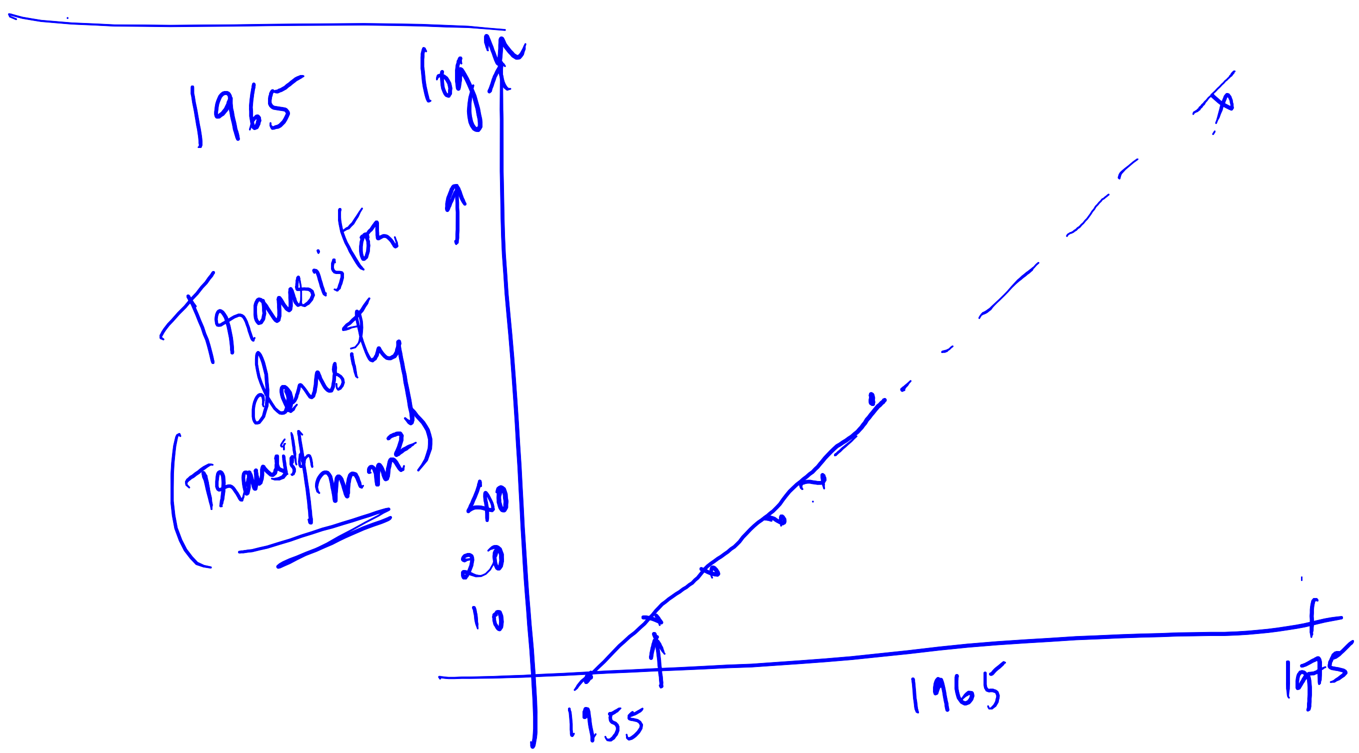
M4_PARALLELISM

Moore's Law and Dennard Scaling

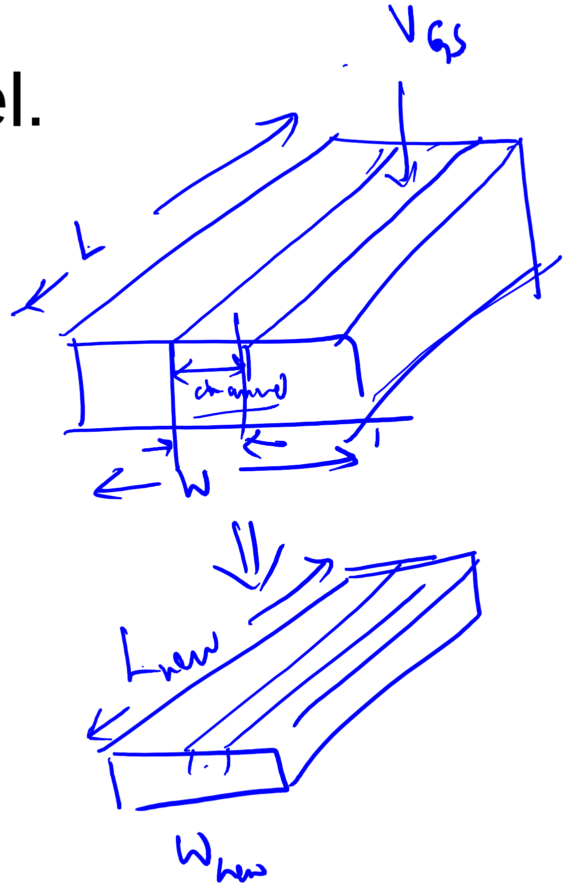
Moore and Dennard

- Gorden E. Moore
  - Fairchild Semiconductors, Intel.



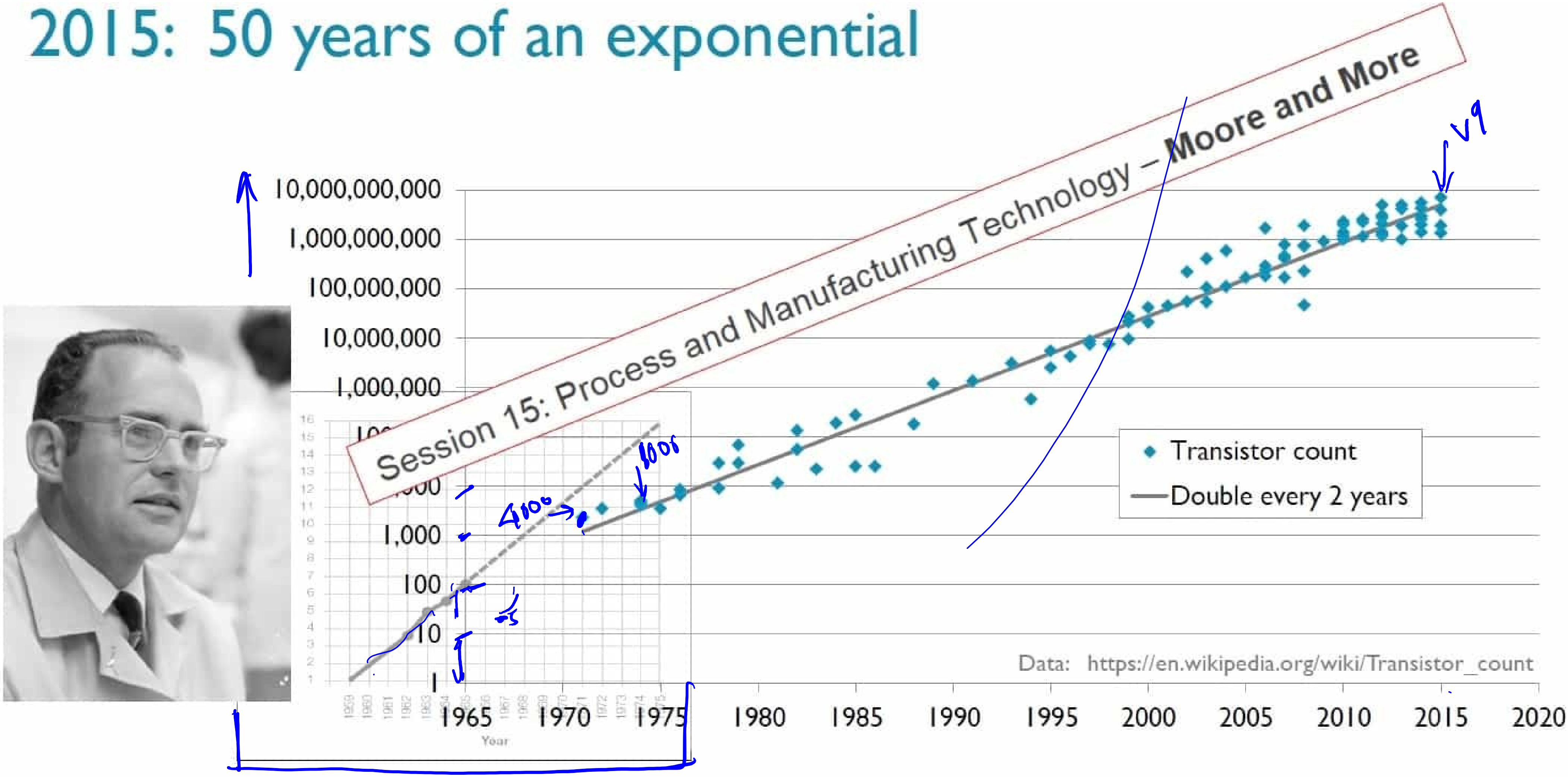
Moore and Dennard

- Gorden E. Moore
  - Fairchild Semiconductors, Intel.
- Robert H. Dennard
  - Inventor of 1T,1C DRAM
  - IBM Fellow



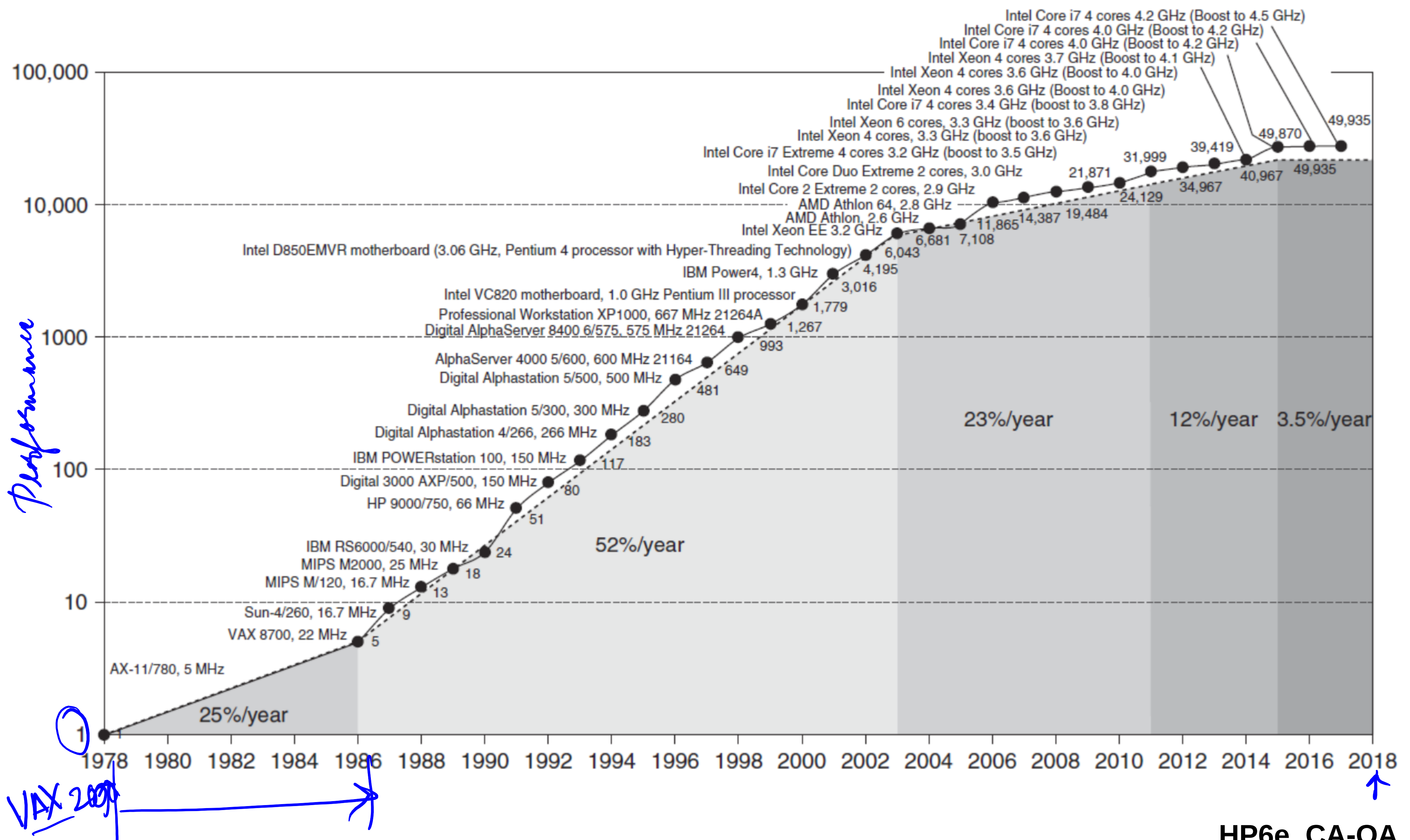
Moore's Law

2015: 50 years of an exponential



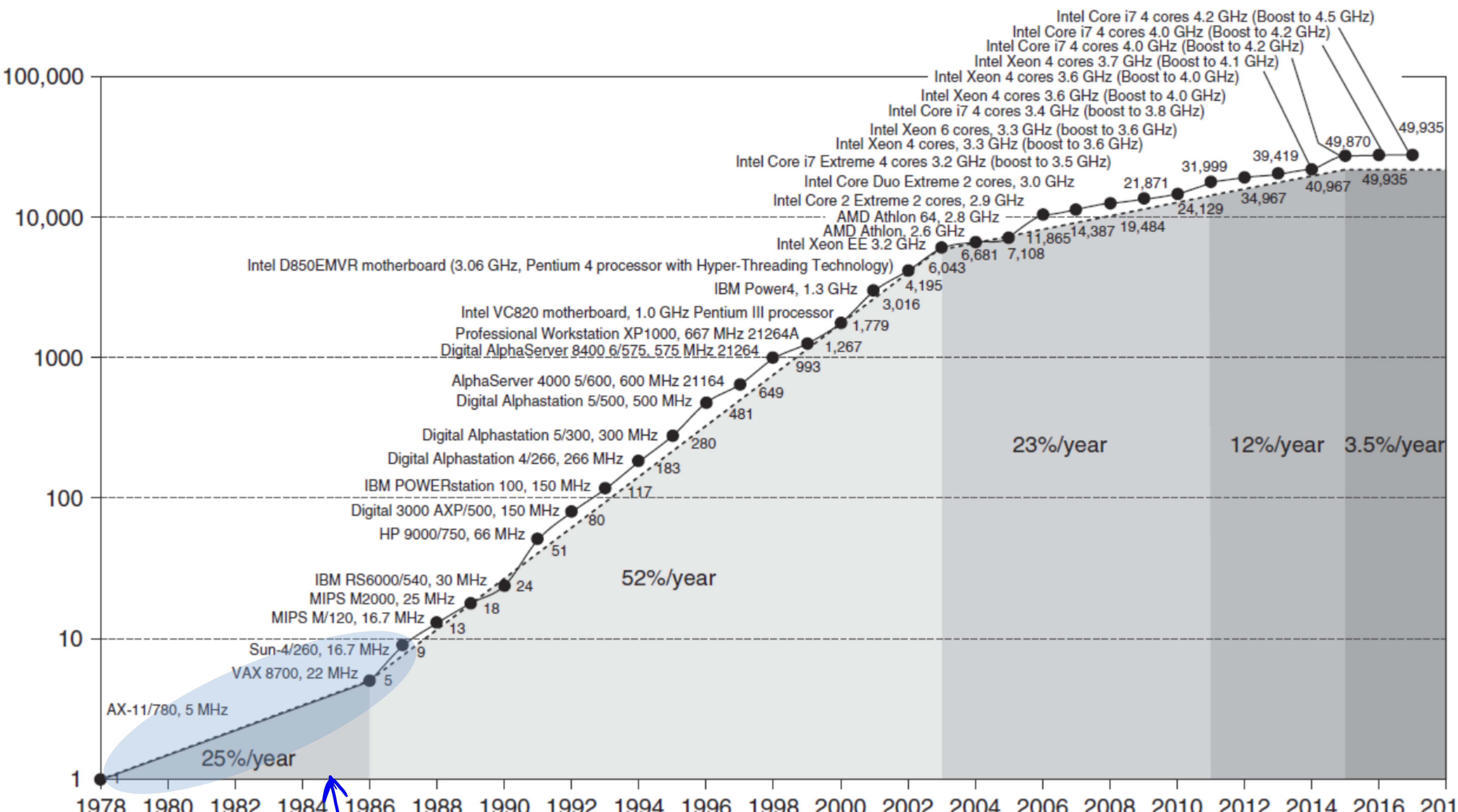
Greg Yeric, ARM

Moore's Law



HP6e, CA-QA

Moore’s Law

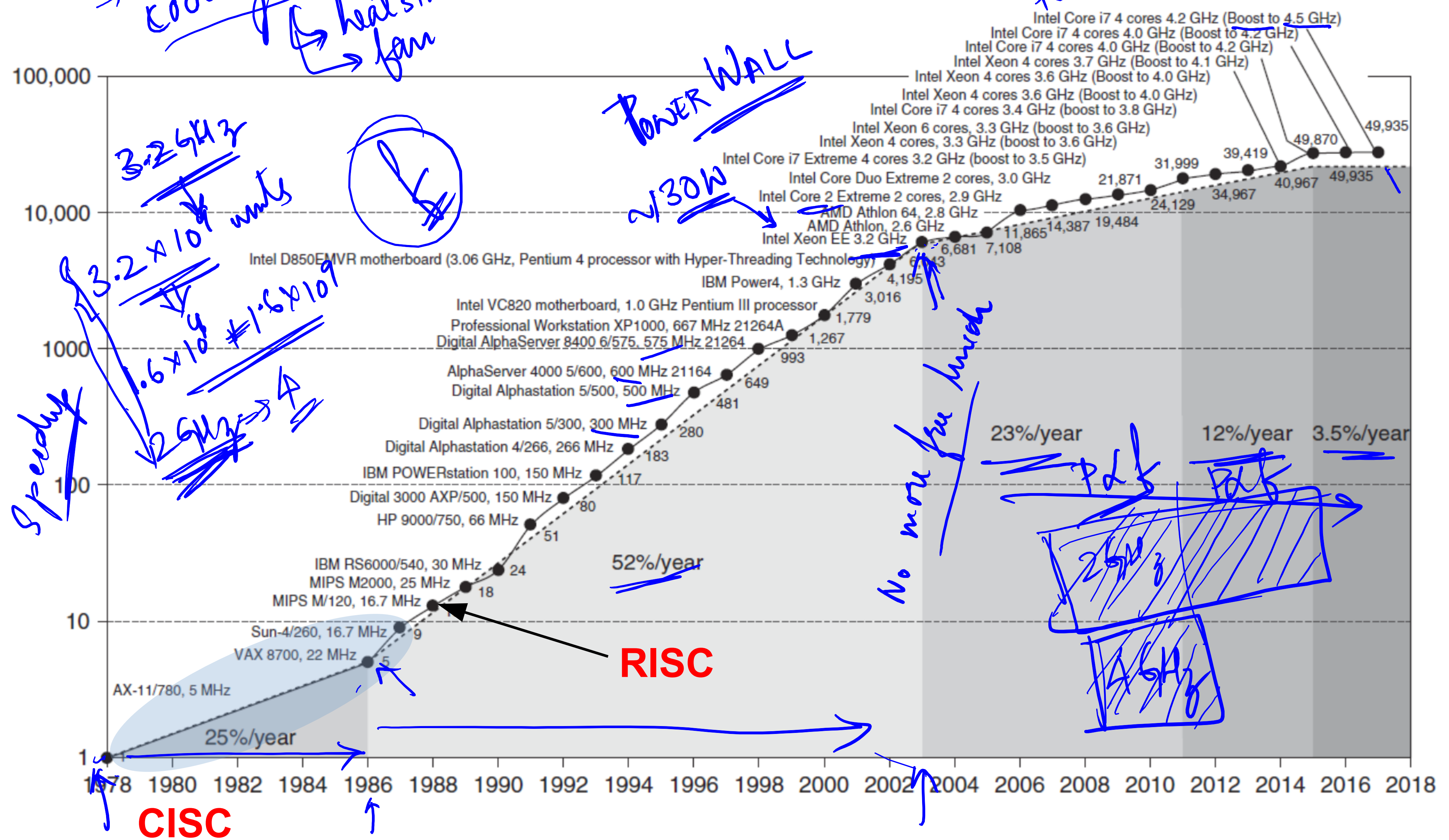


CISC

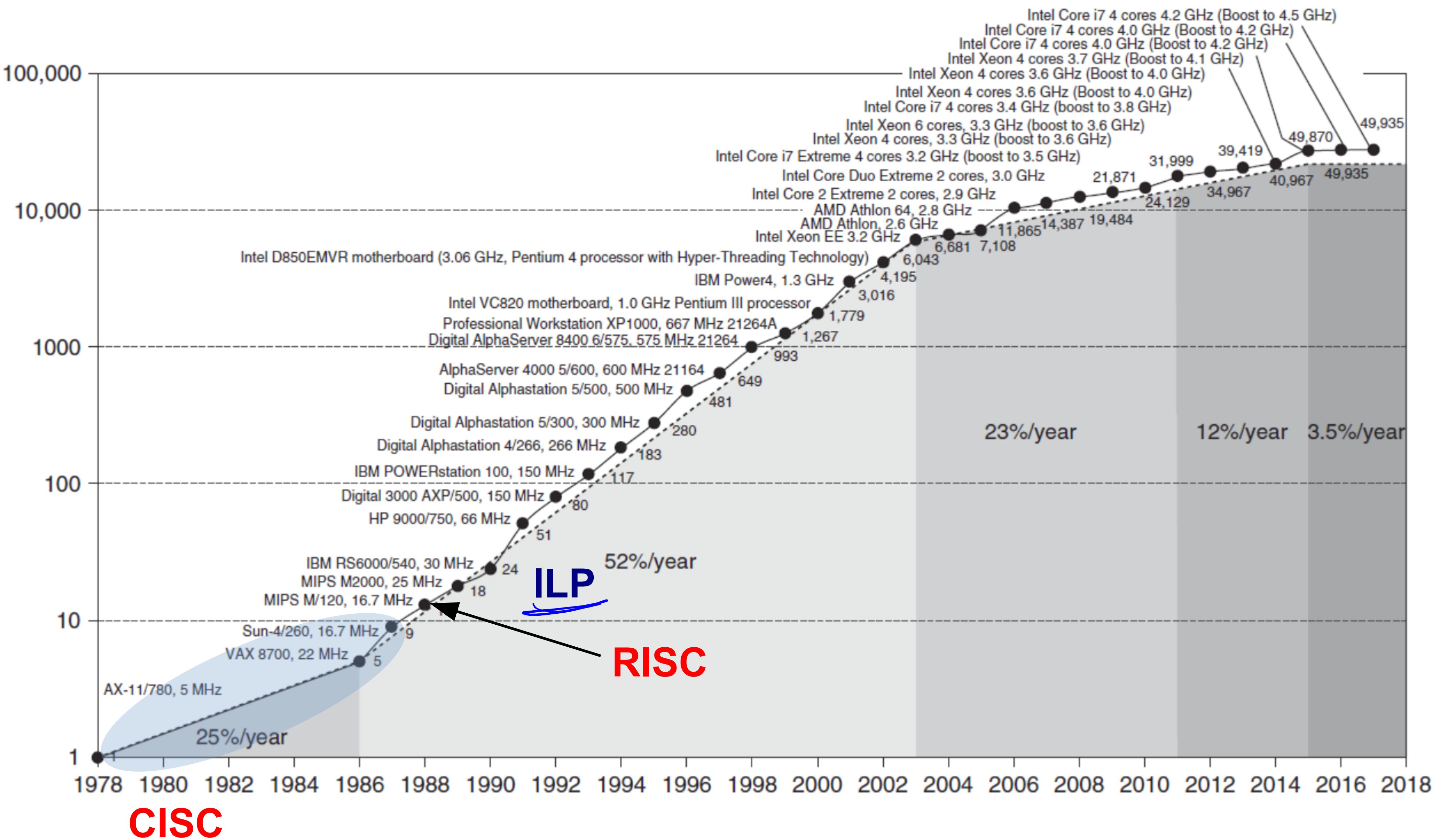
HP6e, CA-QA

Moore's Law

work → heat
$P \propto CV^2 f$
↑heat → reliability ↓
→ V_{DD} → const ~
Temp. ~
Feature length ↓
GPU → Xeon Phi
72C
32C
cooling soln
heat sink
fan



Moore's Law


Intel Core i7 4 cores 4.2 GHz (Boost to 4.5 GHz)
Intel Core i7 4 cores 4.0 GHz (Boost to 4.2 GHz)
Intel Core i7 4 cores 4.0 GHz (Boost to 4.2 GHz)
Intel Xeon 4 cores 3.7 GHz (Boost to 4.1 GHz)
Intel Xeon 4 cores 3.6 GHz (Boost to 4.0 GHz)
Intel Xeon 4 cores 3.6 GHz (Boost to 4.0 GHz)
Intel Core i7 4 cores 3.4 GHz (boost to 3.8 GHz)
Intel Xeon 6 cores, 3.3 GHz (boost to 3.6 GHz)
Intel Xeon 4 cores, 3.3 GHz (boost to 3.6 GHz)
Intel Core i7 Extreme 4 cores 3.2 GHz (boost to 3.5 GHz)
Intel Core Duo Extreme 2 cores, 3.0 GHz
Intel Core 2 Extreme 2 cores, 2.9 GHz
AMD Athlon 64, 2.8 GHz
AMD Athlon, 2.6 GHz
Intel Xeon EE 3.2 GHz
Intel D850EMVR motherboard (3.06 GHz, Pentium 4 processor with Hyper-Threading Technology)
IBM Power4, 1.3 GHz
Intel VC820 motherboard, 1.0 GHz Pentium III processor
Professional Workstation XP1000, 667 MHz 21264A
Digital AlphaServer 8400 6/575, 575 MHz 21264
AlphaServer 4000 5/600, 600 MHz 21164
Digital Alphastation 5/500, 500 MHz
Digital Alphastation 5/300, 300 MHz
Digital Alphastation 4/266, 266 MHz
IBM POWERstation 100, 150 MHz
Digital 3000 AXP/500, 150 MHz
HP 9000/750, 66 MHz
IBM RS6000/540, 30 MHz
MIPS M2000, 25 MHz
MIPS M/120, 16.7 MHz
Sun-4/260, 16.7 MHz
VAX 8700, 22 MHz
AX-11/780, 5 MHz
1
5
9
13
18
24
51
80
117
183
280
481
649
993
1,267
1,779
3,016
4,195
6,043
6,681
7,108
11,865
14,387
19,484
21,871
24,129
31,999
34,967
39,419
40,967
49,870
49,935
49,935
25%/year
52%/year
23%/year
12%/year
3.5%/year
ILP
RISC
CISC
100,000
10,000
1000
100
10
1
1978
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1982
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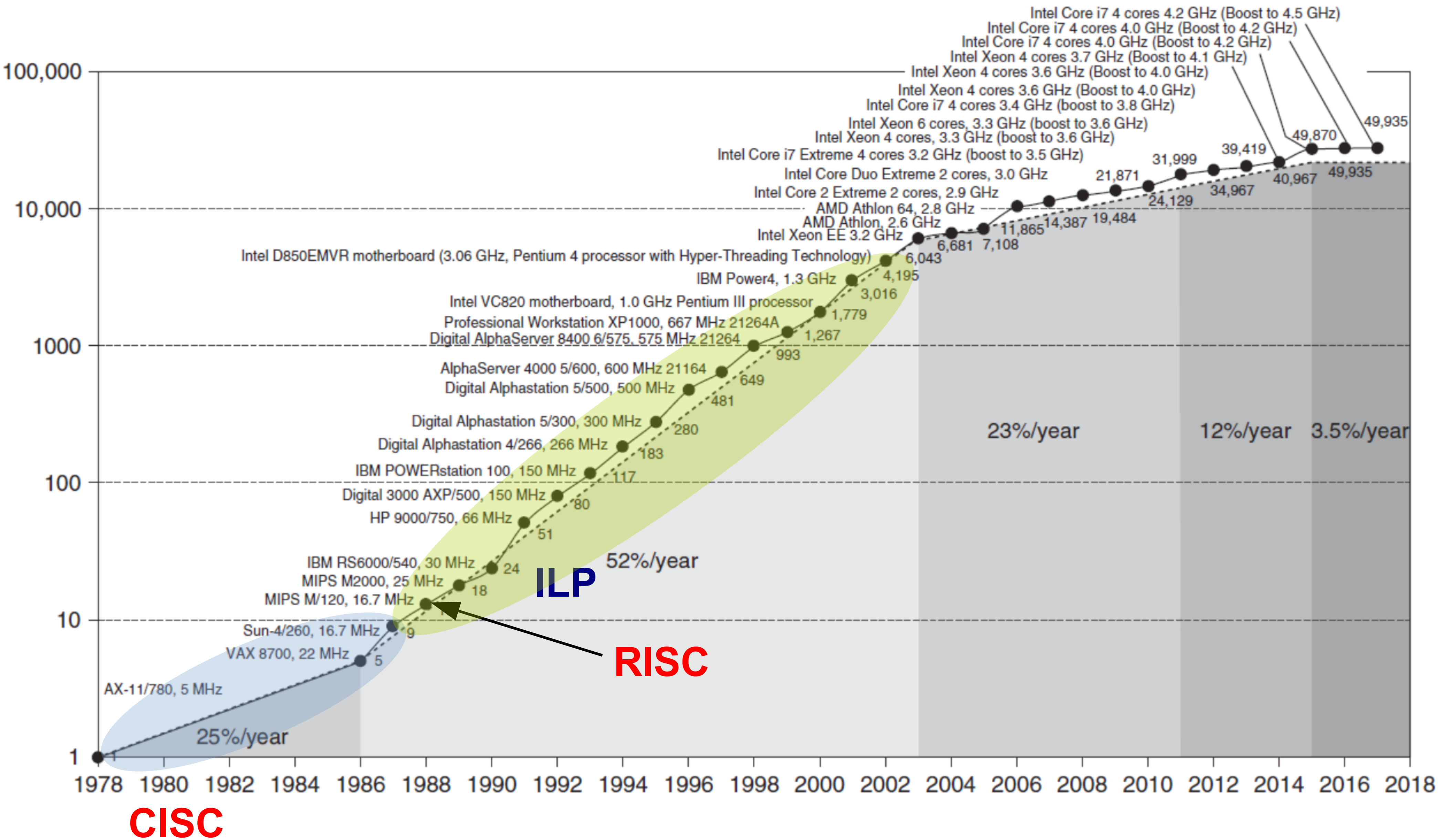
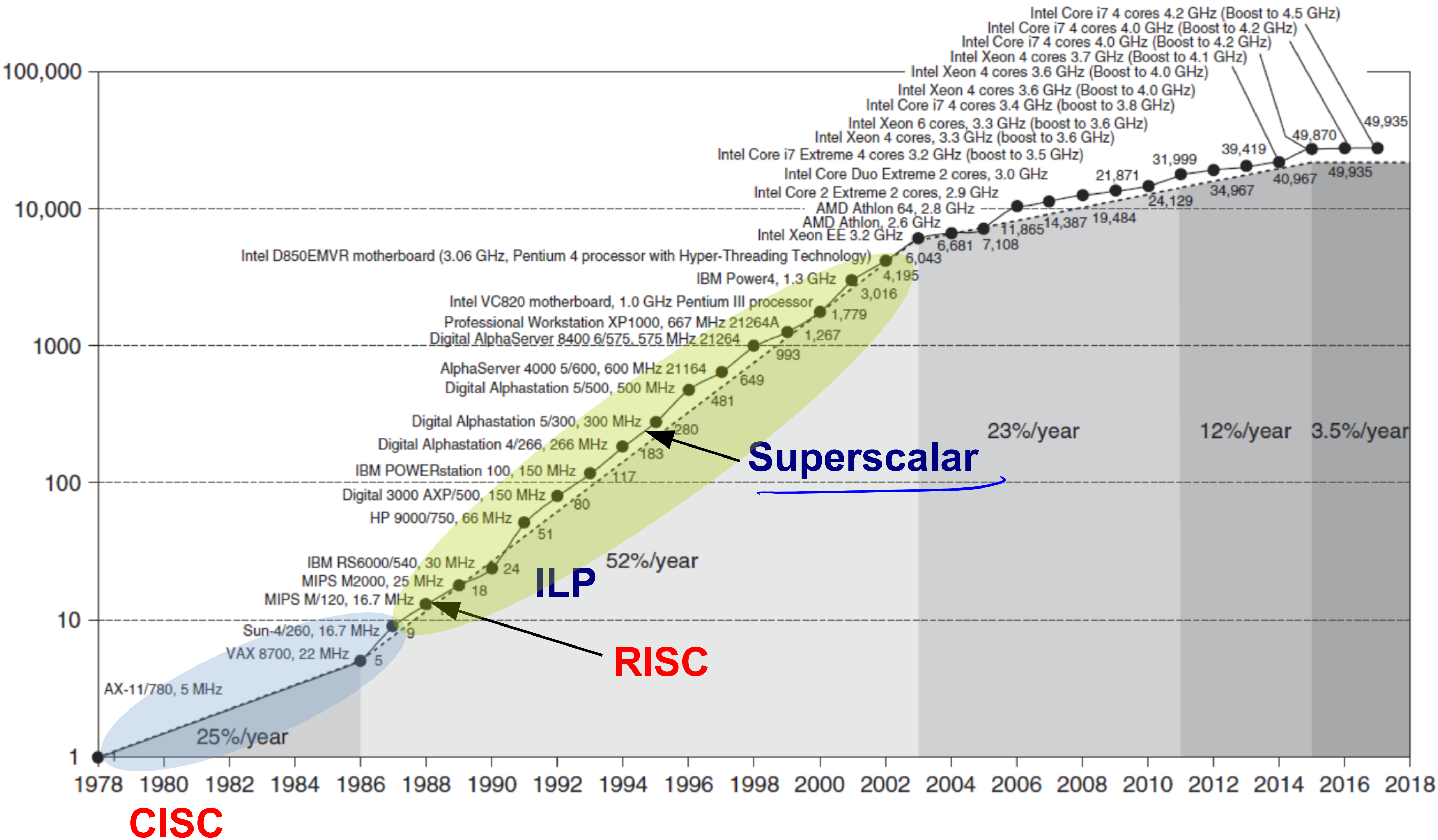
2018

Moore’s Law



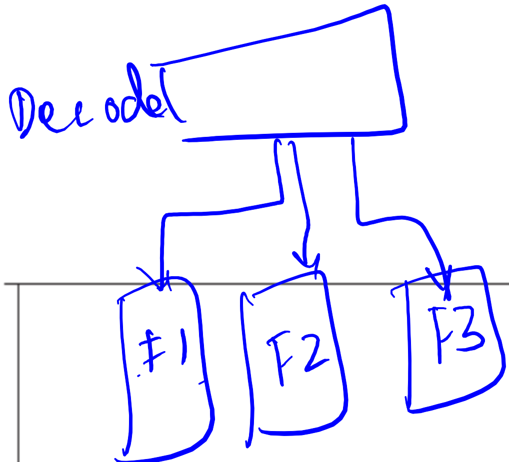
HP6e, CA-QA

Moore's Law

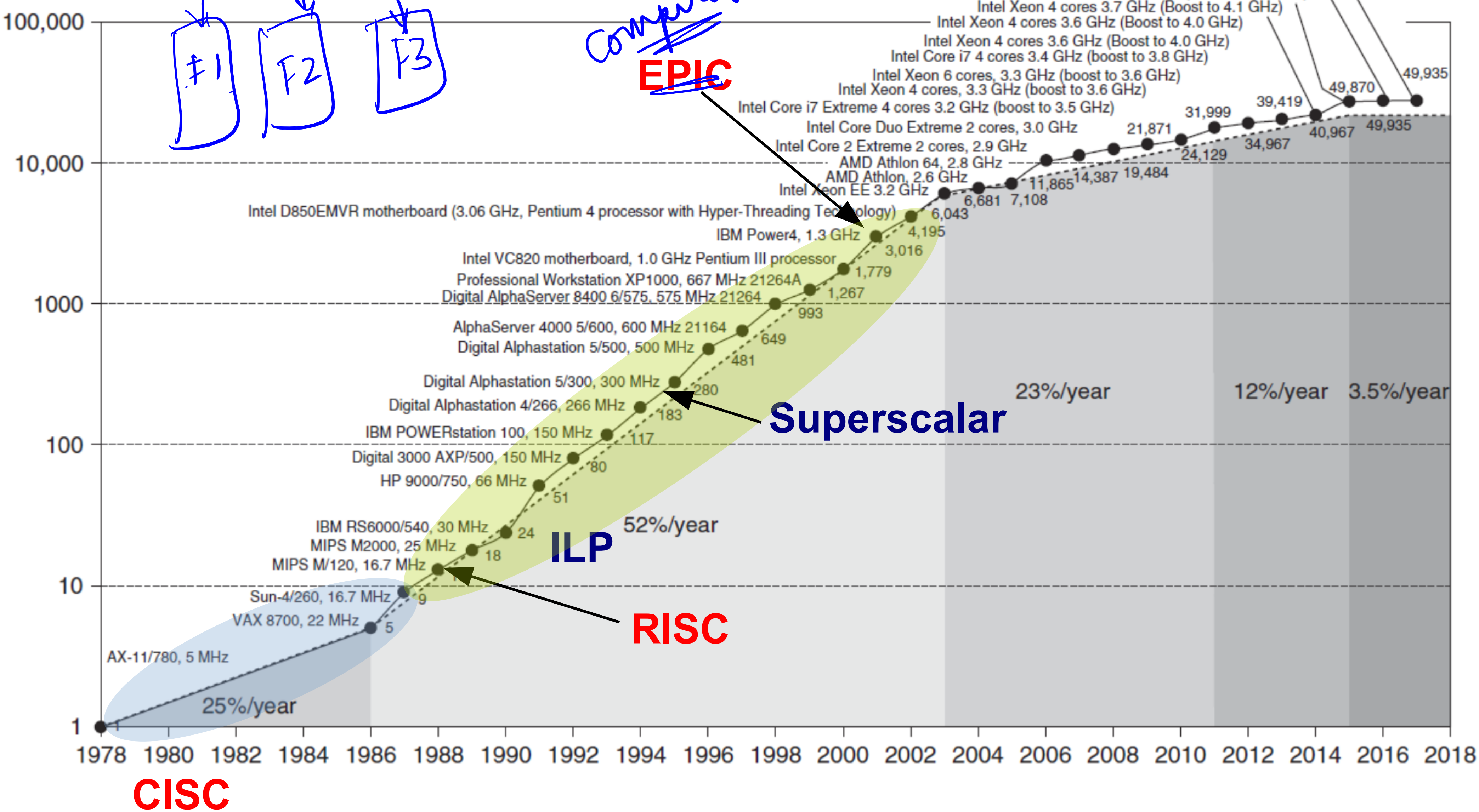


HP6e, CA-QA

Moore's Law

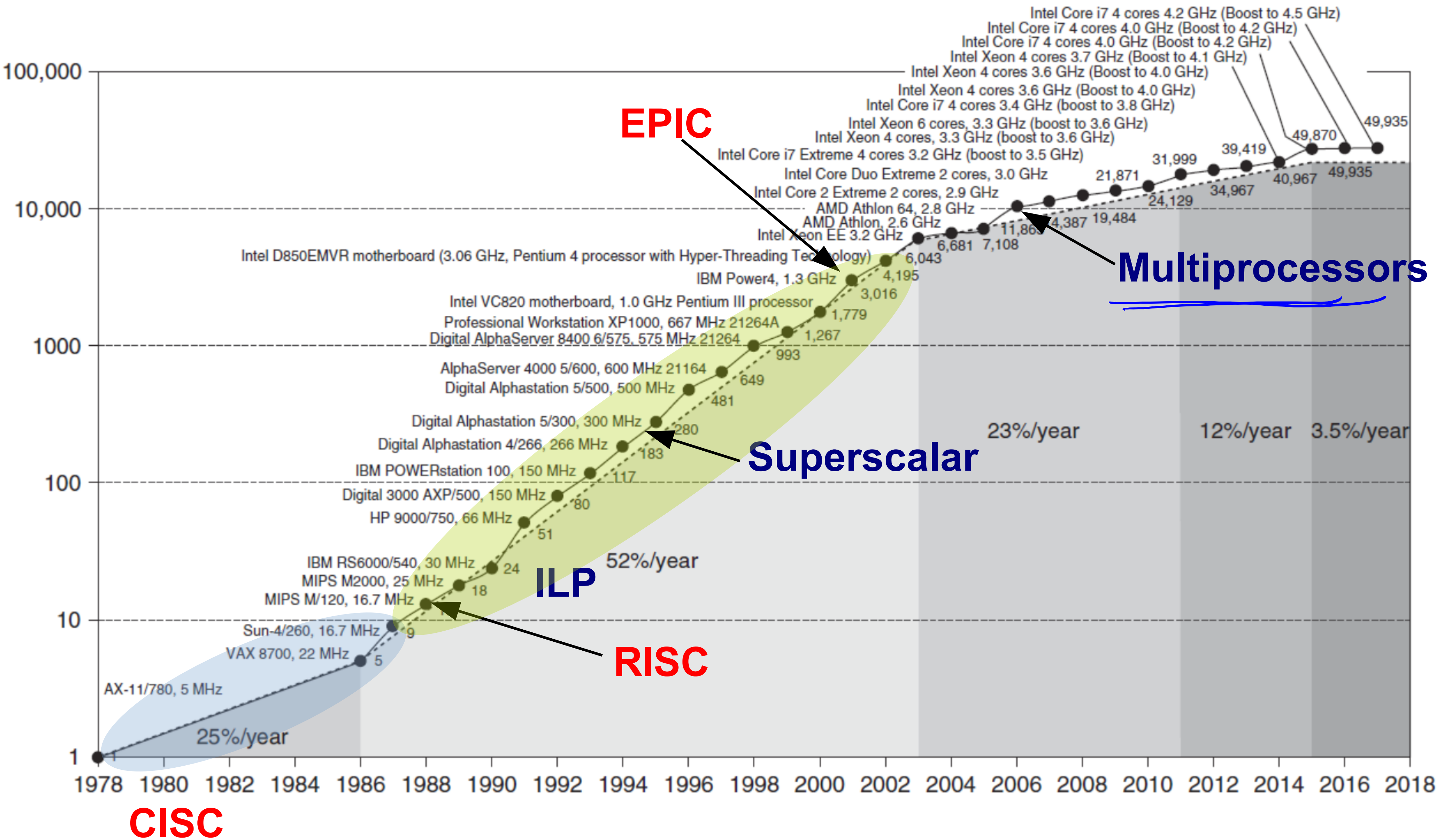


Compiler



HP6e, CA-QA

Moore's Law



HP6e, CA-QA

Dennard Scaling

Dennard Scaling

- Power density remains constant

W/mm^2

$A_{new} = \frac{A_{old}}{2}$

$SF = 1/2$

$A = W \times L$

$1/2 = \frac{1}{\sqrt{2}} \times \boxed{\frac{1}{\sqrt{2}}}$

JSSC, 1974

Dennard Scaling

SCALING RESULTS FOR CIRCUIT PERFORMANCE

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$

$\kappa = \sqrt{2}$

Dennard Scaling

Scaling Results for Circuit Performance

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$
Area	$1/\kappa^2$

Dennard Scaling

SCALING RESULTS FOR CIRCUIT PERFORMANCE

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$
Doping concentration N_a	κ
Voltage V	$1/\kappa$

Dennard Scaling

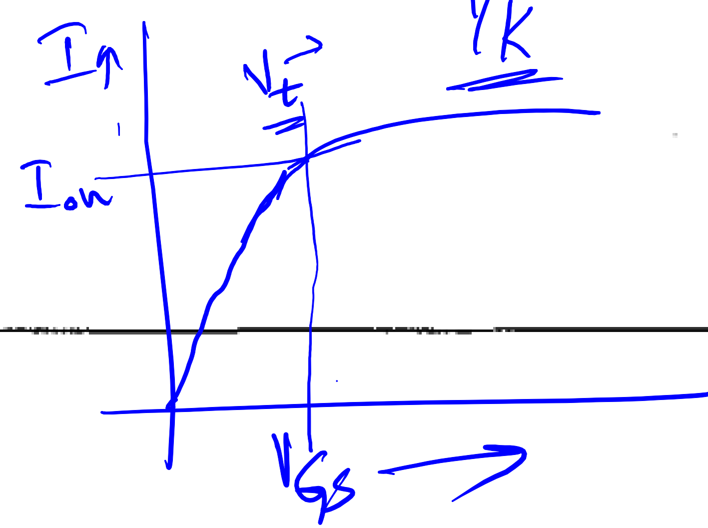
Scaling Results for Circuit Performance

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$
Doping concentration N_a	κ
Voltage V	$1/\kappa$
Current (I) →	$1/K$

$$I \propto \frac{W/K}{L/K}\times\frac{1}{t_{ox}}\times\left(V_{GS}-V_t\right)^2$$

→ threshold

$$\frac{1}{t_{ox}/K} * \left(V_{GS}-V_t\right)^2 \frac{1}{K^2}$$



Dennard Scaling

SCALING RESULTS FOR CIRCUIT PERFORMANCE

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$
Doping concentration N_a	κ
Voltage V	$1/\kappa$
Current I	$1/\kappa$

Dennard Scaling

Scaling Results for Circuit Performance

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$
Doping concentration N_a	κ
Voltage V	$1/\kappa$
Current I	$1/\kappa$
Capacitance $\epsilon A/t$ $\frac{1/\kappa^2}{1/\kappa}$	$1/\kappa$

Dennard Scaling

SCALING RESULTS FOR CIRCUIT PERFORMANCE

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$
Doping concentration N_a	κ
Voltage V	$1/\kappa$
Current I	$1/\kappa$
Capacitance $\epsilon A/t$	$1/\kappa$
Delay time/circuit $\boxed{VC/I}$	$1/\kappa$

Dennard Scaling

Scaling Results for Circuit Performance

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$
Doping concentration N_a	κ
Voltage V	$1/\kappa$
Current I	$1/\kappa$
Capacitance $\epsilon A/t$	$1/\kappa$
Delay time/circuit VC/I	$1/\kappa$
Power dissipation/circuit VI	$1/\kappa^2$

Dennard Scaling

Scaling Results for Circuit Performance

Device or Circuit Parameter	Scaling Factor
Device dimension t_{ox}, L, W	$1/\kappa$
Doping concentration N_a	κ
Voltage V	$1/\kappa$
Current I	$1/\kappa$
Capacitance $\epsilon A/t$	$1/\kappa$
Delay time/circuit VC/I	$1/\kappa$
Power dissipation/circuit VI	$1/\kappa^2$
Power density VI/A $\frac{1/\kappa^2}{1/\kappa^2}$	1

Dennard Scaling – Non Idealities

- Power dissipation does not remain constant
  - Rise in frequency ==> Rise in power dissipation

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- Power dissipation does not remain constant
  - Rise in frequency ==> Rise in power dissipation
- Increases power density
- V_t does not scale as 1/k

$\text{delay} = \frac{VC}{I}$

$\text{delay} \propto \frac{1}{(V_{GS} - V_t)^2}$

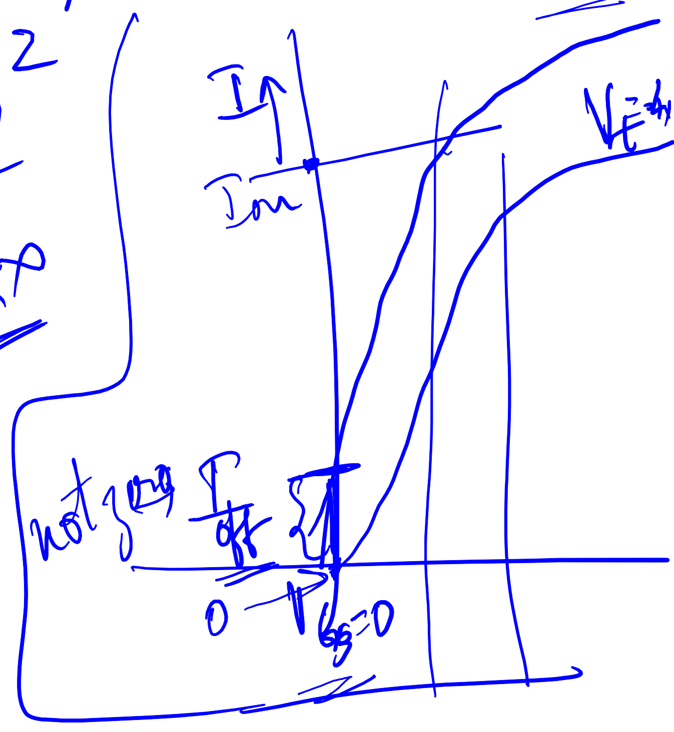
$I \Rightarrow 1/K$

leakage

$\frac{I_{on}}{I_{off}} = 10^4$

low V_t

$V_t = 0.3$



Dennard Scaling – Non Idealities

- Power dissipation does not remain constant
  - Rise in frequency ==> Rise in power dissipation
- Increases power density
- V_t does not scale as 1/k

$$I \propto (V_{GS} - V_t)^2$$

delay ↑

Dennard Scaling – Non Idealities

- Power dissipation does not remain constant
  - Rise in frequency ==> Rise in power dissipation
- Increases power density
- V_t does not scale as 1/k
- I and V couldn't decrease any further without affecting reliability of transistors

$V(t) \downarrow$