Team Members:

1. **Ayelet Bendor**
2. **Varun Gunda**
3. **Chandu Chinta**

Q1-

A. In my opinion the number of cores/threads won't change drastically in the next 5 years in comparison to what exists in the market today. We've seen that the number of cores/threads and performances are not a linear line, meaning, adding more cores/threads will not necessarily improve the overall performances. I think that the focus in the next 5 years will be on how to fine-tune the processor and hardware while decreasing hardware parts size and improving overall computer's performance and battery life.

B. The future processors will be different than today's processors in a number of ways:
   a. Powerful high speed processors with low energy consumption
   b. Bigger memory bandwidth and/or additional caches
   c. Faster and more efficient communication between cores
   d. Processors will be more functionality oriented versus one processor that execute all instructions e.g CPU and GPU

C. The challenges as follow:
   a. Increasing the memory bandwidth and/or the number of caches as it is currently designed will increase the time to access the memory or cache since the algorithm needs to run on a bigger array
   b. Utilize multi-core processes for parallized computations
   c. While the CPU speed can be increased, memory reads are slower than CPU cycles. Using cache mitigate the memory as being a bottleneck, however, there can be room for improvements
   d. Increasing the speed means creating more heat and consuming more power. This can be solved by adding more fans, however the challenge is also decreasing overall computer dimensions, power consumption and heat dispensing

D.

E. Image processing - rendering an image, pixel by pixel using threads and therefore multi-processing can expedite the processing
   GUI - Essential to create interactive user interface.
   CPU - Threads inter communication and context switching is less expensive. In some cases (depending on the numbers of cores and how the code is written), executing threads instead of process can improve the workload. For example, when one thread is blocked (e.g waiting for input), another thread can run and perform other tasks.

F.

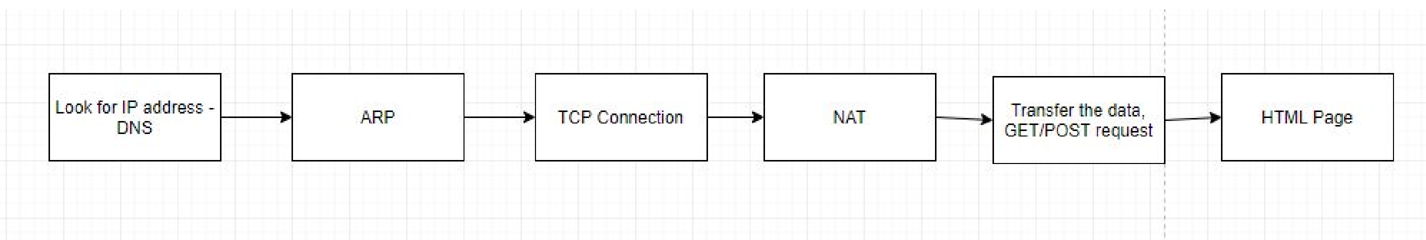
Criteria	**CPU**	**GPU**
Use	Process all types of instructions and perform arithmetic actions	Processes instructions most common for rendering images, animation, and videos for computer's screen
Purpose	Versatile, can manage all types of instructions and any output and input of the computer	Quickly render high resolution video and images, analyze large amounts of information. Design for data intensive application. Also good for computation of massive data sets with simple mathematical operations.
# Of cores	Contains 1 or a few cores	Contain hundreds of cores
Execution	Serials instructions	Due to the large number of cores, GPU execute instructions in parallel
RAM memory	GPU and CPU each have their own memory (although CPU memory is shared with processes that are currently running), each memory's clock runs at a different speed and as a result they run at a different speed	
	• RAM	• vRAM
	• Attached to motherboard	• Attached to harddrive
Design goals	CPU has less cores than GPU and more caches with larger bandwidth, this allow the CPU minimize its latency so it can be more responsive	GPU has multiple cores, usually organized by a block of a number of cores, each block executes the same instruction, it design maximize the throughput handle a large set of data. GPU has little cache memory in comparison to CPU.
Speed	Single CPU core is smarter and faster than a single GPU, however a server usually contains hundreds of GPU core which perform better than a CPU core	Faster than CPU
Coast	There Are a few processor's manufacturer in the market, each have a number of processors model per the different type of use	Compare to processor's manufacturer companies, there are more players in the market. The cost of GPU is more expensive, especially for high graphic resolution. A new GPU is being released roughly every year
Power Consumption	Variable consumption depending on usage, on average has a low consumption	Much higher power consumption than CPU

Q2 -
B. Threads share the same address space and can access the same data, however, they have their own:

- Program counter
- Private registers saved in TCB (thread control block)
- Stack space
- Scheduling properties (policy and priority)

G. OpenMP is a library that supports shared memory multiprocessing for C/C++ and Fortran programing languages.
Pthread requires the developer to define and control every related aspect of the pthreads, meaning, the developer needs to create and join threads, take in account challenges related to threads like: race conditions, mutex, etc. and optimize the code to the number of available processors, otherwise, computational and running time performances will not be effective for using multi-threading.
OpenMP is much more straightforward, by adding a pragma statement to your code, you're defining a block of code that will run in parallel. It solves the need of controlling threads and defining it to a granular level. In addition, OpenMP is scalable, it will spawn and join threads as needed until performance goals are met.

Q3-



On clicking a URL in the browser, there are a series of actions that happen to fetch the HTML page. Lets see how it works with www.iit.edu.
1. Every domain has a unique IP address. The first job is the browser checks for IP address for the domain we are searching for. Domain Name System is the database where the list of domains and their corresponding unique IP addresses are maintained.

2. Finding the domain, address pair can happen in various ways like

a. Local browser Cache
b. OS cache
c. Router
d. ISP

a. Browser maintains the Domain,IP address pair in its cache which is stored if visited that domain previously. This would probably be the first place to check.

b. If not found in the browser cache, the next search would be in OS cache, where the browser makes a system call like 'gethostname' to check for the (Domain, IP) pair. Because OS also has a repository of DNS list.

c. If not found in OS cache, the third fetch would be from the routers cache.

d. Also, if not found in routers cache the fourth check would be in the Internet Service Providers cache, where all ISP's maintain a repository of list of DNS.

Even if not found in ISP's cache, the ISP's DNS server will start a DNS query to fetch the address of the server hosting the domain(i.e., www.iit.edu).

3. After a successful fetch of IP address, ARP(Address resolution protocol) is used by the IP address to map the IP address to the hardware, which means a MAC address which is unique to every hardware.

4. A TCP connection is initiated by the browser to the server. A TCP connection is required between the server and browser to transfer the required information (3 way handshake). This process takes in 3 steps, exchanging Synchronise(SYN), Acknowledge(ACK) messages to establish a connection.

5. NAT (Network address translation) comes into play, where a private IP address is translated to the public. This has to be done because a unique identification is required for the internet to reply to the particular browser.

6. After establishing the connection, to transfer the data the browser will send a HTTP GET request for a HTML page (or) HTTP POST request to submit something(ex: entering credentials).

7. The server maintains the data. Webserver receives the request from the browser and sends back a response.

8. Finally the browser shows the HTML page. Some static files are stored in the cache by the browser to load the page faster or not fetching them again on the further vists to the same domain.

Q4-

A. Power consumption is a critical metric that can alter both the construction of a datacenter as well as its daily operations. Higher power consumption requires more specialized power transmission infrastructure that is (1) harder to maintain, (2) costs more money to purchase (during installation) and (3) has higher monthly electricity costs.
In addition, higher power consumption generates more heat, which in return requires better cooling systems, which also cost more money to install and also increases electricity costs.
Lastly, power consumption in data centers can be used as an indication of performance

and utilization. For example, peaks in power consumption can point out of applications that are heavily using the CPU thus resulting in degrading of total performances.
Also, high power consumption over significant amount time is a warning sign for hardware components being over utilized, and the danger in such a scenario is a failure of hardware and potential loss of data and downtime.

B. DVFS is a technique for managing power by dynamically adjusting the power consumption and the frequency of the processor, based on the target performances of the application.
This technique aims at conserving power or reducing the amount of heat generated by the processor, however, in order to achieve its goals, it reduces the applications' performances.

C. I. Hot/cold air aisle - designing the server racks in alternating rows where all intakes are facing one side (for cold air to come in) and all of the exhausts (where hot air goes out) are turned to the other side. This will create aisles where the front is called a cold aisle and we could design the datacenter such that these cold aisles face the A/C's output ducts, setting the temperature as we wish. Furthermore, the side that has the heated outputs poured into is called a hot aisle and these should be designed to face the A/C's return ducts (pulling the hot air out).
II. Organization - it is critical to design each room's layout and size such that there will be sufficient space between the racks, and the racks and the walls, for air to flow correctly and as designed with the A/C systems. While we usually wish to crowd servers as much as possible to get maximum utilization per sqft, overcrowding servers could result in odd airflow and overheating of the datacenter.

D. Yes, there are ways to reduce the cooling costs, for example: designing an airflow tunnel to use the air from outside to cool the room temperature. Every change in the room temperature degree requires the cooling system to work less, and it consumes less power. For example, the datacenter could be built in a cold weathered area (Scandinavian countries, Canada, Russia, Antarctica, etc.).
According to PGE, combining cooling systems with side-air can reduce data center cooling cost by 60%.

Q5-

A. This can’t be true. Suppose let average latency be 0.5 milliseconds. This implies one full rotation takes 1 ms. Hence disk should run at 60,000 rotations per minute speed which is unachievable. Most of the HDDs today run at 7200 RPM at the maximum.
B. SSD memory can deliver better performance for applications that require a lot of read/write operations. Since SSD is much faster in retrieving data compared to HDD, SSD outperforms HDD.
C. 1) Workloads that require a lot of read write operations. (High IOPS)
   2) Databases, OLTP and web applications.
   These are the applications where users expect a real time response.
D. The current highest speed of the internet is in tens of Gbps. Hence achieving 1 Tbps speed is impractical as of now. Also, using the fastest protocol for accessing high-speed storage media (NVMe), NVMe controller can offer only upto 3 Gbps which is very less compared to 1 Tbps. Hence, the claim can’t be true.

5e. Single threaded file server:-

75% of the time – 8 ms
25% of the time – 24 ms (Additional 16 ms)

Assume throughput is y reqs/sec

$$\frac{3y}{4} \times 8 \times 10^{-3} + \frac{y}{4} \times 24 \times 10^{-3} = 1$$

$$12y = 1000$$

$$y = \frac{1000}{12} = 83 \text{ reqs/sec}$$

Multithreaded file server:-

We have 4 cores and 4 threads server.

$\therefore$ Throughput $= 4 \times 83$ reqs/sec
$= 332$ reqs/sec.

6. SQL vs Spark (20 points):

Requirements:
a. 224-cores
b. 2.7 GHz
c. 500 TB storage
d. 5 TB RAM (1% of the dataset)
e. 100 Gigabit Ethernet (100 GbE)

For MySQL:

Description	Quantity	Cost
Server: **HDX XN24-52S1** Configuration: a. 2U 4-Node - Intel® C621 Chipset - 24x NVMe - 2200W Redundant Power	1	$ 349,809
b. Intel® Xeon® Platinum 8280L Processor 28-Core 2.7GHz 39MB Cache (205W) -	8	
c. 128GB PC4-23400 2933MHz DDR4 ECC RDIMM	48	
d. 15.36TB Micron 9300 PRO Series U.2 PCIe 3.0 x4 NVMe Solid State Drive	20	
e. Supermicro SIOM 100-Gigabit EDR InfiniBand Adapter AOC-MHIBE-m1CGM (1x QSFP28 & 1x RJ45)	4	
f. Mellanox 100-Gigabit Ethernet Adapter ConnectX®-5 EN MCX516A (2x QSFP28) - PCIe 3.0 x16	4	
g. IEC60320 C13 to C14 Power Cable, 16 AWG, 240V/15A, Black – 3'	2	
h. Thinkmate® Update Manager (OOB Management Package)	4	
i. Red Hat® Enterprise Linux® 8 Server (Premium) (1 Year)	4	

j. 5 Year Advanced Parts Replacement Warranty	1	
Storage: a. STX-JB JE44-0410-SAS3 b. 14.0TB SAS 3.0 12.0Gb/s 7200RPM - 3.5" - Seagate Exos X14 Series FastFormat™ (512e/4Kn) c. LSI SAS 9300-8e SAS 12Gb/s PCIe 3.0 8-Port Host Bus Adapter d. 3-Meter External SAS Cable - 12Gb/s to 12Gb/s SAS - SFF-8644 to SFF-8644 e. IEC60320 C13 to C14 Power Cable, 16 AWG, 240V/15A, Black – 6' f. 5 Year Advanced Parts Replacement Warranty	 1 14 1 2 2 1	 $10,726
Administration Cost ($20,000 * 5)		$100,000
Power cost (0.15 KW/hour * 5.12 KW * 43,800 hours**)** for 5 years **Total Power consumption :** 5.12 KWh		$33,638
Cooling cost (0.15 KW/hour * 5.12 KW * 43,800 hours**)** for 5 years		$33,638
Total Cost		$527,811

Hence MySQL solution will cost $527,811 for 5 years.

For Spark:

Description	Quantity	Cost for 7 nodes
Server: **AMD EPYC™ 7002 Series - 1U - 10x NVMe - Dual 1-Gigabit Ethernet - 1200W Redundant Power Supply**	7 (Total)	7 * $ 42,308
Configuration: (per node) a. AMD EPYC™ 7302 Processor 16-core 3.00GHz 128MB Cache (155W)	2	
b. 64GB PC4-23400 2933MHz DDR4 ECC RDIMM	16	
c. 7.68TB Intel® SSD DC P4610 Series U.2 PCIe 3.1 x4 NVMe Solid State Drive	10	
d. Mellanox 100-Gigabit Ethernet Adapter ConnectX®-5 EN MCX515A (1x QSFP28) - PCIe 3.0 x16	1	
e. IEC60320 C13 to C14 Power Cable, 16 AWG, 240V/15A, Black – 6	2	
f. Red Hat® Enterprise Linux® 8 Server (Premium) (1 Year)	1	
g. 5 Year Advanced Parts Replacement Warranty and NBD Onsite Service	1	

Mellanox MFA1A00-C003 Active Fibre Cable Ethernet 100 GbE (For connecting master and worker nodes**)**	6	6 * $455
Administration Cost ($20,000 * 5)		$100,000
Power cost (0.15 KW/hour * 0.31 KW * 43,800 hours**)** per node for 5 years **Total Power consumption :** 1.51 KWh		7 * $2,036
Cooling cost (0.15 KW/hour * 0.31 KW * 43,800 hours**)** per node for 5 years		7 * $2,036
Total Cost		$427,390

We took a model of having 7 nodes working together. For these nodes, identical configuration is used. The total cost came up to $427,390.