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Problem 2.1

a.

1. Active Networks
2. 4D
3. Sane

b.

- i. FEs and CEs responsibilities

Forwarding elements (FEs) are typically ASIC, network-processor, or general-purpose processor-based devices handle data path operations for each packet

Control elements (CEs) are typically based on general-purpose processors that provide control functionality, like routing and signaling protocols.

- ii. Reason for the separation between FEs and CEs

Separate components would allow component vendors to specialize in one component without having to become experts in all components. Standard protocol also allows the CEs and FEs from different component vendors to interoperate with each other and hence it becomes possible for system vendors to integrate together the CEs and FEs from different component suppliers.

Problem 2.2

- a. **SDN Control Program** : Provides an API to specify the behaviour of flows using well defined rules

Network Virtualization layer : Compiles a network topology based on the rules specified and provides an abstract network model

Network OS : Gives a global view of the network. Also handles transmissions to the switches.

- b. Southbound API refers to the Hardware
Northbound refers to the API of the Network Operating system
East-/Westbound could refer to the packet forwarding
- c. Implications of running the OpenFlow client as part of the software layer :
 - Speed, scale, fidelity of vendor hardware
 - Flexibility and control of software and simulation
 - Vendors don't need to expose implementation
 - Leverages hardware inside most switches today (ACL tables)
- d. Flow matching to a higher layer would imply running of higher layers software layers in the switch. Given the extensive abstractions and overhead of decoding and encoding packets at each layer, it would be a computation intensive task and also damps the speed of operation of the switch

Problem 2.3

- a. Upto layer 4
- b. For fail safe operation
- c. Instructions are executed on each packet to determine the action-set to be applied on the packet. Instructions operation on a packet takes precedence over the action-set.
- d. The Output action forwards a packet to a specified OpenFlow port. The reserved port "CONTROLLER" may be used to forward a packet to the controller, say for logging or debugging

Problem 2.4

Assuming that a new connection would mean a new TCP connection, we shall see a SYN on each new connection. We shall apply OpenFlow rules to forward all connections with a SYN flag to be forwarded to VM2. And also we create new rules based on the TCP connection parameters to forward all subsequent communication over this connection to be forwarded to VM2. Now, every new connection that arrives at the OpenFlow switch is forwarded to VM2 and also the subsequent communication over that connection to VM2. Any other communication that doesn't match the above rules will be forwarded to VM1 until the connection is terminated by the user or VM1. We will also create a new flow for all

connections going to VM1 - anything that doesn't match the rules set for VM2 forwarding flow. We will impose a timeout on the OpenFlow rules of this flow - higher than connection timeout so that when all the connections to VM1 are closed, the migration can start. This can be alternatively handled by VM1 trigger the migration when all connections to it closed.

We repeat the above process for VM1 and VM2 backward when the VM1 migration has finished.