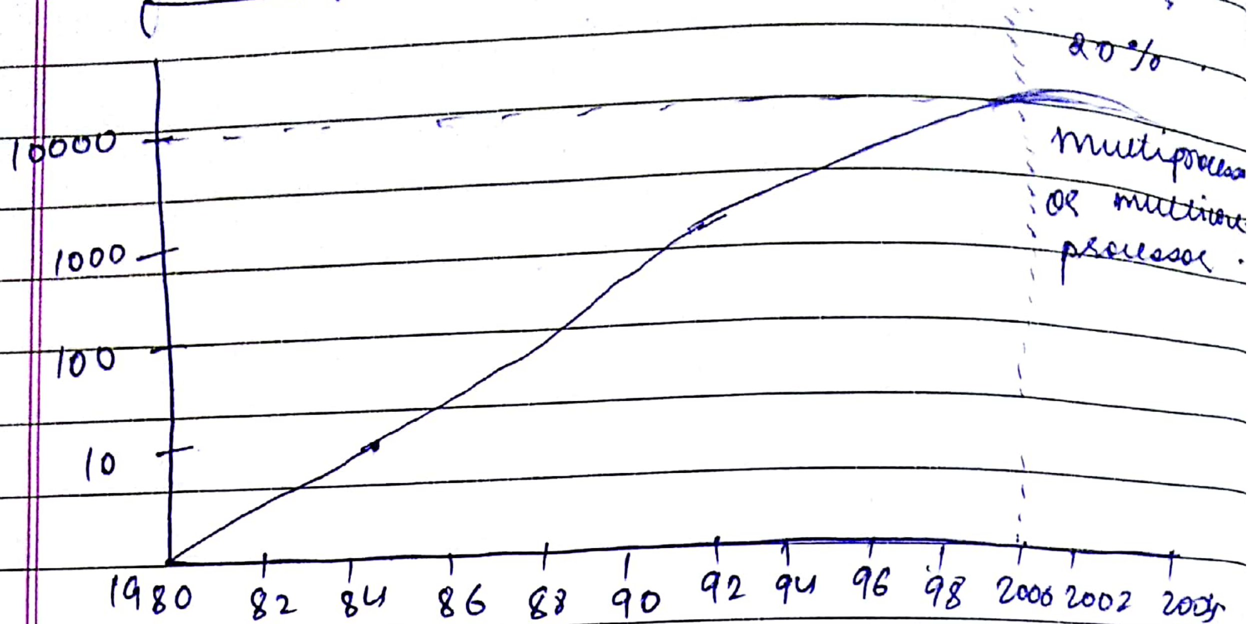
## growth in uniprocessor performance




## Trend in power in Integrated circuit.

CMOS chip.

(i) dynamic power $= \frac{1}{2} C V^2 f$.

C = capacitive load

5 volt → 1 volt

voltage scaling

clock scaling.

(ii) static power = $I_{leakage}$ × voltage

25% of total power.

Ex:- Some microprocessors today are designed to have adjustable voltage, so that if 15% reduction in voltage may result in a 15%. reduction in frequency. what would be impact on

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dynamic power.

$$P_{old} = \frac{1}{2} C V^2 R.$$

$$P_{new} = \frac{1}{2} C (0.85V)^2 \times (0.85R)$$

$$\frac{P_{old}}{P_{new}} = \frac{1}{(0.85)^3} = 1.628.$$

**Multiprocessor or Multicore processor.**

A summary of 3 main stream computing classes (1980s onwards).

| Feature | Desktop | Server | Embedded |
|---|---|---|---|
| 1. price of system | \$500 - \$5000 | \$5000 - \$5,000,000. | \$10 - \$10,000. |
| 2. price of microprocessor module | \$50 - \$500 | \$200 - \$10,000 | \$0.01 - \$100. |
| 3. critical system design issues | price - performance graphic, performance | throughput, availability, scalability | price power const, appln specific performance |

| time | decimal term | decimal value | binary value | decimal value. |
|---|---|---|---|---|
| sec | KB | $10^3 B$ | $2^{10}$ | 1 |
| millisec | MB | $10^6$ | $2^{20}$ | $10^{-3}$ |
| microsec | GB | $10^9$ | $2^{30}$ | $10^{-6}$ |
| nanosec | TB | $10^{12}$ | $2^{40}$ | $10^{-9}$ |
| picosec | PB | $10^{15}$ | $2^{50}$ | $10^{-12}$ |
| femto | EB | $10^{18}$ | $2^{60}$ | $10^{-15}$ |
| | ZB | $10^{21}$ | $2^{70}$ | |
| | YB | $10^{24}$ | $2^{80}$ | |

## Measuring and comparing computer performance.

$$\text{performance} \propto \frac{1}{\text{Execution time}}$$

Execution time = $IC \times CPI \times T$

T = clock period, CPI → cycles per instruction.
IC = Instruction Count.

A program runs in 10s on comp A with 400 MHz. We want a comp B that could run the program in 6 sec. Substantial rise in clock speed is possible, 1.2 times as many clock cycle of computer A. what would be the clock rate of computer B.

| given | Comp. A | Comp B. |
|---|---|---|
| Ex. Time | 10 sec | 6 sec. |
| Clock Rate | 400 MHz | ? |
| CPI | $x$ | $1.2x$. |

$$6 \text{ sec} = \frac{IC \times 1.2x}{f}$$

$$10 = \frac{IC \times x}{400 \times 10^6}.$$

$$IC \times x = 400 \times 10^7.$$

$$6 = \frac{400 \times 10^7 \times 1.2}{f}$$

$$f = 8 \times 10^8.$$
$$= 800 MHz$$

## Measuring and comparing performance.

Execution Time = $IC \times CPI_{avg} \times T$.

MIPS ( Million Instruction Per sec)

$$= \frac{IC}{Ex.\ Time}.$$

$$= \frac{IC}{10^6}$$

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$$1 \text{ sec} = \frac{IC}{\text{Ex. Time} \times 10^6} \quad (\text{MIPS}).$$

$$= \frac{IC}{IC \times CPI \times T \times 10^6} = \frac{f}{CPI \times 10^6} \quad (\text{MIPS}).$$

Q:- A 400 MHz Computer is running a program of 100,000 instruction. The program mix and their CPI is given in the below table. Calculate the execution time of the program and in MIPS rating.

| Instruction type | CPI | % of the prog. |
|---|---|---|
| Integer arithmetic. | 1 | 60 |
| data transfer | 4 | 20 |
| control Instruction | 2 | 20 |

Average CPI.

$$= 1 \times 0.6 + 4 \times 0.2 + 2 \times 0.2$$

$$= 1.8.$$

$$\frac{1 \times 60 \times 100{,}000 + 4 \times 0.20 \times 100{,}000 + 2 \times 0.2 \times 100{,}000}{100{,}000}$$

Execution Time $= IC \times CPI \times T = \frac{100{,}000 \times 1.8}{400 \times 10^6}$

$= 0.450$ µsec.

MIPS Rating $= \frac{400 \times 10^6}{1.8 \times 10^6} = 222.222$

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~~Execution~~ Now when the task is performed in a 4 processor system due to synchronisation 2000 instructions are added per processor. Now find the avg. CPI.

$1 \times 0.6 + 4 \times 0.2 + 2 \times 0.2 = 1.8$.

Determine the corresponding MIPS rate

$$\frac{400 \times 10^6}{1.8 \times 10^6} = 222.22$$

Execution time $= \frac{27000 \times 1.8}{400 \times 10^6} = 121.5\,\mu sec.$

MIPS rating of comp $= 222.22 \times 4$.

Q:- Suppose we have made the following frequency of FP operations = 25%. Average CPI of FP operation = 4.0. Average CPI of other instructions = 1.33. frequency of FPSQR = 2%, CPI of FPSQR = 20. Assume that the two design alternation are to decrease the CPI of FPSQR to 2 or to decrease the avg. CPI of all FP operation to 2.5. Compare these two design alternatives using processor performance ~~instruction~~ equations.

| Original | (all FP operation) design-1 | (only FPSQR operation) design-2 |
|---|---|---|
| CPI avg: $0.25 \times 4 + 0.75 \times 1.33 = 2$ | $0.25 \times 2.5 + 0.75 \times 1.33 = 1.624$ | $(2 - 0.2)\ (20-2) = 1.64$ |

design-1 is better all FP operation (common case fast)

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Complete performance.

Execution Time $= IC \times CPI\ avg \times \tau$.

MIPS Rating $= \dfrac{f}{CPI_{avg} \times 10^6}$

Q: we have two implementation of the same ISA.

Machine A has clock cycle time 1ns and CPI of 2 for same program

Machine B " " " " 2 ns " "
" 1.2 " " "

Which machine is faster for this program and by how much.

Soln

Ex. Time$_A$ $= IC \times 2 \times 10^{-9}$

Ex. Time B $= IC \times 1.2 \times 10^{-9}$

$$\frac{\text{Ex. Time 'B'}}{\text{Ex. Time 'A'}} = \frac{IC \times 1.2 \times 2 \times 10^{-9}}{IC \times 2 \times 10^{-9}}$$

$= 1.2$ times.

Ex: Consider the machine with the following 3 instruction classes and CPI.

| ~~Inspection~~ Instruction class | CPI for instruction |
|---|---|
| A | 1 |
| B | 2 |
| C | 3 |

Suppose we measure the code of the same program from two compilers

| Code from | A | B | C |
|---|---|---|---|
| compiler - 1 | 5 | 1 | 1 |
| " - 2 | 10 | 1 | 1 |

Assume that the machine's clock rate is 500 MHz. which code sequence will execute faster acc. to execution time? Acc. to MIPS

Execution Time compiler -1 $= 5 \times 1 + 1 \times 2 + 1 \times 3$
$= 10$ billion cycles.

Ex. Time compiler 2 $= 10 \times 1 + 1 \times 2 + 1 \times 3$
$= 15$ billion cycles.

$$MIPS_{compiler-1} = \frac{f}{CPI_{avg} \times 10^6}$$

$$CPI_{avg}(compiler-1) = \frac{5 \times 1 + 1 \times 2 + 1 \times 3}{7}$$

$$= \frac{10}{7} = 1.42$$

$$MIPS_{compil 1} = \frac{f}{1.42 \times 10^6}$$

$$CPI_{avg}(compiler-2) = \frac{10 \times 1 + 1 \times 2 + 1 \times 3}{12}$$

$$= \frac{15}{12} = 1.25$$

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$$MIPS_{compiler-2} = \frac{f}{1.25 \times 10^6}$$

## Performance Summary

| | Compiler-A | Compiler-B | % time |
|---|---|---|---|
| Program-1 (sec) | 1 | 10 | 50% |
| Program-2 (sec) | 1000 | 100 | 20% |
| total | 1001 | 110 | |
| Time AM | 500.5 | 55 | |

$$\text{Arithmetic Mean} = \frac{1}{n} \sum_{i=1}^{n} Ex\text{-}Time_i$$

Weighted Arithmetic Mean (WAM)

$$= \sum_{i=1}^{n} w_i \times ExTime_i$$

$$WAM_{comp-A} = 0.8 \times 1 + 0.2 \times 1000 = 200.8$$

$$WAM_{comp-B} = 0.8 \times 10 + 0.2 \times 100 = 28$$

## System Performance Evaluation Cooperative (SPEC). → 1980.

| Sr. no | Benchmark programs | Instruction count ($10^9$) | CPI |
|---|---|---|---|
| 1. | Interpreted string processing | 2252 | 0.60 |
| 2. | Block sorting compressor | 2390 | 0.36 |
| 3. | GNU C compiler | 794 | 0.376 |
| 4. | Combinational optimization | 221 | 2.66 |
| 5. | Go Game (AI) | 2250 | 0.60 |

Scanned by CamScanner

| | | | |
|---|---|---|---|
| 6. | Search gene sequence | 2216 | .70 |
| 7. | Video compression | 3793 | .5 |
| 8. | XML parsing | 1045 | 0.7 |

$$\text{SPEC Ratio}_i = \frac{T_{ref\text{-}i}}{T_{compA\text{-}i}}.$$

$$\text{Geometric Mean} = \sqrt[n]{\prod_{i=1}^{20} \text{ExecutionTimeRatio}_i}$$

**SPEC** (System Performance Evaluation cooperative).

SPEC 1989

SPEC 2000

SPEC 2006

$$\text{SPEC Ratio} = \frac{T_{ref*i}}{T_{test*i}}.$$

$$\text{SPEC Rating} = \sqrt[n]{\prod_{i=1}^{n} (\text{SPEC Ratio})_i}$$

$$= \sqrt[n]{(\text{SPEC-Ratio})_1 \times (\text{SPEC-Ratio})_2 \times \dots \times (\text{SPEC-Ratio})_n}.$$

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Ex:- There are two machines A and B and a sequence machine. There are two tests T1 and T2 and we obtain the scores for the machines

| Machines | Test T1 | Test T2 |
|---|---|---|
| Machine-A | 10 sec | 100 sec |
| " -B | 1 sec | 500 |
| " -C | 1 sec | 100 |

What is the SPEC Rating for Machine A & B?

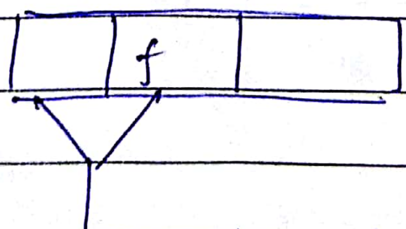
$$SPEC\text{-}Rating_{comp\text{-}A} = \sqrt[2]{\frac{1}{10} \times \frac{100}{100}} = 0.316$$

$$SPEC\text{-}Rating_{comp\text{-}B} = \sqrt[2]{\frac{1}{1} \times \frac{100}{500}} = 0.4$$

Speed-up.

Uniprocessor → Multiprocessor.

Amdahl's law:




(1-f) = function of code that can't be parallelized.

N = No. of processors

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Told = Time taken to run the code on a uniprocessor

$$T_{new} = (1-f)\,T_{old} + \frac{f\,T_{old}}{N}$$

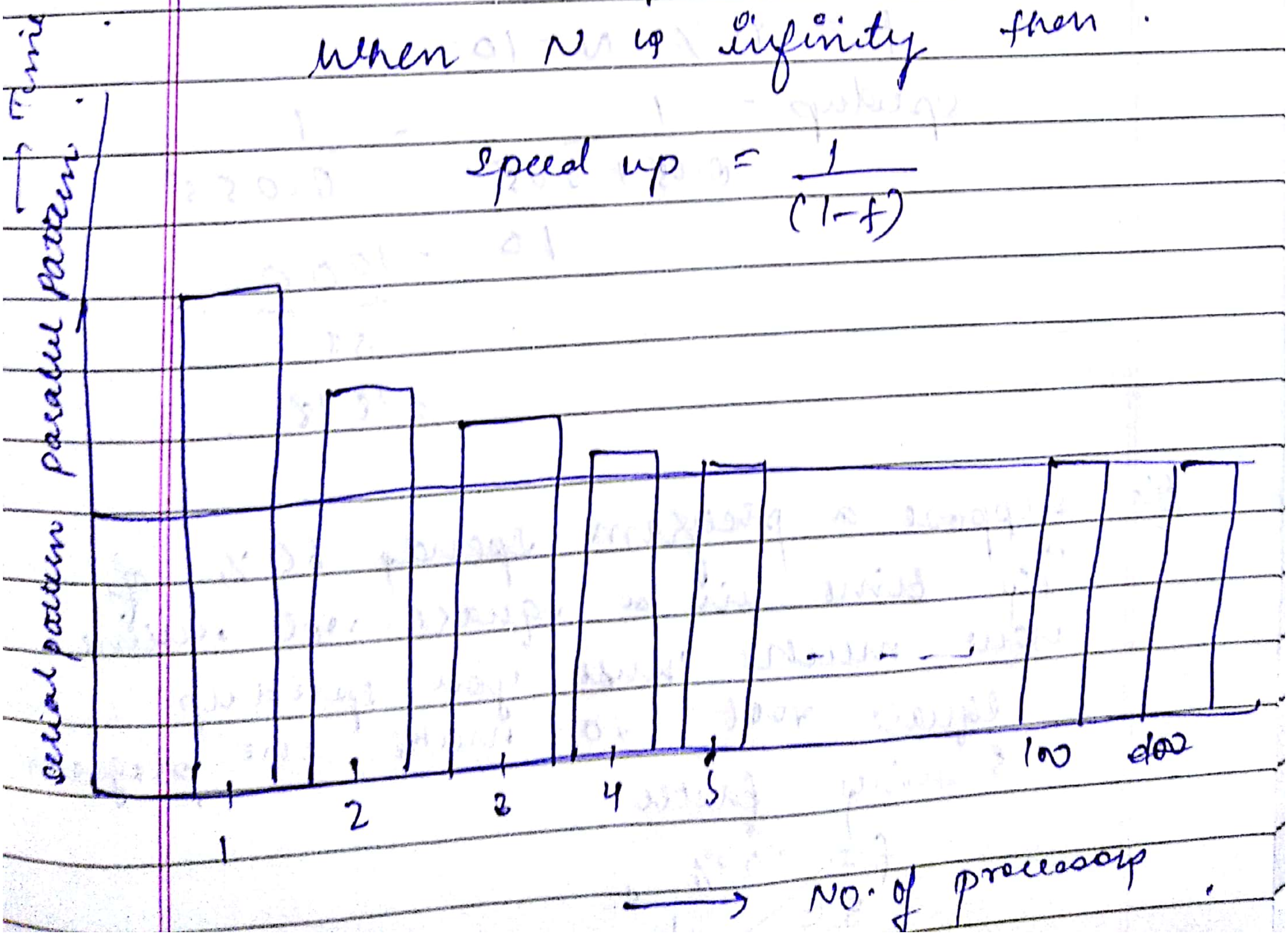
$$\text{Speedup} = \frac{T_{old}}{T_{new}}$$

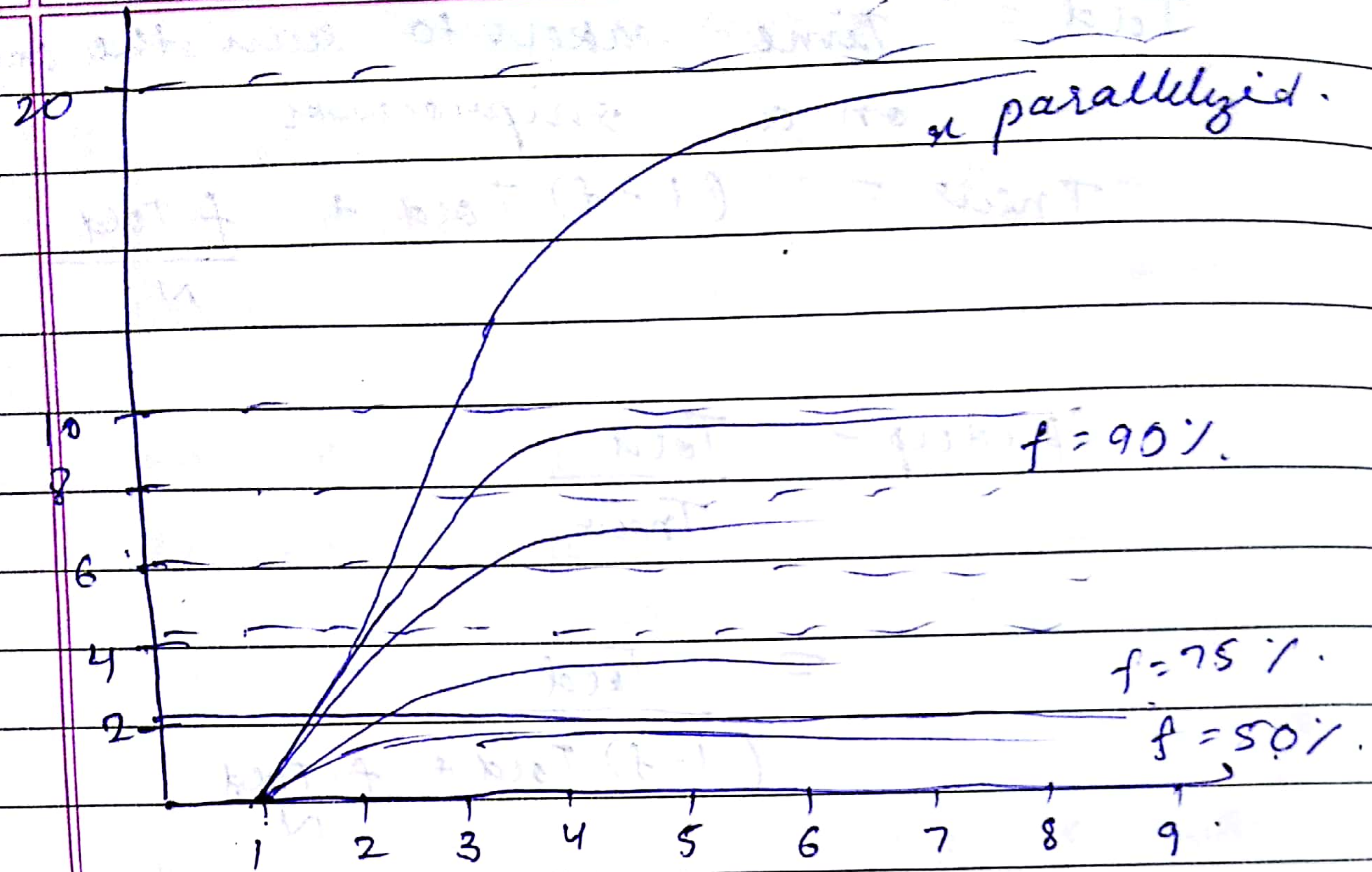
$$= \frac{T_{old}}{(1-f)\,T_{old} + \frac{f \cdot T_{old}}{N}}$$

$$= \frac{1}{(1-f) + \frac{f}{N}}$$

When N is infinity then

$$\text{speed up} = \frac{1}{(1-f)}$$






→ No. of processors.

~~speedup~~ =

$f = 95\%$. $N = 10$.

$$\text{Speedup} = \frac{1}{0.05 + \frac{0.05}{10}} = \frac{1}{0.055}$$

$$= \frac{1000}{55}$$

$$= 18.18$$

Q:- Suppose a program spends 80% of its time in a square-root routine. How much must you speed up square root to make the program 5 times faster.

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$$5 = \frac{1}{(-0.8) + \frac{0.8}{N}}$$

$$1 = 8 + \frac{4}{N}$$ (Not possible)

~~$-1 = 4$~~