Question 1. Processors

a. Today's commodity processors have 1 to 64 cores, with some more exotic processors boasting 72-cores, and specialized GPUs having 5000+ CUDA-cores. About how many cores/threads are expected to be in future commodity processors in the next five years?

→ **We could see 190-250 cores in next few years not more than that due to limited number of sockets. But generally speaking, as per me, having many cores will not help people normally using the computers.**

Having multiple cores doesn't guarantee higher performance. Bottlenecks being limited memory bandwidths and memory management schemes. Even if we have programs that are parallelized, we need to move data between cores and this taken time and bandwidth decreasing the performance.

b. How are these future processors going to look or be designed differently than today's processors?

→ **Maybe in future we will need to have more bigger processors along hybrid computers with optical transistors. Optical transistors could be useful for distributing clock signals as well as for being consistent between caches in multicore CPUs.**

c. What are the big challenges they need to overcome?

→ **Major challenges that would need to be overcome are of memory management, cooling issues leading to power and temperature management, memory bandwidth, larger cache memories.**

d. What type of workloads are hardware threads trying to improve performance for?

→ **Hyper threading or hardware threads are mostly useful only in cases where the software or application has multiple small tasks to be completed. Because if hyper threading is used in case where the tasks are larger then it will not be beneficial.**

Some type of workload that can benefit from hyper threading are:

Workflows with huge multi-tasking wherein the workflow has lengthy and chains of tasks to be completed in parallel.

Another use case can be where we need to keep CPU continuously busy. Or use 100% of CPU. Some examples of such cases is rendering 3d pictures or editing videos

e. Compare GPU and CPU chips in terms of their strength and weakness. In particular, discuss the tradeoffs between power efficiency, programmability and performance.

→ **CPU is designed for handling various distinct tasks but have limitation in how many tasks can be performed simultaneously. Whereas, GPUs are designed specifically for rendering high-quality images and videos at same time.**
GPUs work highly in parallel and process data very fast as compared to CPU, but GPUs are not as versatile as CPUs.

GPUs are more useful for tasks that require very repetitive and high parallel computing whereas CPUs. Even if GPUs provide faster performance, applications where we require sequential processing GPUs performance degrades as compared to CPU.

As CPU performs multiple and distinct types of tasks, it requires more memory as compared to GPUs.

Even though the number of cores is less in CPU they are more powerful as compared to cores of GPUs

f. Identify what a thread has of its own (not shared with other threads):

→ **OS stores below list of items for each thread which are not shared among other threads:**
Thread ID, the registers, pointers like instruction pointer and stack pointer, whole stack and scheduling information.

g. What is the advantage of OpenMP over Pthreads?
→ **OpenMP, as opposed to pthreads provides a high level api for working of threads. It is not limited to C and useful in cross platform and is portable as well. It is simple to use than pthreads.**

Question 2. Network
a. A user is in front of a browser and types in www.iit.edu, and hits the enter key. Think of all the protocols that are used in retrieving and rendering the main webpage from IIT. Describe the entire sequence of operations, commands, and protocols that are utilized to enable the above operation.

ANSWER:
1. When we enter the link www.iit.edu https is automatically prepended to the link informing browser that a secure version of http is required.
2. Now for browser to be able to communicate with the website it requires the IP address corresponding to the URL
3. DNS is used to locate the IP address for website.
- Once the URL is hit in browser, first browser cache is checked to find IP address corresponding to the URL
- If, IP address is not found in browser cache, IP address is searched in operating system cache.
- If at all IP address is not found, then it resolver is asked for the IP address. Here resolver is the Internet service provider. ISP has its own cache where mapping of IP address and URL is stored.
- If in any case, we do not get IP address from ISP as well, then request is sent to TLD (top level domain) server which in return redirects to Authoritative Name Server.
- Authoritative name server is the server which has all information and send back IP address to resolver which in return sends it back to browser.
4. After getting the IP address, browser initiates a TCP connection with the IP address and to connect over network IP (internet protocol) is used.
5. Post this, a three-way handshake process is used for establishing connection.
6. Once connection is established, HTTP request is sent by browser and the results are sent by client using HTTP response.

Here, if we have to see protocols corresponding to layers we can see as below:

1. **Application – where request is initialized**
2. **Presentation - HTTP**
3. **Session - TLS**
4. **Transport - TCP**
5. **Network - IP**
6. **Data Link – the frames/data being sent**
7. **Physical – data in bitstreams**

Question 3. Power
a. Why power consumption is critical to data center operations?

→ **Data center is place where all data is stored/computed from applications as well as shared with other applications. It has servers, routers, switches, storage systems, etc. Now as all these systems use power for operating. As per study, the power consumption distribution is servers, cooling systems, storage devices and network (arranged in decreasing order)**

We can see that, because these systems/devices like servers, storage systems, these generate lot of heat during computations or processing, major power is consumed to cool these devices.

b. What is dynamic voltage frequency scaling (DVFS) technique?

→ **DVFS, which is dynamic voltage and frequency scaling is a method which is very useful for reducing the power consumption effectively.**

It reduces power consumption means it provides ways to dynamically reduce power consumption of chips by reducing voltage and frequency based on performance required for application. Basically it helps to increase passive cooling (by adjusting frequency of core clock) and helps reduce the active cooling.

c. If you were to build a large $100 million data center, which would require $5M/year in power costs to run the data center and $5M/year in power costs to cool the data center with traditional A/C and fans. Name 2 things that the data center designer could do to significantly reduce the cost of cooling the data center?

→ **There can be various things or steps done to reduce cost of cooling the data center. Some of the majors taken at renowned IT companies are as below:**

<u>1. Utilizing free cooling -</u>

Selecting location for data center which has benefit of natural (environmental) cooling. Example for this can be, Facebooks' data center in Sweden which is very near to arctic. Google uses seawater cooling, Microsoft has tried to install under water data centers and is assessing its reliability.

<u>2. Manage airflow within data centers -</u>

This steps is to ensure that the hot air flow and cold air flow do not get mixed. We need to identify hotspots and try to align in such a way that cold air is directed towards data centers.

Google makes use of heat lock curtains which help to refrain hotter air from getting near racks.

Based on recent study, if the servers are placed horizontally on racks, then there are more chances of cold air being mixed with hot air flows which reduces the efficient of power management system.

So this point can be taken in consideration while looking for cooling cost reduction options.

Various other steps can be like:

a. Measuring the PUE (power usage effectiveness) as frequently as possible.
b. Adjust thermostat to correct temperature
c. Optimize power distribution by minimizing the conversion stages.
d. Remove zombie or decommissioned servers.
e. Reduce the area of data center that requires cooling
f. Using water cooling instead of air cooling

d. Is there any way to reduce the cost of cooling in (C)? If yes, how low could the costs go? Explain why or why not?

→ **Yes there are multiple ways to reduce the cost of cooling. Explained in answer for question 3.c. Considering that containment saves about 30%-50% of yearly power bill, we could say that we can lower the cost to 3.5M (considering 30% savings)**

The numbers will differ based on what all methods are used for efficiently reducing cooling costs. Personally I don't think the cost of cooling data centers will go down to 0, but can be reduced marginally using multiple techniques

Question 4. Storage

power on memory is fastest possible speed. This includes L1 cache, registers

a. If a manufacturer claims that their HDD can deliver sub-millisecond latency on average, can this be true? Justify your answer?

→ Submillisecond latency is possible. It is possible using SSDs. Amazons EBS volume using SSD provides this latency of submilliseconds.

b. Explain why flash memory SSD can deliver better performance for some applications than HDD.

→ SSDs deliver significantly faster performance with almost real time data access because there is no mechanical process involved or read/write heads or seek limits. As these provide instant access to data from anywhere on drive, they also provide faster file transfer rate and faster boot time. This provides advantage for some applications like gaming.

c. What types of workloads benefit the most from SSD storage?

→ SSDs are useful for intensive workloads like website streaming or transactional databases or video gaming experience systems.

d. If a manufacturer claims they have built a storage system that can deliver 1 Terabit/second of persistent storage per node, would you believe them? Justify your answer to why this is possible, or not. Make sure to use specific examples of types of hardware and expected performance.

→ It is not possible to get speed of 1 terabit per second because using latest PCI express link we get throughput of maximum 126 Gbps. (the one planned in 2021)

Even if we double this we will get maximum of 256 Gbps but it will be difficult rather bit impossible to reach 1 Terabit/second

e. In this problem you are to compare reading a file using a single-threaded file server with a multi-threaded file server. It takes 8 msec to get a request for work, dispatch it, and do the rest of the necessary processing, assuming the data are in the block cache. If a disk operation is needed (assume a spinning disk drive with 1 head), as is the case one-fourth of the time, an additional 16 msec is required. What is the throughput (requests/sec) if a multi-threaded server is required with 4-cores and 4-threads, rounded to the nearest whole number?

→ Time taken for one request – 8 msec

Time taken for request with cache miss – 8 msec + 16 msec = 24 msec

For single thread, the total hit and miss time is:

$\frac{3}{4} * 8 + \frac{1}{4} * 24 = 12$ msec

Number of requests for single threaded server will be 1000/12 = 83.33 requests/sec

Now for a multi-threaded server, we can assume that there is overlapping between wait times and hence there is no miss time which makes total number of requests = 1000/8 = 125 requests/sec

Question 5. SQL vs Spark

ANSWER →

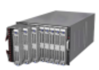
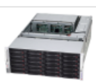
We need s/w and h/w stack to adopt, store, process and analyze 500TB data.
Mostly only 1% of data will be accessed by most queries, using random access pattern.

System configs required:

1. Number of cores - min 224 cores of
2. Processing speed – min 2.7GHz
3. Processor – should be x86 compatible
4. Memory enough to store 1% of dataset in memory i.e. minimum 5TB
5. Storage for 500TB min
6. If its multi-node system then network speed expected is very fast - ~100GbE

Administration cost = 20% or $20k/year
Power costs = $0.15/KWH
Cooling costs = $0.15/KWH

Solution 1 – Using MySQL

	Product	Unit Price	Quantity	Subtotal
	SuperServer 7089P-TR4T (My System February 26th, 10:42 am EST) Thinkmate Config ID 486422 Supermicro SuperServer 7089P-TR4T - 7U - 16x SATA/SAS - 2x M.2 - 96x DDR4 - Quad 10-GbE - 1600W N+2 Redundant **8 x** Intel® Xeon® Platinum 8280 Processor 28-Core 2.7GHz 39MB Cache (205W) **96 x** 64GB PC4-23400 2933MHz DDR4 ECC RDIMM Included Supermicro SIOM 10-Gigabit Ethernet Adapter AOC-MTG-i4TM (4x RJ45) **8 x** Supermicro Update Manager (SUM) (OOB Management Package) No Operating System System Assembly and Testing (8-blade enclosure) 3 Year Depot Warranty (Return for Repair) Reconfigure Add A Spares Kit	$155,707.00	1 Remove	$155,707.00
	STX-JB JE44-0410-SAS3 (My System February 26th, 10:51 am EST) Thinkmate Config ID 486424 Thinkmate® STX-4344 4U Chassis - 44x Hot-Swap 3.5" SATA/SAS3 - 12Gb/s SAS Single Expander - 1200W 1+1 Redundant Power **28 x** 18TB SATA 6.0Gb/s 7200RPM - 3.5" - Ultrastar™ DC HC550 (512e/4Kn) LSI MegaRAID 9380-8e SAS 12Gb/s PCIe 3.0 8-Port Controller with 1GB Cache **2 x** 3-Meter External SAS Cable - 12Gb/s to 12Gb/s SAS - SFF-8644 to SFF-8644 Thinkmate® ISO 9001 Certified Assembly, Testing, and Quaility Control Thinkmate® 3 Year Depot Warranty (Return for Repair) Reconfigure Add A Spares Kit	$15,019.00	1 Remove	$15,019.00
			Update	$170,726.00

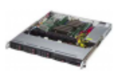
MySQL CGE (cluster carrier grade edition) = $10k/year x 5 years = **$50k**
Total storage and server cost approx **$170k**
Power cost – we take average of 5 x 1600W, around half of it, so 4000W for superserver as we are not using it to full capacity

360W for storage server

So, total power cost = 4000 + 360 = 4360 W
Considering this power, we get around 4.36 kWh/hour
So power consumption of 5 years on average would be = 190968 kWh
So total power consumption cost = 190968 * $0.15 = **$28645**
Total cooling cost same as power consumption cost = **$28645**
So, total cost for hardware + software for 5 years = $277290

Solution 2 – Using Spark
Apache Spark is open source so cost = $0
Total server cost approx **$187k**
Power consumption:
Based on configurations, we get around (285.5 W) 0.2855 kWh/hour
So power consumption of 5 years on average would be = 12504.9 kWh
So total power consumption cost = 12504.9 * $0.15 = **$1875.735**
Total cooling cost same as power consumption cost = **$1875.735**
So, total cost for hardware + software for 5 years = $191192.47

Your Order

	Product	Unit Price	Quantity	Subtotal
	RAX XT8-11S1-SH (My System February 26th, 8:08 pm EST) Thinkmate Config ID 486591	$13,388.65	14 Remove	$187,441.10

Intel® C621 Chipset - 12x SATA3 - 1x M.2 - Dual Intel® 1-Gigabit Ethernet (RJ45)
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