# CS528
# Energy/Power Aware Scheduling of Tasks

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# Outline

- Power Aware
- Task with Hard Deadlines
- Energy Efficiency
- Energy Efficient Scheduling
- Real Time Tasks

# Announcement

Mid-Sem Paper Showing

Friday 5PM to 6PM, CSE Seminar Room

Class AVG: **26.09 out of 50**

# Power Aware Scheduling Vs Energy Aware Scheduling

- Power Budget should not exceed
  - Minimized
  - Monthly Expenses: CAP ===> Solution is EMI
  - Power CAP: If your system have 100W design, at any instance of time you should not run things above 100W
    - Suppose you have 3KW wiring in your home, you have 3 AC with each of 1.5KW rating, At a given time, you can run maximum of 2 AC.
- Total energy budget should not exceed
  - Battery capacity, mah (mobile), AH (UPS)
  - Minimized: EC
  - Power and Time

# Top 500 HPC System

https://www.top500.org/lists/top500/2021/11/

1. Fugaku remains the No. 1 system. Japan
   - 7,630,848 cores : **442 Pflop/s** on HPL Benchmarks.
   - This puts it 3x ahead of the No. 2 system in the list.
2. Summit, an IBM-built system at the Oak Ridge National Laboratory (ORNL), USA,
   - **148.8 Pflop/s** on the HPL benchmark
   - 4,356 nodes, each housing
     - two Power9 CPUs with 22 cores each
     - and six NVIDIA Tesla V100 GPUs, each with 80 streaming multiprocessors (S.M.).
   - Nodes are linked together with a Mellanox dual-rail EDR InfiniBand network.
3. Sierra, at Lawrence Livermore National Lab, USA,
   - Architecture is very similar to Summit.
   - 4,320 nodes with two Power9 CPUs and four NVIDIA Tesla V100 GPUs. Sierra achieved **94.6 Pflop/s.**

# Top 500 HPC System

https://www.top500.org/lists/top500/2022/11/

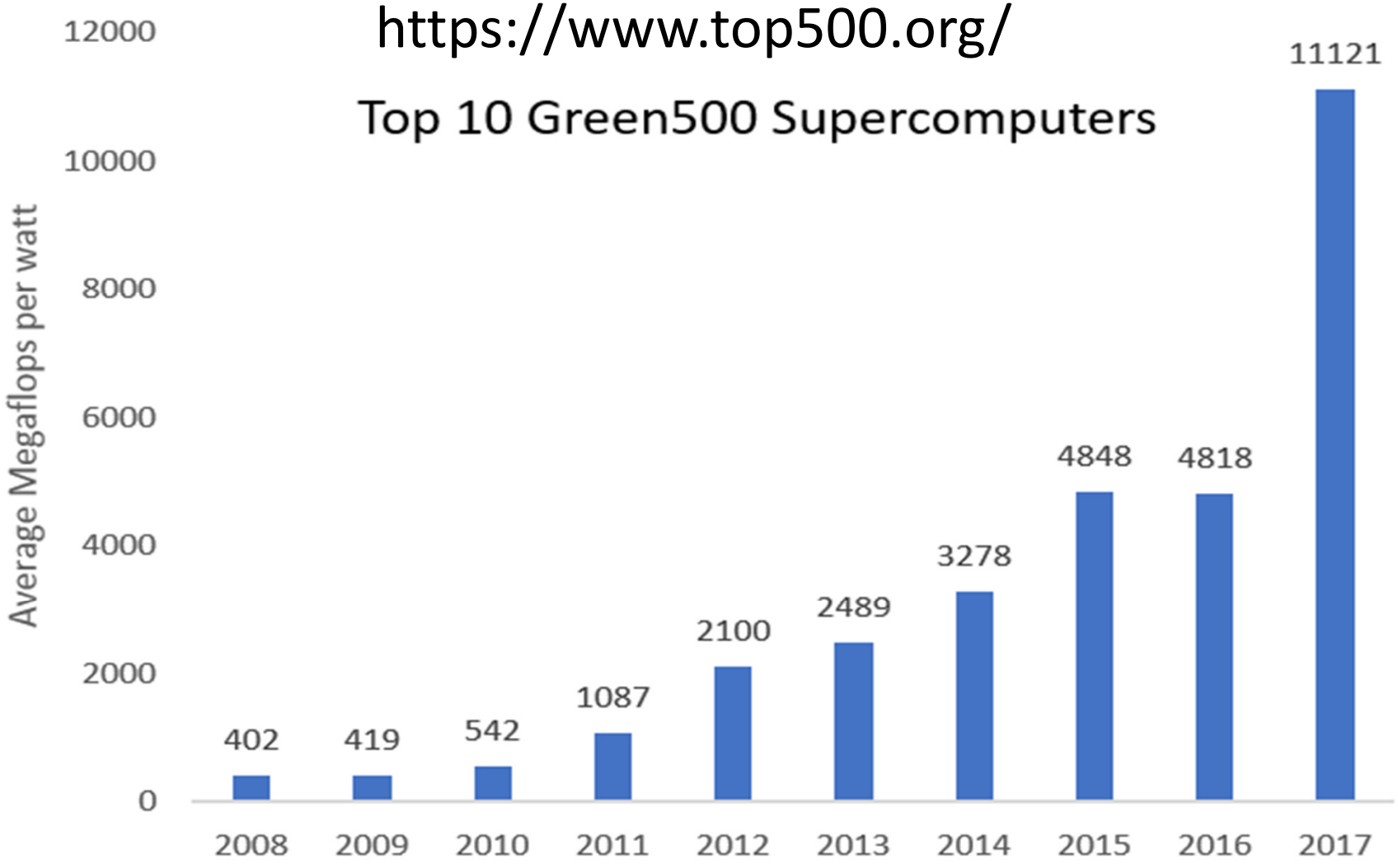
| | | Cores | Pmax-Pflop/s | Ppeak-Pflop/s | Power KW |
|---|---|---|---|---|---|
| 1 | **Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE<br>DOE/SC/Oak Ridge National Laboratory<br>United States | 8,730,112 | 1,102.00 | 1,685.65 | 21,100 |
| 2 | **Supercomputer Fugaku** - Supercomputer Fugaku, A64FX 48C 2.2GHz, Tofu interconnect D, Fujitsu<br>RIKEN Center for Computational Science<br>Japan | 7,630,848 | 442.01 | 537.21 | 29,899 |
| 3 | **LUMI** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE<br>EuroHPC/CSC<br>Finland | 2,220,288 | 309.10 | 428.70 | 6,016 |
| 4 | **Leonardo** - BullSequana XH2000, Xeon Platinum 8358 32C 2.6GHz, NVIDIA A100 SXM4 64 GB, Quad-rail NVIDIA HDR100 Infiniband, Atos<br>EuroHPC/CINECA<br>Italy | 1,463,616 | 174.70 | 255.75 | 5,610 |

# Green500: evolution

- 2008: best result = 536 MFlops/Watt
- 2009: best result = 723 MFlops/Watt
  - Cell cluster, ranking 110 in top500
- 2010: best result = 1684 MFlops/Watt
  - IBM BlueGene/Q prototype 1, ranking 101 in top500,
  - Peakperf: 65 TFlops;
- 2011: best result = **2097 MFlops/Watt**
  - IBM BlueGene/Q prototype 2
  - power consumption: 41 kW / Peak 85 TFlop/s

# Green500: evolution

https://www.top500.org/



# https://www.top500.org/lists/green500/2022/11/

| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **Top 500 rank** :405 | **Henri** - Lenovo ThinkSystem SR670 V2, Intel Xeon Platinum 8362 2800Mhz (32C), NVIDIA H100 80GB PCIe, Infiniband HDR, Lenovo<br>Flatiron Institute<br>United States | Cores: 5,920 | PF/S 2.04 | Power KW 31 | GF/W 65.091 |
| 2 | 32 | **Frontier TDS** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE<br>DOE/SC/Oak Ridge National Laboratory<br>United States | 120,832 | 19.20 | 309 | 62.684 |
| 3 | 11 | **Adastra** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE<br>Grand Equipement National de Calcul Intensif - Centre Informatique National de l'Enseignement Suprieur (GENCI-CINES)<br>France | 319,072 | 46.10 | 921 | 58.021 |

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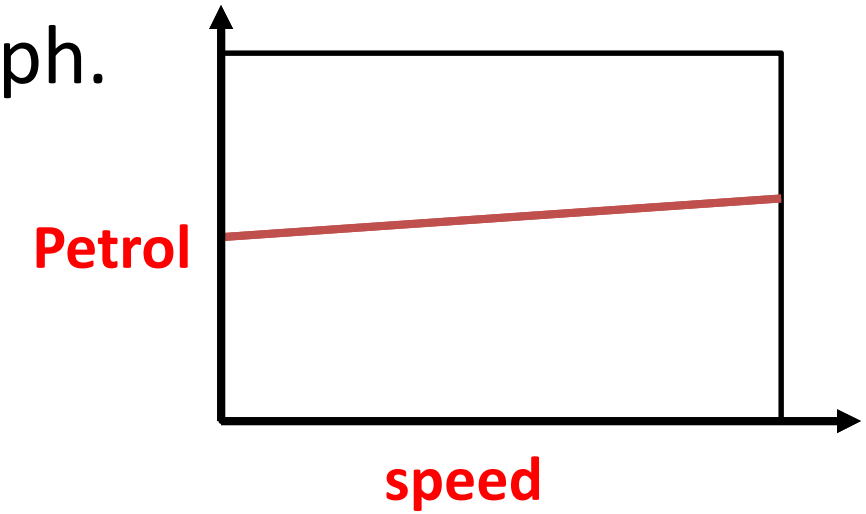
  - Minimized: EC
  - Power and Time

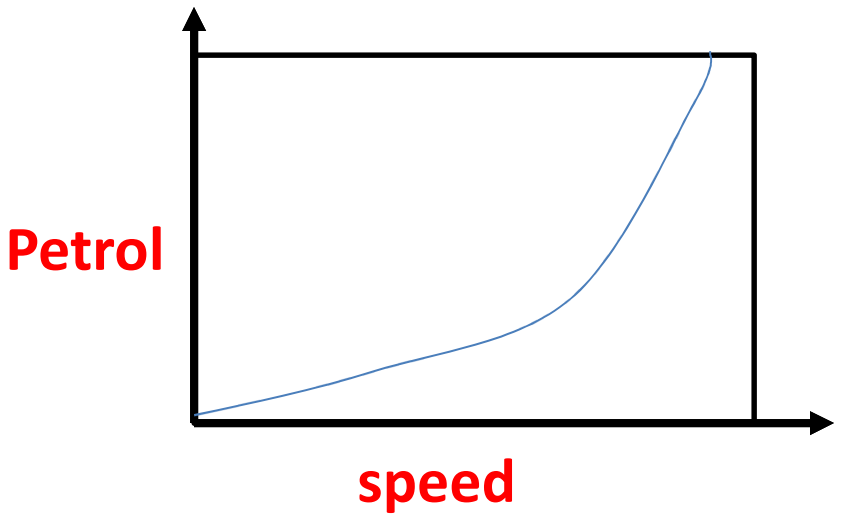
# Speed Matters or Not : I

- Assume you have an Royal Enfield Bullet, you need to go from IITG to GS road, 30KM in 1 hours
- Petrol consumption is almost same at any speed. Example it 2ml/minute at 10kmph and 2.1ml/minute at 100kmph.
- How to save petrol ?
  - Sol: Go at higher controllable speed



# Speed Matters or Not : I

- Assume you have an Bike, you need to go from IITG to GS road, **30KM in 1 hours**
- Petrol consumption is exponentially/quadratic increasing with speed. Example it 2ml/minute at 10kmph and 20ml/minute at 100kmph.
- How to save petrol ?
  - Sol: Go at slower speed to meet the deadline
  - Above example 30kmph
  - **Critical Speed**



# Power and Energy Consumptions

- CPU: dynamic power $P_d = C_{ef} * V_{dd}^2 * f$
  - $C_{ef}$ : switch capacitance, $V_{dd}$ : supply voltage
  - f : processor freq → linear related to $V_{dd}$

$$P \ \alpha \ f^3$$

  - Battery Powered System Reduce Energy usage

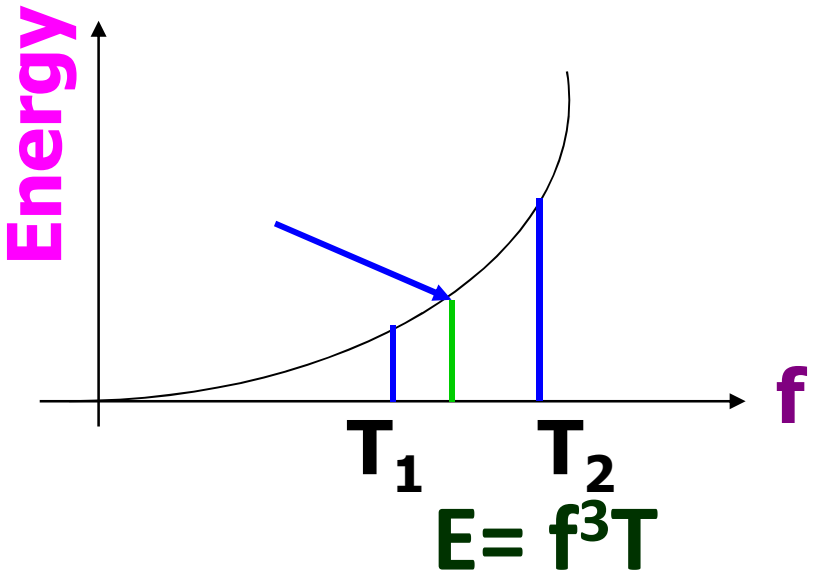
$$E = P.\ t \quad \alpha \quad f^3 t$$

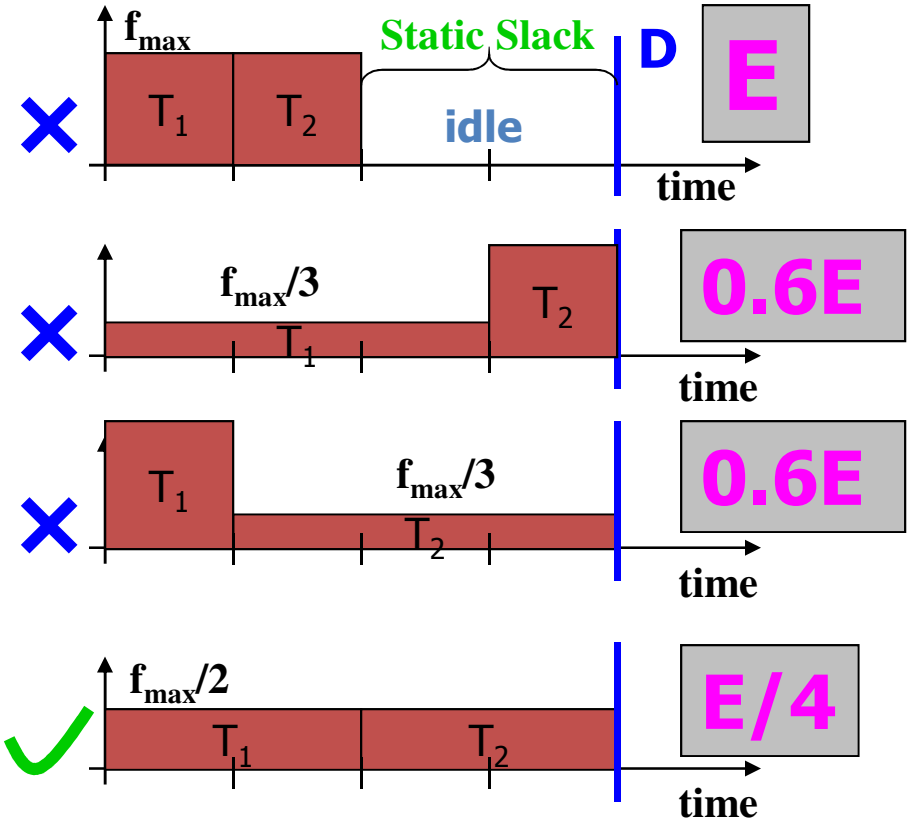
  - Execution time t is inverse to f, $t \ \alpha \ 1/f$

So $E \ \alpha \ f^2$

# Power Aware Scheduling

**Static slack: uniformly slow down all tasks**




I. $f^3T+f^3T=2.f^3T=E$

II. $3(f/3)^3T+f^3T=0.57.E$ ✓

III. $f^3T+3(f/3)^3T=0.57.E$

IV. $2(f/2)^3T+ 2(f/2)^3T=E/4$

# Energy Aware Scheduling

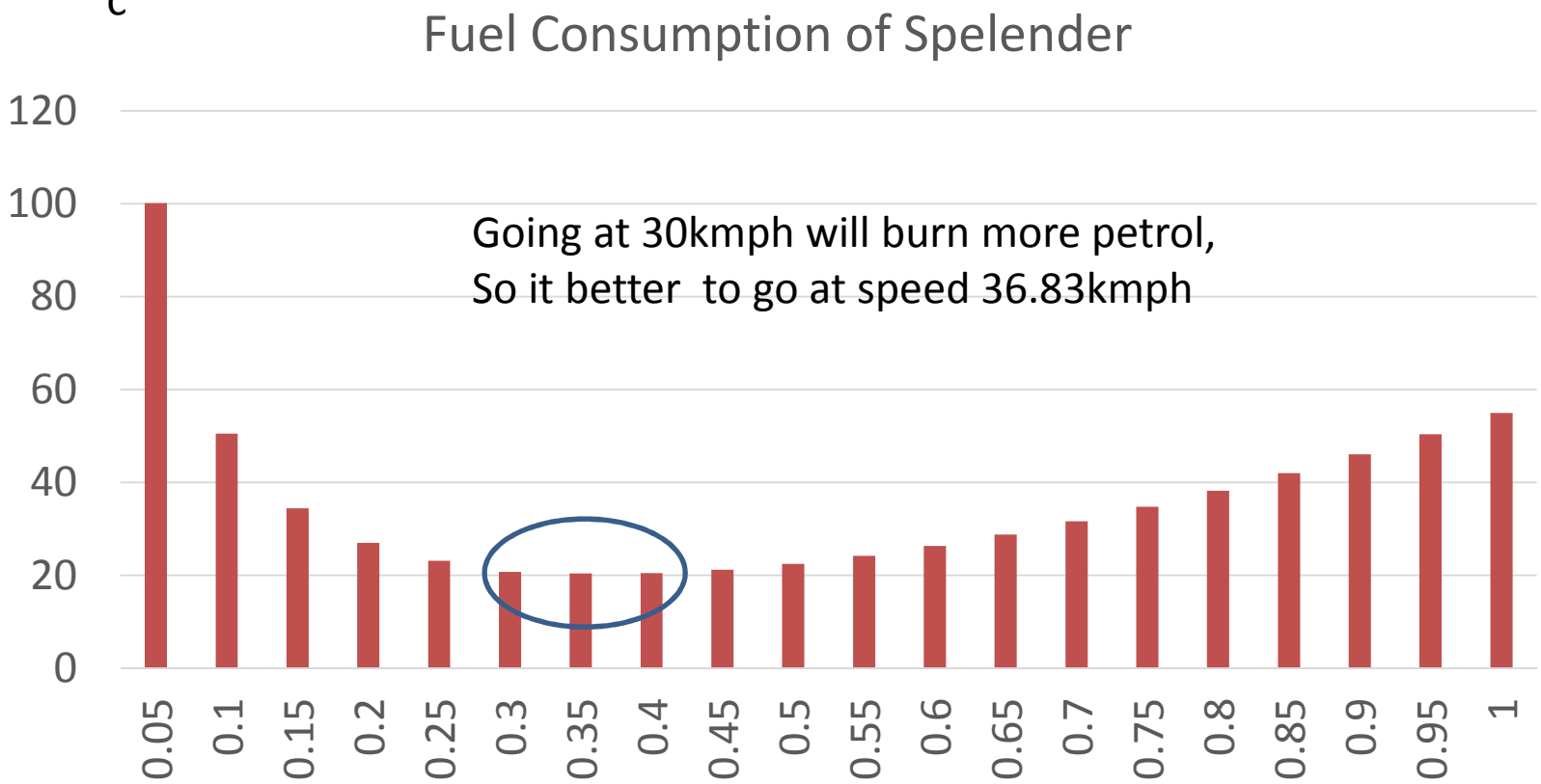
- E= P * T,  More refined model $P=P_s+\alpha*f^3$
- Suppose f=[0:1].
- $E= (P_s+ \alpha *f^3)*T/f = T*[ P_s/f + \alpha.f^2]$
- Min at $dE/df=0$,  $-P_s*1/(f^2)+2.\ \alpha.f =0$

➔  $2.\alpha.f=P_s/(f^2)$ ➔ $f^3 =P_s/2.\ \alpha$

➔ $\mathbf{f_c = \sqrt[3]{P_s/2.\alpha}}$

# Full consumption of Splendor

- Instantaneous Petrol Consumption: P= 5+50f^3
- Distance to travel 30km in 60 minutes deadline
  - $F_c$=0.368399



# Full consumption of Bullet

- P= 200+20f^3
- Distance 30km in 60 minutes
  - Fc =1.709