Exercise for Lecture
Software Defined Networking

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Contact: Please use the Moodle forum to post questions and remarks on the exercise.
Web: `http://www.ps.tu-darmstadt.de/teaching/ws1617/sdn/`
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– Example Solution –

Problem 2.1 - SDN and OpenFlow Basics

Hint: A 30-minutes version of Scott Shenker's talk on "The Future of networking, and the Past of Protocols" that the lecture was partially based on is available on YouTube: `https://www.youtube.com/watch?v=YHeyuD89n1Y`. It might help you to revisit some of the concepts presented in the lecture.

a) Separation of Concerns: Briefly explain in your own words the different responsibilities of the SDN layers described by Scott Shenker: *Control Program*, *Network Virtualization* layer, and *NOS*.

Solution:
Control Program:

- Express desired behavior without specifying the details on how to implement it on physical network structure.
- Examples: ACLs, high-level requirements on routing, QoS requirements.

Network Virtualization:

- Provides a logical network view to control programs. This view is virtual and can differ from the physical network.
- Different control programs can work on different virtual views that the virtualization layer aligns and maps to the global network view.

NOS:

- Provides a global network view to the upper layers.
- Translates abstract behavior as specified by the control program into physical configurations on forwarding elements. This happens after the network virtualization mapped

the potentially virtualized network view used by the control programs to the global network view provided by the NOS, which then translates the specified behavior to device configurations.

b) Foundation of layers: What are the key abstractions that provide the foundation of SDN? Briefly explain what exactly is abstracted, how the interfaces of the abstractions look like, and who uses them.
Note: This task overlaps with the previous one but requires you to take a more conceptual perspective.

Solution:

- Distributed state abstraction: The fact that forwarding state is distributed among network (forwarding) devices is shielded from control programs and control layers above a network operating system (NOS). They use the abstraction by accessing a *global network view* that is exposed by the NOS. The global network view, most likely, is an annotated network graph (a data structure, representing the physical network).
- Configuration/specification abstraction: The global network view provided by the NOS is abstracted and exposed to control programs as a simplified network model. In best case, the exposed model only contains details that the control program requires to express its desired *behavior*. The interface is an annotated network graph that abstracts the global network view, originally, exposed by the NOS.
- Forwarding model: Here, the forwarding behavior of network devices/forwarding elements of the physical network is abstracted. The NOS uses this abstraction to control the forwarding behavior of the forwarding elements, without knowledge on the actual implementation of the forwarding in hardware or software. The interface is a protocol, such as OpenFlow. Others could be used as well. OpenFlow mostly abstracts the forwarding behavior that could be implemented by ASICs (in hardware). Abstractions could be also defined on a higher level, including management aspects realized, e.g., using the management CPU of a hardware switch.

c) Briefly explain the concept of a "scale-out router" in the context of network virtualization (slide 42, lecture 2). What is the advantage of using this abstraction in the context of the above discussed abstractions?

Solution:
The concept of the "scale-out router" is to provide a highly abstracted network view to a routing control program in form of a single virtual router. The physical network, however, is a collection of interconnected switches/routers. In case more network capacity is required, additional routers can be added to the setup (scale out) instead of increasing the capacity of individual physical routers (scale up) to increase the overall capacity of the virtual router. The advantage of exposing such a highly abstracted network view is that it enforces the specification abstraction. As the routing control program cannot take any assumptions on the physical realization of the physical network structure, it is forced to focus on the desired routing behavior on an abstract level.

d) When network engineers start learning about SDN, they often get the impression that the concept introduces a single point of failure to the process of network control. Why is this the case and why is it not true after what you learned in the first lectures? Please briefly explain.

Solution: As the NOS exposes a global network view to control programs and usually is depicted as an abstract block in architectural pictures, one might get the impression that the NOS is a centralized component and, thus, a single point of failure. Indeed, when working with simple setups and implementing first control applications, usually, the NOS is realized as centralized component. In some cases, this might even be an adequate approach. The SDN concept, however, does not imply a centralized controller but rather leaves the realization intentionally open. In most productive environments, the NOS will be a distributed system itself. Often, works discuss the NOS to provide a logically centralized view on the global network state, while envisioning a physically distributed realization.