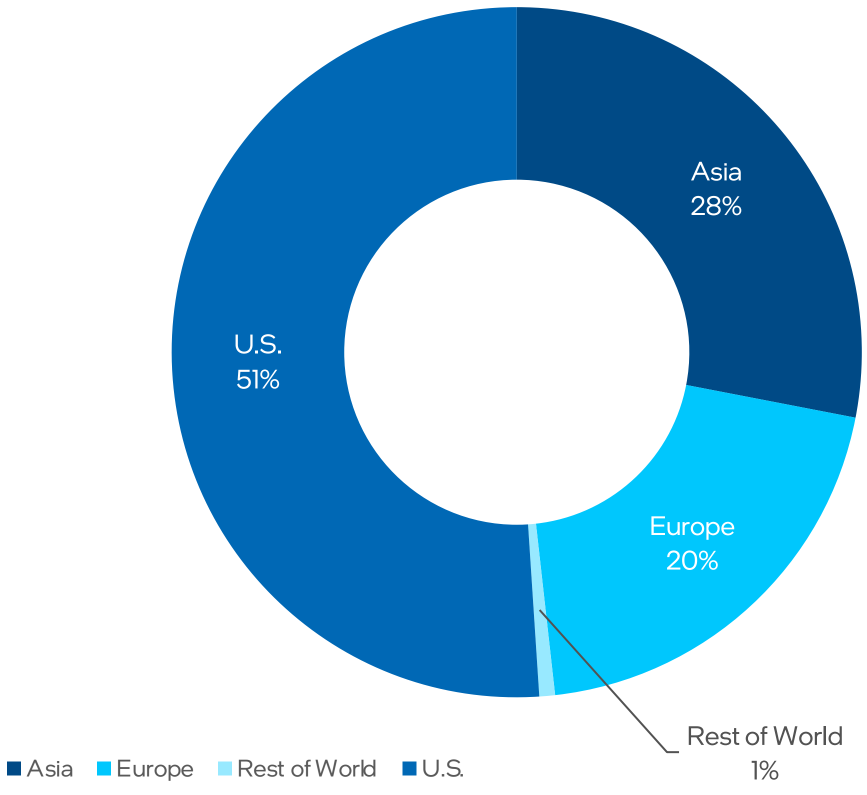


Quick **tip**

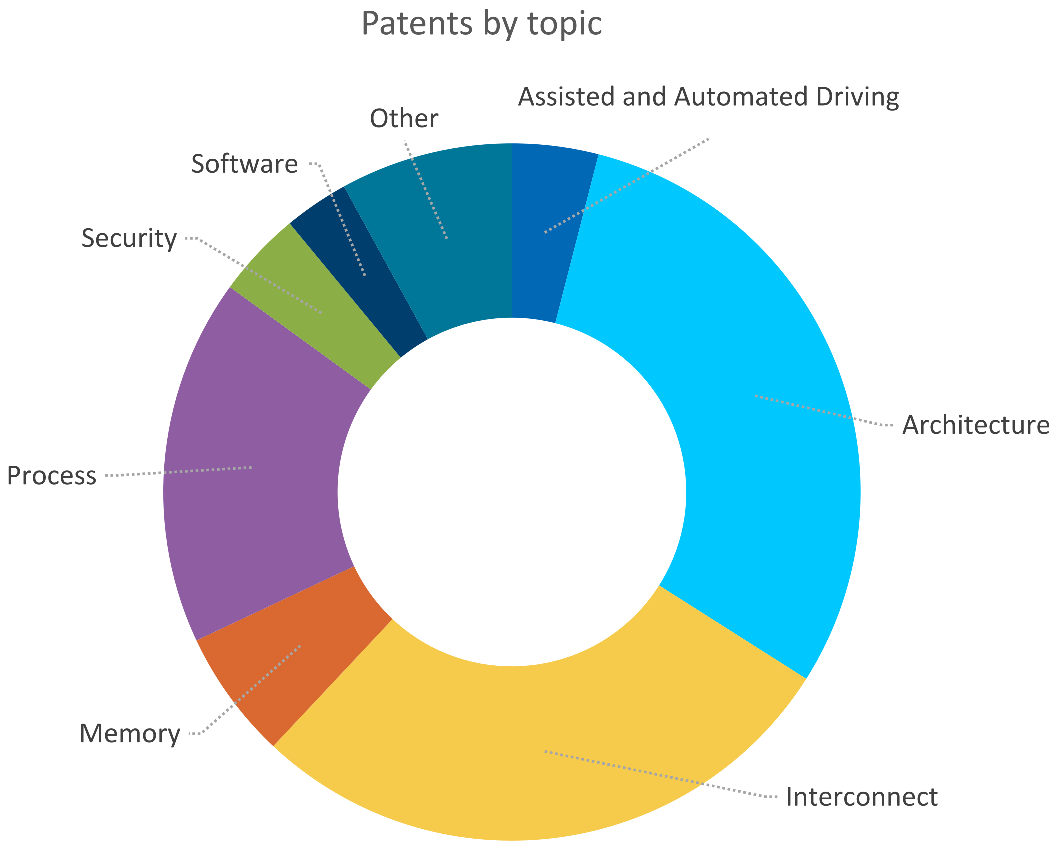
Intel's first patent — "Resistor for Integrated Circuit," #3,631,313 — was granted to Gordon Moore on Dec. 28, 1971.

Intel owns nearly 70,000 active patents worldwide

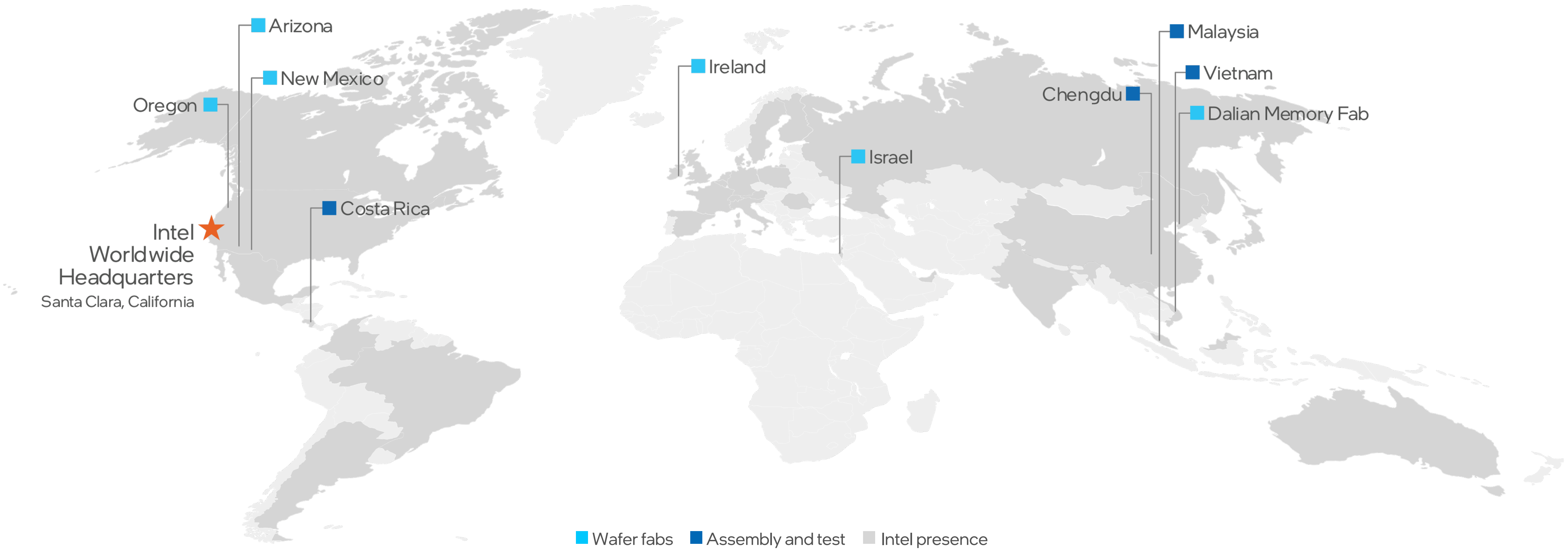
Intel patents by region



Intel invents across an unmatched span of technologies



Intel's global manufacturing footprint



Glossary

Assembly/test: The second half of chip manufacturing, where bare silicon die are encased in a protective package and undergo final inspection; also refers to factories dedicated to this function.

Chip: A tiny, thin square or rectangle that contains integrated electronic circuitry. A chip contains one or more die, which are built in batches on wafers of silicon.

Die: A single integrated circuit cut from a wafer after fabrication.

Fab: A factory that performs the first half of silicon chip manufacturing (fabrication), where bare silicon wafers undergo weeks of processing to become integrated circuits.

Foundry: A silicon fabrication business (TSMC, Global Foundries) that offers manufacturing as a service to outside chip design companies, which are referred to as "fabless semiconductor companies" (AMD, Nvidia); contrasts with an IDM (Intel, Samsung).

Integrated circuit: A semiconductor device that includes many transistors and electrical circuits, designed to perform one or many functions.

Integrated device manufacturer or IDM: Company that both designs and manufactures silicon chips, such as Intel and Samsung.

Intellectual property or IP: A functional unit of an integrated circuit, such as CPU cores, graphics and media, memory and AI.

Package: A protective enclosure around one or many silicon die that includes connectors to the computer.

Semiconductor: A material (such as silicon) that can be altered to conduct electrical current or block its passage; common shorthand for computer chips and the industry.

Transistor: A type of switch that controls the flow of electricity. A chip can contain millions or billions of transistors.

Wafer: A round slice of purified silicon less than 1 mm thick, up to 12 inches or 300 mm in diameter, upon which integrated circuits are implanted and etched and later sliced into individual die.