Evolution of Computing Machinery

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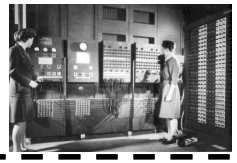
Sandia National Laboratories

Energy Per Mathematical Computation

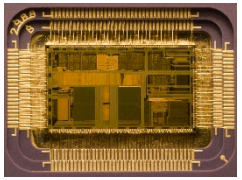
100 J
100 µJ
10 µJ
1 µJ
100 nJ
10 nJ
1 nJ
100 pJ
10 pJ
1 pJ
100 fJ
10 fJ
1 fJ
100 aJ
10 aJ
1 aJ

ENIAC



IBM PC

i486DX PC



Dennard Scaling Era

Pentium III PC

Sony PS3

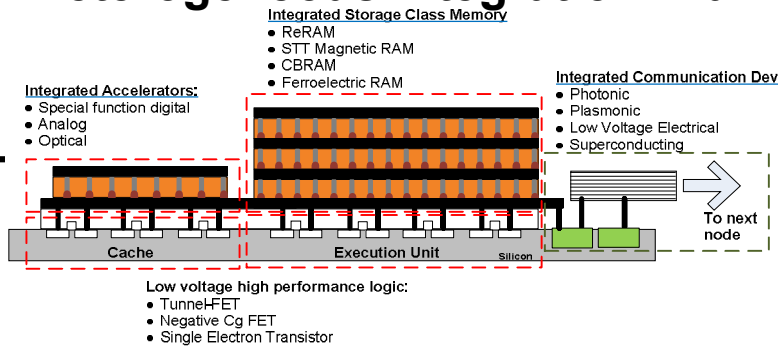
Today's Best Systems

Nvidia P100

Heterogeneous Integration Era

Pessimistic

Optimistic

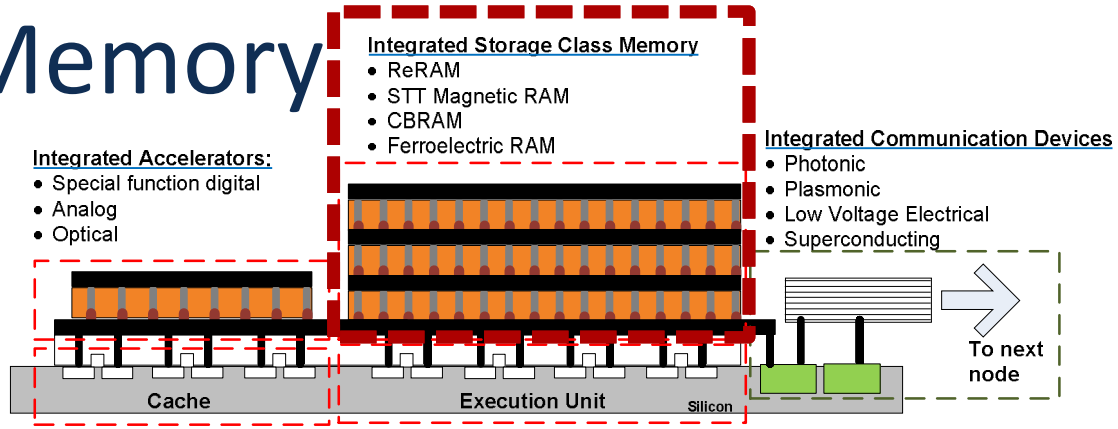


New paradigms: Neuromorphic, analog, quantum, approximate

Landauer Limit = 3 zJ

1946 1980 1990 2000 2010 NOW 2025 2035

IRDS Emerging Memory



Biggest challenges for ReRAM/CBRAM: Relative Maturity Reliability/Mechanisms

	DRAM	NAND Flash	PC-RAM	STT-MRAM	FeRAM	ReRAM	CBRAM
Maturity	Production (20 nm)	Production (16 nm)	Production (45 nm)	Production (65 nm)	Production (180 nm)	Production (180 nm)	Production (180nm)
Min device feature F (nm)	20	16	<10	16	28 nm	5	20 (5 est.)
Density (F^2)	6	10 (single layer)	4	8-20	22	4	4
Write Time (ns)	< 10	10000	50	13	<100	2	2
Write Energy (pJ/bit)	0.005	100	6	4	270	<1	<1
Endurance (W/E Cycles)	$>10^{16}$	10^4	$>10^9$	10^{12}	10^{14}	10^{12}	10^{10}
Retention	64 ms	1 - 10 y	> 10 y	weeks	> 10 y	> 10 y	> 10 y
Stackable	No	Yes	Yes	No	No	Yes	Yes
Process complexity	High/FE	High/FE	Low/BE	High/BE	High/BE	Low/BE	Low/BE

Biggest challenges for PCM: High erase current → Poor endurance

Biggest challenges for STT-MRAM: Balancing Retention/Scaling/Temperature/Write current

*****DISCLAIMER: Due to 10s of thousands of references on these technologies – many of these numbers are not universally agreed on!**

IRDS Emerging Logic