Semiconductor Markets: Key Applications and Players

September 2024

SELECTED PLAYERS

- **Fabless Companies** (chipset design companies with limited or no wafer fabrication capability)
- **Integrated Design Manufacturers** (vertically integrated semiconductor companies that design, manufacture and sell chipsets)
- **Pure-Play Foundries** (manufacture chipsets exclusively for Fabless Companies and do not market or sell chipsets into downstream markets)

KEY SEMICONDUCTOR APPLICATIONS

AUTOMOTIVE
- Advance Driver Assistance Systems (ADAS)
- Autonomous Vehicles
- Digital Cockpit (in-vehicle infotainment)
- Vehicle Motion and Dynamics Systems

NETWORKING AND COMMUNICATIONS
- Networking Equipment and Fiber to the Home (FTTH) (connectivity solutions)
- Wireless Solutions (cellular, IoT, Bluetooth)
- Satellite Communication Systems (SATCOM)
- Radio Frequency Integrated Circuits (transceivers and radio frequency front end)
- 5G Telecom Networks

INDUSTRIAL, IoT AND ROBOTICS
Access Control, Warehouse Management and Logistics, Smart Sensors, Industrial Machine Vision, Occupancy Monitoring, and Elder Care
- Energy (Crude Oil, Natural Gas, NGL, and Refined Petroleum Products Pipelines)
- Robots and Robotic Arms
- Factory Automation Systems
- Building Control (optical devices/smart vision, security)
- Power Storage, Generation & Transmission (wind power, HVDC, solar cells)
- Telemedicine and Medical Devices (e.g., industrial diagnostic equipment)

CONSUMER
Appliances, Consumer Electronics, HVAC, and Smart Home IoT
- Appliances (washing machines, refrigerators, microwaves, dishwashers, cleaning robots)
- TVs, Speakers, Displays and Projectors
- Heating, Ventilation and Air Conditioning (HVAC)

RETAIL
- Commercial Self-Service Devices (ATMs, point-of-sale devices, biometrics, subway channel gates, mobile payments)

AEROSPACE & DEFENSE
- Military Aircraft, Drones, Rotorcraft, Missiles, and Weapons Systems (control, monitoring, communication, navigation, safety, and emergency systems)
- Commercial Aerospace (control, monitoring, communication, navigation, safety, and emergency systems)

INFORMATION TECHNOLOGY
Hyperscale Data Centers/Cloud Computing, Core Computing, and Edge Computing
- Servers: AI Computing (for the AI data center)
- Servers: High-Performance Computing
- Servers: Standard Computing
- Servers: Edge Computing
- Data Storage (compression, duplication, data reconstruction)

Personal Computers
- Desktops and Laptops (includes gaming desktops and laptops)
- Tablets
- Smart Phones
- Videogame Consoles and Mobile Gaming Devices
- Extended Reality Headsets (AR, VR, MR, XR)
- Wearables (smart watches and fitness trackers)

Players

Ambarella; amazon.com (Home Grown Chip Design); AMD; Analog Devices (Analog ICs: Mixed-signal); Ampere; Apple (Home Grown Chip Design); arm (Closed Chip Design Architect Only); Broadcom; Fujitsu; Google (Home Grown Chip Design); GlobalFoundries; Huawei / HiSilicon; Infineon (Microcontrollers, Power Chips); intel; intel foundry; Lattice; Marvell; MediaTek; Micron; Microchip (Micro-controllers, Mixed-signal Chips, Memory); Microsoft (Home Grown Chip Design); Mitsubishi Electric; Nordic (Wireless, Analog ICs: Power Control); Northrop Grumman; NVIDIA (GPUs, CPUs); NXP (Analog ICs: Mixed-signal, Power Control); onsemi (Analog ICs: Power Control); Qorvo; Qualcomm (CPUs, RF, CDMA); Renesas (Analog: General, Mixed-signal); RISC-V (Open Chip Design Architect Only); RTX; Samsung; Samsung Foundry; SK hynix; Skyworks (Analog ICs: Mixed Signal, Power Control); SMIC; ST (Microcontrollers, Memory, Analog ICs: General, Mixed-signal); Sony; Tesla; Texas Instruments (Microcontrollers, Analog ICs: General, Mixed-signal, Power); Toshiba; TSMC; UMC; Western Digital

arm — License of Instruction Set Architecture

Arm Holdings plc is the leading technology provider of processor IP, offering the widest range of processors to address the high-performance, power/energy-efficient, and low-cost requirements of every device. Its primary business is the design of central processing unit (CPU) cores that implement the ARM architecture family of instruction sets. It also designs other chips, provides software development tools and provides systems IP, physical IP and platforms, system-on-chip (SoC) infrastructure, and software.

Over 70% of the world's population uses ARM-based products. ARM processor designs run most of the world's software, such as operating systems and applications for smartphones, tablets and personal computers, data centers and networking equipment, vehicles, and embedded operating systems in devices such as smartwatches, thermostats, drones and industrial robotics.

ARM's customers are many of the world's leading semiconductor companies (e.g., Advanced Micro Devices, NVIDIA, Qualcomm, and Samsung Electronics) and original equipment manufacturers (e.g., Amazon, Apple, Google, and Microsoft). These customers put ARM's processor designs in physical chips that will be incorporated into a wide variety of computing devices. ARM is majority owned by Japanese conglomerate SoftBank Group.

GlobalFoundries — Foundry Manufacturing and Assembly Services

Global Foundries is the world's fourth largest chipmaker (by revenue). However, Global Foundries does not focus on leading-edge chips (which are the focus of Taiwan Semiconductor Manufacturing Company), such as powerful graphics processing units used to train large language models like ChatGPT. Instead, the company manufactures chips that perform functions like power management, connecting to displays, or enabling wireless connections.

intel foundry — Foundry Manufacturing and Assembly Services

Intel Foundry is a newly established operating segment of Intel that includes foundry technology development, foundry manufacturing and supply chain, and foundry services. Intel's seeks to become a world-class foundry with the goals of being the number two foundry by 2030, delivering five new process nodes by 2030, and expanding its lead in advanced processing.

In addition to its own manufacturing facilities, Intel Foundry is partnering with (1) Tower Semiconductor, which will be investing in new equipment to be installed in Intel's New Mexico facility for analog products, and (2) UMC, which will leverage three of Intel's older Arizona fabs and process nodes to support applications like industrial IoT, mobile, communications, infrastructure, and networking.

RISC-V — Open Source Instruction Set Architecture

RISC-V International is a non-profit organization that promotes the adoption and development of an open standard instruction set architecture (ISA) called Reduced Instruction Set Computer – V (or RISC-V). Founded to provide a free and open ISA that is extensible and suitable for various computing applications, RISC-V International oversees the development of the RISC-V ecosystem, including hardware implementations, software tools, and community engagement.

RISC-V International aims to drive innovation and collaboration among hardware and software developers, ensuring that RISC-V remains a competitive and accessible alternative to proprietary ISAs, such as ARM plc's proprietary and tightly-controlled ISA) that offers established reliability and compatibility but limits customization.

By contrast, open ISAs, exemplified by RISC-V, are community-driven and provide greater flexibility for customization, fostering innovation and adaptation to specific needs. RISC-V is well-suited for embedded systems, such as microcontrollers, IoT devices, and industrial control systems, due to its simplicity, efficiency, and customizable instruction set.

Samsung Foundry — Foundry Manufacturing and Assembly Services

Founded in 2005, Samsung Foundry is the world's second largest semiconductor foundry company. The company offers a full suite of competitive, advanced process technologies, design technologies, IP, and high-volume manufacturing capability to over 150 customers through its facilities in South Korea and Texas.

Samsung Foundry also offers advanced packaging solutions and application-specific technologies for radio frequency or RF, eNVM, high voltage, BCD, CMOS image sensors, and fingerprint sensors. Along with TSMC, Samsung is able to produce 3-nanometer chips; the smaller the nanometer size, the more advanced and efficient the chip.

SMIC — Foundry Manufacturing and Assembly Services

State-backed Semiconductor Manufacturing International Co. (SMIC) is China's largest chipmaker and the world's third-largest foundry (by revenue). The company's chips are found in automobiles, smartphones, computers, and IoT technologies. China consumes nearly 50% of the world's semiconductors because it is the biggest assembly market for consumer devices. Huawei/Hisilicon is SMIC's largest customer, accounting for 19% of 2023 revenues.

In light of the U.S. sanctions that restrict the ability of U.S. chipmakers to sell certain U.S. technology and chips in China, SMIC is critical to China's hopes of reducing dependence on foreign technology in its domestic semiconductor industry. As a result, the Chinese government has invested billions in yuan in subsidies in Chinese chip makers (including SMIC) to boost domestic chip production.

TSMC — Foundry Manufacturing and Assembly Services

Taiwan Semiconductor Manufacturing Company (TSMC) is the world's second-most valuable semiconductor company, the world's largest dedicated independent ("pure-play") semiconductor foundry, and its country's largest company, with headquarters and main operations located in the Hsinchu Science Park in Hsinchu, Taiwan.

Chips for PCs and smartphones account for most of TSMC's revenue. TSMC also focuses on manufacturing sophisticated GPUs essential to training AI models. Patents around TSMC's chip-packaging process give TSMC a competitive advantage. There are plenty of companies in the semiconductor foundry space, but none of the competitors' chips compares to the advanced capabilities of TSMC chips.

TSMC's competitive advantage lies in the end stages of chip production and a process called "packaging"—i.e., the process of enclosing the chip and putting in electrical connections vital for the chip's ability to function in different electronics. The packaging process is done by chip producers, but TSMC has an extensive list of patents (approximately 3,000) that protect its advanced chip-packaging technology, which enables TSMC to essentially stack and combine multiple chip components into a single item, leading to higher performance than others.

UMC — Foundry Manufacturing and Assembly Services

United Microelectronics Corporation (UMC) designs, manufactures, and markets integrated circuits and related electronic products. UMC was founded in 1980 as Taiwan's first semiconductor company as a spin-off of the government-sponsored Industrial Technology Research Institute (ITRI).

United Microelectronics UMC is headquartered in Hsinchu, Taiwan also has facilities and local offices in the U.S., Europe, China, Japan, South Korea, and Singapore. UMC has total of 12 fabs in production with combined capacity of more than 400,000 wafers per month. The company has a worldwide total of 20,000 employees.

As a pure-play foundry, UMC provides high quality integrated circuit (IC) fabrication services, focusing on analog chips (such as logic, mixed-signal, and embedded high voltage chips), memory chips and various specialty technologies to serve all major sectors of the consumer electronics, displays, personal computer peripherals, automotive, and communications industries.

Arm Holdings Ecosystem

September 2024

AUTOMOTIVE LINE OF BUSINESS

The automotive market includes all chips with processors within vehicles. This includes chips used for (1) in-vehicle-infotainment ("IVI"), (2) advanced driver assistance systems ("ADAS") with automated technology such as as sensors and cameras to detect nearby obstacles and respond accordingly, (3) engine management, and (4) body and chassis control. Today, Arm's market share in the automotive market is highest in more technologically advanced functional areas such as IVI and ADAS.

- In Vehicle Entertainment (IVI)
- Advanced Driver Assistance (ADAS)
- Engine Management
- Body and Chassis Control

INTERNET OF THINGS LINE OF BUSINESS

The industrial IoT and embedded semiconductor market includes chips used by a wide range of goods, including washing machines, thermostats, digital cameras, drones, sensors, surveillance cameras, manufacturing equipment, robotics, electric motor controllers and city infrastructure and building management equipment. Manufacturers and logistics companies are using advanced sensors and smart machines capable of capturing and analyzing data in real time to improve and/or automate industrial processes, logistics systems, manufacturing yield, and system throughput.

- Consumer
- Industrial

CLIENT/CONSUMER TECHNOLOGY LINE OFBUSINESS

The Client Line of Business (also known as Consumer Technology) defines and builds the foundational computing platforms that enable industry-leading OEMs to deliver essential products, services, and experiences on smartphones, gaming devices, laptops, tablets, digital TVs, wearables, and the metaverse—e.g., virtual reality (VR), augmented reality (AR), and extended reality (XR) headsets.

- Mobile Processor
- Other Mobile Chips
- Consumer Electronics

INFRASTRUCTURE LINE OF BUSINESS

The Infrastructure Line of Business leverages the Arm Neoverse technology (a series of 64-bit Arm processor cores) for use in chips used for computing, networking and data processing in high-performance computing (HPC) data center, Edge, and 5G network environments, which have increased due to the rapid increase in data traffic generated by consumers and enterprises globally and by the migration of enterprise workloads to the cloud.

- Networking Equipment
- Cloud Compute
- Other Infrastructure

Arm Holdings Ecosystem

Arm Holdings plc
110 Fulbourn Road
Cambridge, CB1 9NJ, England
Phone: +44 (0)1223 400400 : Website: www.arm.com

Outside Relationships

Regulators

Subjects of Regulation (U.K., China, Europe, U.S.)

Intellectual Property
(Regulation for the creation, promotion, utilization and protection of intellectual property, including the registration of ownership, protection, and prevention of infringement of intellectual property rights, such as patents, trademarks, copyrights and designs)

Privacy and Data Protection Regulators
(Regulation governing the collection, use, sharing, profection, and retention of personal data, data localization, and cybersecurity)

Environment Protection
(Regulation regarding environmental pollution prevention, waste management, resource conservation, and other activities related to industrial operations)

International Trade
(Regulation regarding international trade activities, export and import procedures, licensing, other requirements, and controls, foreign investment, tariff rates, information handling, economic and trade sanctions, and other aspects in accordance with the rules of the World Trade Organization (WTO) and other international trade agreements)

Government and Public Sector Contracting
(Regulation regarding government and defense procurement and contracting, including, formation, national security, administration, performance, audits, investigations, security, financial reporting, and certification)

Taxation
(Regulation of Taxation, Foreign Exchange Controls and Cash Repatriation)

Anti-Corruption
(Enforcement of anti-bribery/anti-corruption laws, including bookkeeping requirements)

Employment and Labor
(Regulation regarding worker rights and working conditions, including working hours, equal opportunity, holidays, annual leave, wages, pensions, layoffs, health, safety, and serious injury reporting)

Anti-Competition
(Enforcement of antitrust/anti-competition and fair-trade laws; business combination/merger reviews and clearances)

Capital

- Hedge Counterparties
- Citibank, N.A. (Depositary Bank for ARM American Depositary Receipts)
- Government Agencies (UK and U.S. federal and state g government grants and/or tax credit for research and development activities)
  - *His Majesty's Revenue & Customs (R&D Expenditure Tax Credits Valued at $64 M in 2023)*
  - HM Revenue & Customs
- Borrowers (Arm carries loans or convertible loans receivable on its books for loans to Arduino SA, Cerfe Labs, Ampere Consulting, and Allia Limited)
  - ARDUINO
  - CerfeLabs
  - Allia
  - AMPERE CONSULTING

Suppliers

Selected Semiconductor Companies, OEMs, and other Designers of Chips with Processors in Vehicles
(e.g., ADAS, digital cockpit, Engine management systems, body and chassis control)

cadence, SYNOPSYS, NVIDIA, ST, TOSHIBA, DENSO, Microsoft, aws, tsmc, intel foundry, Continental, AMD, XILINX, Silicon Mobility, CEVA

Licensing of Automotive Chip Technologies and Platforms for Use in (1) Advanced Driver Assistance Systems (ADAS) with Automated Technology such as Sensors and Cameras, Software-Defined Vehicles (SDVs), (3) In-Vehicle Infotainment (IVI) Systems (also known as Digital Cockpits), and (4)Vehicle Motion and Dynamics Systems
(e.g., Engine Management Systems, Body and Chassis Control)

Customers

- Business Regulation
- Foreign Currency Exchange Contracts (to mitigate foreign currency risk—e.g., British Pound Sterling cash flows)
- Depositary Services in Connection with ARM American Depositary Receipts on behalf of American Investors (each representing one ARM ordinary share)
- Grants to Fund Research Activities and R&D Expenditure Tax Credits
- Loans to Third Parties

Arm Holdings plc (a public limited company under the laws of England and Wales)

Debt Structure

Debt ($0 @ 3/31/2024) | Credit Ratings: N/A

Long Term Debt: None	Non-Current Contractual Liabilities: $915 Million

Equity Structure

Equity Capital

Shareholder's Governance Agreement
Upon the IPO, SoftBank and Arm entered into an agreement under which SoftBank has, among other things (1) the preemptive right to acquire any shares issued by arm, (2) right to designate directors for election proportionate to its ownership (e.g., 7 candidates if equity exceed 70%), and (3) right to cause ARM to register additional ordinary shares without limitation as to the number of registrations — SoftBank

Equity Pledged by SoftBank Group
No. of Shares: 769 Million
(73.4% of Stake in Arm)
Purpose: To Secure a Loan of $8.5 Billion by a Lender Group Led by JPMorgan SE

Employee Benefit Trust
Purpose: To facilitate the settlement of employee share-based compensation arrangements
Shares Held: 603.450 American Depositary Shares

Share Repurchase Program
(ARM does not have a share repurchase program)

American Depositary Shares
(each representing one ordinary share)
Issued and Outstanding: 1.025B shares
Record Holders: 1

Ordinary Shares
Authorized: 1.088B shares
Issued and Outstanding: 1.04B shares
Record Holders: Not Available

Governance

Board of Directors

Masayoshi Son (Chair)	Rene Haas	Ronald D. Fisher (A,R)	Jeffrey A. Sine (R)
Karen E. Dykstra (A)	Paul E. Jacobs, PhD	Anthony Michael Fadell	Rosemary Schooler (A,R)
Committees: Audit (A) and Remuneration (R)			

Executive Leadership Team/Management Team (What the company refers to them as)

CEO: Rene Haas	EVP and CFO: Jason Child	Chief People Officer: Kristy Gill	EVP and Chief Legal Officer: Spencer Collins
EVP, Strategy and Ecosystem: Drew Henry	EVP and Chief Commercial Officer: Will Abbey	Chief Marketing Officer: Ami Badani	SVP and GM, Automotive Line of Business: Dipti Vachani
SVP and GM, IoT Line of Business: Paul Williamson	SVP and GM, Client Line of Business: Chris Bergey	EVP and Chief Architect: Richard Grisenthwaite	SVP and GM, Infrastructure Line of Business: Mohamed Awad
EVP, Central Engineering: Gary Campbell	EVP, Solutions Engineering: Kevork Kechichian	SVP and Chief Diversity Officer: Tamika Curry Smith	

Finance and Accounting
- Accounting
- Investor Relations
- Investments (Arm has agreed to make a $35 million cornerstone investment in Raspberry Pi, which intends to conduct an IPO in 2024)
- Raspberry Pi
- (Other investments include Arm IOT Fund-25.8%, Accelerator Advisory-32.1%, HOPU-ARM Holding Company-10%, DeepTech Labs Fund-42.9%, Acetone-10%, Ampere Computing-6.7%, China Walden Ventures Investments I and II-7.5% and 8.1%, respectively, HOPU-ARM Innovation Fund-5.3%, and Catapult Ventures I-18.1%
- Tax
- Risk Management
- Financial Planning & Analysis
- Global Finance and Strategy

People
- Talent Acquisition, Management and Development
- Total Rewards
- Executive Remuneration
- Workplace Safety and Culture
- People Services
- Diversity, Equity, and Inclusion Strategy (building high-performing teams, inclusive environments, and DEI-enabled business results)
- Sustainability
- People Systems
- Organizational Effectiveness

Information Technology
- Network
- Business Management
- Agile Coaching
- Project Management
- Security

Architecture
- Long-Term Evolution of ARM Architecture
- Armv9 Development

Strategy and Ecosystem
- Strategic Growth Initiatives
- Ecosystems for Software, Customers, Partners, Influence Developers, and Products

Legal
- Global Legal Services
- Government Affairs
- Transactions
- Compliance
- Intellectual Property Management
- Corporate Development
- Litigation Management
- Privacy
- Corporate Governance and Company Secretary

Corporate Matters

Commercial
- Sales
- Field Engineering
- Partner Enablement (Helping many of the world's most innovative organizations leverage the newest technologies to ready themselves for a next wave of digital transformation)

Marketing
- Technology Marketing
- Developer Ecosystems
- Product Management
- Go-to-Market Strategies

Engineering
- Central Engineering for CPU and System IP
- Product Technology Development and Acceleration
- Central Technology and Solutions Engineering
- Hardware Engineering (Design processor IP)
- Software Engineering (Operating systems, device drivers, graphics quality, web development)
- Applications Engineering (SoC designs integrating ARM CPUs and system IP)

Operations

ARM Segment (FY 2024): $3.233 Billion

Automotive Line of Business

The automotive market includes all chips with processors within vehicles. This includes chips used for (1) in-vehicle-infotainment ("IVI"), (2) advanced driver assistance systems ("ADAS") with automated technology such as as sensors and cameras to detect nearby obstacles and respond accordingly, (3) engine management, and (4) body and chassis control. Currently, market share in the automotive market is highest in more technologically advanced functional areas such as IVI and ADAS.

SVP and General Manager: Dipti Vachani

In Vehicle Infotainment (IVI)

The Arm architecture is a key enabler of automotive technology, with more than 90 percent of in-vehicle infotainment (IVI) systems and many under-the-hood applications powered by Arm-based chips, including meter cluster, HVAC control, side-/rear-view mirrors, and other systems

Vehicle Function	Arm Chip Solution
heads-up display, driver/cabin monitoring, instrument cluster, steering wheel, center stack/head unit, cockpit domain controller, rear-view mirror/camera, human-machine interface, side-view mirror/camera, rear passenger entertainment	Cortex-A CPU, Cortex-M CPU, Cortex-R CPU, Mali GPU, Mali ISP, CryptoCell, TrustZone®

Advanced Driver Assistance Systems (ADAS)

This business unit focuses on specialized computing advanced driver assistance systems (ADAS), from sensor and response to automatic emergency braking, driver monitoring, and lane and highway assistance.

Vehicle Function	Arm Chip Solution
Sense – Gather environment information from cameras/sensors	Cortex-A CPU, Cortex-M CPU, Neoverse CPU
Perceive – Filter, interpret, and understand sensor data	Cortex-A CPU, Mali ISP, Mali GPUs and ML
Decide – Safely choose actions	Cortex-A, Cortex-R CPUs
Actuate – Initiate actions	Cortex-R, Cortex-M CPUs

Engine Management

Arm high performance processors enable real-time, efficient, safe "compute" for advanced engine control systems. Applications include ignition/eco stop/start, fuel injection and pump, battery management systems, engine sensors, and on-board chargers.

Vehicle Function	Arm Chip Solution
Electronics, safety, engine control – fuel injection, ignition, engine performance	Cortex-M CPU

Body and Chassis Control

Arm high performance processors enable real-time, efficient, safe "compute" for advanced control systems for (1) vehicle motion applications and (2) vehicle dynamics systems.

Vehicle Function	Arm Chip Solution
Chassis – vehicle frame	Cortex-M CPU
Powertrain – motor/engine plus the drivetrain	Cortex-R CPU
Drivetrain – transmission, axles, driveshaft, differential, CV joints	Cortex-R CPU
Body control – windows, mirrors, HVAC, locks, lights, turn signals, wipers, horns, seats/seatbelts, theft alarm, cruise control, sunroof	Cortex-M CPU

Internet of Things (IoT) Line of Business

The industrial IoT and embedded semiconductor market includes chips used by a wide range of goods, including washing machines, thermostats, digital cameras, drones, sensors, surveillance cameras, manufacturing equipment, robotics, electric motor controllers and city infrastructure and building management equipment. Manufacturers and logistics companies are using advanced sensors and smart machines capable of capturing and analyzing data in real time to improve and/or automate industrial processes, logistics systems, manufacturing yield and system throughput.

SVP and General Manager: Paul Williamson

Consumer

Arm's IoT solutions subsystem consists of customer application codes, ecosystem middleware, operating system/firmware, and processing unit (CPU, GPU, and NPU) designs for the connected smart arm home automation, drones and autonomous vehicles.

Device	Arm Chip Solution
Smart home -- digital assistant/smart speakers, door-locks, thermostats, smart TVs, set-top-boxes, and smart refrigerators	Corelink Interconnect, Ethos-U NPU, Cortex-A CPU, Cortex-M CPU, Mali GPU, Balletto family of edge AI/ML MCU
Smart cameras	Cortex-A CPU, Ethos-U NPU
Drones	Cortex-M CPU
Autonomous toys and appliances – autonomous decision-making, virtualization, computer vision and safety	Cortex-A CPU, Mali GPU, Arm Safety Ready IP, Neoverse CPU

Industrial

Arm is the leading CPU architecture for IoT devices and embedded computers. Billions of these devices are in use today gathering and analyzing fast new sources of data, and billions more will be deployed to solve complex challenges of climate change, urban infrastructure, accelerating supply chains, and healthcare accessibility. Arm's intelligent solutions are being incorporated increasingly in smart manufacturing devices to improve productivity, increase safety, reduce energy consumption, and reduce costs.

Device	Arm Chip Solution
Industrial PC – Housing the software and components in the factory automation systems, robots, and other operational technology	Cortex-A CPU
Edge Server	Neoverse CPU, Cortex-A CPU
Network hub	Cortex-A CPU, Cortex-R CPU
Industrial/Smart display	Cortex-A CPU, Mali GPU

Client Line of Business (Mobile)

The Client Line of Business (also known as Consumer Technology) defines and builds the foundational computing platforms that enable industry-leading OEMs to deliver essential products, services, and experiences on smartphones, gaming devices, laptops, tablets, digital TVs, wearables, and the metaverse–e.g., virtual reality (VR), augmented reality (AR), and extended reality (XR) headsets.

SVP and General Manager: Chris Bergey

Mobile Processor

The mobile applications processor is the primary chip in a smartphone and runs the operating system and applications in addition to controlling many of the device functions, including gaming, music, video, and other apps. While high compute performance is required for today's apps, processors also must be highly energy efficient so that the smartphone's battery will last all day. ARM has a 99%+ market share in the mobile apps processor market by virtue of all key mobile operating systems depending on Arm processors.

Other Mobile Chips

Mobile phones contain many chips beyond the main applications processor, including the modem, Wi-Fi, Bluetooth and NFC connectivity chips, GPS chips, touchscreen controllers, power management chips, camera chips, and audio chips ("other mobile chips market"). The market share of Arm-based chips in this market varies by device and is generally higher in chips that run more software (such as modem and connectivity chips) and is lower in chips that require less software (such as power management chips).

Consumer Electronics

Consumer Electronics includes products found in the home, such as digital TVs, tablets, laptops, XR headsets and wearables. The opportunity for Arm-based chips in consumer electronics is increasing as new product categories, such as smart speakers, virtual reality headsets and laptops, need CPUs that can deliver high performance without sacrificing efficiency.

Device(s)	Arm Chip Solution
AR/VR/XR	Cortex-A CPU, Ethos NPU, Mali GPU
Tablets/Laptops	Cortex-A CPU, Cortex-X CPU, Corelink Interconnect CI-700, Ethos NPU
Wearables	Cortex-A CPU, Cortex-M CPU, Ethos NPU
Smartphones/Mobile Gaming	Cortex-A CPU, Immortalis and Mali GPU, Corelink Interconnect CI-700

Infrastructure Line of Business (Cloud)

The Infrastructure Line of Business leverages the Arm Neoverse technology (a series of 64-bit Arm processor cores) for use in chips used for computing, networking and data processing in cloud, high-performance computing (HPC) data centers, Edge, and 5G network environments, which have increased due to the rapid increase in data traffic generated by consumers and enterprises globally and by the migration of enterprise workloads to the cloud.

SVP and General Manager: Mohamed Awad

Networking Equipment

The networking equipment market includes chips deployed into wireless networking such as base-station equipment, enterprise Wi-Fi, and wired networking equipment such as routers and switches. The networking equipment market is growing as more wired and wireless infrastructure is deployed, as much of the data consumed in the cloud is created at the edge and needs to be transmitted over networks to the data center for 5G processing. The deployment of 5G networks as infrastructure scales from lower large cell towers covering a wide area to a large number of small cells providing high-speed coverage creates further demand for architecture that allow for flexible deployment of software and workloads.

Devices	Arm Chip Solution
5G Network Infrastructure (Including 5G Radio Access Network)	Cortex-A CPU, Cortex-R CPU, Ethos NPU, Neoverse CPU
Wired (Routers and Switches)/Wireless (Base station equipment and Enterprise Wi-Fi) Networking	Cortex-A CPU, Neoverse CPU

Cloud Compute

The cloud compute market includes the main server chips, data processing units, and smart network interface cards used by cloud service providers ("CSPs") to run their operations. Arm-based chips have been gaining market share as CSPs have started to deploy Arm products in their own in-house designed chips used in their data centers, and as other CSPs start to deploy chips designed by Arm licensees.

Devices	Arm Chip Solution
Cloud Computing	Cortex-A CPU, Ethos NPU, Neoverse CPU

Other Infrastructure

Other Infrastructure are technological components that support various aspects of computing, networking, and data processing, such as chips for HPC systems, enterprise servers, and edge networking equipment.

Devices	Arm Chip Solution
HPC Systems	Cortex-A CPU, Cortex-R CPU, Ethos NPU, Neoverse CPU
Enterprise Servers/Computing	Neoverse CPU
Edge Networking Equipment (E.g., access points, switches, control plane and embedded gateways and routers, wireless LAN controllers, universal customer premise equipment, and more).	Ethos NPU, Neoverse CPU

Competition

X86 ARCHITECTURE
The once-standard x86 is a family of complex instruction set computing (CISC) instruction set architectures (ISAs) initially developed by Intel in 1978. Today, most processors in desktop and laptop computers are based on the x86 architecture family, while most processors in mobile phones and tablets are based on the Arm architecture. In computation-intensive data center and cloud computing markets, x86-based processors also dominate.

OPEN-SOURCE ARCHITECTURES (e.g., RISC-V)
RISC-V is a free open-source instruction set architecture (ISA) based on the reduced instruction set computing (RISC) principles. It is Arm's primary competitor in risk-based architecture. In August 2015, a group of over 100 technology companies (including 20 Arm customers) formed RISC-V Foundation to govern, standardize, control, protect, and accelerating the adoption and standardization of the RISC-V architecture.

OTHER ARCHITECTURES
Certain semiconductor companies, including some Arm customers, have designed or are in the process of designing their own architectures for use in the smartphone application processor, other mobile chip, consumer electronics, IoT and embedded computing, networking equipment, automotive, and cloud compute markets.

Licensing of IoT Chip Technologies and Platforms for Use in Washing Machines, Thermostats, Digital Cameras, Drones, Sensors, Surveillance Cameras, Manufacturing Equipment, Robotics, Electric Motor Controllers, City Infrastructure, and Building Management Equipment

Selected Semiconductor Companies, OEMs, and other Designers of Chips with Processors in IoT Appliances and Devices
(e.g., smart home, industrial, smart vision)

lite.augmented, TOSHIBA, Raspberry Pi, eurotech, RENESAS, IAR SYSTEMS, NXP, SIEMENS, Ansys, sensory, MEDIATEK, cadence, ADLINK

R&D Consulting Services

Licensing of Client Chip Technologies and Platforms for Use in Mobile Smartphones, Gaming Devices, Laptops, Tablets, Digital TVs, Wearables, and Metaverse Devices

Selected Semiconductor Companies, OEMs, and other Designers of Chips with Processors in Client Devices
(e.g., smart phones, wearables, laptops, mobile gaming, and VR/AR/XR headsets)

Qualcomm, aws, NXP, Google, SYNOPSYS, Mentor, SIEMENS, UBISOFT, Microsoft Surface, Microsoft HoloLens, Microsoft Windows-Based Laptops, Windows, ACTIVISION BLIZZARD, Unity, chromebook, SAMSUNG, RIOT GAMES, cadence, FUJITSU, ROBLOX, MEDIATEK, MARVELL, vmware by Broadcom

Third-Party Consultants
(research, development, professional, and design services)

Outside Relationships

Customers

Selected Semiconductor Companies, OEMs, and other Designers of Chips with Processors in Hyperscale Data Center/Cloud Computing Appliances and Devices
(e.g., general purpose and high-performance computing servers, edge servers, and 5G networking equipment)

Microsoft Azure, aws, Google Cloud, ORACLE Cloud Infrastructure

Arm CPU designs have only a 10% share of the cloud computing market.

Licensing of Computing Infrastructure Chip Technologies and Platforms for use in Cloud, High-Performance Computing Data Centers, Edge, and 5G Network Environments

Technology Licenses (in FY2023, Chinese customers contributed 21% (or $679 M) of Arm's $3.233B revenue, substantially all of which came from Arm China, an independent entity. As of March 31, 2024, Arm held a net receivable of $175.8 million from Arm China)

Distribution Agreement (Arm granted Arm China the exclusive rights to distribute Arm's technology in China)

ARM China
安谋科技 arm CHINA
Arm owns a 10% non-voting interest in Acetone Ltd., which owns a 48.18% interest in Arm China; Arm China is the company's largest global customer.

Suppliers

Professional Service Firms
- Deloitte & Touche (audit services) — Deloitte.
- Invariant LLC. (lobbying services) — Invariant
- Raine Securities (Financial Advisory Services including in connection with the 2023 ARM IPO) — RAINE
- Morrison Foerster (legal services) — MORRISON FOERSTER
- Amazon Web Services (AWS) (cloud computing, storage, and data analytics services including running electronic design automation workloads) — aws

Capital

Significant Shareholders
- Softbank Group (88.06%) — SoftBank
  - SoftBank is led by Masayoshi Son
  - SoftBank has pledged a 73.4% stake in Arm to secure an $8.5B loan to its group
- Goldman Sachs (0.14%) — Goldman Sachs
- Schroders Investment Management (0.52%) — Schroders
- Citadel Advisors (0.24%) — CITADEL
- Artisan Partners (0.23%) — ARTISAN PARTNERS
- Non-Insider Institutional Ownership (5.95%)

Regulators

Securities and Corporate Governance Regulators
- U.S. Securities and Exchange Commission (regulation of offers and sales of securities, material event disclosure and financial reporting requirements; recordkeeping requirements under anti-bribery law)
- NASDAQ Global Select Market (listing, maintenance and corporate accountability rules) — Nasdaq
- Public Limited Company (PLC) under the Laws of England and Wales (Companies Act 2006 regulates the formation, operation, and dissolution PLCs, including (1) shareholder approval of boards of directors, board of directors oversight of strategic decision-making, and officers (such as the CEO and CFO) management of daily operations and ensuring accurate financial reporting, (2) directos' fiduciary duties to act with loyalty and care, (3) strict financial reporting standards for the preparation and disclosure of annual accounts, (4) shareholder approval for changes to the articles of association, and (5) shareholder approval for mergers and adherence to the UK Takeover Code) — UK Parliament

Securities Law Regulation and Stock Listing Requirements

Equity Capital

Dividends and Common Stock Repurchases

Professional Services

Key Company Data (as of 03/31/2024)

Business Overview: Arm Holdings plc, a global leader in the semiconductor industry, develops, markets and licenses high-performance, low-cost, energy-efficient central processing units (CPUs) designs and related technology--systems IP, graphics processing units, physical IP, software, and tools. Its 1,000+ customers (called technology partners) are many of the world's leading semiconductor companies (e.g., Advanced Micro Devices (AMD), NVIDIA, Qualcomm, and Samsung Electronics) and original equipment manufacturers (e.g., Amazon, Apple, Google, and Microsoft). These customers put Arm's processor designs in physical chips (more than 280 million to date) that will be incorporated into a wide variety of computing devices. Today, Arm processor designs run most of the world's software, such as operating systems and applications for smartphones, tablets and personal computers, data centers and networking equipment, vehicles, and embedded operating systems in devices such as smartwatches, thermostats, drones and industrial robotics. Over 70% of the world's population uses Arm-based products.

Share Data
- Stock Exchange (NASDAQ) Ticker Symbol: ARM
- Share Price: $132.88 (08/30/2024)
- Earnings Per Share (Trailing 12 Months): $0.41
- Forward Annual Dividend: None (ARM does not currently intend to pay dividends)
- Market Cap: $139.3B (08/30/2024)

Resources
- Employees: 7,096 (80% focused on research, design and technical innovation)
- Headquarters: Cambridge, United Kingdom (U.S. Headquarters: San Jose, California)
- Global Operations and Research and Centers: U.K., Europe, North America, India, Asia-Pacific
- Patents: 6,800 issued patents (2,700 patent applications pending worldwide)
- ARM North Star: *Building the future of computing, on Arm. Together. For Everyone.*

Financial Highlights

Statement of Income
- Revenues: $3.233B
- Cost of Sales: $154M
- Gross Profit: $3.079B (95.2% Margin)
- Operating Expenses: $2.962B
- R&D Expenses: $1.070B
- Operating Income: $117M
- Net Income: $306M

Balance Sheet
- Total Assets: $7.927B
- Total Liabilities: $2.632 B
- Long-Term Debt: None
- Equity: $5.295B

Cash Flow
- From Operations: $1.09 B
- Used in Investing: $(516)M
- Used in Financing: $(208)M

Financial Returns
- Return on Equity: 5.78%

Key Developments

Background. Founded in 1990, Arm began as a joint venture between Acorn Computers, Apple Computer and VLSI Technology. Arm was publicly traded from 1998 until 2016 when private investor SoftBank Group bought the company and took it private. In November 2023, SoftBank sold an approximately 10% stake in Arm via an initial public offering for $4.87 billion, valuing the company at $54.5 billion.

August 2024

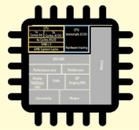
ARM Holdings: Supplement

September 2024

TECHNOLOGY PLATFORM AND BUSINESS MODEL

COMPUTE TECHNOLOGY

Central Processing Units



Cortex: ARM's Cortex CPUs are a family of processors for various applications, ranging from mobile devices to embedded systems. Known for their energy efficiency and scalability, Cortex CPUs are widely used in smartphones, tablets, smart TVs, and IoT devices due to their low power consumption and high performance-per-watt ratio. The Cortex series includes different models tailored to specific performance needs. ARM's Cortex CPUs are renowned for their versatility, contributing significantly to the widespread adoption of ARM architecture across diverse computing platforms.

- **Cortex-A CPUs** (high-performance, low-power processors used in mobile devices)
- **Cortex-M CPUs** (energy efficient CPUs optimized for micro-controllers)
- **Cortex-R CPUs** (for real-time processing performance in embedded systems)
- **Cortex-X CPUs** (known for peak performance in high-end smartphones and performance-sensitive devices, customizability for demanding applications like gaming and AI, and energy efficiency with scalability and enhanced capabilities such as improved caching and security)

Graphics Processing Units and Other Specialized Processors

Arm Mali GPUs are image signal processors (ISPs) and graphics processing units (GPUs) optimized for mobile devices like smartphones and embedded systems such as smart TVs, and automotive applications. They deliver high performance and energy efficiency for smooth graphics rendering, gaming, and machine learning tasks. Key product lines include (1) G Series for gaming and graphics-intensive applications, (2) D Series for display processing, enabling advanced video playback and image enhancements, (3) C Series: For camera processing, supporting image capture in mobile devices, (4) QPUs for Machine Learning, optimized for AI applications on mobile platforms. Arm also provides software development kits (SDKs) and tools, including the Mali SDK and Arm Compute Library, to help developers optimize applications for Mali GPUs.

- **Mali ISPs/GPUs** (deliver high-performance graphics and compute capabilities for smartphones, tablets, and automotive and embedded systems. Mali GPUs are known for their efficiency and scalability, supporting advanced graphics technologies)
- **Immortalis GPUs** (visual experience across multiple devices)
- **Ethos Processors** (specialized chips optimized for machine learning inferencing and AI applications, designed for a range of uses from mobile devices to data centers; they work alongside Arm's existing CPU and GPU technologies to provide enhanced performance and energy efficiency for AI tasks, such as neural network inference)
- **Neoverse** (processors designed specifically for 5G network infrastructure and advanced cloud and edge data center computing workloads, including AI, ML and data analytics; they offer high performance, robust security and energy efficiency)

Intellectual Property

ARM IP refers to the designs and architectures developed by ARM Holdings, which are licensed to other companies like Apple, Qualcomm, and Samsung, who then customize and integrate these into their own processors and other computing components. ARM's IP includes CPU and GPU architectures, system-on-chip (SoC) designs, security, and related technologies that are highly energy-efficient and widely used in mobile devices, embedded systems, and increasingly in servers and high-performance computing. ARM IP collectively enables companies to design and produce highly integrated, efficient, and secure semiconductor products for a wide range of applications.

- **Physical IP and Implementation** (the building blocks used in the physical implementation of semiconductor devices, including standard cell libraries, memory compilers, and process technology optimization tools, which help companies achieve optimal silicon performance, power efficiency, and area (PPA) when fabricating chips)
- **System IP** (interconnects, memory controllers, and other system-level components that enable efficient communication and data transfer within a System-on-Chip (SoC). System IP is critical for optimizing performance, power consumption, and scalability in complex chip designs)
- **Security IP** (the foundation for building secure systems, including technologies like TrustZone, which enables secure and non-secure worlds on the same processor. This IP helps protect sensitive data and operations from threats, ensuring the integrity and confidentiality of systems across various industries)
- **Subsystems IP** (IP blocks needed to build SoC; Subsystems IP are pre-integrated, pre-verified modules that combine multiple IP components to create specific functional blocks, such as audio, video, or networking subsystems. These are designed to simplify and accelerate the development of SoCs by providing ready-to-use, modular components that handle specialized tasks)

ENABLING TECHNOLOGY

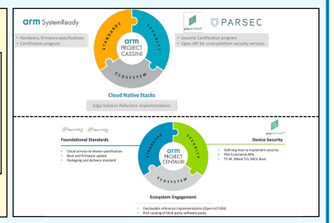
Enabling Technology

Chip enabling technology encompasses tools, techniques, and processes that facilitate the design, manufacturing, and deployment of semiconductor chips, including:

- *Design Tools:* EDA software for creating and verifying chip designs.
- *Process Technologies:* Advanced methods for fabricating chips, like FinFET.
- *Packaging and Assembly:* Protecting and integrating chips into systems.
- *Testing and Validation:* Ensuring chips meet specifications and are defect-free.
- *Integration:* Incorporating chips into larger systems, such as SoCs.
- *Yield Improvement:* Enhancing manufacturing efficiency and reducing costs.

These technologies are essential for producing functional, high-performance chips for electronic devices.

- **Architecture** (Arm family of reduced instruction set computing (RISC) architectures for computer processors)
- **Developers Tools and Software** (Helps engineers develop products for the Arm architecture)
- **Project Cassini** (Arm and its ecosystem are building open, collaborative standards to enable the cloud-native IoT and intelligent Edge with hardware based on Arm Cortex-A CPUs)
- **Project Centauri** (Arm is working with partners on standards to solve common industry challenges, reduce barriers to deployment, and enable scale across the Arm Cortex-M microcontroller ecosystem)
- **System Ready** (compliance certification program based on a set of hardware and firmware standards: Base System Architecture (BSA) and Base Boot Requirements (BBR) specifications, plus a selection of supplements)



ARM BUSINESS MODEL

Arm Holdings plc
(Arm customers can choose from several licensing models, each with its own pricing mechanics and level of access to Arm products: Arm Total Access, Arm Flexible Access, TLAs and Architecture Licenses. Regardless of the license model a customer uses, Arm receives (1) an initial license fee and (2) a per-unit royalty fee on substantially every chip shipped. Because each chip may ship for many years, and each Arm CPU can be reused in new products as new applications emerge, these licensing agreements contribute to a long tail of recurring royalty revenues, which provide visibility into future revenue streams.

- **1A** Arm Technology License to Chip Partners
- **1B** Arm Technology License Fee
- **6** Per Chip Royalty Payment

Semiconductor Partners
(consists of (1) fabless semiconductor companies whose research and integrated circuit designs set the stage for chip production,, (2) pure-play fabs/foundries and integrated circuit manufacturers that perform front-end wafer manufacturing operations, and (3) device OEMs that design their own chips)

Fabless Companies: Marvell, NP, Renesas, MediaTek, Qualcomm, NVIDIA, Fujitsu, Ansys, STMicroelectronics, AMD
OEM Designers: Siemens, Google, Microsoft, AWS, Apple
Foundries: Samsung, Intel

- **0** Business Development
- **2** Partners Develop Chips and Ship to OEMs
- **5** Chip Payments

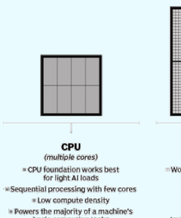
Device Original Equipment Manufacturers
(Device OEMs, such as Apple, Samsung, Dell, and Lenovo, design, manufacture, and sell various consumer electronics under their own brand. They integrate components from other suppliers, ensuring the overall design, assembly, and quality of the final product)

Dell Technologies, Sony, AWS, Apple, HP, Samsung, Google, Microsoft, Cisco, Hewlett Packard Enterprise

- **3** Device Sales
- **4** Device Payments

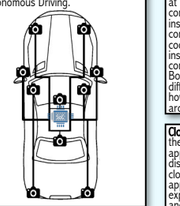
End or Downstream Customers
(purchasers of smartphones, tablets, VR headsets, automobiles, IoT and embedded devices such as smart TVs and refrigerators, and cloud data center infrastructure equipment)

CPU vs. GPU chips

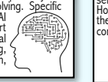


GLOSSARY

ADAS: Refers to "advanced driver assistance systems," which are technologies that assist drivers with the safe operation of a vehicle. Examples of these technologies are sensors and cameras used to detect nearby obstacles or driver errors and respond accordingly. ADAS can enable one or more levels of Autonomous Driving.



AI: Refers to "artificial intelligence," which is the simulation of the human brain by machines/computer systems to enable problem solving. Specific applications of AI include expert systems, natural language processing, speech recognition, and machine vision.



APIs: Refers to application programming interface, a set of rules, methods, data formats, and protocols that allows different software applications to communicate and interact with each other (i.e., request and exchange information). APIs enable developers to integrate third-party services and functionalities into their applications without needing to understand the underlying code.

- *Data Retrieval.* APIs allow applications to fetch data from external sources, such as weather information, financial data, or social media feeds.
- *Integration of Services.* APIs enable different services to work together, such as integrating payment gateways (e.g., PayPal, Stripe) into e-commerce platforms.
- *Accessing Functionality:* Applications can use APIs to access specific functionalities of other software, like sending emails through an email service API (e.g., SendGrid).
- *Mobile and Web Applications.* APIs power mobile and web applications by allowing them to communicate with back-end servers for data processing and storage.
- *Automation:* APIs can automate workflows by connecting different applications. For example, an API can trigger an action in one application when a specific event occurs in another.
- *Third-party Services:* Many platforms offer APIs to allow developers to extend their services, such as integrating with customer relationship management (CRM) systems, analytics tools, or social media platforms.

Overall, APIs play a crucial role in enhancing interoperability, enabling developers to build more flexible, powerful, and interconnected applications.

AR: Refers to "augmented reality," which is the integration of digital information with the user's environment in real time. Unlike VR, which creates a totally artificial environment, AR users experience a real-world environment with generated perceptual information overlaid on top of it.

Arm: Arm Holdings plc, a legal entity. The acronym "Arm" stands for "Advanced RISC Machine." Arm uses an architecture based on RISC that is different from the once-standard x86 architecture built by Intel in the early days of computing that is based on CISC.

ASIC: Refers to "application-specific integrated circuit," which is a chip on which the pattern of connections has been set up exclusively for a specific function. Any chip that is custom-made is an ASIC, designed for a specific purpose. ASICs are typically designed and used by a single company in a specific system. They are expensive, time-consuming, and resource-intensive to develop, but they are extremely high performance coupled with low power consumption.

ASSP: Refers to "application-specific standard processors." In contrast to ASICs, ASSPs are general-purpose devices intended for use by multiple system design houses.

Autonomous Driving: Also known as self-driving, driverless car or robotic car, autonomously driven cars can travel without human input and are capable of perceiving the environment, monitoring important systems, and control (including navigation) due to their ADAS technologies.

CISC: Refers to "complex instruction set computing," which is distinct from RISC. RISC-V and Arm processors are based on RISC concepts and computing architectures while x86 processors from Intel and AMD employ CISC designs. CISC processors seek to minimize the number of instructions per program at the expense of the number of computer clock cycles per instruction. CISC computing seeks to complete a task in as few lines of code as possible, but a single CISC instruction may take multiple computer clock cycles to complete. Both RISC and CISC can be seen as different "schools of thought about how to design a processor's ISA, or architecture for short.

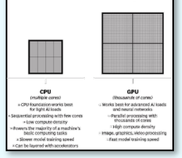
Cloud Native Environment: Refers to the concept of building and running applications to take advantage of distributed computing offered by the cloud delivery model. Cloud native apps are designed and built to exploit the scale, elasticity, resiliency, and flexibility the cloud provides. In a cloud-enabled solution, a company's application is deployed in the public cloud but still requires a physical server of its own for operations. However, with a cloud-native system, the company does not require any computing infrastructure onsite.

Cores: Cores are individual processing units within a CPU or GPU that execute instructions. Each core can independently perform tasks, allowing for parallel processing and improved performance. More cores enable a chip to handle multiple tasks simultaneously, enhancing multitasking capabilities and overall efficiency. Cores are essential for running applications more quickly and efficiently, particularly in modern computing environments that require high processing power for tasks like gaming, data analysis, and machine learning (ML).

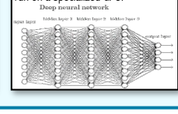
Cortex: ARM's Cortex CPUs are a family of processors designed by ARM Holdings for various applications, ranging from mobile devices to embedded systems and beyond. Known for their energy efficiency and scalability, Cortex CPUs are widely used in smartphones, tablets, smart TVs, and IoT devices due to their low power consumption and high performance-per-watt ratio. The Cortex series includes different models tailored to specific performance needs, from low-power Cortex-A cores used in mobile devices to Cortex-M cores optimized for microcontrollers and Cortex-R cores for real-time processing in embedded systems. ARM's Cortex CPUs are renowned for their versatility, contributing significantly to the widespread adoption of ARM architecture across diverse computing platforms.

CPU: Refers to "central processing unit," which is a chip that functions as the brains of computing devices. Also called the central processor, main processor or just processor, the CPU is made up of a set of electronic circuits that execute instructions comprising a computer program to perform basic arithmetic, logic, controlling and I/O (input/output) operations specified in a computer program.

CPU vs. GPU chips



Deep Learning: A subset of ML, deep learning is a computer science approach where neural networks (1) are trained to recognize patterns from massive amounts of data (in the forms of images, sounds and text), often better than humans, and in turn (2) provide predictions in a production process. Deep learning is often used to make non-linear, complex correlations, and needs to run on a specialized GPU.



DPU: Refers to "data processing unit," which is a programmable computer processor designed to efficiently handle data-centric workloads, such as data transfer, reduction, security, compression, analytics and encryption, at scale in data centers. A DPU tightly integrates a general-purpose CPU with network interface hardware.

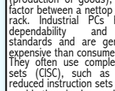
EDA: Electronic Design Automation (EDA) involves software tools for designing electronic systems like integrated circuits (ICs) and printed circuit boards in four focus areas:

Technology Computer-Aided Design (TCAD): EDA tools are used to design and validate semiconductor manufacturing processes to ensure optimal performance and density.
Design for Manufacturability (DFM): These tools verify that a design meets all manufacturing requirements. Issues in DFM can lead to chips that do not function properly or have reduced capacity, along with reliability risks.

Silicon Lifecycle Management (SLM): After manufacturing, EDA tools monitor chip performance from testing to field deployment, ensure long-term performance, and guard against tampering.

Semiconductor Intellectual Property (IP): This area offers pre-designed circuits that can be used as-is or adapted, facilitating faster and less complex chip design by reusing existing designs.

Edge: Refers to the "edge of a network." In a centralized network, client devices are connected to one server whose job is to process the information requested by the users and hand it back to them. While a centralized network is good enough to interact with simpler websites, companies have found that complex projects involving a great bank of customers work better with an edge server. Unlike a centralized network, because an edge server sits at the edge of a network (i.e., near where the data are generated by client machines), it improves latency, reduces loading times, and removes the load from the origin server. Instead of sending unprocessed data to the data center, edge servers process it themselves and send it back to the client machines.



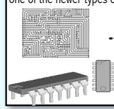
Embedded: Refers to micro-processors that used in embedded systems such as electronic products ranging from video games to automotive control systems, industrial automation, sensors, signage and transportation, and home appliances, among other things. While these microprocessors are invisible and inaccessible to the end user, product designers use the computational capabilities of these embedded microprocessors to implement the operating features of electronic products and control systems. Both CISC and RISC microprocessors are used in the embedded market. Although the distinctions between RISC and CISC microprocessor technology have blurred considerably, CISC technology generally increases performance by using more complex instructions to achieve higher code density, while RISC technology generally achieves substantial system performance and price/performance advantages by reducing the complexity of the processor instruction set, thereby enabling more effective use of pipe-lining and optimizing compilers, powerful hardware and software design techniques.

GPU: Refers to "graphics processing unit," a type of microprocessor capable of rendering graphics display on an electronic device, such as a gaming console or vehicle infotainment system. GPUs are also used for video editing and content creation, machine and deep learning, and artificial intelligence.

HPC: Refers to "high performance computing," which is the ability to process data and perform complex calculations at high speeds. To put it into perspective, a laptop or desktop with a 3 GHz processor can perform 3 billion calculations per second. While that is much faster than any human can achieve, it pales in comparison to HPC solutions that can perform quadrillions of calculations per second.

IC: An "integrated circuit" (also referred to as a chip or microchip) is a set of electronic circuits on one small flat piece of semiconductor material, usually silicon. Large numbers of miniaturized transistors and other electronic components are integrated together on the chip. This results in circuits that are orders of magnitude smaller, faster, and less expensive than those constructed of discrete components, allowing a large transistor count. The IC's mass production capability, reliability, and building-block approach to integrated circuit design have ensured the rapid adoption of standardized ICs in place of designs using discrete transistors.

These general-purpose devices that can be used for a variety of purposes and are found in everything from cell phones to cars to spacecraft. Unlike a microprocessor, which is designed to run software applications and gives better performance, integrated circuits are ideal for smaller applications that don't require as much computing power. Integrated circuits allow devices to be smaller and more lightweight. However, an integrated circuit cannot function independently because it doesn't have any program instructions or other information stored inside itself. In general, there are three types: (1) commodity integrated circuits, which are simple chips produced in large batches and used in single purpose appliances to perform repetitive processing routines (e.g., barcode scanners), (2) ICs made for a specific purpose, called application-specific integrated chip (ASIC) and (3) the all-in-one SoC, one of the newer types of chips.



Industrial PC: Refers to a computer intended for industrial purposes (production of goods), with a form factor between a nettop and a server rack. Industrial PCs have higher dependability and precision standards and are generally more expensive than consumer electronics. They often use complex instruction sets (CISC), such as x86, where reduced instruction sets such as ARM would otherwise be used.

IoT: Refers to "Internet of Things," which describes physical objects that are embedded with sensors, processing ability, and other technology that connects and exchanges data with other devices over the internet.

IP: Refers to Arm "intellectual property", including (1) architecture IP such as the company's RISC-based ISA, (2) physical IP, consisting of components used in the process of translating a design of complex SoC integrated circuits into manufactured chip, (3) system IP consisting of components used in an SoC design (other than the GPU and CPU), such as interfaces to external components and on-dash chip interconnects that bridge functional components within the SoC, and (4) version extensions, updates, support, patches, and bug fixes.

ISA: Instruction Set Architecture (ISA) defines how software interacts with a CPU, detailing the instructions a processor can execute. ISAs influence performance and software development and are categorized into:

Closed ISAs: Proprietary and controlled by their owners, like Arm, offering reliability but limiting customization.

Open ISAs: Like RISC-V, these are community-driven, promoting customization and innovation.

ISP: Refers to an "image signal processor" used to process images from sensors in digital cameras and other devices. It is often included in a SoC.

Mali: ARM's Mali GPU is a series of graphics processing units designed to deliver high-performance graphics and compute capabilities for a wide range of devices, from smartphones and tablets to automotive and embedded systems. Mali GPUs are known for their efficiency and scalability, supporting advanced graphics technologies such as OpenGL ES, Vulkan, and more. They are optimized to handle demanding graphical tasks and provide smooth, high-quality visuals while maintaining energy efficiency, making them a popular choice for mobile and embedded applications where power and performance balance is crucial.

Memory Chips: A memory chip is a semiconductor comprising numerous capacitors and transistors that can hold data (a) temporarily through random access memory (RAM) or (b) permanently through read only memory (ROM). Memory chips can be volatile (i.e., require power to maintain the stored information) or non-volatile (i.e., does not require a continuous power supply to retain the data or program code stored in a computing device).

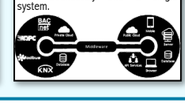
Microcontrollers: A microcontroller is a small computer on a single VLSI integrated circuit. A microcontroller contains one or more CPUs (processor cores) along with memory and programmable input/output peripherals and program memory.

In contrast to the microprocessor which is used in applications where (a) the task is not pre-defined but depends on the user or (b) intensive processing is required), a microcontroller is used for a specific task. Based on input given by the user or a sensor, the microcontroller performs a light amount of processing and gives the result as an output. In other words, microcontrollers are designed for embedded applications. Examples include the washing machine and microwave oven, where the task is pre-defined -- once the user sets the power and timing, the microwave gives the user cooked food; once the user sets the parameters, the washing machine gives the user clean clothes.

In modern terminology, a microcontroller is similar to, but less sophisticated than, a SoC. An SoC may include a microcontroller as one of its components, but usually integrates it with advanced peripherals like a GPU, a Wi-Fi module, or one or more co-processors.

Microprocessors: Microprocessors are used in (and mounted on the mother-boards of) virtually all desktop and laptop computers and other types of electronic equipment, such as cell phones, tablets, and components of cars. Microprocessors require extremely precise manufacturing to function properly, are power-hungry, and are better suited for more demanding tasks. They respond to user input, process instructions and perform the calculations and logic operations used to run software programs—i.e., play games, browse websites, edit photos, create documents, stream media, and perform mathematical calculations. The microprocessor contains all the components found in an IC -- a CPU, input / output ports, and memory -- but it also includes its own non-volatile storage for data. This allows users to run software on computers without needing additional hardware devices.

Middleware: Refers to software that different applications use to communicate with each other. Middleware acts as a bridge between diverse technologies, tools, and databases so the user can integrate them seamlessly into a single system.



ML: Refers to "machine learning," which is a subset of AI. ML is a computer science approach used in data science that leverages algorithms and data to learn how to make predictions or determinations. In other words, ML is an application of AI where machines/computer programs are given access to data and then use algorithms to find patterns in data (i.e., learn from the data). ML applications are often used to make simple, linear correlations, and can run on a CPU instead of a GPU that excels at running many smaller tasks at once.

With ML, a machine can automatically learn new information and improve itself from experiences without having to be programmed in a certain way since the machine will be able to teach itself new forms of information. However, the machines are not sentient (yet) and must be (1) told when they get something wrong or (2) given new data to figure out what the correct answer is. If new data or feedback is not given to the machine, it will not organically "learn" from its mistakes and adjust accordingly. As a result, ML does not provide "feedback"; it needs to be told explicitly how to fix a problem. AI, on the other hand, operates off a feedback loop. By contrast to ML where new data must be input to make corrections, AI is able to seek out new sources of data on its own and rebuild itself based on those feedbacks.

ML Inferencing: Refers to the process of using a trained machine learning model to make predictions or decisions based on new input data. During inferencing, the model applies its learned patterns and relationships from training to analyze the input and generate outputs, such as classifications, predictions, or recommendations. This process is crucial in applications like image recognition, natural language processing, and autonomous systems, where real-time or batch processing of data is required.

Nettop: A nettop is a small, low-power desktop computer designed for basic tasks like web browsing, email, and word processing. Key features include a compact size, low power consumption, affordability, and limited performance, making them suitable for light computing needs in home and school settings.

NPU: Refers to "neural processing unit" (also known as a neural processor, tensor processing unit, or AI accelerator), a specialized processor that implements all necessary control and arithmetic logic necessary to execute ML algorithms, typically by operating on predictive models such as artificial neural networks or random forests. In short, NPUs, such as the M2 chip used in latest versions of Apple laptops, and tablets, specialize in the acceleration of ML algorithms (10,000 times less time than a GPU).

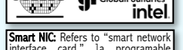
RF: Refers to "radio frequency," which is used in various electronics and appliances (e.g., radios and microwave ovens), TV broadcasting cellular telephones, satellite communications, radars, and industrial heaters and seaters. RF is the oscillation rate of an electromagnetic field.

RISC: Refers to "reduced instruction set computing" architectures and principles on which Arm's proprietary ISA is based. A RISC architecture has simple instructions that can be executed extremely quickly in a single computer clock cycle. Arm's RISC-based ISA has become the dominant choice for embedded systems and mobile devices due to its long-standing presence in the market, as well as years of trust and expertise cultivated, resulting in a widespread positive reputation.

SDVs: Autonomous / self-driving, software-defined vehicles. See Autonomous Driving.

Semiconductors: Also known as chips or processors, semiconductors are made by imprinting a network of electronic circuits/components onto a wafer that partially conducts electricity, which can then perform various functions, including (a) processing amplifying and selectively filtering electronic signals, (b) controlling electronic system functions and processing, and (c) transmitting and storing data.

Semiconductor Foundries: Also known as fabs, foundries are the facilities in which semiconductor chips or devices are manufactured. These highly complex and expensive facilities are either owned and operated by large, vertically integrated semiconductor companies (e.g., Infineon, Samsung, Intel, and Renesas) or operated as independent, "pure-play" manufacturing service providers (e.g., TSMC or Global Foundries). This latter category has become the dominant business model.



Smart NIC: Refers to "smart network interface card," a programable accelerator that makes data center networking, security, and storage efficient and flexible. See DPU above.

SOAFEE: An open, standards-based framework to enable cloud-native software development for mixed-critical workloads from cloud to automotive edge.

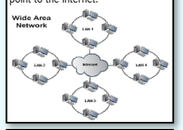
SoC: Refers to "system on a chip" or system-on-chip, which are among the newest types of chips. SoCs integrate or build into one chip most or all electronic components needed for an entire electronic system, such as an on-chip central processing unit (CPU), memory interfaces (RAM or random-access memory), input/output ports, input/output interfaces, and secondary storage interfaces, often alongside other components such as radio modems and GPU – all on a single substrate or microchip. SoCs may contain digital, and also analog, mixed-signal, and often radio frequency signal processing functions. SoCs break from the traditional approach to system design—architecture—e.g., motherboards on which each component is discretely installed. This enables the creation of smaller and more efficient devices. For this reason, SoCs are driving innovation in the creation of netbooks, laptops, smartphones, and IoT devices.

Transistors: A miniature semi-conductor that regulates or controls current or voltage flow in addition to amplifying and generating these electrical signals and acting as a switch/gage for them.

VR: Refers to virtual reality. VR is distinct from AR because VR creates a totally artificial world.

VLSI: Refers to "very-large-scale-integration," which is the process of creating an integrated circuit by combining thousands of transistors into a single chip.

WLAN: Refers to "wireless local area network," which is a wireless distribution method for two or more devices. WLANs use high frequency radio waves and include an access point to the Internet.



x86: x86 is a family of complex ISAs (or CISCs) initially developed by Intel. x86 processors from AMD and Intel dominate in computers and servers, while Arm RISC-based processors from Apple and Qualcomm dominate in tablets and smartphones. Arm-based processors have also been strong in embedded applications. That strength is being challenged by RISC-V, which is increasingly being used in embedded systems, automotive systems, disc drives, AI, and ML applications.

3G, 4G, and 5G: 3rd, 4th , and 5th generations of wireless, mobile, Broadband / cellular network technology. The latest generation is designed to deliver higher multi-Gbps peak data speed, ultra-low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience than all previous generations.

Semiconductor Industry: Landscape

September 2024

KEY PLAYERS

Software

EDA*

ORIGINAL EQUIPMENT MANUFACTURERS

Google, amazon.com, Lenovo, Microsoft, Hewlett Packard Enterprise, SONY, SAMSUNG, JUNIPER NETWORKS, hp, DELL Technologies, CISCO, IBM, NetApp

SEMICONDUCTOR FOUNDRIES

Pure Play: tsmc, GlobalFoundries, SMIC, UMC

Integrated: Micron, RENESAS, intel, intel foundry, SAMSUNG, SAMSUNG Foundry, Infineon, FUJITSU, Texas Instruments

CHIP DESIGNERS

NVIDIA, Qualcomm, RENESAS, BROADCOM, intel, TOSHIBA, SAMSUNG, FUJITSU, NXP, Infineon, life.augmented

OEM Designers: aws, Microsoft, Google

PROCESSOR DESIGN, IP, SOFTWARE, AND TOOLS DEVELOPERS

RISC-V, arm, intel

EDA: Refers to "electronic design automation", a market segment consisting of software, hardware and services that assist in the definition, planning, design, implementation, verification, and subsequent manufacturing of semiconductor devices (i.e., chips). The four focus areas of EDA are:

- *Technology Computer-aided Design (TCAD).* EDA tools are used to design and validate the semiconductor manufacturing process to ensure it delivers the required performance and density.
- *Design for Manufacturability (DFM).* EDA tools are used to verify that a design will meet all the requirements of the manufacturing process. Deficiencies in this area can cause the resultant chip to either not function or function at reduced capacity. There are also reliability risks.
- *Silicon Lifecycle Management (SLM).* After the semiconductor device is manufactured, there is a growing requirement to (1) monitor the performance of the device from post-manufacturing test to deployment in the field, (2) ensure the device continues to perform as expected throughout its lifetime, and (3) ensure the device is not tampered with.
- *Semiconductor Intellectual Property (or semiconductor IP).* This market segment provides pre-designed circuits of varying complexity that may be used as-is or adapted for a particular application. Semiconductor IP allows highly complex chips to be designed in far less time since a lot of existing design work can be reused.

Source of Concept: Arm Holdings Preliminary Prospectus on SEC Form F-1, p.4.

WHAT SEMICONDUCTORS DO

Overview: Semiconductors are an essential component of modern life! They are tiny electronic circuits made up of materials that partially conduct electricity. A broad portfolio of semiconductors are essential components of electronic devices and enable these devices to perform their functions. As such, semiconductors are considered the brains for millions of electronic devices and electrical systems located inside space vehicles, TVs, radios, video game consoles, car computers and electrical systems, smartphones, personal computers, supercomputers, advanced medical diagnostic equipment, appliances, military weapons systems, renewable energy systems, industrial equipment, data center servers, and telecommunications networks.

Composition and Function: A semiconductor is a material that allows current to flow more than an insulator but less than a pure conductor. Memory chips, microprocessors, and integrated chips are some examples of semiconductors. Semiconductors are made by imprinting a network of electronic components onto a semiconductor wafer. These devices are designed to perform various functions such as processing, amplifying and selectively filtering signals, controlling electronic system functions and processing, and transmitting and storing data.

GENERAL APPLICATIONS

- Embedded Systems (Small Computers that Form Part of a Larger Machine; They Control the Device and Allow User Interaction)
  - GPS Systems
  - TVs
  - Smart Watches
  - Fitness Trackers
  - Engine Management Systems
  - Central Heating Systems
- Solar Cells and Other Renewable Energy Systems
- Thermoelectric Applications (Including Lighting and LED Displays)
- Vehicles (See Specific Cases)
- IT Devices (see Specific Cases)
- Railcars
- Robotic Welding Machine
- Video Game Consoles
- Networking Equipment
- Medical Diagnostic Equipment
- Appliances
- Smart Phones
- Supercomputers
- Oil, Gas and NGL Pipelines
- Military Weapons Systems
- Telecommunications Networks
- Space Vehicles
- Factory Automation Systems
- Radios
- Data Center Servers

SPECIFIC CASES

Vehicles

The typical modern car is loaded with over 1,400 semiconductors to control safety, powertrain, electrical, comfort, infotainment, and connectivity systems. For this reason, vehicles are often referred to as "computers on wheels."

Connectivity
- Controller Area Network (CAN)
- Broadband, Wi-Fi, Bluetooth
- Over-the-Air Software Updates

Comfort
- Window/Mirror Controls
- Vibration Control
- Seat Controls
- Climate Controls
- Noise Suppression
- Adaptive Cruise Control

Infotainment
- Audio/Video
- Driver Display
- Navigation

Powertrain
- Engine Control
- Fuel-Injection System
- Hybrid-Electric Control
- Transmission Control
- Electric Power Steering

Safety
- Airbag Controls
- Collision Avoidance
- Parking-Assist
- Power Locks
- Braking-Assist
- Tire-Pressure-Monitoring
- Traction-Control System

Electrical
- Starter
- Lighter
- Vehicle-Diagnostics

IT Devices

Most people associate semiconductors with information technology devices, such as personal computers (desktop and laptop computers), mobile devices (smart phones and tablets), and servers in data centers.

Personal Computers

In 2021, 342 million PCs were shipped around the world. It was expected that 310 million PCs were to be shipped in 2022. However, PC shipments only reached 286.2 million units in 2022, a 16.2% decrease from the previous year. Most PCs include only one chip.

Mobile Devices

There are 6.7 billion smartphone subscriptions globally (85% of the world population). By 2028, the rise in the number of smartphone subscriptions is projected to grow to 7.7 billion. Current generations of smartphones come in a range of multi-range of processors, such as Dual-Core (2), Quad-Core (4), and Octa-Core (8), with the Octa-Core processor (used by Apple in iPhone 13 and 14) being the most powerful.

Servers

Servers today feature one or two x86 chips, or maybe an Arm processor. In 5 or 10 years they will feature many more. The typical data center with 850 Megawatts of capacity can run thousands to millions of servers:

- 803,608 High-Powered 1U Servers
- 1,768,000 Mid-Powered 1U Servers
- 6,314,256 Low-Powered 1U Servers

Semiconductor Industry Ecosystem

September 2024

SEIMCONDUCTOR ECOSYSTEM

INDUSTRY PARTICIPANTS

Key semiconductor players include:

1. **DESIGN ARCHITECTS**
(Design architects research and develop instruction set architectures for processors as well as physical and system IP, which they license to system companies for customization and manufacturing of chips.)
arm

2. **SYSTEM COMPANIES**
(Semiconductor companies whose research and integrated circuit designs set the stage for chip production.)
AMD Qualcomm BROADCOM

3. **FABS OR FOUNDRIES**
(Pure-play foundries and integrated circuit manufacturers perform front-end wafer manufacturing operations. Foundry operators may be system companies or third-party contract manufacturers (if the system company operates on a "fabless" basis).)
tsmc Infineon intel

4. **ELECTRONICS MANUFACTURING SERVICES (EMS)**
(Companies provide integrated circuit assembly, packaging, testing, and repair services to the system company. These companies are also capable of designing and manufacturing semiconductors.)
Amkor Technology JABIL FOXCONN ASE GROUP

5. OEM CONSUMERS
(OEM consumers are the original equipment manufacturers of electronic devices (or the makers of electronic components and assemblies of such devices) into which finished chips will be incorporated.)
DELL Technologies verizon aws Ford RTX

PRODUCTION PROCESS

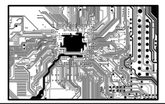
According to the Semiconductor Industry Association, the semiconductor production process consists of nine steps—research, design, raw materials procurement, ingot production, blank wafer production, finished wafer production, finished wafer cutting, finished wafer packaging, and embedding finished wafers in circuit boards.

FABLESS SYSTEM COMPANY → **FOUNDRY** (May partner with System Company on Design and R&D) → **EMS COMPANY** → **OEM CONSUMER**

FABLESS MODEL

1. RESEARCH
Pre-competitive research is conducted.

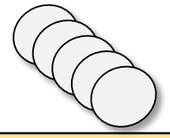
2. DESIGN
Engineers use highly sophisticated equipment to design semiconductors, similar to how architects design buildings.



3. RAW MATERIALS
Many semiconductors start out as germanium or sand, which contains a large amount of silicon, or compounds such as gallium arsenide. In a process called doping, small amounts of impurities are added to these pure elements or compounds, causing large changes in the conductivity of the material.

4. INGOT
The sand is purified and melted into solid cylinders called ingots, weighing up to 200+ lbs.

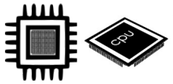
5. BLANK WAFER
The ingot is then sliced into very thin (1mm) silicon discs and polished to a flawless finish.



6. FINISHED WAFER
Next, wafers are printed with highly intricate circuit designs that will later become individual chips.

7. CUT WAFER
The silicon wafer containing finished semiconductors, sometimes as many as 70,000 per wafer, is then cut up into tiny individual semiconductors called dies.

8. PACKAGED CHIP
The dies are then packaged into finished semiconductors, which can then be placed into electronic devices.

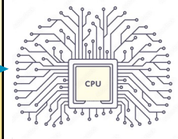


Fab-less Model

8A. DELIVERY CHIPS TO FABLESS SYSTEM COMPANY
The packaged chips are delivered to the Fabless System Company.

Fabless Model

9. CHIP ON CIRCUIT BOARD
Finished semiconductors are embedded in countless electronics devices, from personal computers, servers and smartphones to highly advanced medical equipment, vehicle electrical systems, and supercomputers.



Foundry Model

FOUNDRY MODEL

FOUNDRY → **FOUNDRY END CONSUMER**

CHIPMAKRERS

SYSTEM COMPANIES

The numerous chipmakers range from (1) household names with global reach to (2) smaller suppliers little known outside their specialized market niche. Semiconductor firms focus their operations around one of three models:

6. **FABLESS**
(Fabless companies focus only on chip design and then outsource the manufacturing of their chip designs to third party producers.)
Qualcomm NVIDIA

7. **INTEGRATED DEVICE MANUFACTURERS (IDMs)**
(IDMs conduct both design and manufacturing activities.)
SAMSUNG intel

8. **FOUNDRIES**
(Pure-play foundries are companies that focus primarily on manufacturing for third parties.)
GlobalFoundries tsmc

DESIGN ARCHITECTS

arm

RISC-V

intel x86

FABLESS COMPANIES

Qualcomm HUAWEI SONY TOSHIBA NVIDIA AMD HISILICON NXP BROADCOM MEDIATEK

Apple-Designed, TSMC-Produced

INTEGRATED DEVICE MANUFACTURERS

FUJITSU SAMSUNG TEXAS INSTRUMENTS intel Infineon SK hynix Micron RENESAS

PURE-PLAY FOUNDRIES

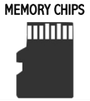
GlobalFoundries tsmc UMC

CHIP TYPES

KEY CHIP CATEGORIES

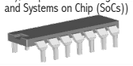
Semiconductors can be divided into three main categories:

9. **MEMORY CHIPS**



10. **PROCESSORS AND CONTROLLERS**

11. **INTEGRATED CIRCUITS**
(Including Accelerated Processing Units (APUs), Neural Processing Units (NPUs), Data Processing Units (DPUs), Graphics Processing units (GPUs), and Systems on Chip (SoCs))



MEMORY CHIPS

MEMORY CHIPS

A memory chip is a semiconductor comprising numerous capacitors and transistors that can hold and process data (a) temporarily through random access memory (RAM) or (b) permanently through read only memory (ROM). Memory chips can be volatile (i.e., require power to maintain the stored information) or non-volatile (i.e., does not require a continuous power supply to retain the data or program code stored in a computing device).

PROCESSORS AND CONTROLLERS

CENTRAL PROCESSING UNITS (CPUs)

The CPU is a chip that functions as the brains of the personal computer (PC). Also called the central processor, main processor or just process, the CPU is made up of a set of electronic circuits that execute instructions comprising a computer program to perform basic arithmetic, logic, controlling and I/O (input/output) operations specified in computer program.

MICROPROCESSORS

Microprocessors are used in (and mounted on the mother-boards of) virtually all desktop and laptop computers. They are also found in other types of electronic equipment, such as cell phones, tablets, and cars. Microprocessors require extremely precise manufacturing to function properly, are power-hungry, and are better suited for more demanding tasks. They respond to user input, process instructions and perform the calculations and logic operations used to run software programs—i.e., play games, browse websites, edit photos, create documents, stream media, and perform mathematical calculations. The microprocessor contains all the components found in an integrated circuit — a CPU, input / output ports, and memory — but it also includes its own non-volatile storage for programs and data. This allows users to run software on computers without needing additional hardware devices.

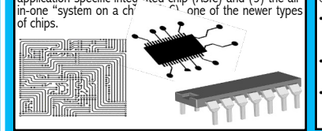
MICROCONTROLLERS

In contrast to the microprocessor (which are used in applications where (a) the task is not pre-defined but depends on the user or (b) intensive processing is required), a microcontroller is used for a specific task. Based on input given by the user or a sensor, the microcontroller performs a light amount of processing and gives the result as an output. Examples include the washing machine and microwave oven, where the task is pre-defined -- once the user sets the power and timing, the microwave gives the user cooked food; once the user sets the parameters, the washing machine gives the user clean clothes.

INTEGRATED CIRCUITS

INTEGRATED CIRCUITS (ICs)

Integrated circuits are general-purpose devices that can be used for a variety of purposes and are found in everything from cell phones to cars to spacecraft. Unlike the microprocessor, which is designed to run software applications and gives better performance, integrated circuits are ideal for smaller applications that don't require as much computing power. Integrated circuits allow devices to be smaller and more lightweight. However, an integrated circuit cannot function independently because it doesn't have any program instructions or other information stored inside itself. In general, there are three types: (1) commodity integrated circuits (CICs), which are simple chips produced in large batches and used in single purpose appliances to perform repetitive processing routines (e.g., barcode scanners), (2) ICs made for a specific purpose, called application-specific integrated chip (ASIC) and (3) the all-in-one "system on a chip" (SoC), one of the newer types of chips.



ANALOG INTEGRATED CIRCUITS (Analog ICs)

Analog integrated circuits act as a link between the real world and the digital world. Whereas digital signals are binary and must have a value of 1 or 0, analog signals are continuous and can have any value between a minimum and maximum. Analog signals represent the "level" of things like voltage, temperature, sound, and radio wave frequencies. While memory chips process digital signals, or data, analog chips amplify, filter, convert, and transmit analog signals. Analog chips don't grab the headlines like the advanced AI accelerators do. However, they are far more common. They play a crucial role in applications (such as audio equipment, sensors, and communications systems) requiring precise signal conditioning, transmission, processing, filtering, and amplification. Devices like smartphones can contain dozens of them, and the number sold each year runs into the hundreds of billions. Analog chips can be divided into three sub-categories:

- *General Analog ICs*—these include sensors or chips that amplify or transmit signals. They are found in older microphones and audio speakers. These are among the most common chips in the world, with over one billion sold each year.
- *Power ICs*—these are used to manage power in systems ranging from smartphones to the most advanced AI accelerators.
- *Mixed-signal ICs*—these ICs process analog and digital signals, typically converting one to the other. Many communications protocols like 5G, Wi-Fi and Bluetooth rely on mixed-signal chips.

ACCELERATED PROCESSING UNITS (APUs)

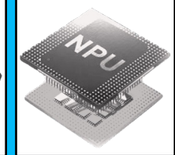
Created by AMD in 2011, an accelerated processing unit (APU) is a microprocessor that combines the central processing unit (CPU) with the graphics processing unit (GPU) on a single computer chip.

GRAPHICS PROCESSING UNITS (GPUs)

A type of microprocessor, a graphics processing unit (GPU) is capable of rendering graphics display on an electronic device, such as a gaming console, personal computer or vehicle infotainment system. GPUs also have application for video editing and content creation, machine and deep learning, and artificial intelligence (AI).

NEURAL PROCESSING UNITS (NPUs)

A neural processing unit (NPU), such as the M2 chip used in latest versions of Apple's laptops and tablets, is a microprocessor that specializes in the acceleration of machine learning algorithms (10,000 times less time than a GPU), typically by operating on predictive models such as artificial neural networks (ANNs) or random forests (RFs). It is also known as neural processor.



DATA PROCESSING UNITS (DPUs)

DPUs are the new kids on the block. A DPU is a programmable processor designed to efficiently handle data-centric workloads such as data transfer, reduction, security, compression, analytics, and encryption, at scale in data centers. DPUs work with CPUs and GPUs to enhance the computing power and handling of increasingly complex modern data workloads. The DPU market has gained traction due to the rise in demand for AI, machine learning, deep learning, Internet of Things, 5G, and complex cloud architectures.

SYSTEMS ON A CHIP (SoCs)

A form of integrated circuit, the SoC is among the newest types of chip. All the electronic components needed for an entire system (e.g., CPU, Random Access Memory (or RAM), storage, I/O (input/out ports) are built into a single chip. SoCs break from the traditional approach to system architecture (e.g., with motherboards) where each component is discretely installed. This enables the creation of smaller and more efficient devices. For this reason, SoCs are driving innovation in the creation of netbooks, laptops, smartphones, Internet of T