Position Proposal: Software-Defined Networks as Databases

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SDN's logically centralized control provides an insertion point for programming the network. Our view is that enabling *flexible, orchestratable, and interoperable abstractions* is one of the keys to move SDN beyond its initial specialized deployments to broader use cases. To this end, we champion a perspective that SDN control fundamentally revolves around *data*: programmable abstractions by representing the network as lower-level data, application-specific abstractions as higher-level derived data, and higher-level orchestration as mediation of data access across multiple applications of disparate abstractions. We propose a novel design point driven by this insight: we take the entire SDN network control system under the hood of a standard SQL database, and rely on SQL for data manipulation and the database runtime for data mediation. This database-centered design also lends itself naturally to a novel solution to SDX via database interoperability, namely, software-defined Internet Exchange as federated databases.

Ad-hoc programmable abstractions via database views. The database *view* construct enables new abstractions to be constructed ad-hoc and enables them to build on each other. For example, from the "base tables" defining the network topology and OpenFlow forwarding rules, one can construct a view representing a virtual network that spans a subset of the topology; and one can further derive a load balancer's view of host availability within the virtual network. These SQL views form the structure of the abstractions; furthermore, integrity constraints over the views express high-level policy invariants and objectives. These views and constraints can be expressed via SQL statements and can even be constructed ad-hoc, i.e., dynamically in the running controller.

Orchestration across abstractions via view mechanisms. Standard view maintenance and update mechanisms — the "runtime" for view abstractions — are used as a means to orchestrate across multiple views of a single network. First, *view maintenance* continuously refreshes the view abstractions of a dynamic network. Second, to translate updates in a derived view back down to a lower-level view, users can define a view update policy that governs how updates on the higher-level abstraction are realized on the underlying data-plane via *triggers*, which can incorporate custom heuristics at runtime to optimize applications.

Orchestration across applications via a data mediation protocol. To mediate multiple applications whose database modifications affect each other, we introduce a protocol that assumes a simple conflict resolution strategy — an ordering of view constraints where lower-ranked constraints yield to the higher-ranked. Given a view update request as input, the protocol produces as output an orchestrated update set that respects all applications' constraints (subject to conflict resolution). The orchestrated set may append to the request additional updates for completion (e.g. invoke a routing application when an access control application attempts to remove an unsafe path) or reject the update if a cohesive update is not possible.

Software-Defined Internet exchange via federated databases. In addition to the use of standalone database for software-defined networks within a single administrative domain, we plan to investigate interoperability of databases as a means to achieve software-defined inter-domain networking. A popular architecture for interoperable databases called federated databases, in particular, is a natural fit for Internet exchange points (IXP): The member ASes — the individual databases — control their interactions with other members via export- and an import- schemas, expressing the information they share and desire. The IXP — a federal mediator database — maintains the topology of the federation (i.e. layer-2 switching fabric), the member schemas, and oversees the bi-lateral member SLAs via global inter-database integrity constraints. Additional database mechanisms for coordinating sharing and exchange among the member and the federal databases is used to actually connect the member ASes and the IXP.

Short bio: Anduo Wang is a postdoctoral researcher at UIUC. She will join Temple University as assistant professor in January 2016. Her research champions a database solution to SDN(X), with preliminary works appearing in ONS'14 (position paper *Software-Defined Networks as Database*) and SOSR'15 (demo *Ravel: Orchestrating Software-Defined Networks*).