Semiconductors: Lessons from the past and what it says for semiconductor manufacturing

Sandip Tiwari
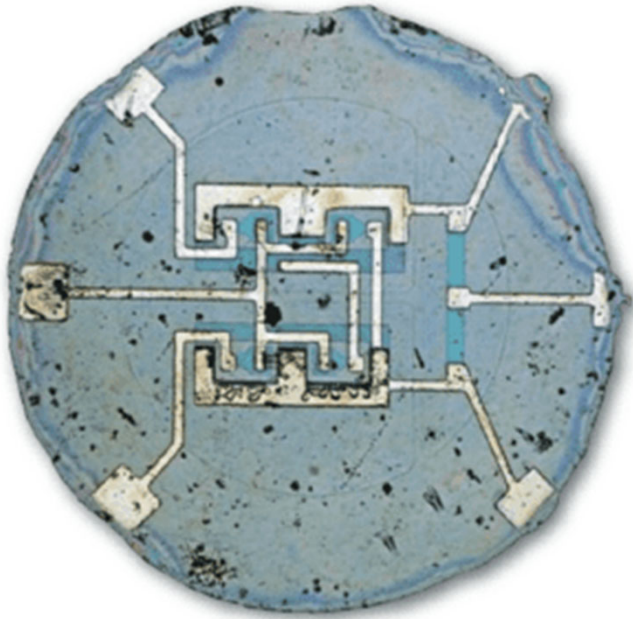
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The aim of science is not to open the door to infinite wisdom, but to set a limit to infinite error.
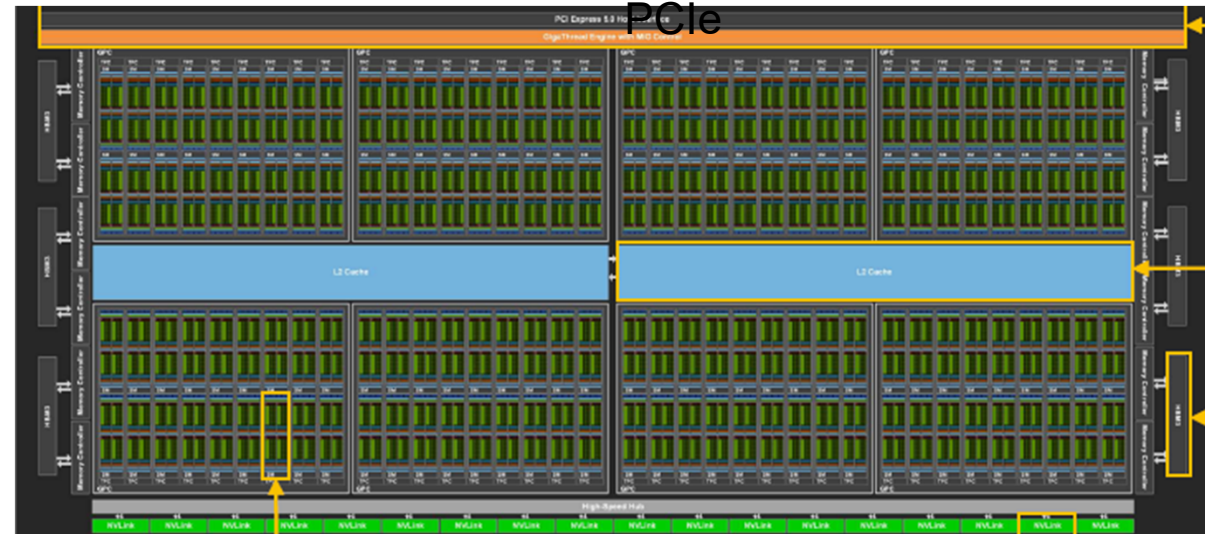
Bertolt Brecht (Leben des Galelei (Life of Galileo))

4 transistors
5 resistors

Nvidia H100

7.7×10^7 transistors
Multiinstance GPU
900 GB/s Nvlink
PCIe

http://www.computerhistory.org/semi
conductor/timeline/1960-FirstIC.html

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*Semiconductors are the foundation of the information edifice
of the modern society*

Communications (cell phones, all the financial transactions, ...): semiconductors based.

Computing (transactions, financial bookkeeping, Aadhar, UPI, education, ...): semiconductors based.
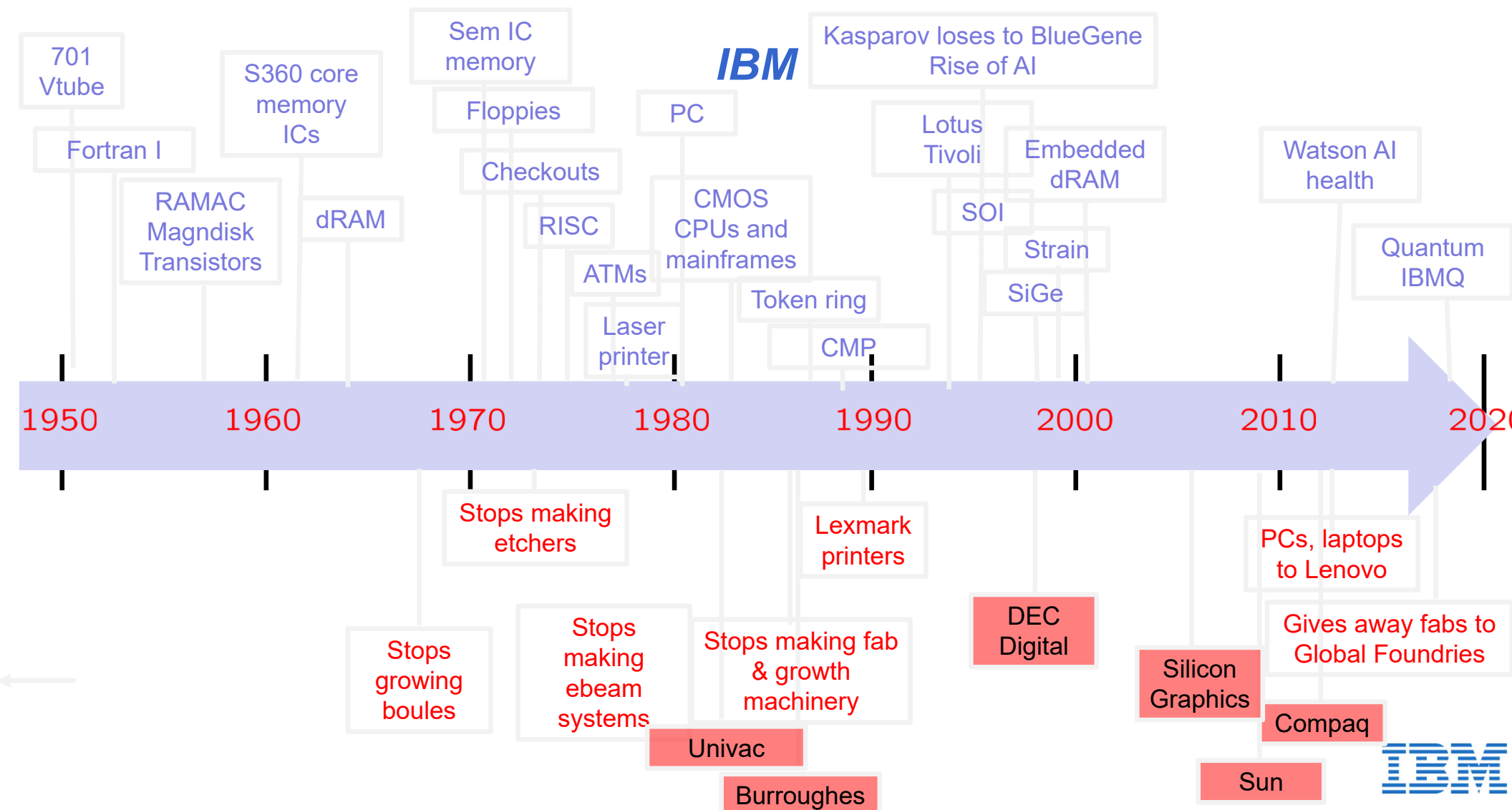
Sensing and decision making (data gathering, inferencing, ...): semiconductors based.

Defense (monitoring, reactions, controls, operations, ...): semiconductors based.

Even cars are increasingly semiconductors and computing on wheels

Like agriculture!

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the Stanford marshmallow experiment
of delayed gratification

IBM timeline

Above the timeline (blue/purple labels):
- 701 Vtube
- Fortran I
- RAMAC Magndisk Transistors
- S360 core memory ICs
- dRAM
- Sem IC memory
- Floppies
- Checkouts
- RISC
- ATMs
- Laser printer
- PC
- CMOS CPUs and mainframes
- Token ring
- CMP
- Kasparov loses to BlueGene Rise of AI
- Lotus Tivoli
- SOI
- Embedded dRAM
- Strain
- SiGe
- Watson AI health
- Quantum IBMQ

Timeline: 1950 — 1960 — 1970 — 1980 — 1990 — 2000 — 2010 — 2020

Below the timeline (red labels):
- Stops making etchers
- Lexmark printers
- PCs, laptops to Lenovo
- Stops growing boules
- Stops making ebeam systems
- Stops making fab & growth machinery
- DEC Digital
- Silicon Graphics
- Gives away fabs to Global Foundries
- Univac
- Burroughes
- Compaq
- Sun

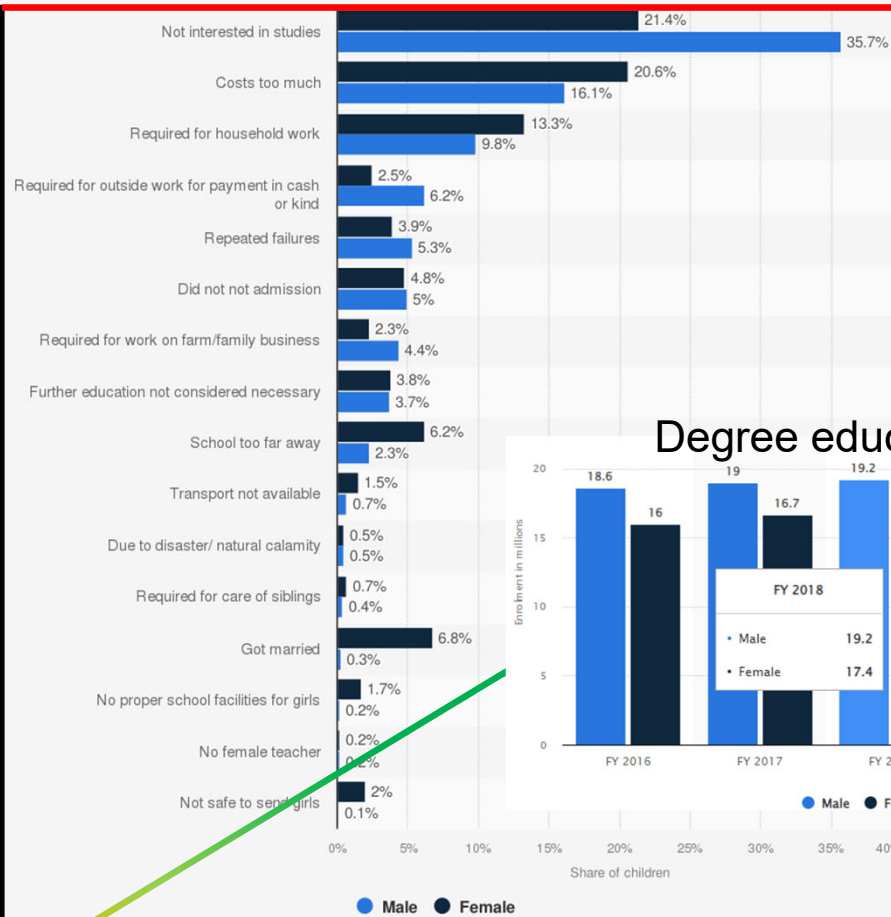© Sandip Tiwari 2023   5   iitk _T5

Development and growth is a flow.

A flow across the entire chain in all its dimensions.
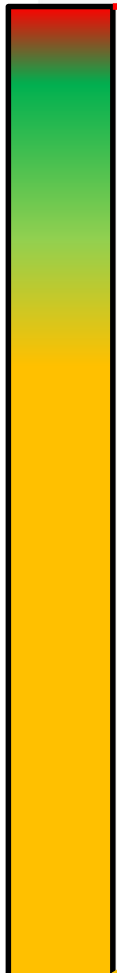
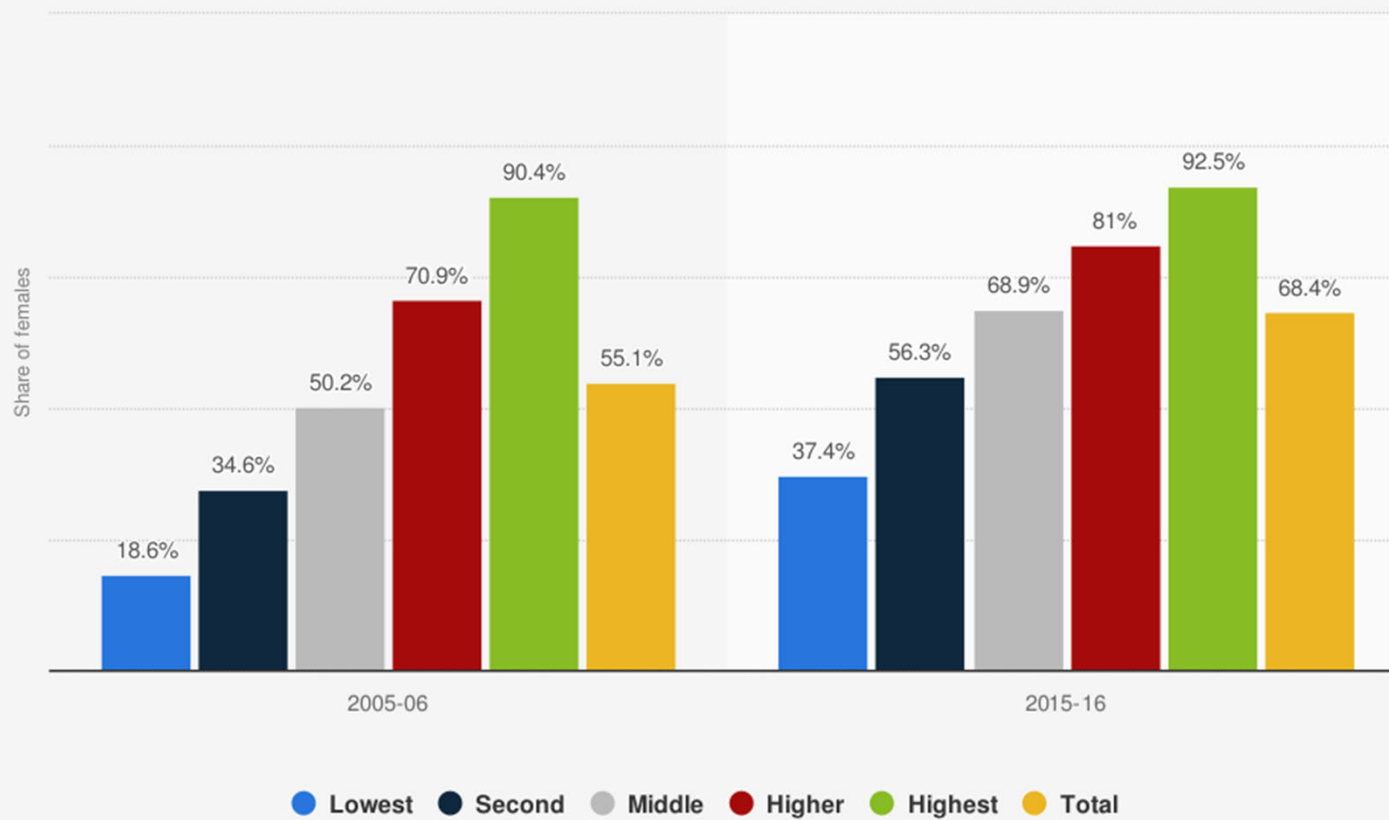*People, ideas, development, products, ... in time*

1% 40% of wealth
10% 63% of wealth

40% of the wealth created in the country from 2012 to 2021 went to top 1%. 3% went to bottom 50%
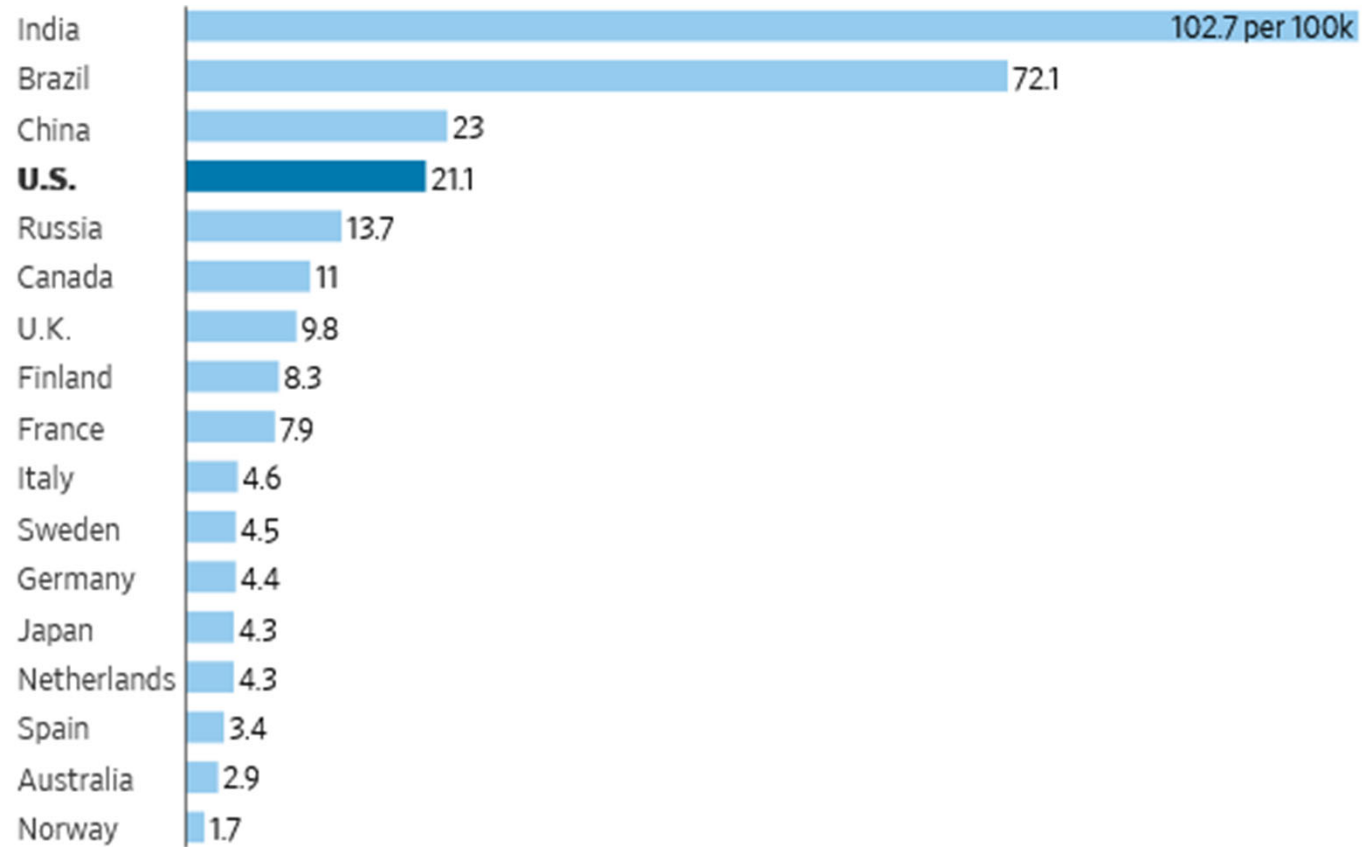
64% of GST from bottom 50%

today

Reasons for not attending school among children aged six to 17 in India as of April 2021, by gender

Reason	Male	Female
Not interested in studies	35.7%	21.4%
Costs too much	16.1%	20.6%
Required for household work	9.8%	13.3%
Required for outside work for payment in cash or kind	6.2%	2.5%
Repeated failures	5.3%	3.9%
Did not not admission	5%	4.8%
Required for work on farm/family business	4.4%	2.3%
Further education not considered necessary	3.7%	3.8%
School too far away	2.3%	6.2%
Transport not available	0.7%	1.5%
Due to disaster/ natural calamity	0.5%	0.5%
Required for care of siblings	0.4%	0.7%
Got married	0.3%	6.8%
No proper school facilities for girls	0.2%	1.7%
No female teacher	0.2%	0.2%
Not safe to send girls	0.1%	2%

Male ● Female

Additional Information:
India; June 2019 to April 2021; 6-17 years; children from 636,699 households; CAPI interview, questionnaire

NFHS
© Statista 2022

Degree education (millions)

FY 2016: 18.6 / 16
FY 2017: 19 / 16.7
FY 2018: 19.2 / 17.4
FY 2019: 19.2 / 18.2
FY 2020: 19.6 / 18.9

FY 2018
● Male   19.2
● Female 17.4

● Male   ● Female

~30% to college

1--2 generations; 25 years

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Share of female literacy in India from 2005 to 2016, by wealth group

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Maternal-mortality death rate per 100,000 live births by select country, 2020 estimates

Country	Rate
India	102.7 per 100k
Brazil	72.1
China	23
U.S.	21.1
Russia	13.7
Canada	11
U.K.	9.8
Finland	8.3
France	7.9
Italy	4.6
Sweden	4.5
Germany	4.4
Japan	4.3
Netherlands	4.3
Spain	3.4
Australia	2.9
Norway	1.7

Source: World Health Organization

WSJ, 03/27/23

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GDP per capita (Dollars) South Korea vs India comparison

GDP per capita (Dollars) China vs India comparison

GDP per capita (Dollars) Türkiye vs India comparison

Low/middle income trap

https://www.statista.com

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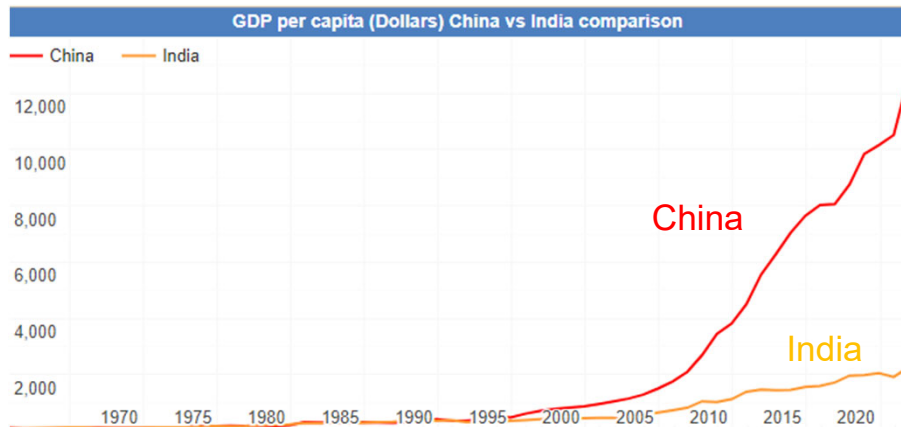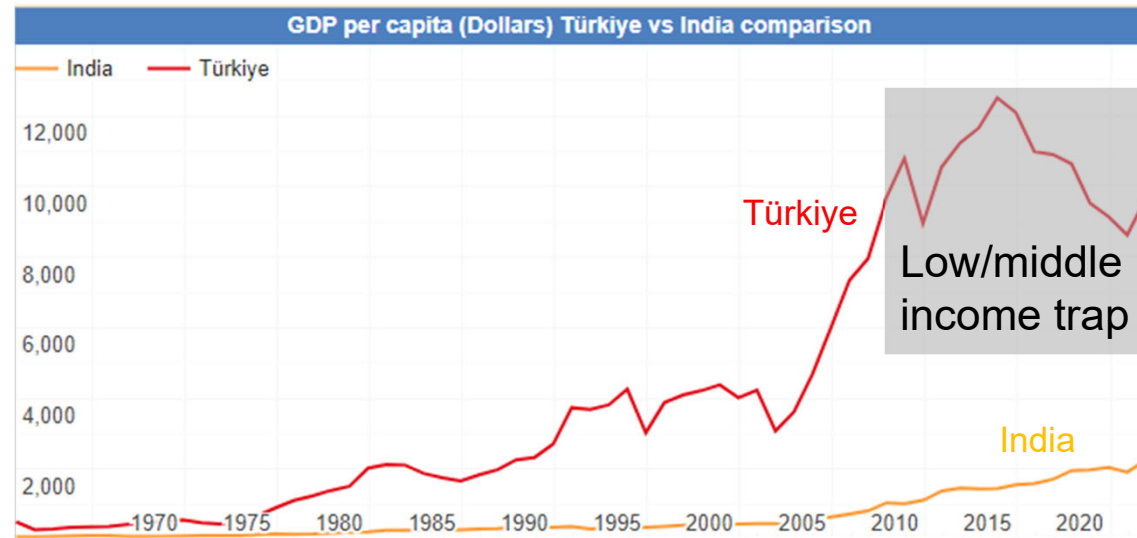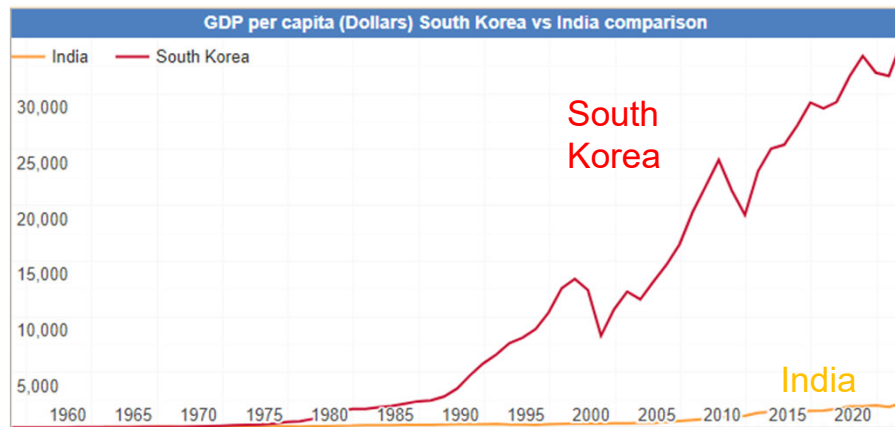
Fast and slow, short and long, scattering and friction, work and heat.

Lower income and middle income trap

UK: Manufacturing gone, class and feudal and financial chicanery
Italy: Tourism and gastronationalism is half of GDP
Greece: Tourism and right-left ancient debates
Türkiye: Tourism and secular-religious cultural fights

When a community finds itself deprived of its sense of identity, because of whatever historical shock or fracture with its past, it invents traditions to act as founding myths.
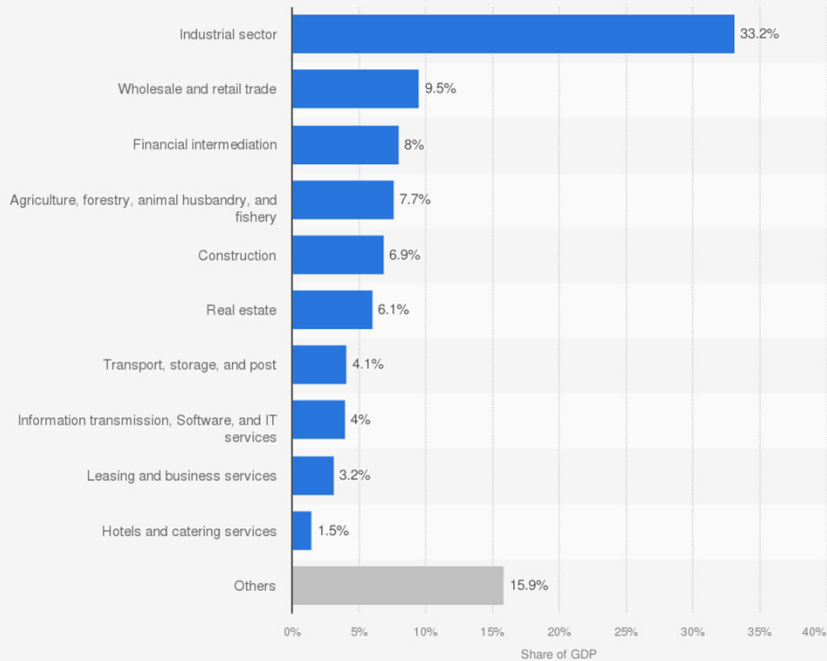
Eric Hobswam

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Different years 2021, 2022

	Türkiye	South Korea	China	India
Annual GDP $M	817,508	1,797,810	17,744,640	3,176,296
GDP/capita	9,654	34,744	12,564	2,257
Debt/GDP %	41.8	51.33	68.06	89.18
Debt/Capita	4,036	17,968	7,164	1,704
Deficit/Gdp %	-3.86	-0.02	-9.72	-12.76
Expenditure $/Capita	3012	9046	3726	588.5
Export/GDP %	26.15	35.61	18.97	12.46
Education $/Capita	395	1487	347	56
Education/Budget %	12.41	24.98	11.45	12.75
Health $/Capita	291	1214	337.9	19.9
Health/Budget %	9.69	13.42	9.07	3.38
Density	108	515	147	428
Life expectancy	75.85	83.5	78.08	70.15
Population	84,680,273	51,736,000	1,412,360,000	1,407,563,842

https://countryeconomy.com 14 *https://www.statista.com* iitk_T5

GDP, China

GVA, India

Distribution of the gross domestic product (GDP) in China in 2022, by industry

Industry	Share of GDP
Industrial sector	33.2%
Wholesale and retail trade	9.5%
Financial intermediation	8%
Agriculture, forestry, animal husbandry, and fishery	7.7%
Construction	6.9%
Real estate	6.1%
Transport, storage, and post	4.1%
Information transmission, Software, and IT services	4%
Leasing and business services	3.2%
Hotels and catering services	1.5%
Others	15.9%

Distribution of gross value added across India in financial year 2022, by sector
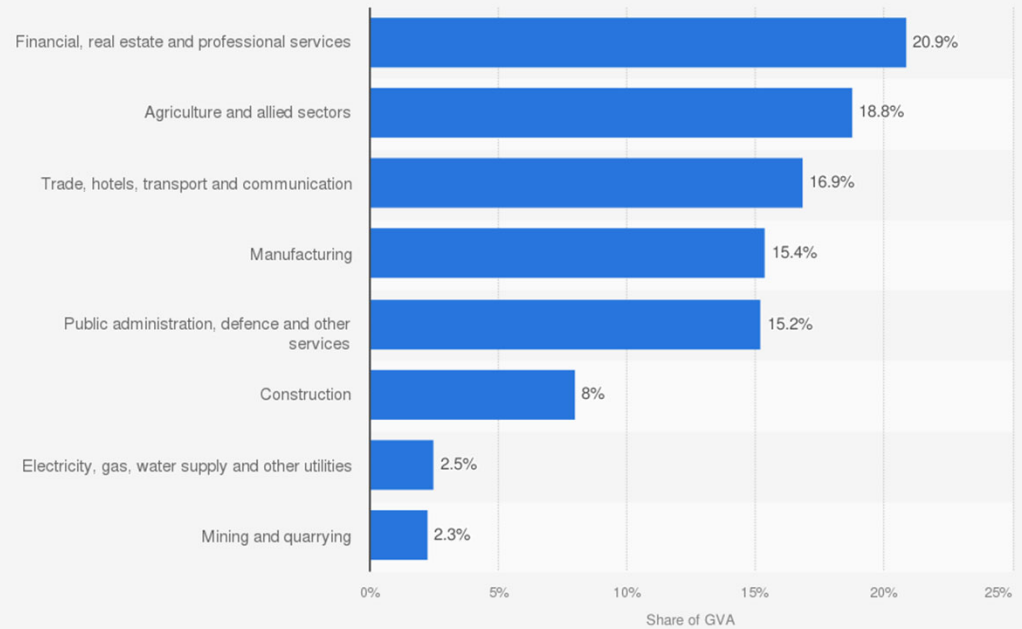
Sector	Share of GVA
Financial, real estate and professional services	20.9%
Agriculture and allied sectors	18.8%
Trade, hotels, transport and communication	16.9%
Manufacturing	15.4%
Public administration, defence and other services	15.2%
Construction	8%
Electricity, gas, water supply and other utilities	2.5%
Mining and quarrying	2.3%

GVA adjusts GDP by the impact of subsidies and taxes (tariffs) on products.

US with China: Total Trade in Goods

■ Exports ■ Imports ■ Deficit □ Surplus

Billions

	2016	2017	2018	2019	2020	2021
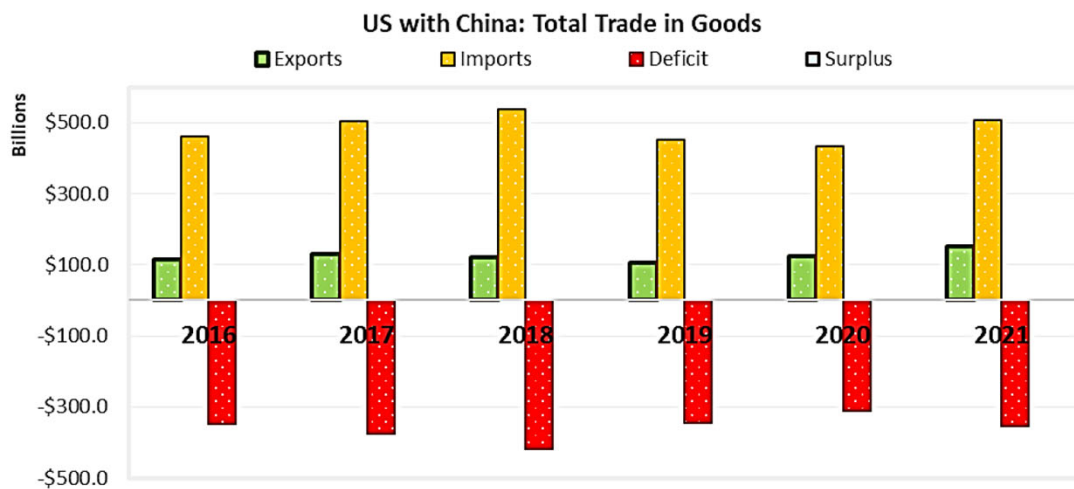
S. Exports to China in Agriculture Products
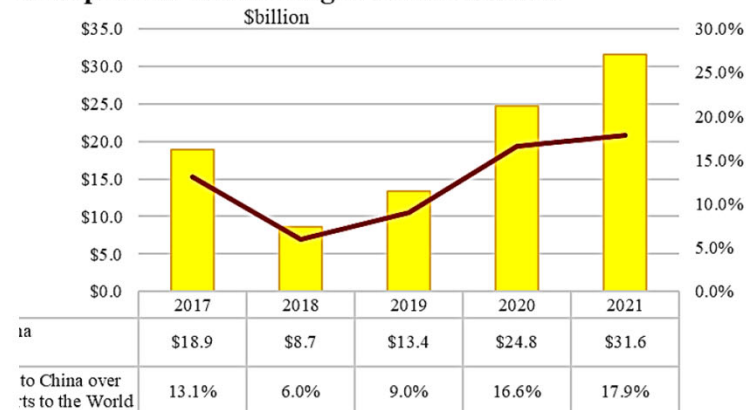
$billion

	2017	2018	2019	2020	2021
...a	$18.9	$8.7	$13.4	$24.8	$31.6
to China over ...ts to the World	13.1%	6.0%	9.0%	16.6%	17.9%

China to USA (left) **USA to China** (right)

China Commodity Trade 2021

Imports from China by Sector			US exports to China by Sector
$506,366,913,672		**Total Value All Commodities**	$151,065,225,124
1.1%		Agriculture (Chapters 01-24)	20.9%
0.1%		Oils, Minerals, Lime, Cement (Chapters 25-27)	11.2%
10.5%		Chemicals, Plastics, Rubber, Leather (Chapters 28-43)	16.6%
1.6%		Wood, Cork, Paper, Printed Books (Chapters 44-49)	3.1%
9.9%		Textiles, Footwear, Headgear (Chapters 50-67)	1.4%
1.7%		Stone, Glass, Metals, Pearls (Chapters 68-71)	3.0%
5.7%		Base Metals, Iron, Steel, Tools (Chapters 72-83)	2.6%
47.7%		Machinery & Mechanical Appliances (Chapters 84-85)	23.9%
3.4%		Transportation Equipment (Chapters 86-89)	8.8%
2.9%		Optical, Measuring, Medical, Other Instruments (Chapters 90-92)	7.2%
0.1%		Arms & Ammunition (Chapter 93)	0.0%
13.5%		Miscellaneous Manufactured Items (Chapters 94-96)	0.2%
0.0%		Art, Collectors' Pieces, Antiques (Chapter 97)	0.1%
1.9%		Special Items (Chapters 98)	0.9%

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American export controls

Top Ten ECCNs to China by Shipment Count — LICENSED

	ECCN	Description
#1	9A991	"Aircraft," n.e.s., and gas turbine engines not controlled by 9A001 or
#2	2B230	All types of "pressure transducers" capable of measuring absolute pres
#3	7A994	Other navigation direction finding equipment, airborne communication e
#4	2B350	Chemical manufacturing facilities and equipment, except valves control
#5	EAR99	Items subject to the EAR that are not elsewhere specified in this CCL
#6	6A005	"Lasers," "components" and optical equipment, as follows (see List of
#7	3A001	Electronic items as follows (see List of Items Controlled).
#8	2B352	Equipment Capable of Use in Handling Biological Materials, as Follows
#9	5A991	Telecommunication equipment, not controlled by 5A001 (see List of Item
#10	3B991	Equipment not controlled by 3B001 for the manufacture of electronic "p

Note: ECCN descriptions have been truncated: please review Commerce Control List for full description

Top Ten ECCNs to China by Shipment Count — EXCEPTIONS

	ECCN	Description
#1	5A002	"Information security" systems, equipment and "components," as follows
#2	EAR99	Items subject to the EAR that are not elsewhere specified in this CCL
#3	9A991	"Aircraft," n.e.s., and gas turbine engines not controlled by 9A001 or
#4	2B230	All types of "pressure transducers" capable of measuring absolute pres
#5	5D002	"Software" as follows (see List of Items Controlled).
#6	7A103	Instrumentation, navigation equipment and systems, other than those co
#7	5B002	"Information Security" test, inspection and "production" equipment, as
#8	7A994	Other navigation direction finding equipment, airborne communication e
#9	3A001	Electronic items as follows (see List of Items Controlled).
#10	6A005	"Lasers," "components" and optical equipment, as follows (see List of

Note: ECCN descriptions have been truncated: please review Commerce Control List for full description

Top Ten ECCNs to China by Shipment Count — NLR with ECCN

	ECCN	Description
#1	9A991	"Aircraft," n.e.s., and gas turbine engines not controlled by 9A001 or
#2	5A992	Equipment not controlled by 5A002 (see List of Items Controlled).
#3	3B991	Equipment not controlled by 3B001 for the manufacture of electronic "p
#4	5A991	Telecommunication equipment, not controlled by 5A001 (see List of Item
#5	3A991	Electronic devices, and "components" not controlled by 3A001.
#6	3B992	Equipment not controlled by 3B002 for the inspection or testing of ele
#7	7A994	Other navigation direction finding equipment, airborne communication e
#8	3A992	General purpose electronic equipment not controlled by 3A002.
#9	2B999	Specific Processing Equipment, n.e.s., as Follows (See List of Items C
#10	3A999	Specific Processing Equipment, n.e.s., as Follows (See List of Items C

Note: ECCN descriptions have been truncated: please review Commerce Control List for full description

Category	Date
Category 0 - Nuclear Materials Facilities & Equipment [and Miscellaneous Items]	2023-02-24
Category 1 - Materials Chemicals Microorganisms and Toxins	2023-02-24
Category 2 - Materials Processing	2023-02-24
Category 3 - Electronics Design Development and Production	2023-02-24
Category 4 - Computers	2023-03-16
Category 5 Part 1 - Telecommunications	2022-05-26
Category 5 Part 2 - Information Security	2023-02-24
Category 6 - Sensors and Lasers	2023-02-24
Category 7 - Navigation and Avionics	2023-02-24
Category 8 - Marine	2020-09-11
Category 9 - Aerospace and Propulsion	2023-02-24

https://www.bis.doc.gov/index.php/regulations/export-administration-regulations-ear

https://www.bis.doc.gov/index.php/country-papers/2971-2021-statistical-analysis-of-u-s-trade-with-china/file

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Semiconductors: TSMC

Founded 1987, $75B/yr (2022), 65000 employees. Foundry (Intel is $62B/yr)
Morris Chang (from TI (founded 1951, made the 1st integrated circuit (Kilby)), $21B/yr Analog/Digital)

Billion

Chart Title

https://companiesmarketcap.com/tsmc/revenue/
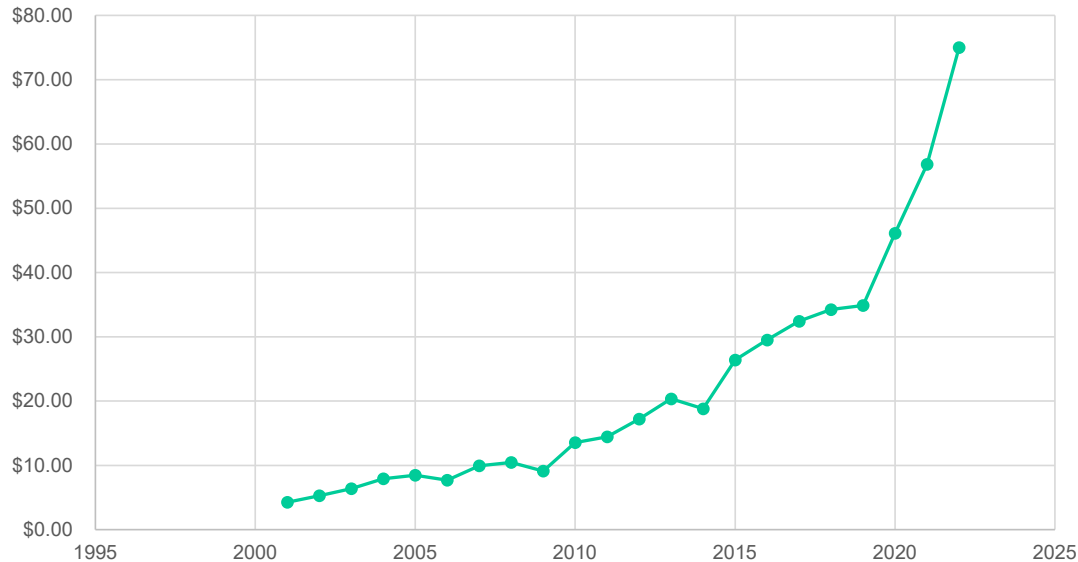
13 foundries.
1/3 of all of world's silicon chips
All of iPhones, Macs, ...

China:
1 B internet users
$6.6T digital economy

USA: CHIPS Act is roughly $280B

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Dirigisme (Fr. diriger)

Technology, value and control

Large cloud providers: Amazon, Google, Microsoft, Alibaba Cloud.

Dominant desktop OS providers: Microsoft, Apple and various Linux

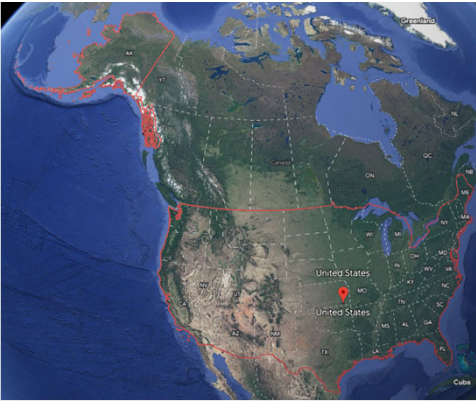Dominant mobile OS providers: Google and Apple.

Chip companies: Samsung, TSMC, Intel, GlobalFoundaries

Design companies: Nvidia, Broadcom, Qualcomm

Social networks: Meta, Whatsapp, Snap, TikTok, WeChat

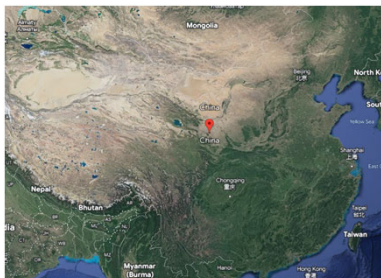Car companies: Tesla, Hyundai, Toyota, VW, Mercedes, BMW

Airplanes: Boeing, Airbus, Comac C919

                                                                     iitk _T5

World change from post WWII order

9,831,510 km²
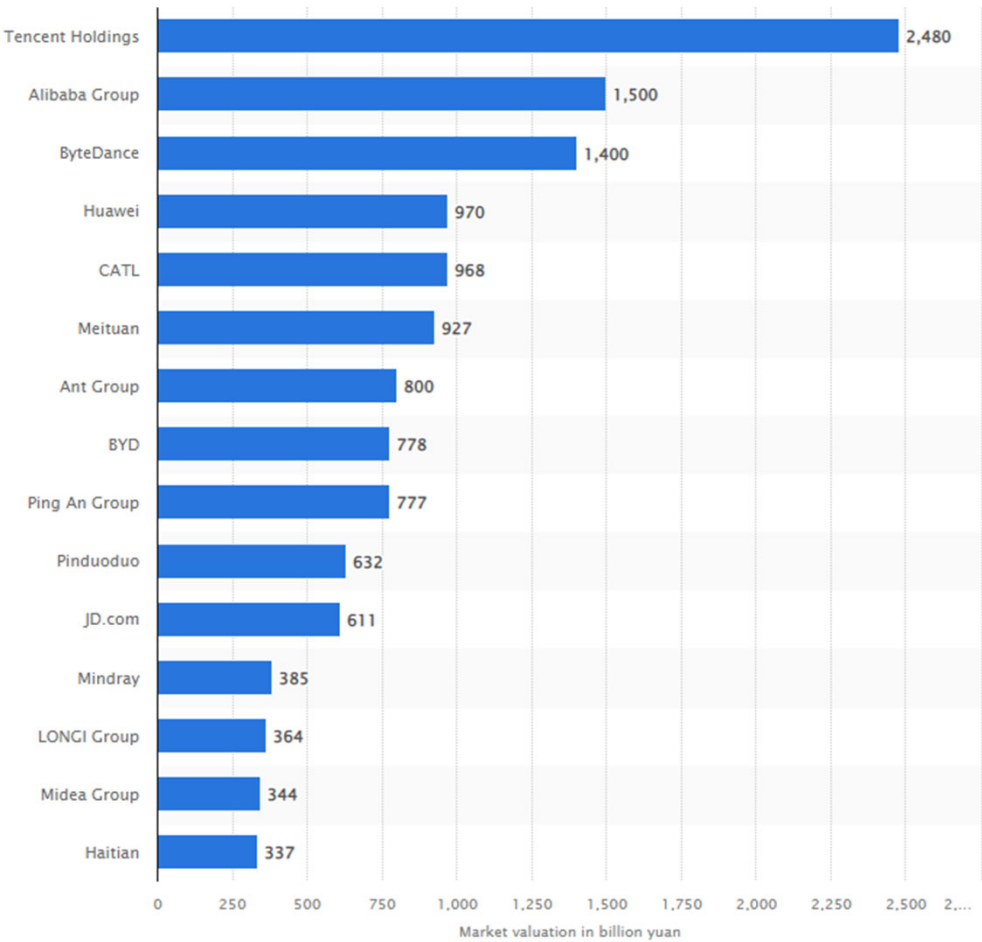331,894,000 people

9,562,910 km²
1,412,360,000 people

GDP: $23,315,081B

GDP: $17,734,063B

Amazon	$514B/yr		Alibaba	$135B/yr		
Apple	$388B/yr		Huawei	$110B/yr		
Google	$283B/yr		Baidu	$20B/yr		
Tesla	$82B/yr		BYD	$52B/yr		
Meta/FB	$117B/yr		ByteDance(TTok)	$58B/yr		
			Tencent(WeChat)	$81B/yr		
Twitter	$4.4B/yr	328M users	Sina(Weibo)	$2.1B.yr	340M users	
Nvidia	$27B.yr	H100	Biren Tech		B100	
	$27B.yr	7.7×10^{10} trx			7.7×10^{10}	
		$7\ nm$			$7\ nm$	

Amazon, Google, Facebook, Snapchat, Pintrest: $380 billion in advertising revenue in 2022.

China spectrum

	Market valuation in billion yuan
Tencent Holdings	2,480
Alibaba Group	1,500
ByteDance	1,400
Huawei	970
CATL	968
Meituan	927
Ant Group	800
BYD	778
Ping An Group	777
Pinduoduo	632
JD.com	611
Mindray	385
LONGI Group	364
Midea Group	344
Haitian	337

Market valuation in billion yuan

BYuan

www.statista.com

Details: China; 2022; among non-state owned enterprises

© Statista 2023

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Total shareholder return for S&P 500 sectors, 03/09-12/21, % annualised

Semiconductors-dominated and based information structure

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https://www.ft.com/content/939e819e-8381-4fee-8639-439847a196b3

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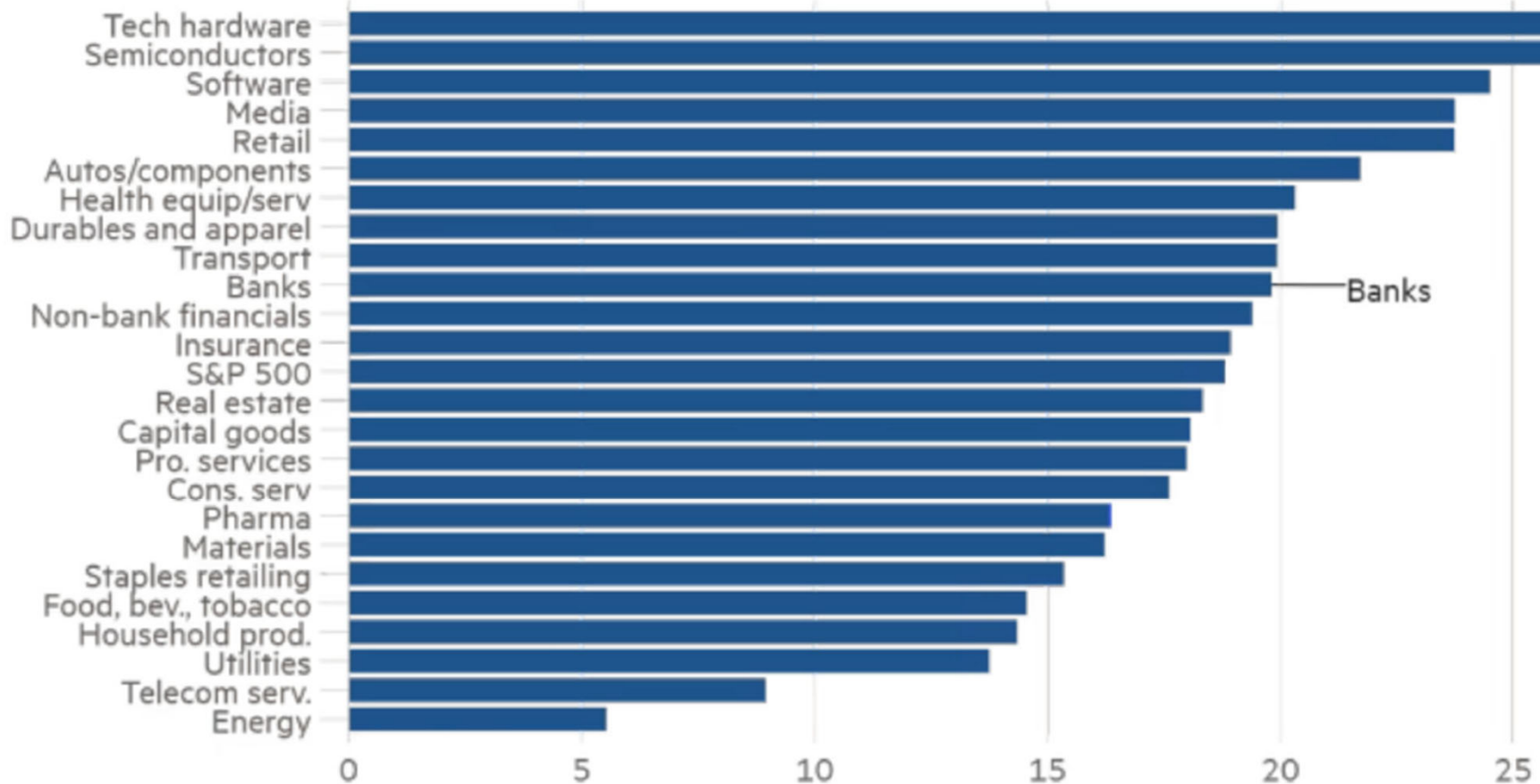
Semiconductor companies market revenue worldwide from 2009 to 2022 (in billion U.S. dollars)
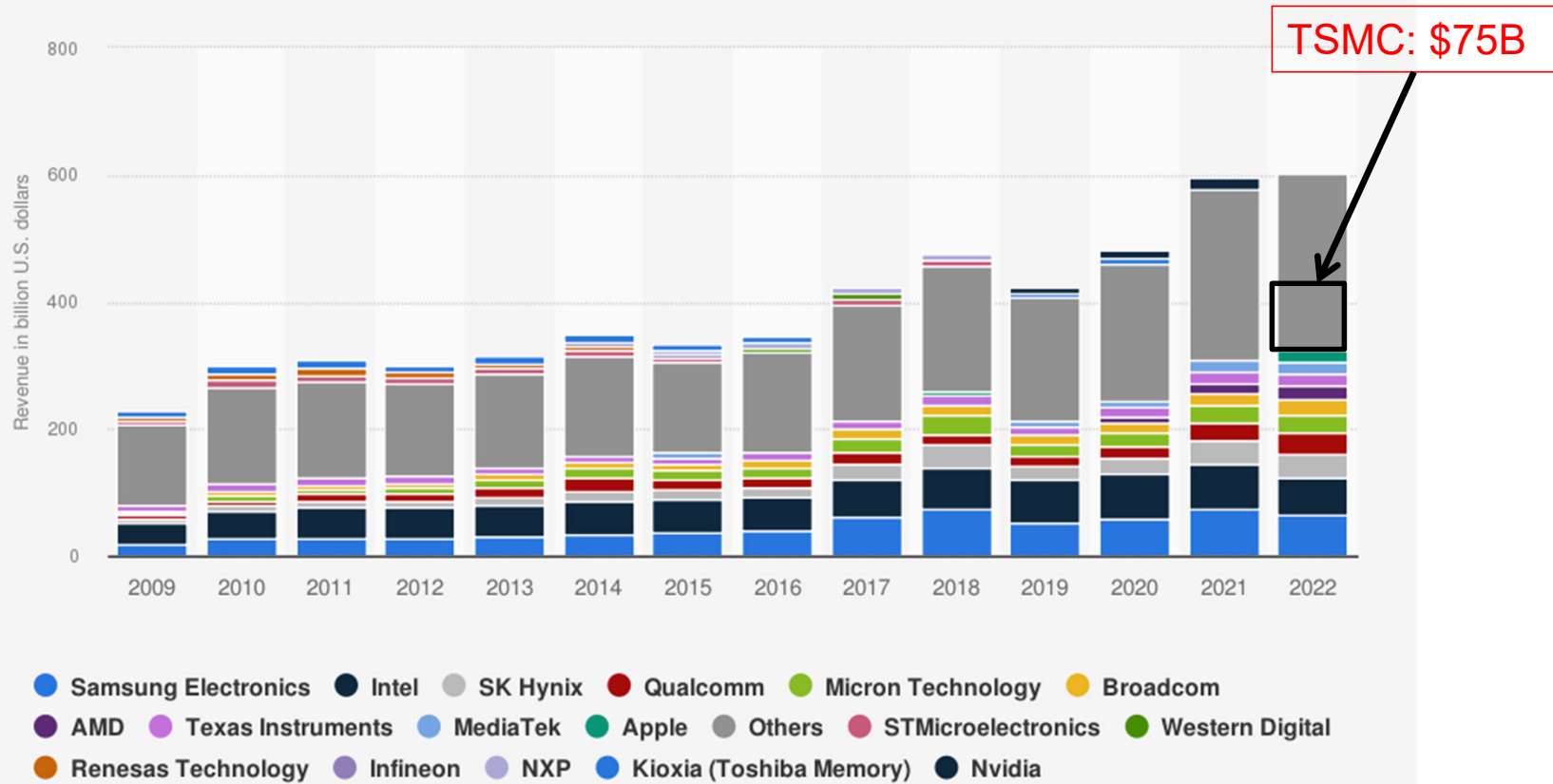
TSMC: $75B

NVidia's competition: Biren Technology

100

Founded Shenzen: 2019
Fabless design
AI and high performance computing
Chips from TSMC

7 nm, 7.7×10^{10}
(Nvidia's H100 is at 4 nm node)
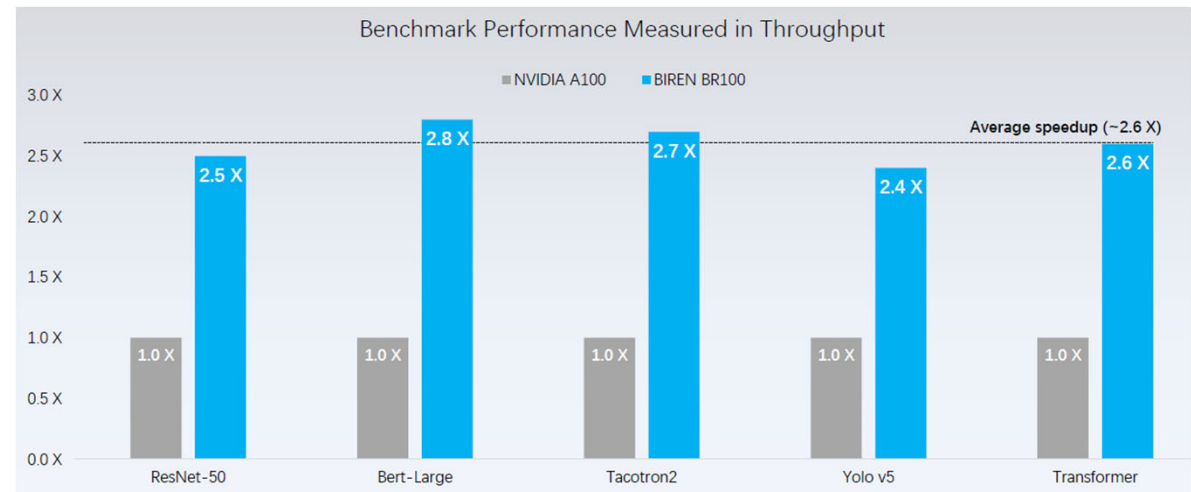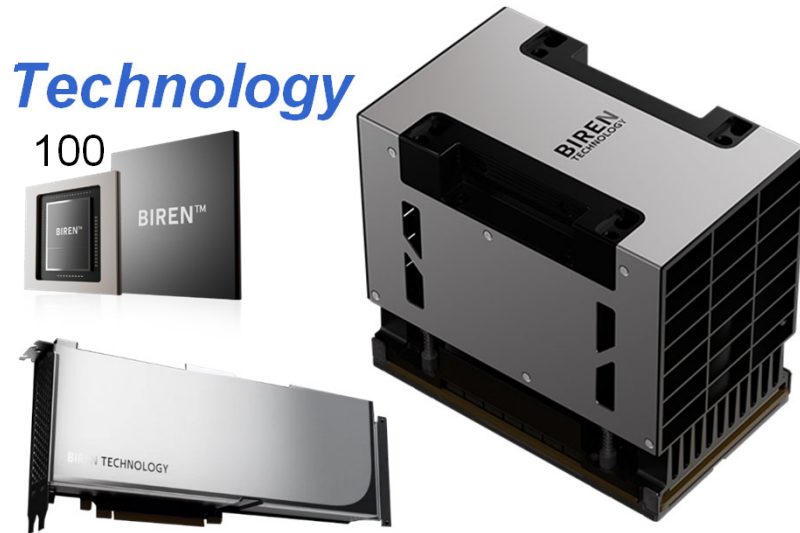300 MB on-chip sram
2048 TOPS INT 8
1024 TFLOPS BF 16
512 TFLOPS TF 32
256 TFLOPS FP 32
64GB HBM2E
8BLinkTM
2.3TB/sexternalI/Obandwidth

550 W

Benchmark Performance Measured in Throughput

NVIDIA A100 ■ BIREN BR100

Average speedup (~2.6 X)

	ResNet-50	Bert-Large	Tacotron2	Yolo v5	Transformer
NVIDIA A100	1.0 X	1.0 X	1.0 X	1.0 X	1.0 X
BIREN BR100	2.5 X	2.8 X	2.7 X	2.4 X	2.6 X

HotChips'22

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ARM

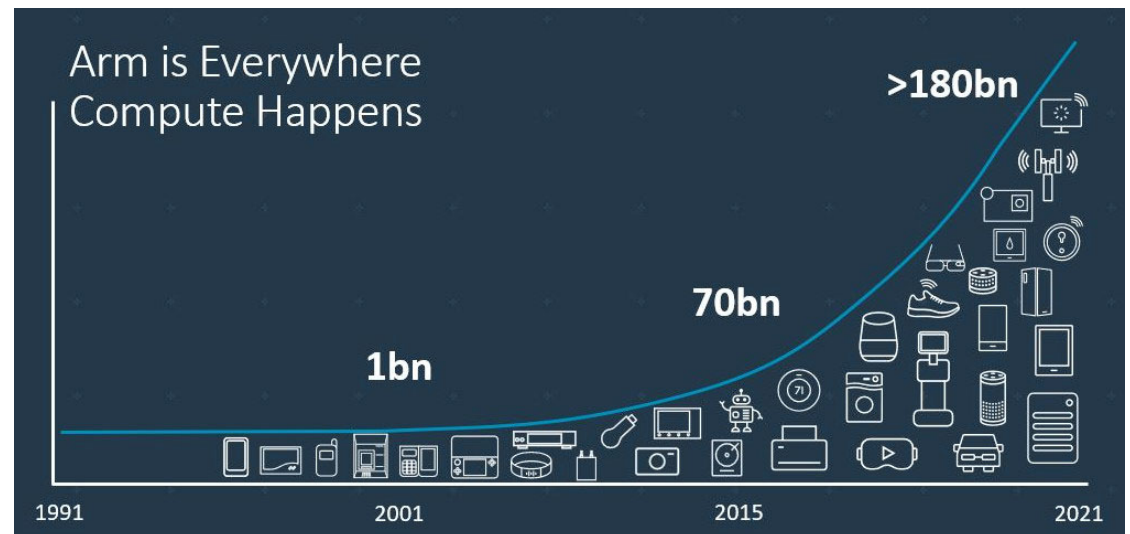230B cumulative ARM-based chips in 2022
80B per year currently
(most going to China, and China's ARM has as strong a control of ARM has Softbank)
Is now pervasive from cloud to edge, with cpus in the middle.)
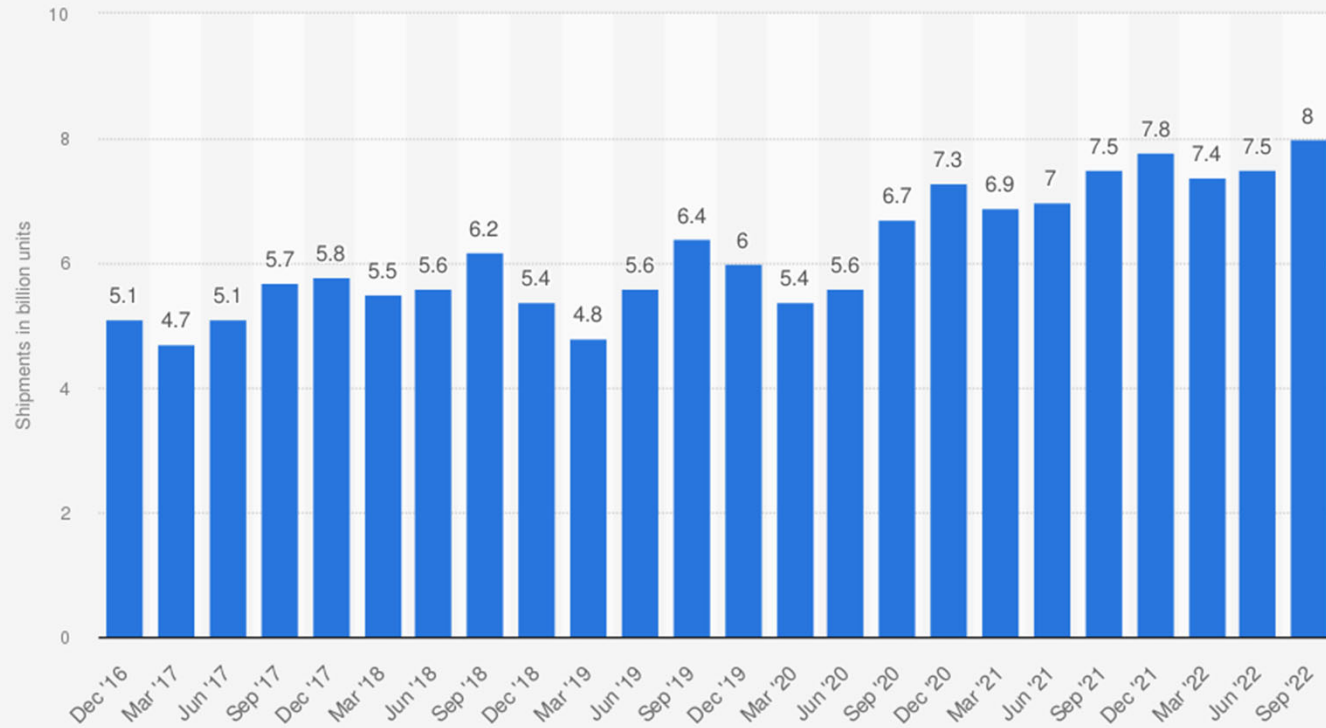Macs, iPhones, Chrome, ...

Cumulative plot

Arm is Everywhere
Compute Happens

>180bn

70bn

1bn

1991   2001   2015   2021

Neoverse V2 : cloud, hyperscale, HPC; AMBA CHI, UCIe and CXL, ...

https://20stech.com/files/arm-pr-image-210211.jpg

Arm Limited royalty unit shipments as reported by licensees worldwide from 2016 to 2022, by quarter (in billions)
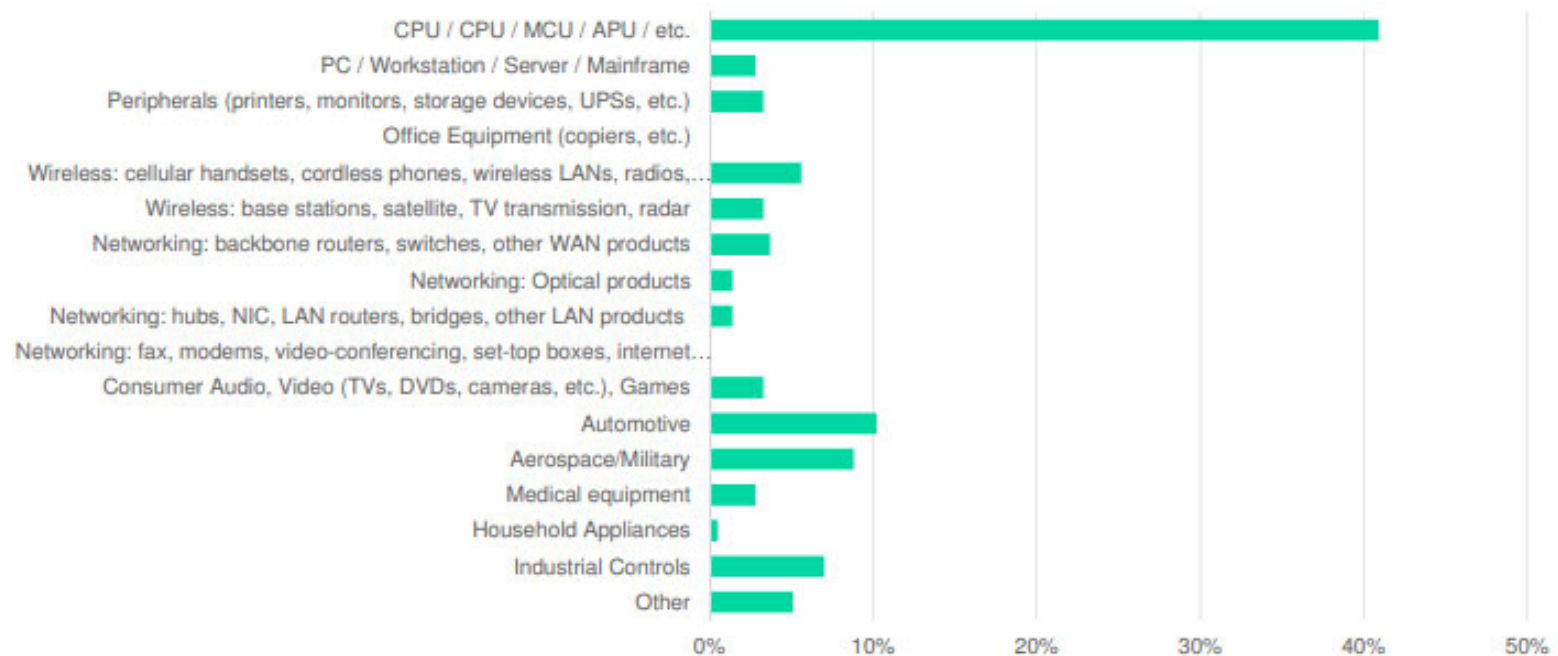
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RISCV

By the end of the decade, open RISC-V will be the dominant instruction set architecture

1/3rd of chip projects (ASIC, FPGA, ...) now employ at least some RISC-V.
Europe is all in RISC-V. (Unix-like open software culture change in design)

Projects Incorporating RISC-V by Market Segment

Wilson Research Group/Siemens

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Borderless architecture: RISCV

2022: 10B chips, with 5B from China (1/6th of ARM volume)

Chinese academy of sciences on 6mo. cycles of upgrading

Starfive (Dubhe, out-of-order cpu, hypervisor,
SiFive (P650 CPU core, ...)

Alibaba (XuanTie custom-built processors based on RISC-V instruction, and is porting Android 10 to RISC-V ISA.)
Ali Pingtou: Xuantie C908 (one of the most energy efficient processor in industry) mult-core, mutli-cluster, 9 state dual issue; Etian 710 for clouds, Hanguang 800 for AI, ..

Baidu
Huawei

Dirigisme and technology

SEMICONDUCTORS

Japan export curbs pay off for South Korean chip materials makers

Profits double as Samsung and others pivot to domestic suppliers

https://asia.nikkei.com/Business/Tech/Semiconductors/Japan-export-curbs-pay-off-for-South-Korean-chip-materials-makers
(March 26, 2023)

Not many give credit to *George Fernandes* who threw IBM out in 1977 (along with Coca Cola) for exercising exclusive control.

It was due to this policy/event that India's software and computing was born.

GF knew the lessons of the Stanford marshmallow experiment.

Education

The strength of the western culture comes from a close relationship between the way in which questions are posed and then acted on.
In practical actions, all cultures are just as experienced.
It is ability to change the questions asked into questions of principle and thus to arrive at new points of view that bring order and insight into the kaleidoscope of experience. This makes it accessible to human thought.
It is this link between the posing of questions of principle and practical action which makes education so powerful and the task for us.

The Humboldt educational model: The university is the environment where students turn to being autonomous individuals and world citizens.

Critical thinking and analysis
Problem solving
Self management
Working with people
Technology use and development
Core literacy

World University Rank 2023	World University Rank 2022	University	Country/region
1	1	University of Oxford	United Kingdom
2	=2	Harvard University	United States
=3	=5	University of Cambridge	United Kingdom
=3	4	Stanford University	United States
5	=5	Massachusetts Institute of Technology	United States
6	=2	California Institute of Technology	United States
7	7	Princeton University	United States
8	8	University of California, Berkeley	United States
9	9	Yale University	United States
10	12	Imperial College London	United Kingdom
=11	11	Columbia University	United States
=11	15	ETH Zurich	Switzerland
13	10	The University of Chicago	United States
14	=13	University of Pennsylvania	United States
15	=13	Johns Hopkins University	United States
16	=16	Tsinghua University	China
17	=16	Peking University	China
18	=18	University of Toronto	Canada
19	21	National University of Singapore	Singapore
20	22	Cornell University	United States
21	20	University of California, Los Angeles	United States
22	=18	UCL	United Kingdom
23	=24	University of Michigan-Ann Arbor	United States
24	26	New York University	United States

By UNIVERSITY OF SCIENCE AND TECHNOLOGY OF CHINA   JANUARY 6, 2021
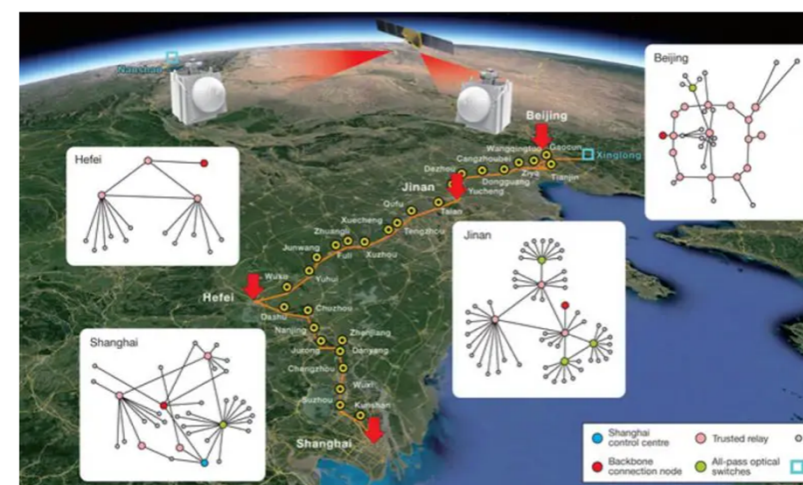
Chinese scientists have established the world's first integrated quantum communication network, combining over 700 optical fibers on the ground with two ground-to-satellite links to achieve quantum key distribution over a total distance of 4,600 kilometers for users across the country. Credit: University of Science and Technology of China
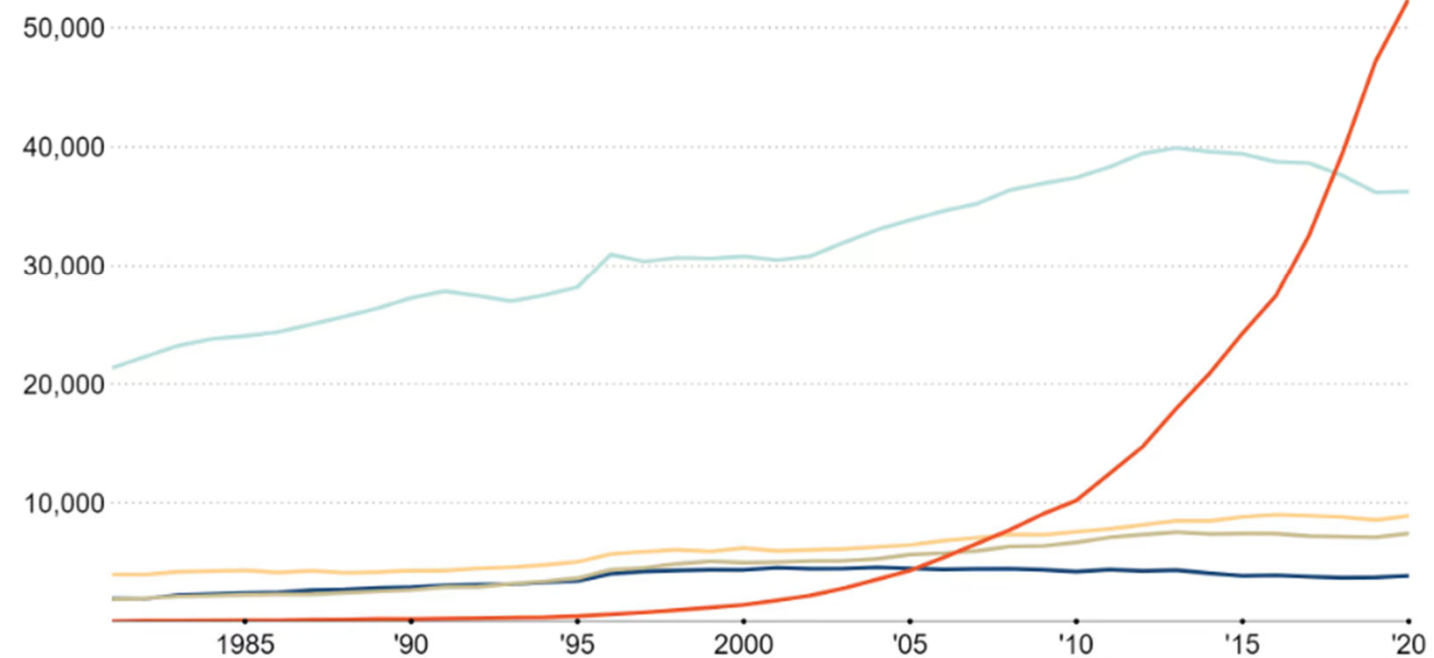
700 optical fibers on the ground with two ground-to-satellite links to achieve quantum key distribution over a total distance of 4,600 kilometers

https://scitechdaily.com/china-builds-the-worlds-first-integrated-quantum-communication-network/

https://www.timeshighereducation.com/student/best-universities/best-universities-world

Number of papers ranked in top 10% by citations

■ Japan ■ U.S. ■ Germany ■ U.K. ■ China

Source: Japan's Ministry of Education, Culture, Sports, Science and Technology; National Institute of Science and Technology Policy

iitk_T5

Institutions of eminence? (2018)

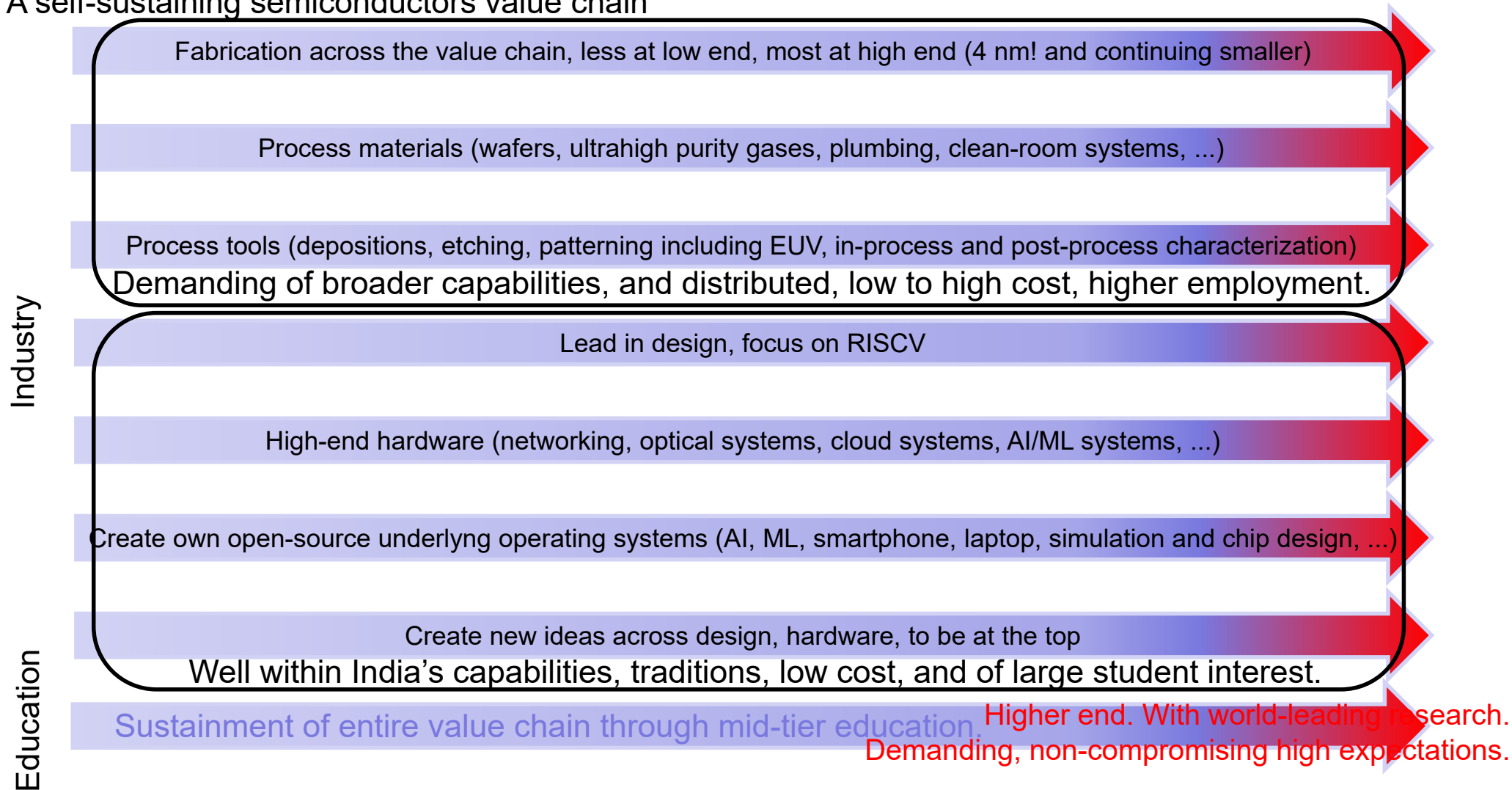Jio Institute
0 students, 52 acres

Today (2023):
2 graduate programs
120 students
6 faculty

Buildings alone do not make an institute.

Creative students and faculty, hard work, world recognition of the work, local impact, serving humanity does.

A self-sustaining semiconductors value chain

Industry

Fabrication across the value chain, less at low end, most at high end (4 nm! and continuing smaller)

Process materials (wafers, ultrahigh purity gases, plumbing, clean-room systems, ...)

Process tools (depositions, etching, patterning including EUV, in-process and post-process characterization)

Demanding of broader capabilities, and distributed, low to high cost, higher employment.

Lead in design, focus on RISCV

High-end hardware (networking, optical systems, cloud systems, AI/ML systems, ...)

Create own open-source underlyng operating systems (AI, ML, smartphone, laptop, simulation and chip design, ...)

Create new ideas across design, hardware, to be at the top

Well within India's capabilities, traditions, low cost, and of large student interest.

Education

Sustainment of entire value chain through mid-tier education.

Higher end. With world-leading research.
Demanding, non-compromising high expectations.

India, as a giant independent nation near the center of the world can sustain a large industry just as China can.

We as faculty like to work with problems that stay within our control.

These are inevitably highly constrained and we all have our own ways.

The world has changed.

A large fraction of the most interesting problems are now complex. *Integrative*.

We have tools to deal with complexity. AI/ML, 500 years of learning, hardware, new ways, ...

We must embrace complexity to avoid trap.

This implies less friction, painless processes, appropriate organization, ... Success, change and well being will be the reward.

iitk _T5

An den Schwankenden

...
Auf wen rechnen wir noch?
Sind wir Übriggebliebene,
herausgeschleudert aus dem lebendigen Fluß?
Werden wir zurückbleiben?
Keinen mehr verstehend und
von keinem verstanden?
Müssen wir Glück haben? So fragst du.

Erwarte keine andere Antwort als die deine.

Bertolt Brecht (1935)

To the waverer

....
Whom do we still count on?
Are we just left over, thrown out
Of the living stream? Shall we remain behind
Understanding no one and understood by none?
Have we got to be lucky?
This you ask.

Expect no answer other than your own.

Bertolt Brecht (1935)