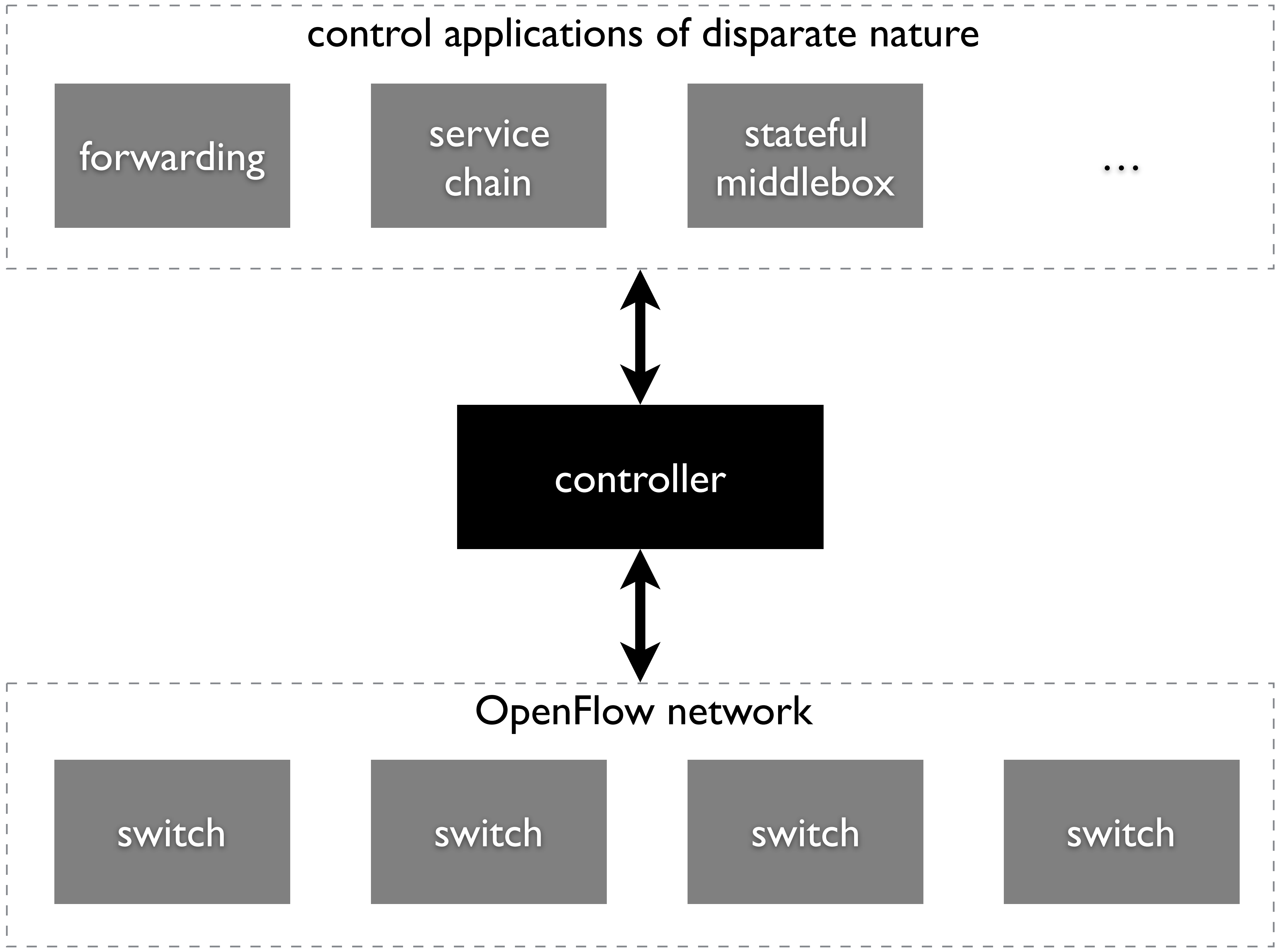
# SDN abstraction and security: a database perspective

Anduo Wang[*] Jason Croft[†] Xueyuan Mei[†]
Matthew Caesar[†] Brighten Godfrey[†]

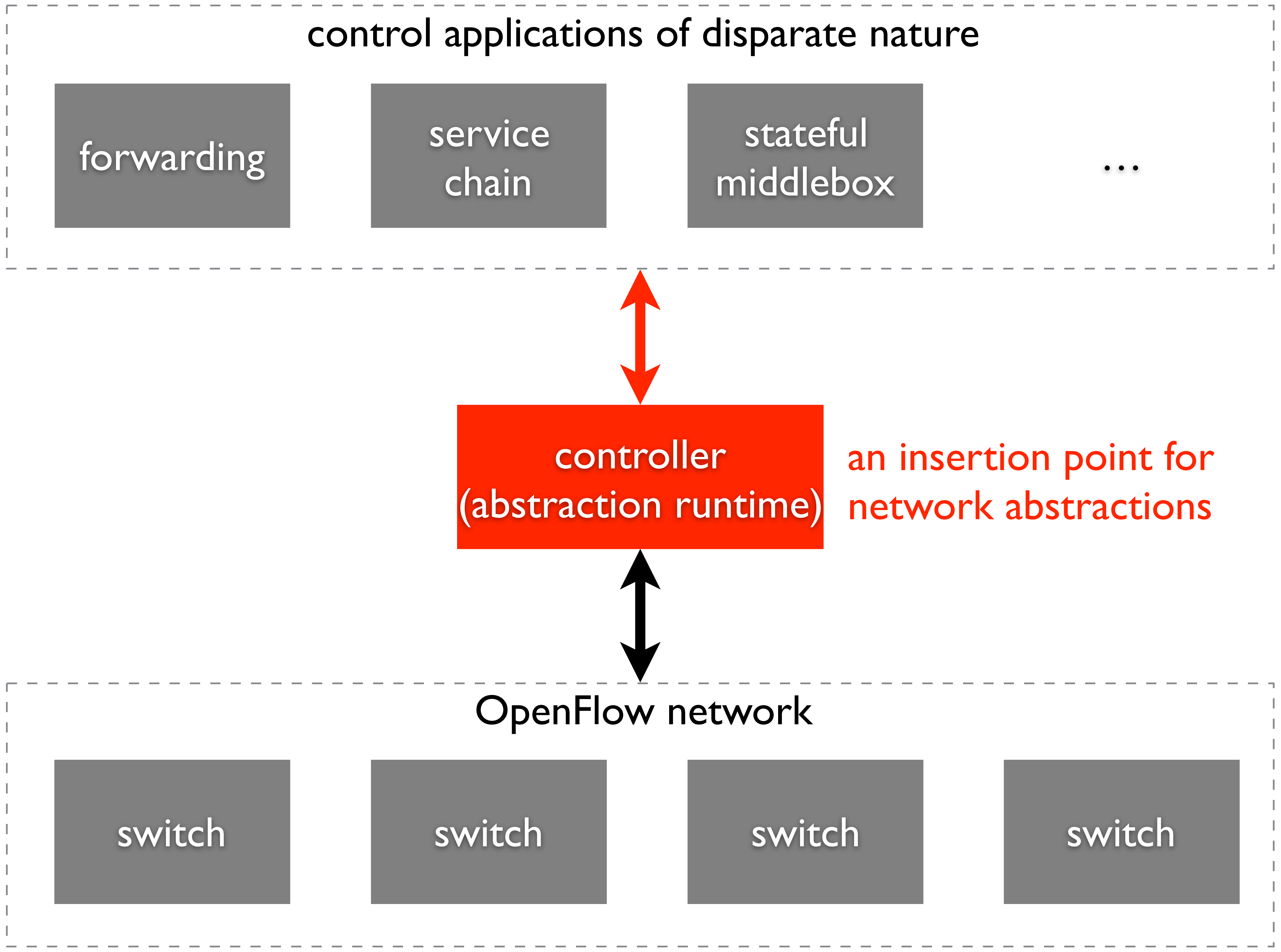
[*]*Temple University* [†]*University of Illinois Urbana-Champaign*

June 17, 2016 SoSSDN

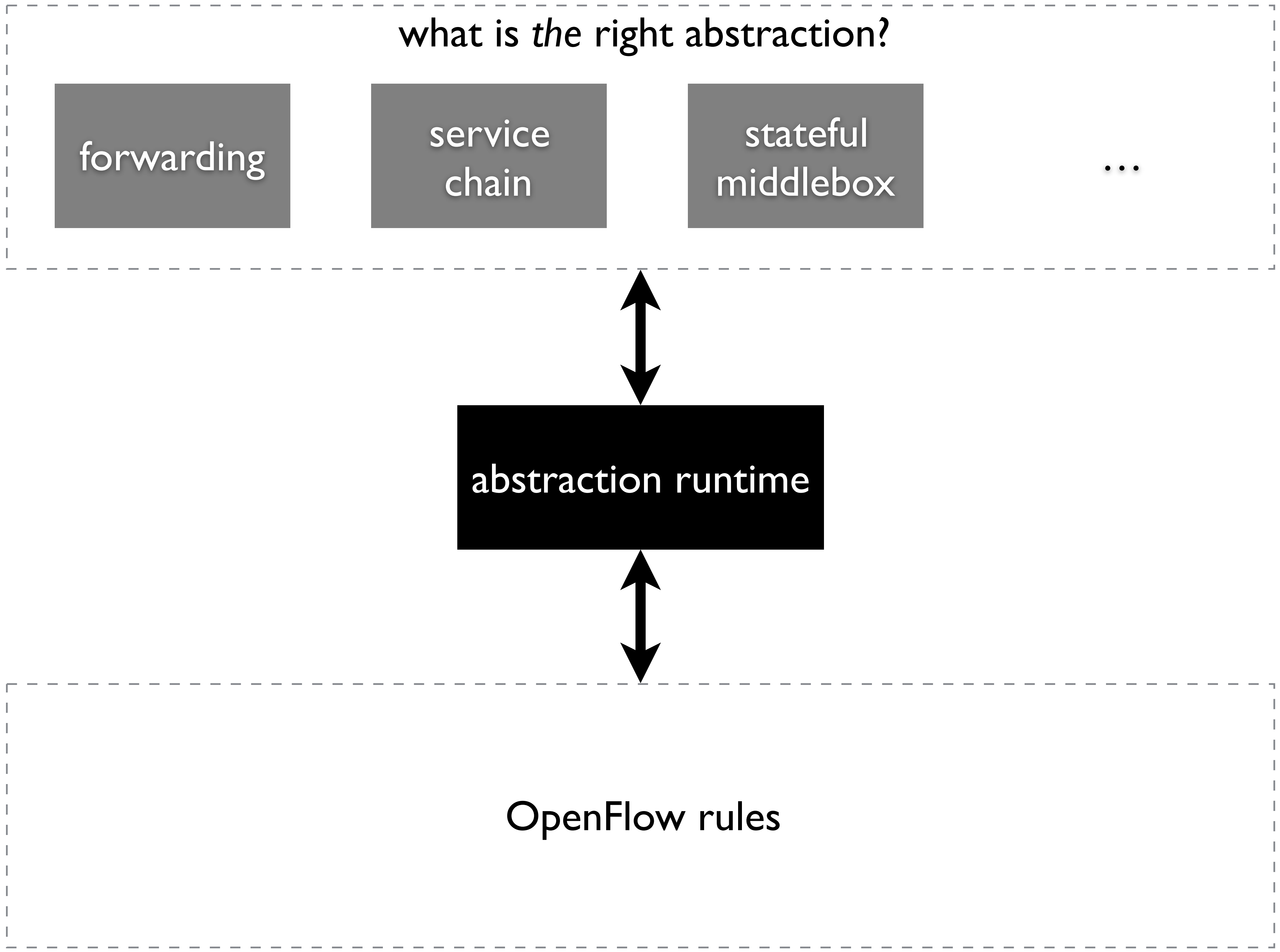
# software-defined network



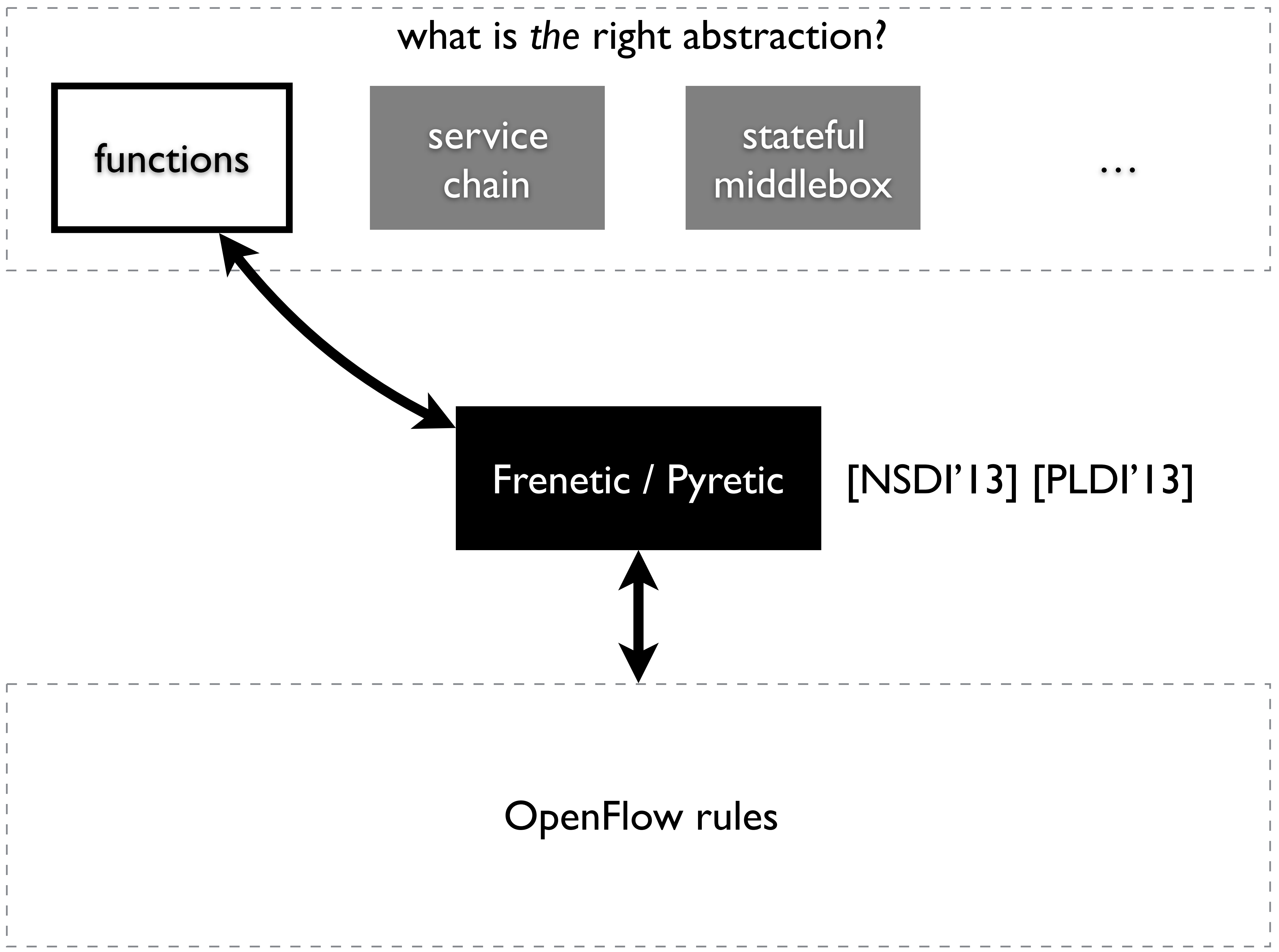
# software-defined network


control applications of disparate nature
forwarding
service chain
stateful middlebox
...
controller (abstraction runtime)
an insertion point for network abstractions
OpenFlow network
switch
switch
switch
switch

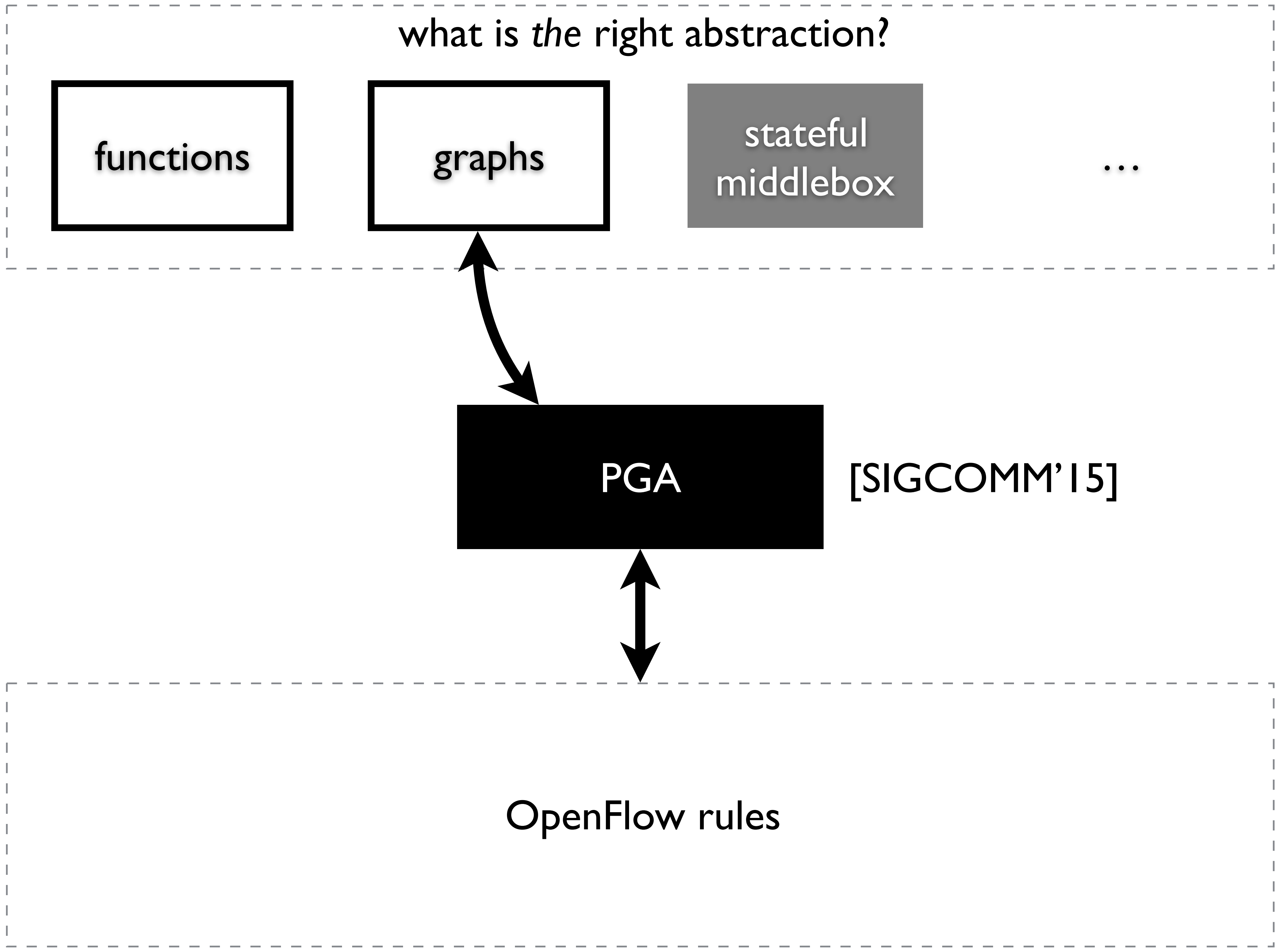
# abstractions



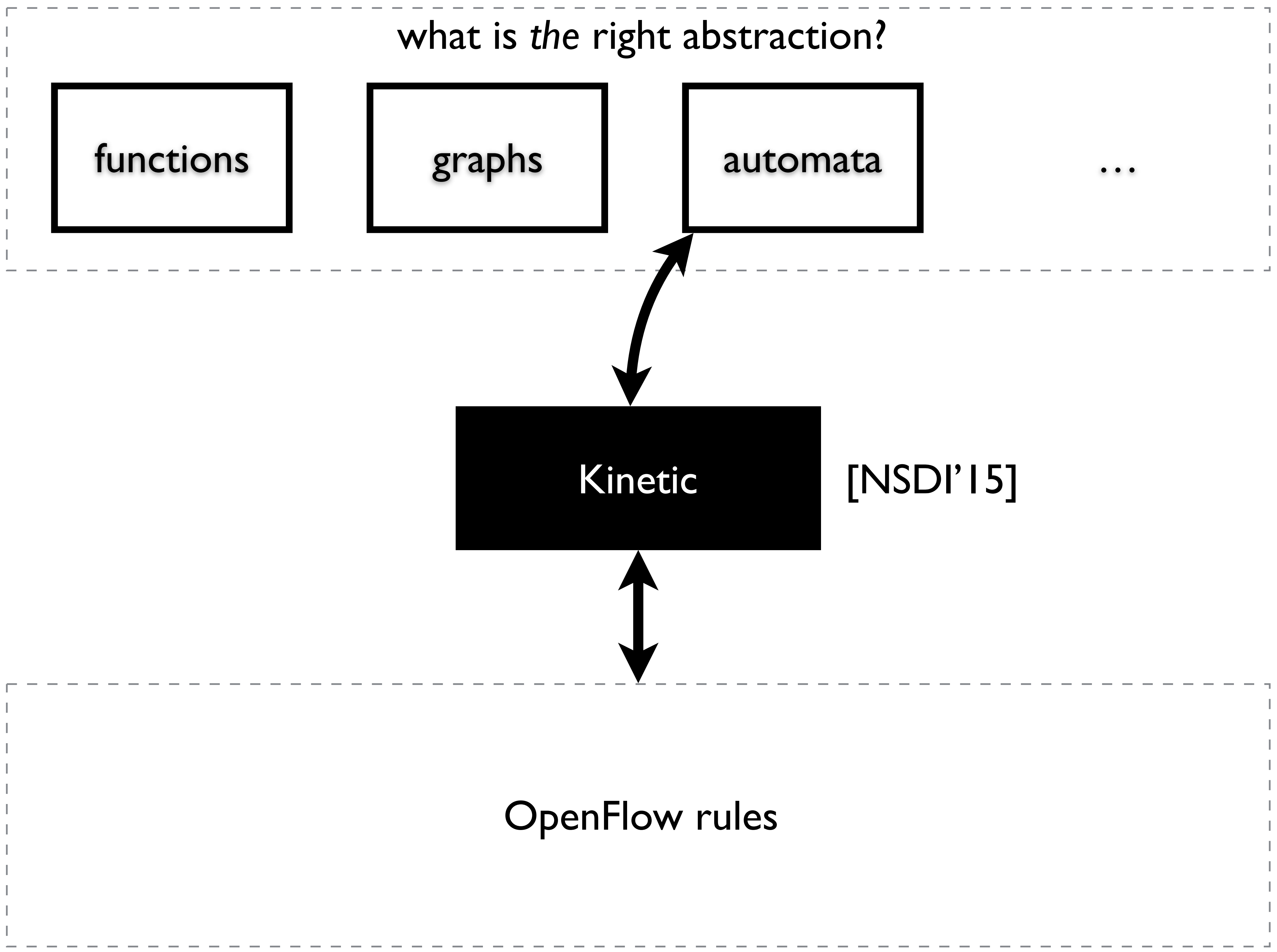
# abstractions



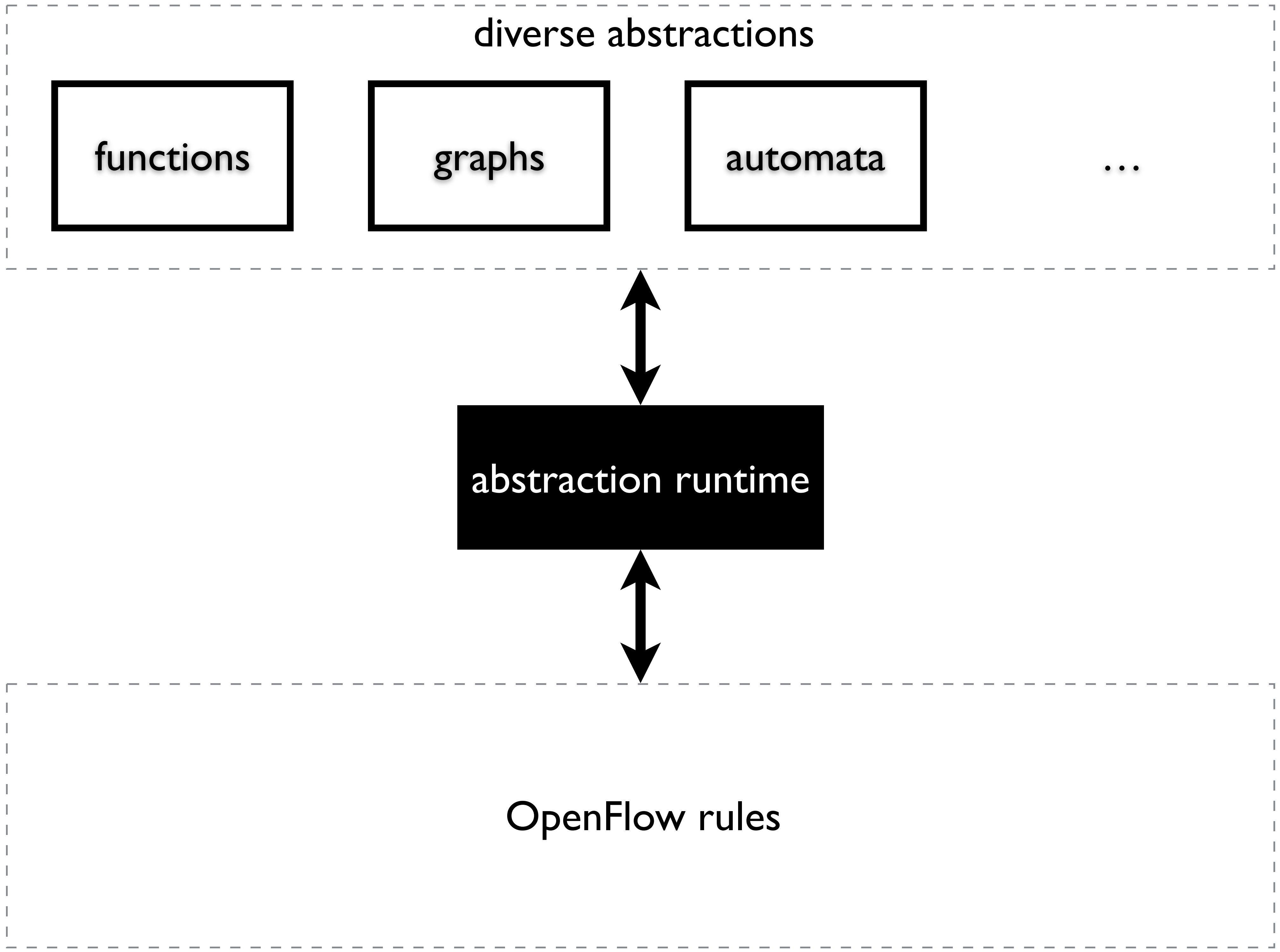
# abstractions



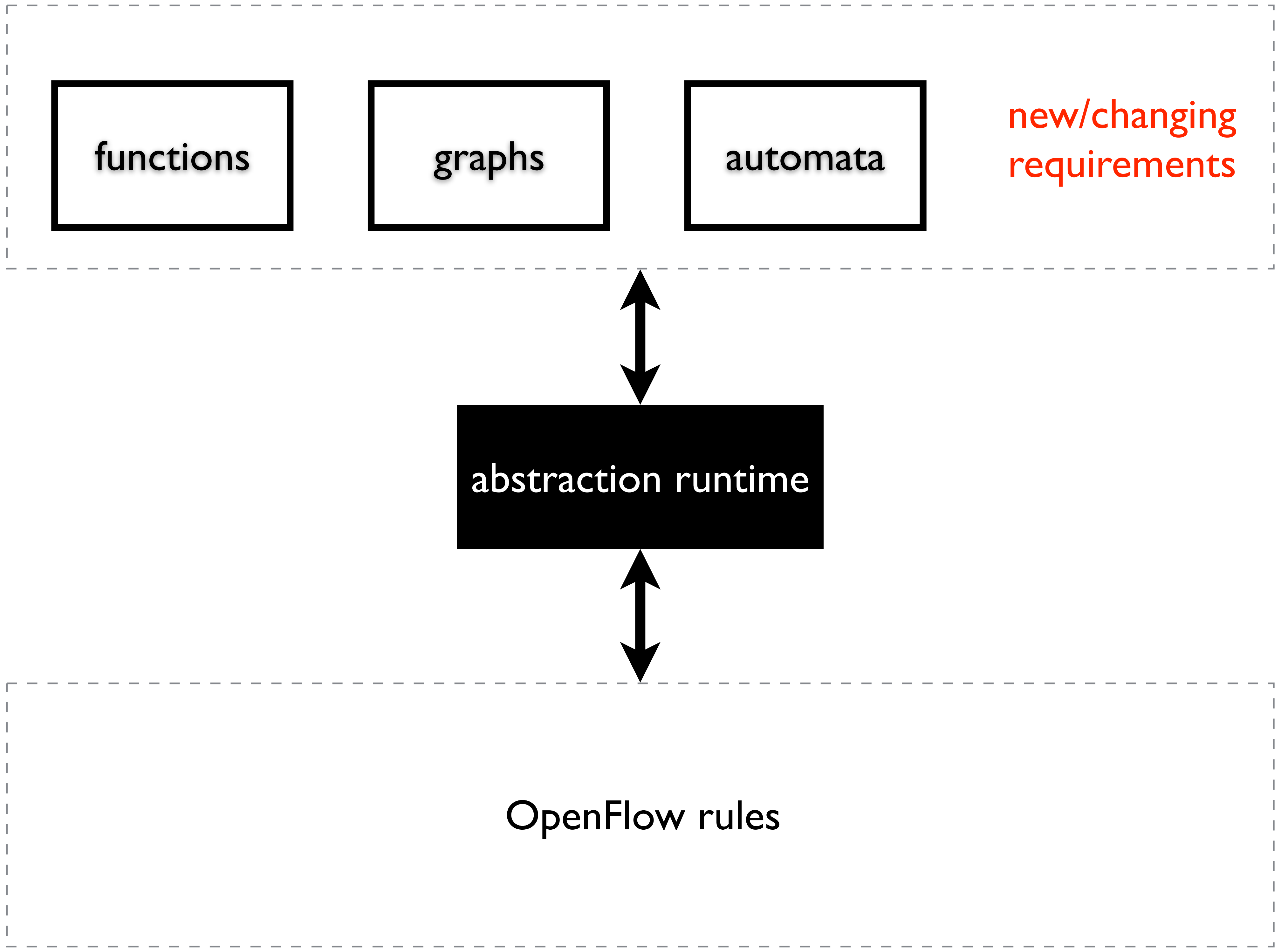
# abstractions



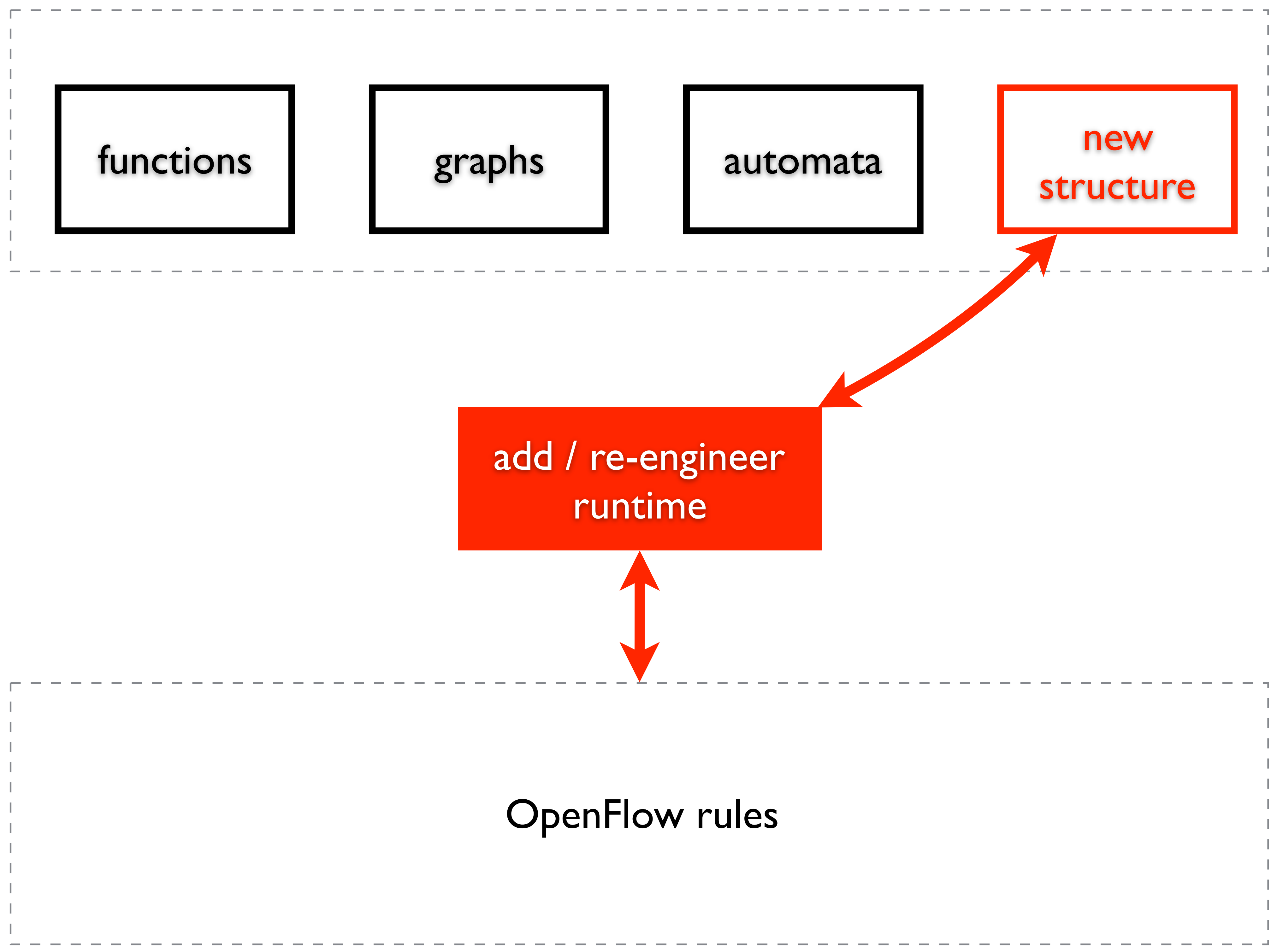
# abstractions



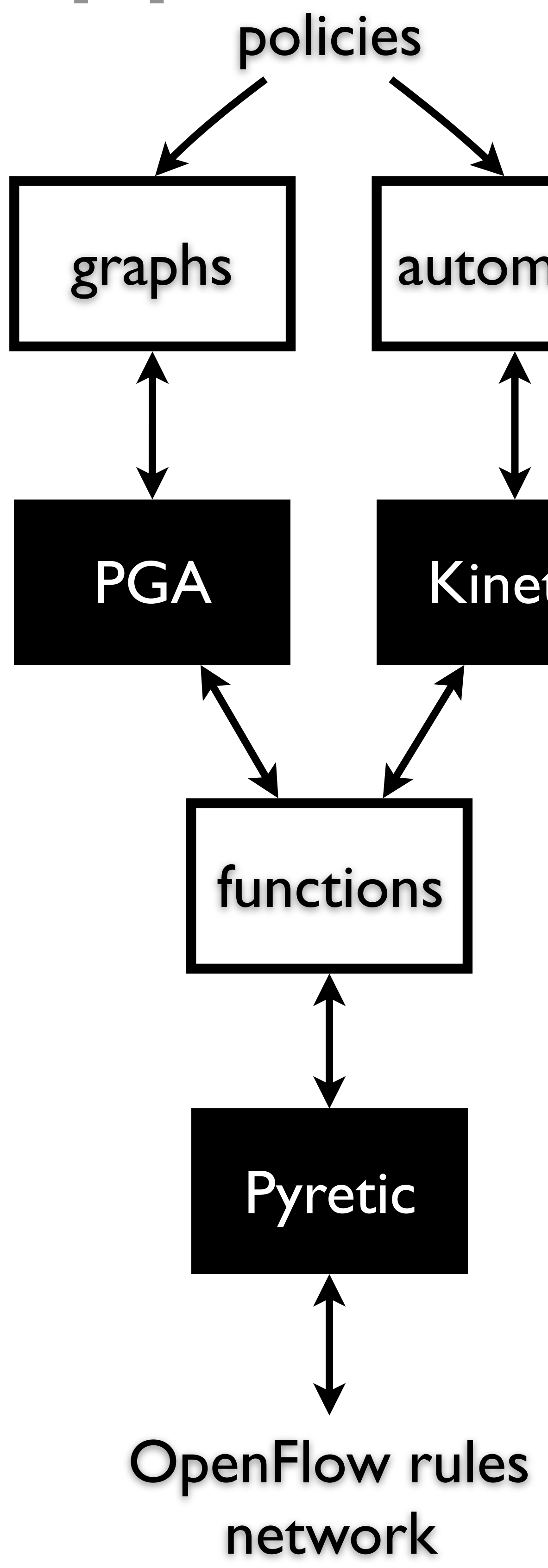
# but network keeps evolving



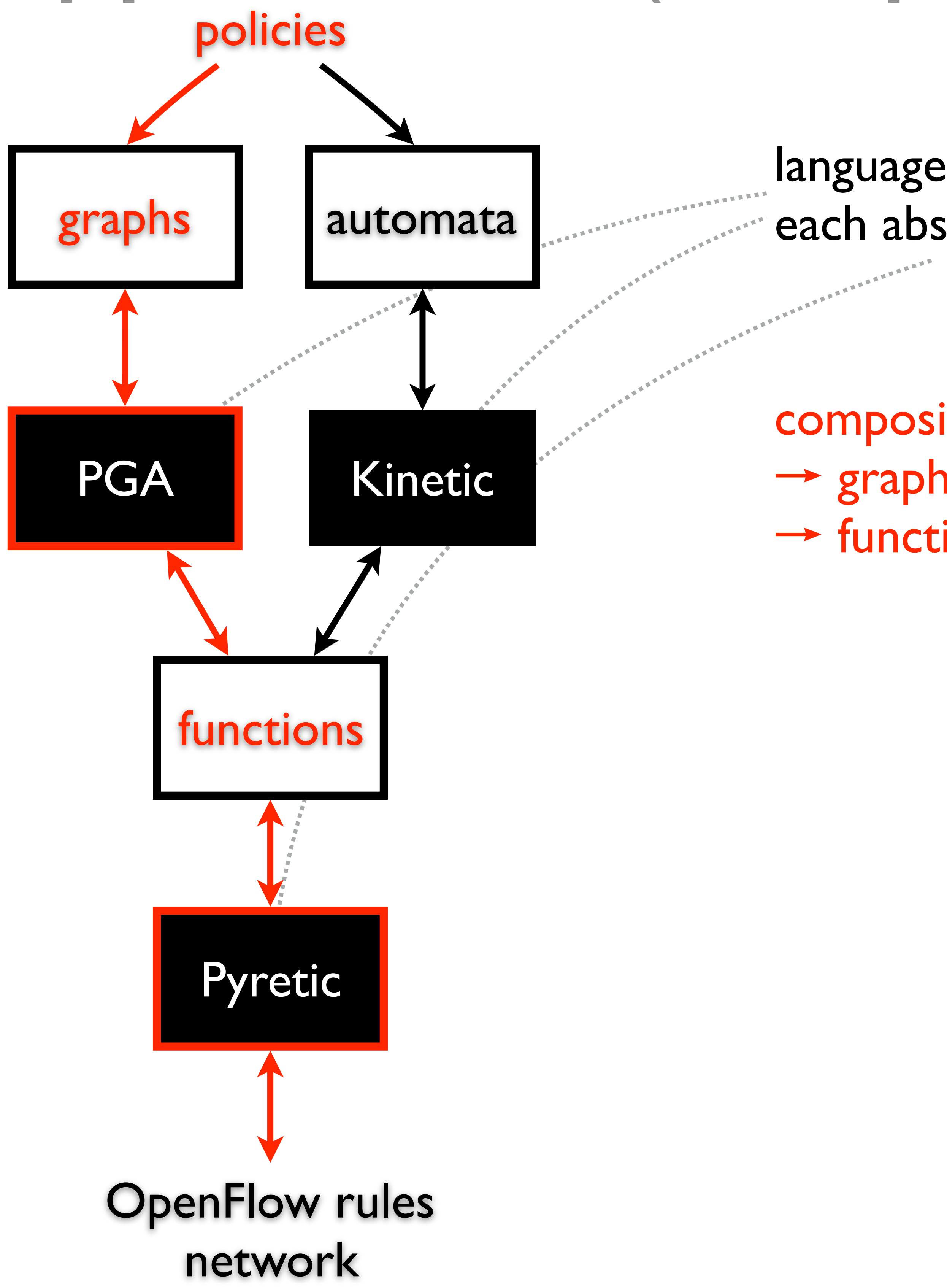
# but network keeps evolving



## and applications (components) interact



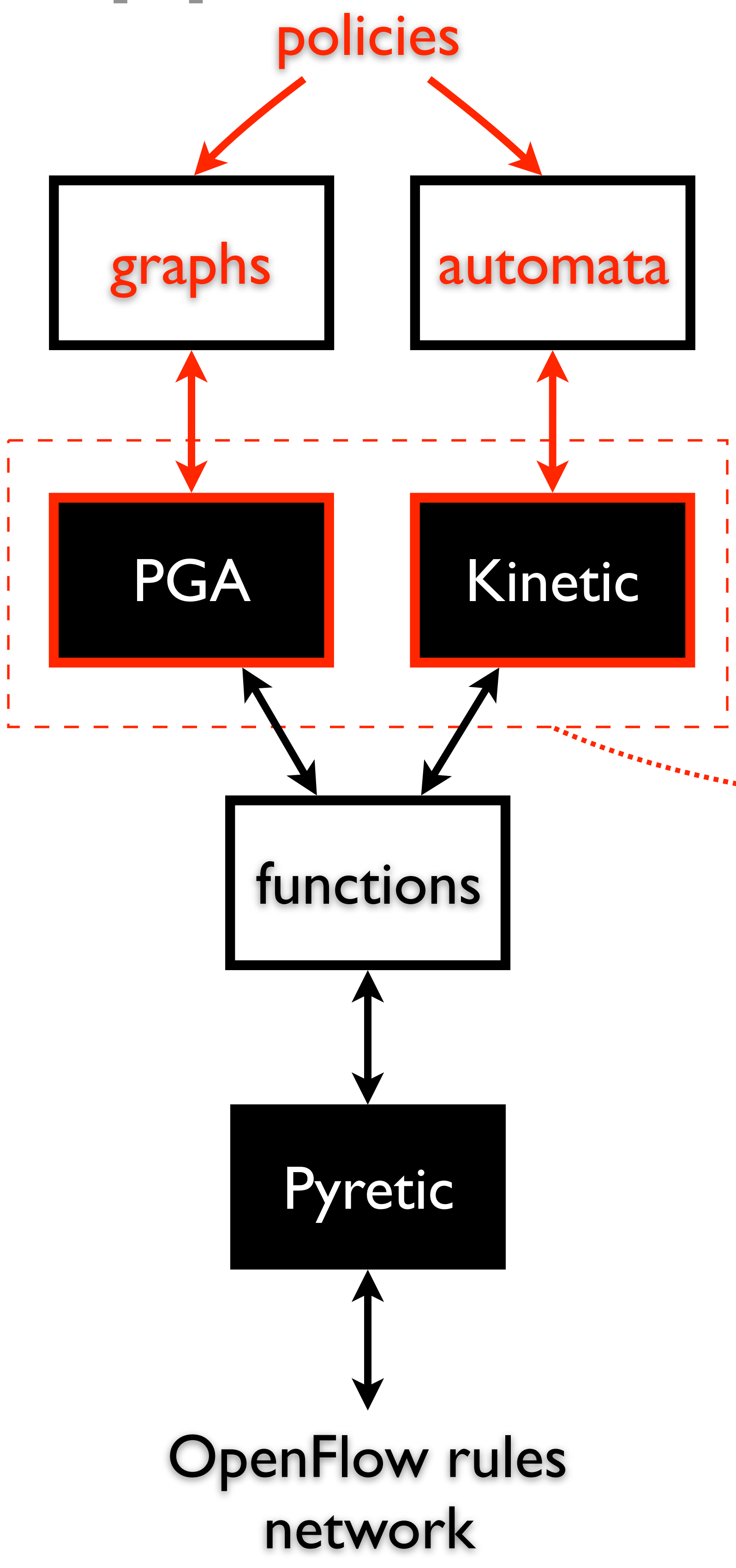
## and applications (components) interact



language-level orchestration restricted to each abstraction

composing (+) policy
→ graph $+_{\text{PGA}}$ graph
→ function $+_{\text{Pyretic}}$ function

# and applications (components) interact

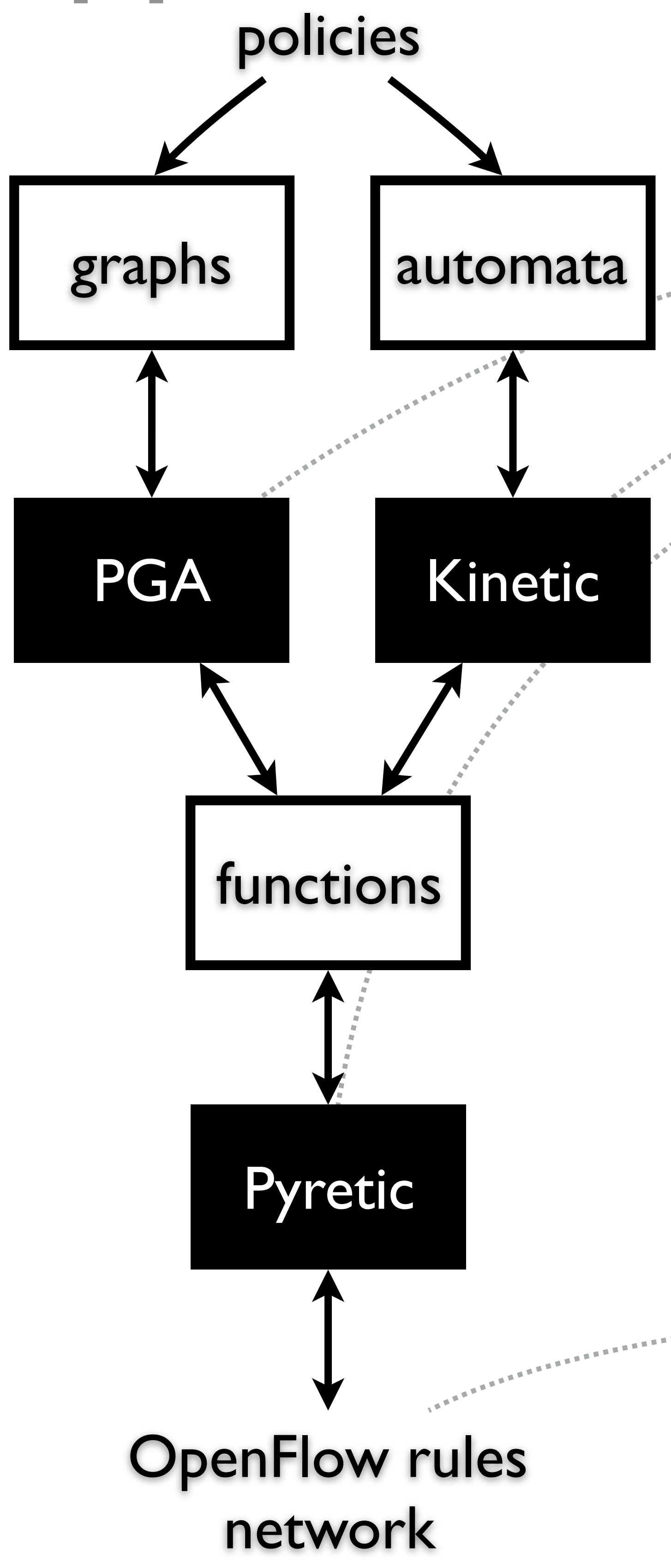


language-level orchestration restricted to each abstraction

composing (+) policy
→ graph $+_?$ automata

how to integrate the runtime?
hard-wire internals?

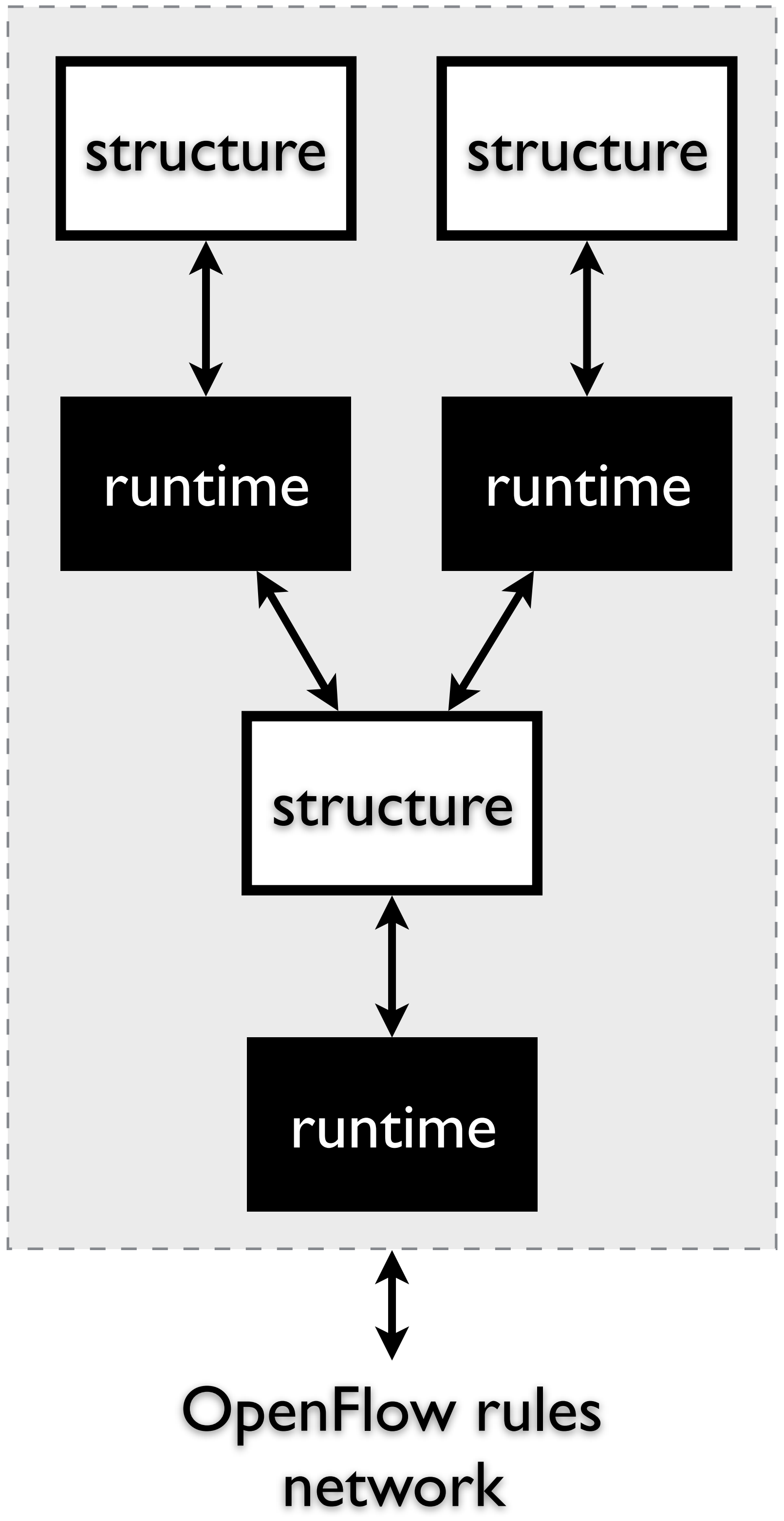
# and applications (components) interact



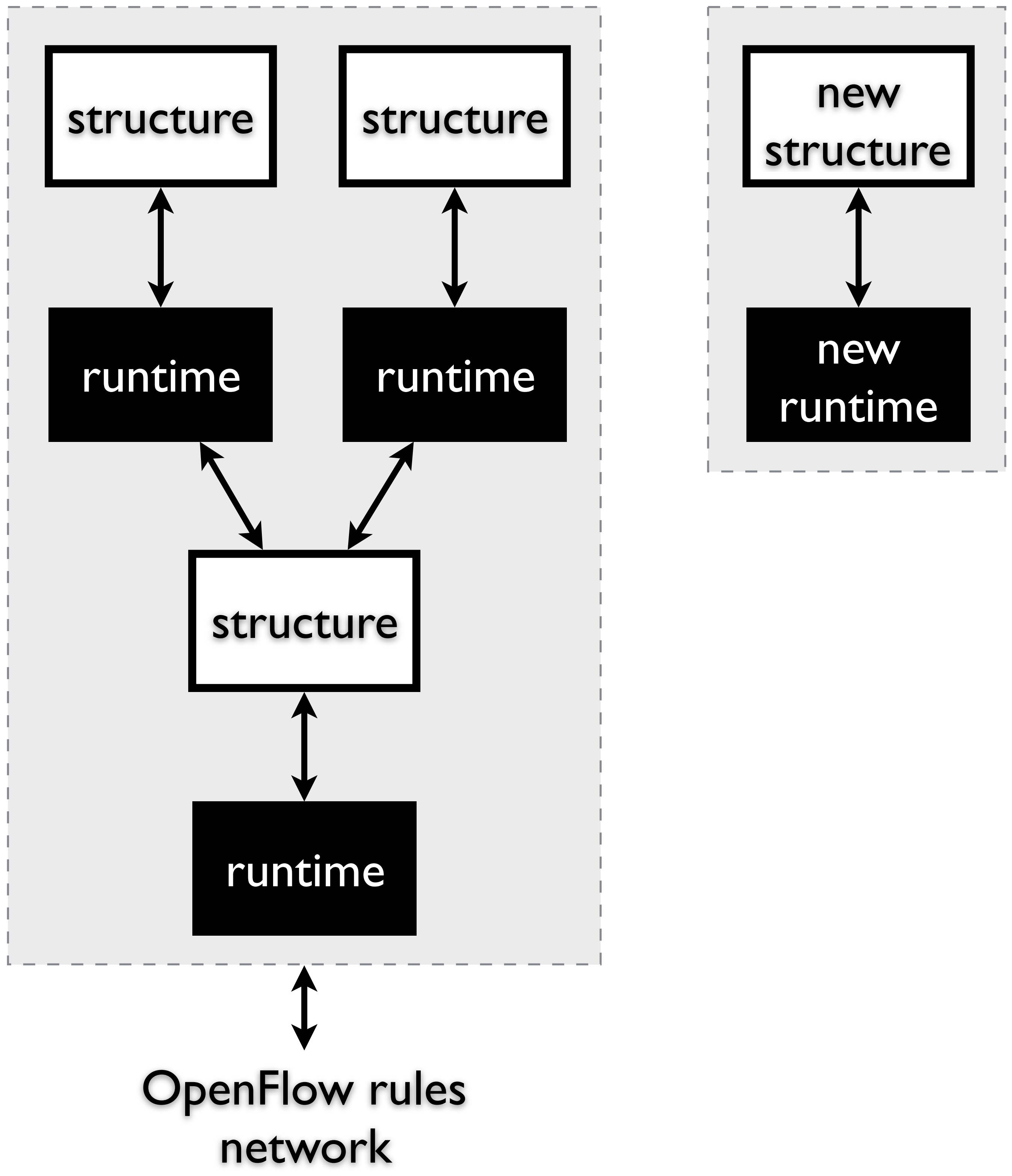
language-level orchestration restricted to each abstraction

abstraction-agonistic coordination often low-level
Co-visor [NSDI'15] statesman [SIGCOMM'14]

# current state of abstraction research

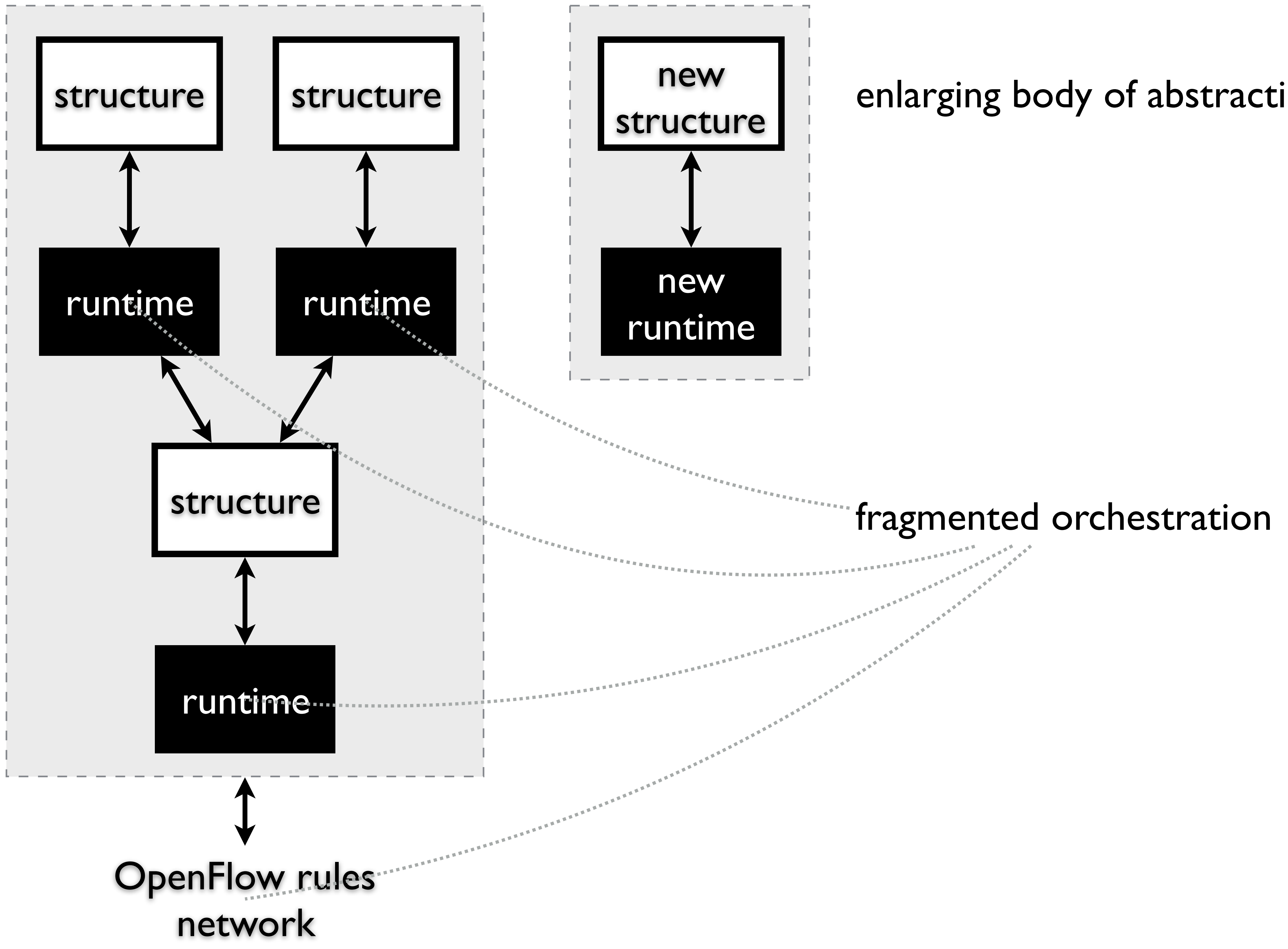


# current state of abstraction research



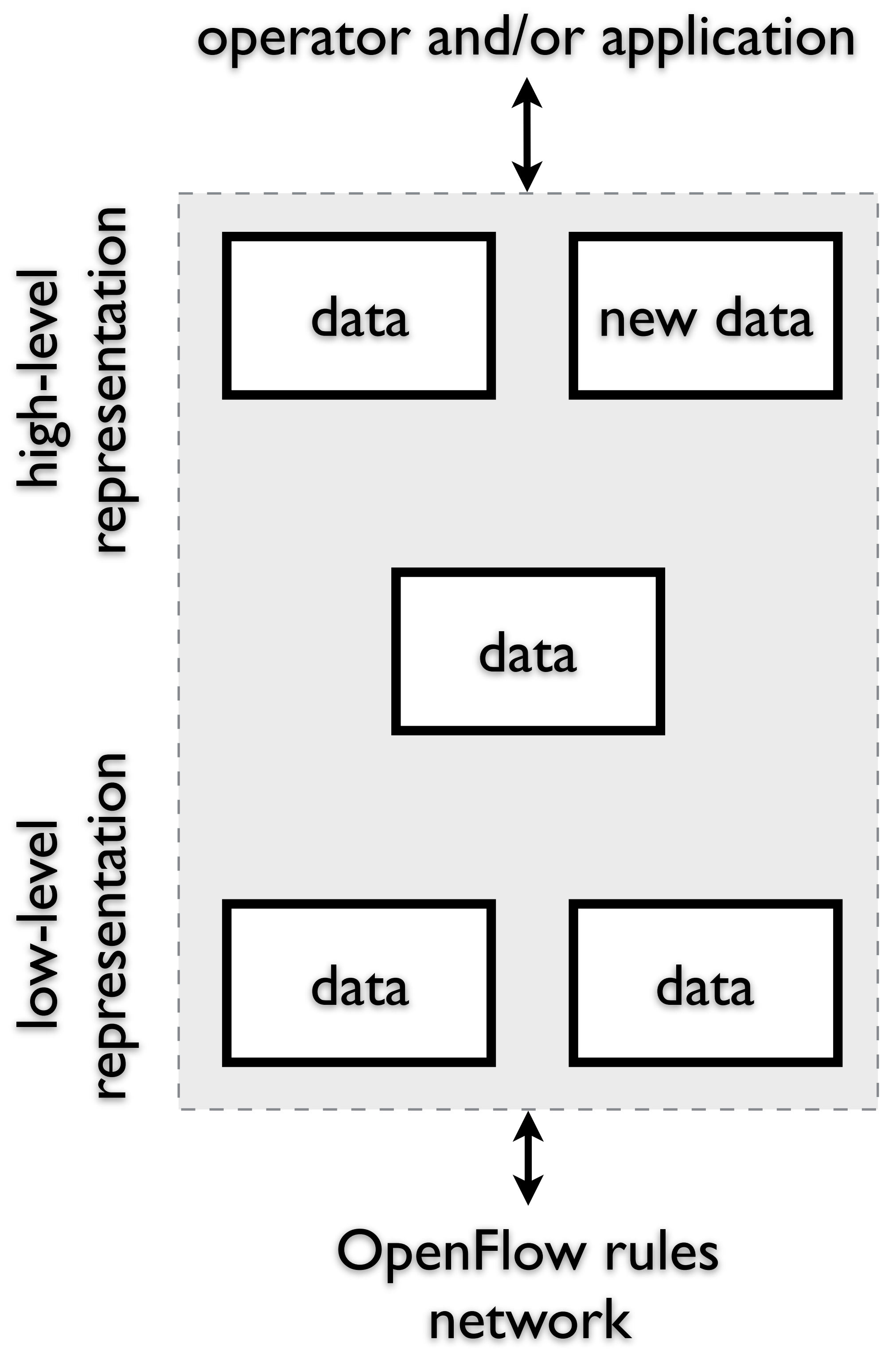
enlarging body of abstractions

# current state of abstraction research



enlarging body of abstractions

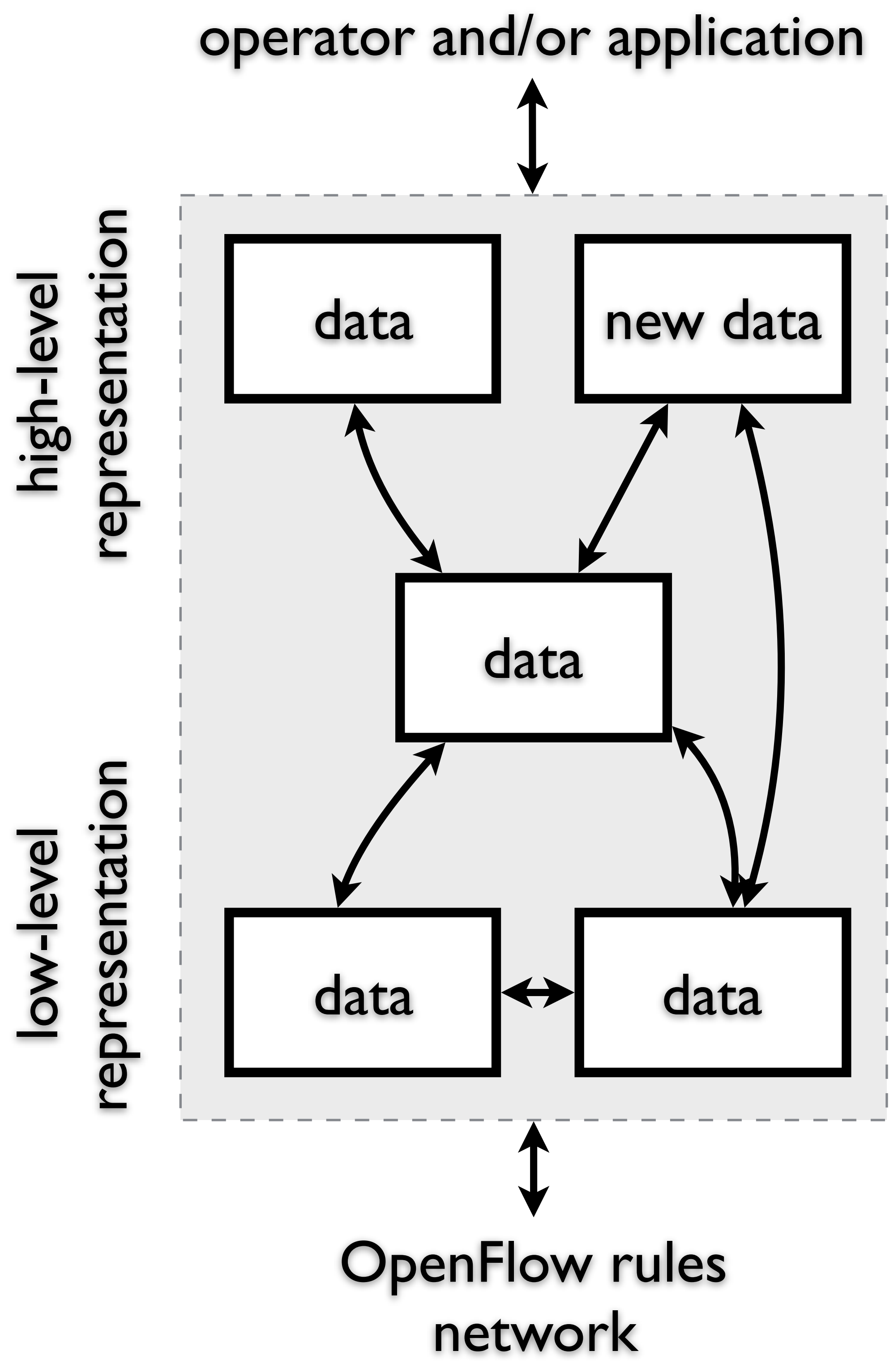
# our perspective



SDN control revolves around data representation

- discard specialized, pre-compiled, fixed structures
- adopt a *plain data representation*

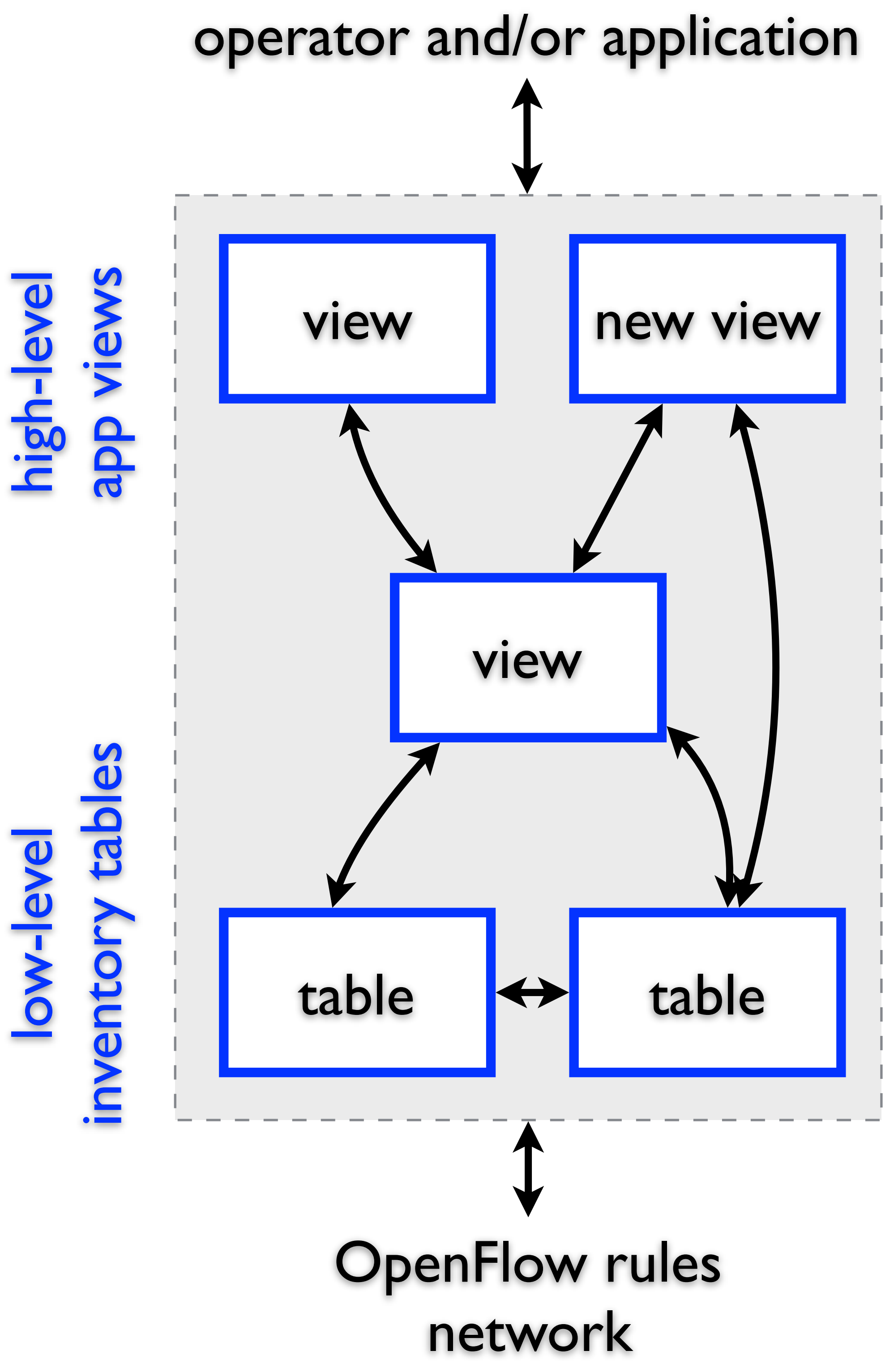
# our perspective



SDN control revolves around data representation

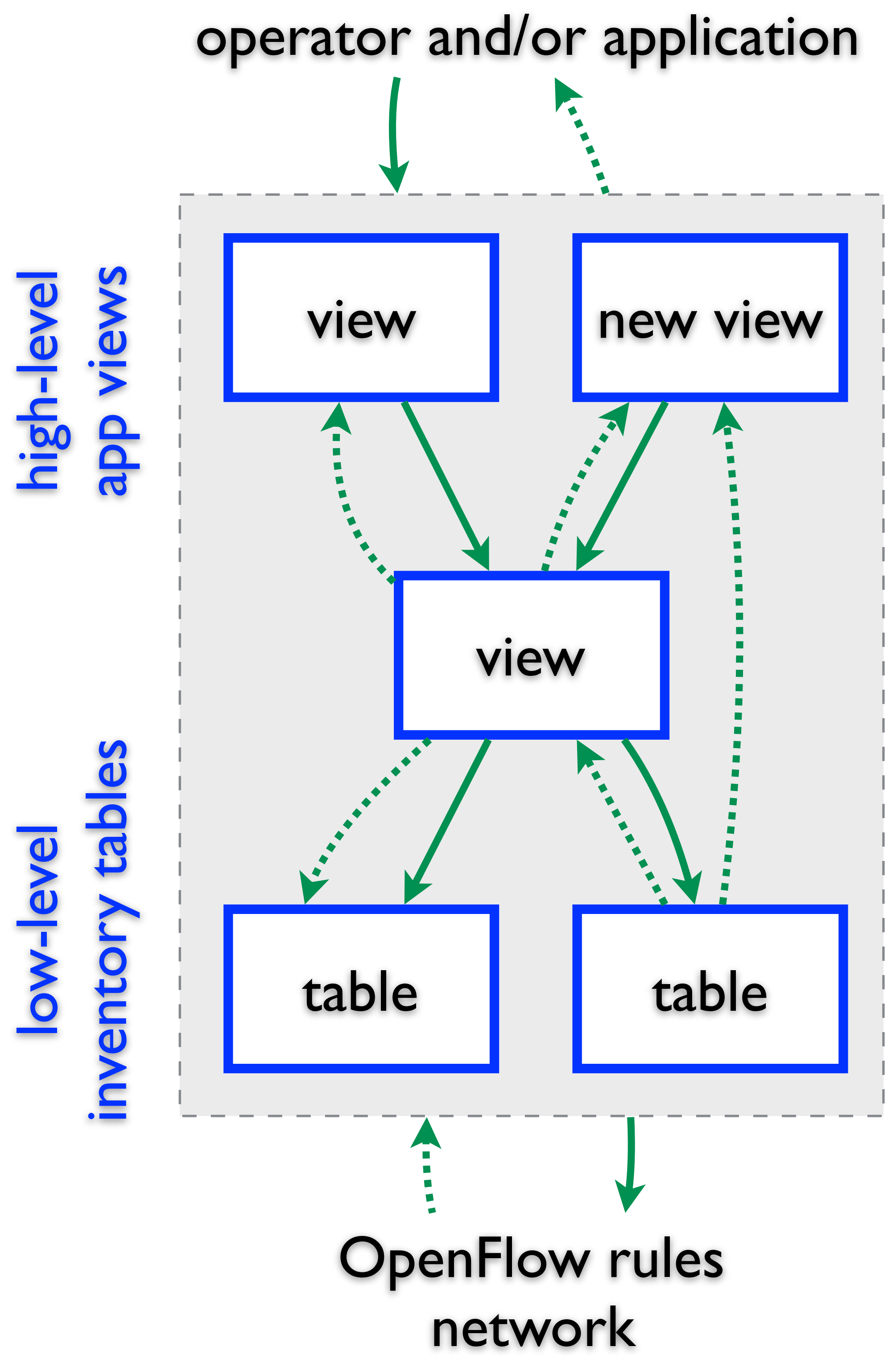
- discard specialized, pre-compiled, fixed structures
- adopt a *plain data representation*
- use a *universal data language*

# a database-defined network



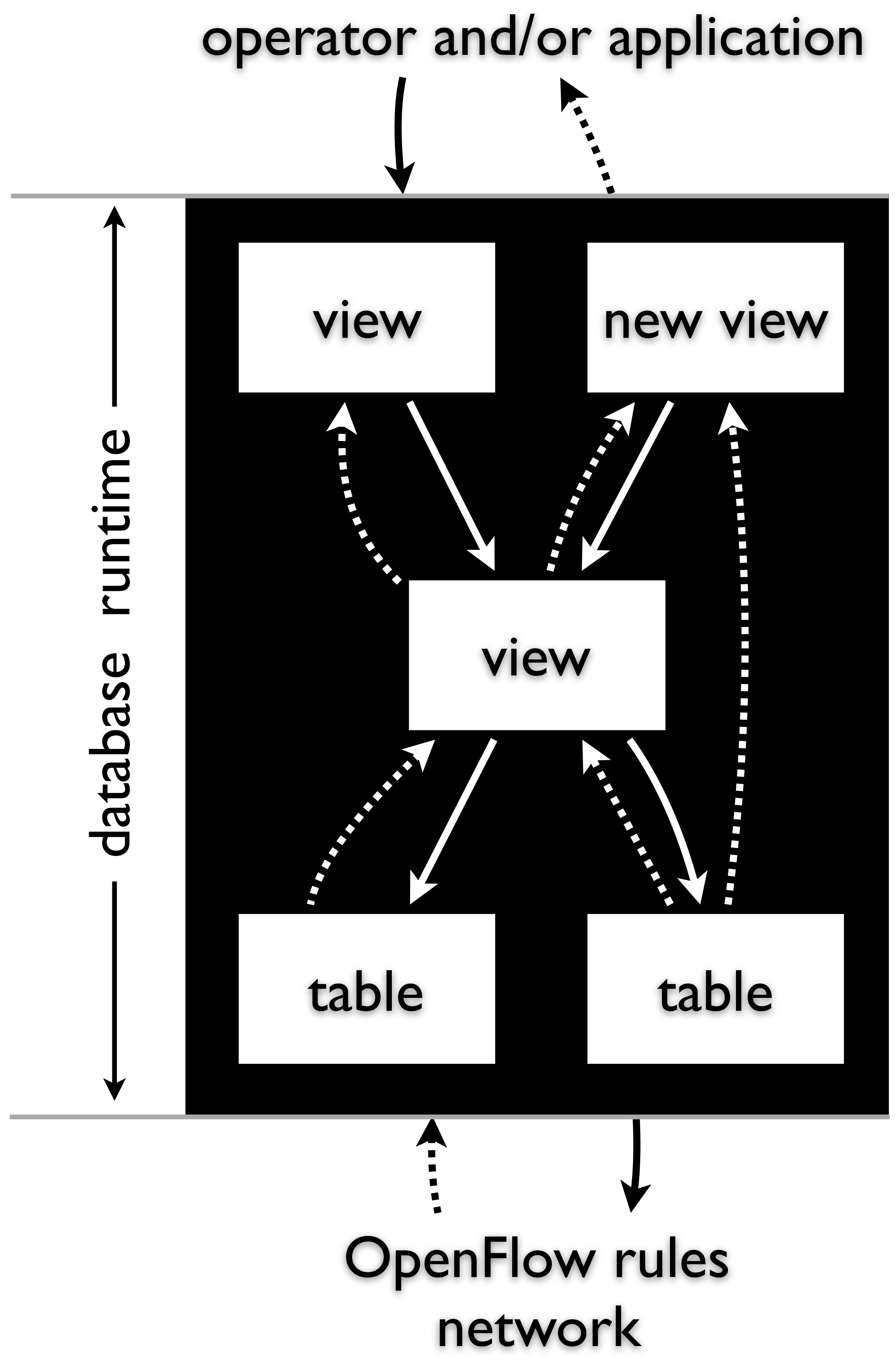
- relation — the plain data representation
  - table — stored relation
  - view — virtual relation

# a database-defined network



- relation — the plain data representation
  - table — stored relation
  - view — virtual relation
- SQL — the universal data language
  - query, update, trigger, rule

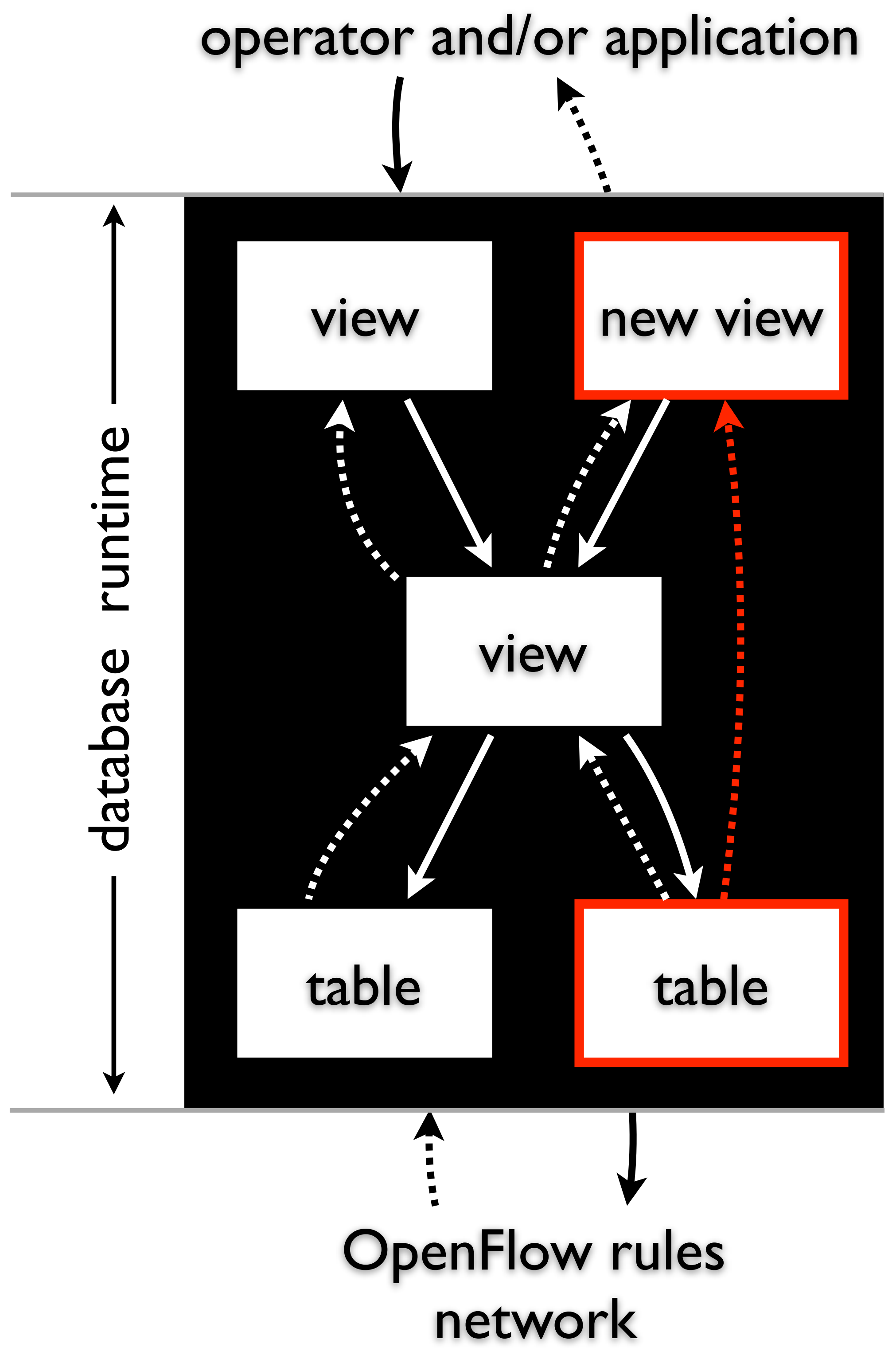
# *Ravel*: a realization with SQL database



## attractive features

- ad-hoc programmable abstraction via views
- orchestration across abstractions via view mechanism
- orchestration across applications via data mediation
- network control via SQL

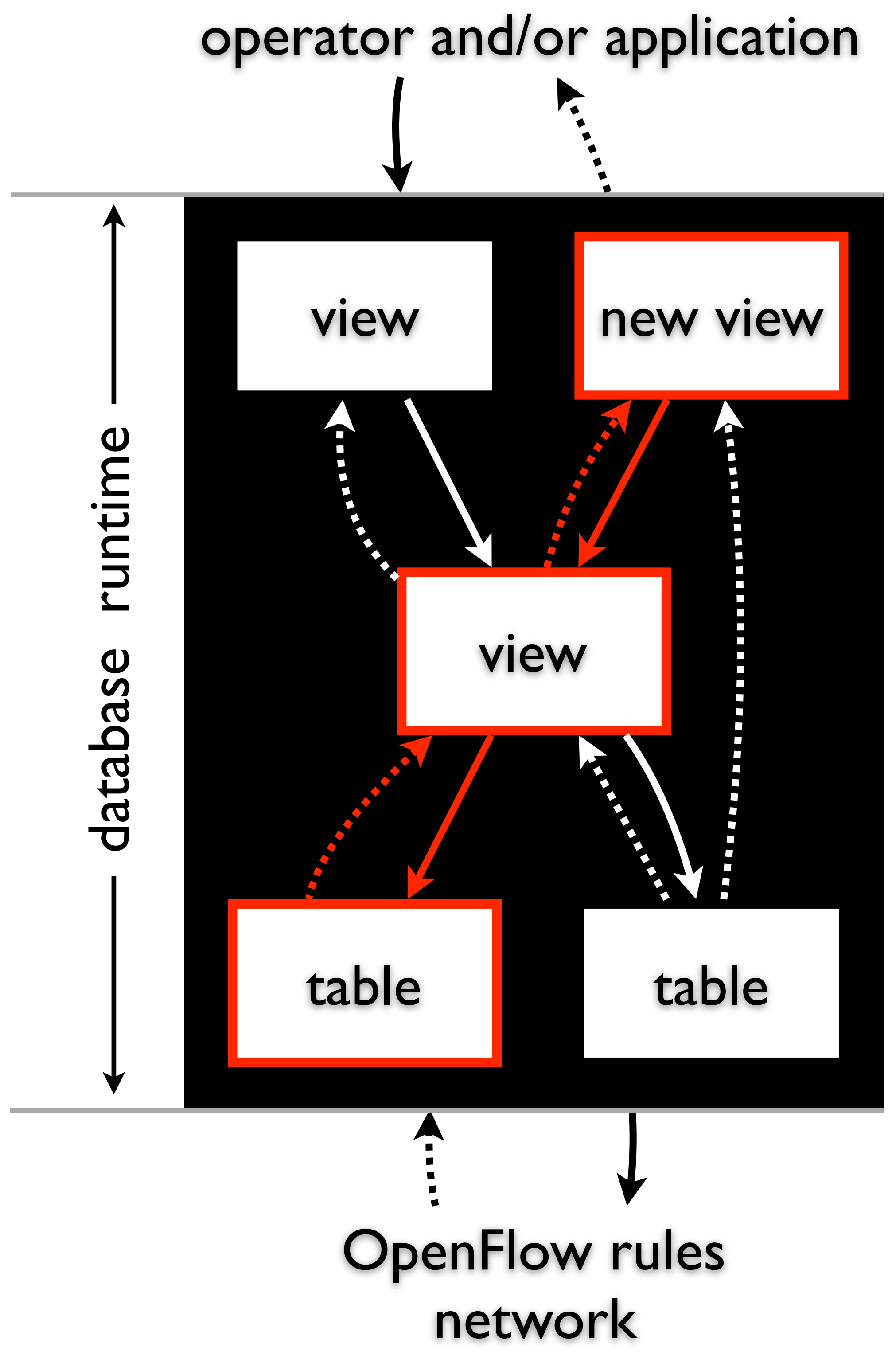
## *Ravel*: a realization with SQL database



attractive features

- ad-hoc programmable abstraction via views
- orchestration across abstractions via view mechanism
- orchestration across applications via data mediation
- network control via SQL

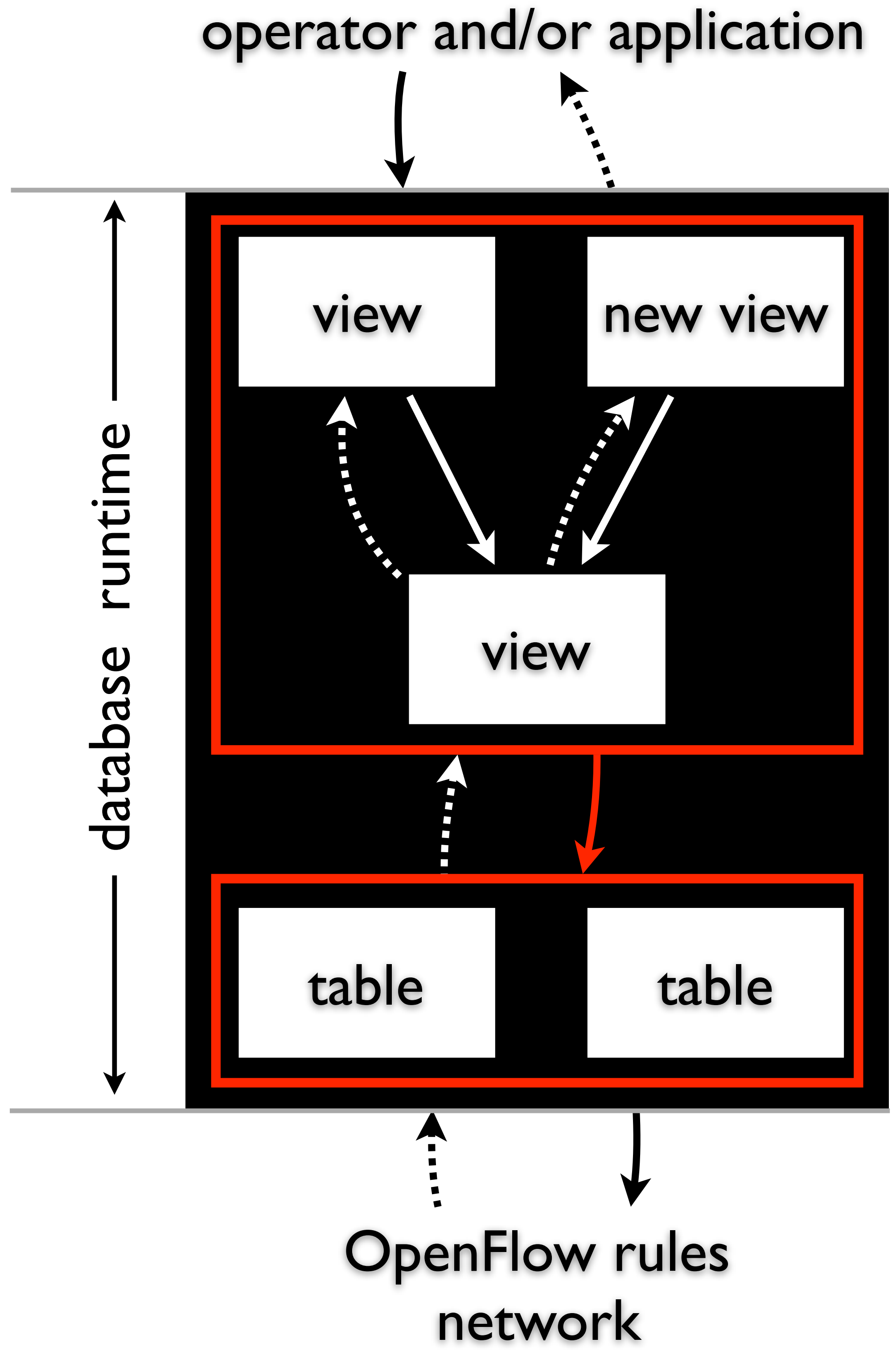
# *Ravel*: a realization with SQL database



attractive features

- ad-hoc programmable abstraction via views
- orchestration across abstractions via view mechanism
- orchestration across applications via data mediation
- network control via SQL

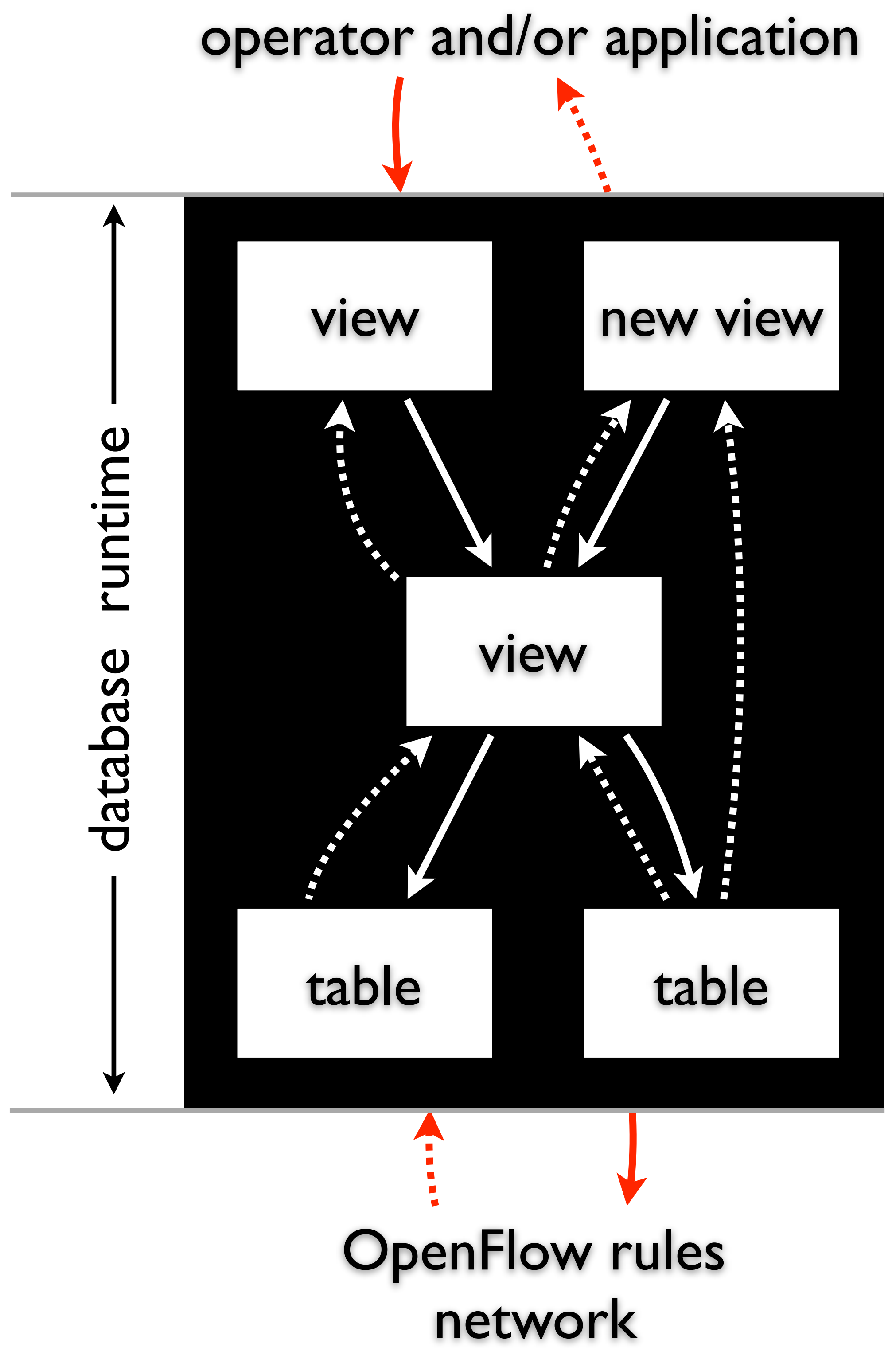
# *Ravel*: a realization with SQL database



## attractive features

- ad-hoc programmable abstraction via views
- orchestration across abstractions via view mechanism
- orchestration across applications via data mediation
- network control via SQL

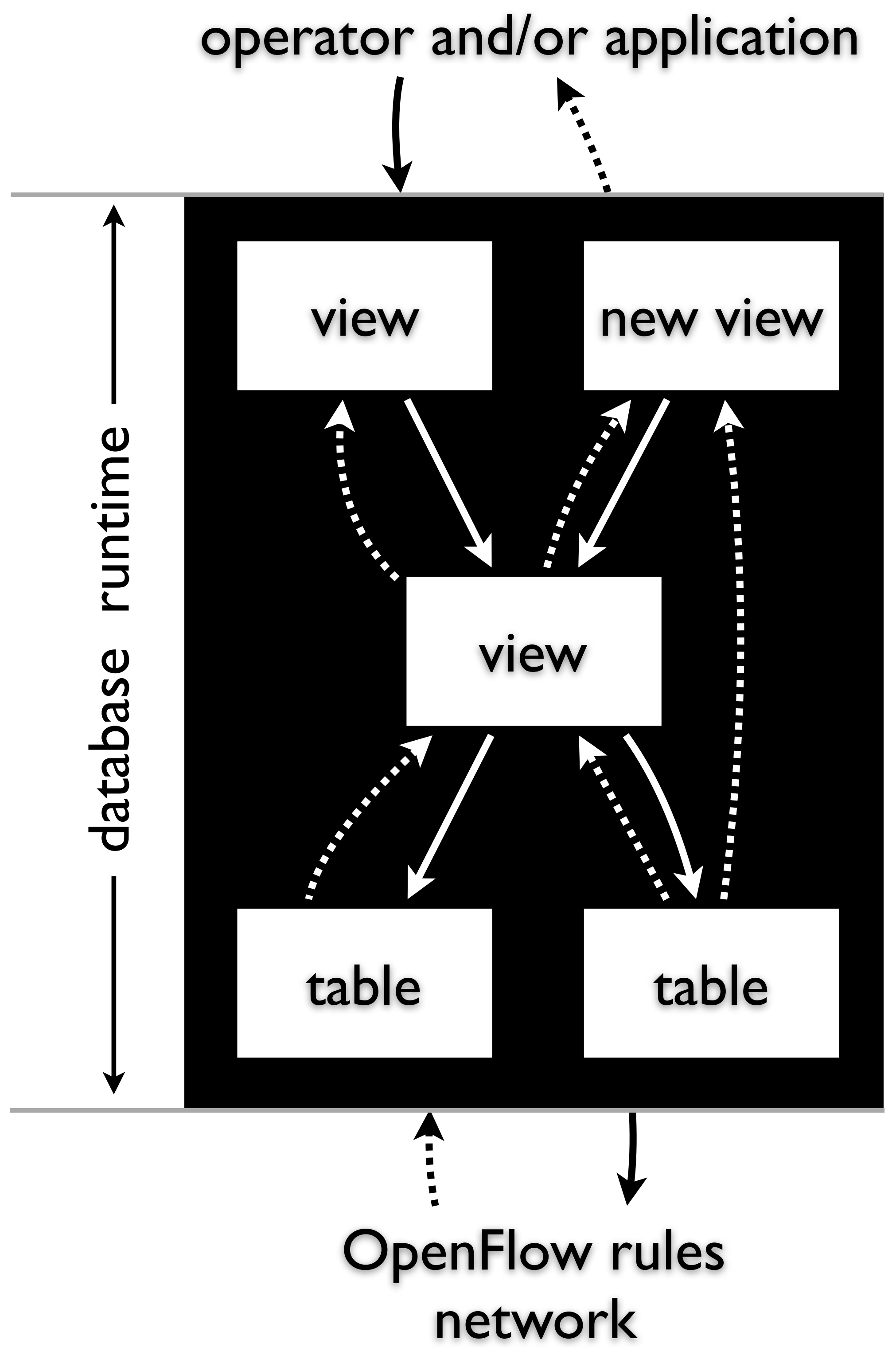
# *Ravel*: a realization with SQL database



## attractive features

- ad-hoc programmable abstraction via views
- orchestration across abstractions via view mechanism
- orchestration across applications via data mediation
- network control via SQL

# *Ravel*: a realization with SQL database



## attractive features

- abstraction
- orchestration
- SQL

# abstraction: network tables

reachability matrix

| fid | src | dst | vol | … |
|---|---|---|---|---|
| 1 | $h_1$ | $h_4$ | 5 | |
| 2 | $h_2$ | $h_3$ | 9 | |

…

topology

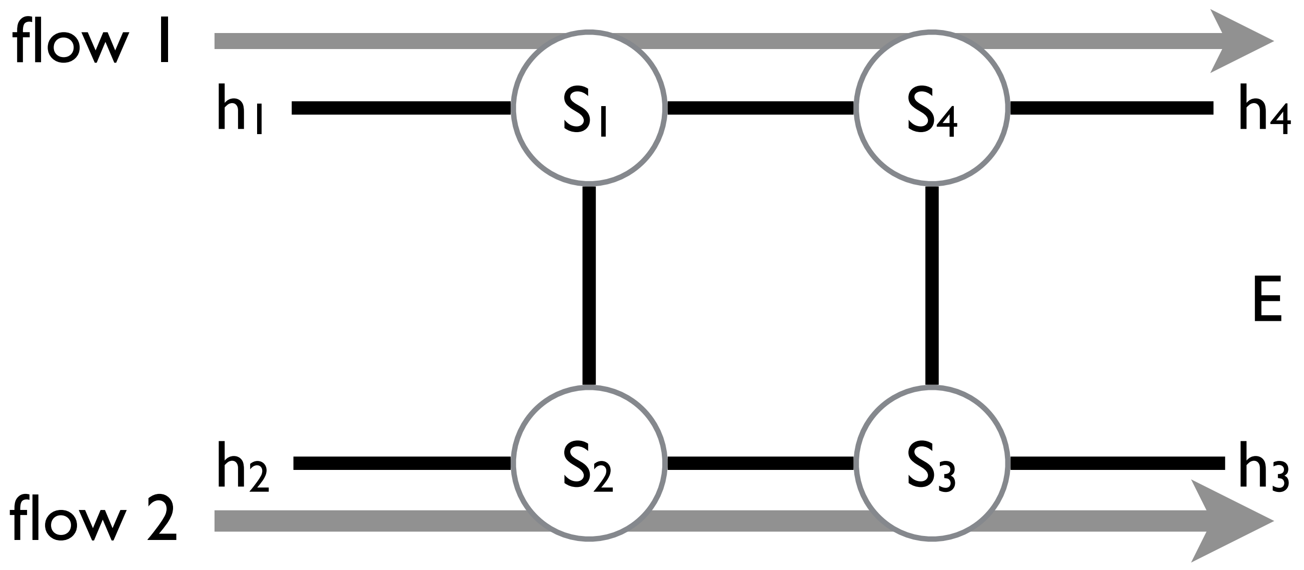
| sid | nid |
|---|---|
| $S_1$ | $S_2$ |
| $S_1$ | $S_3$ |
| $S_1$ | $h_1$ |

…

configuration

| fid | sid | nid |
|---|---|---|
| 1 | $S_1$ | $S_4$ |
| 1 | $S_4$ | $h_4$ |

…



## abstraction: application view

firewall view: monitoring unsafe flows violating acl policy

```
CREATE VIEW acl_violation AS (
   SELECT fid
   FROM rm
   WHERE FW = 1  AND
     (src, dst) NOT IN
     (SELECT end1, end2 FROM acl
                        WHERE allow = 1)
);
```

```
CREATE TABLE acl (
  end1 integer, end2 integer, allow integer
);
```

firewall control: repairing violation

```
CREATE RULE acl_repair AS
   ON DELETE TO acl_violation
   DO INSTEAD
         DELETE FROM rm WHERE fid = OLD.fid;
```

# abstraction: application view

firewall view: monitoring unsafe flows violating acl policy

```
CREATE VIEW acl_violation AS (
   SELECT fid
   FROM rm
   WHERE FW = 1  AND
     (src, dst) NOT IN
     (SELECT end1, end2 FROM acl
                        WHERE allow = 1)
);
```

```
CREATE TABLE acl (
  end1 integer, end2 integer, allow integer
);
```

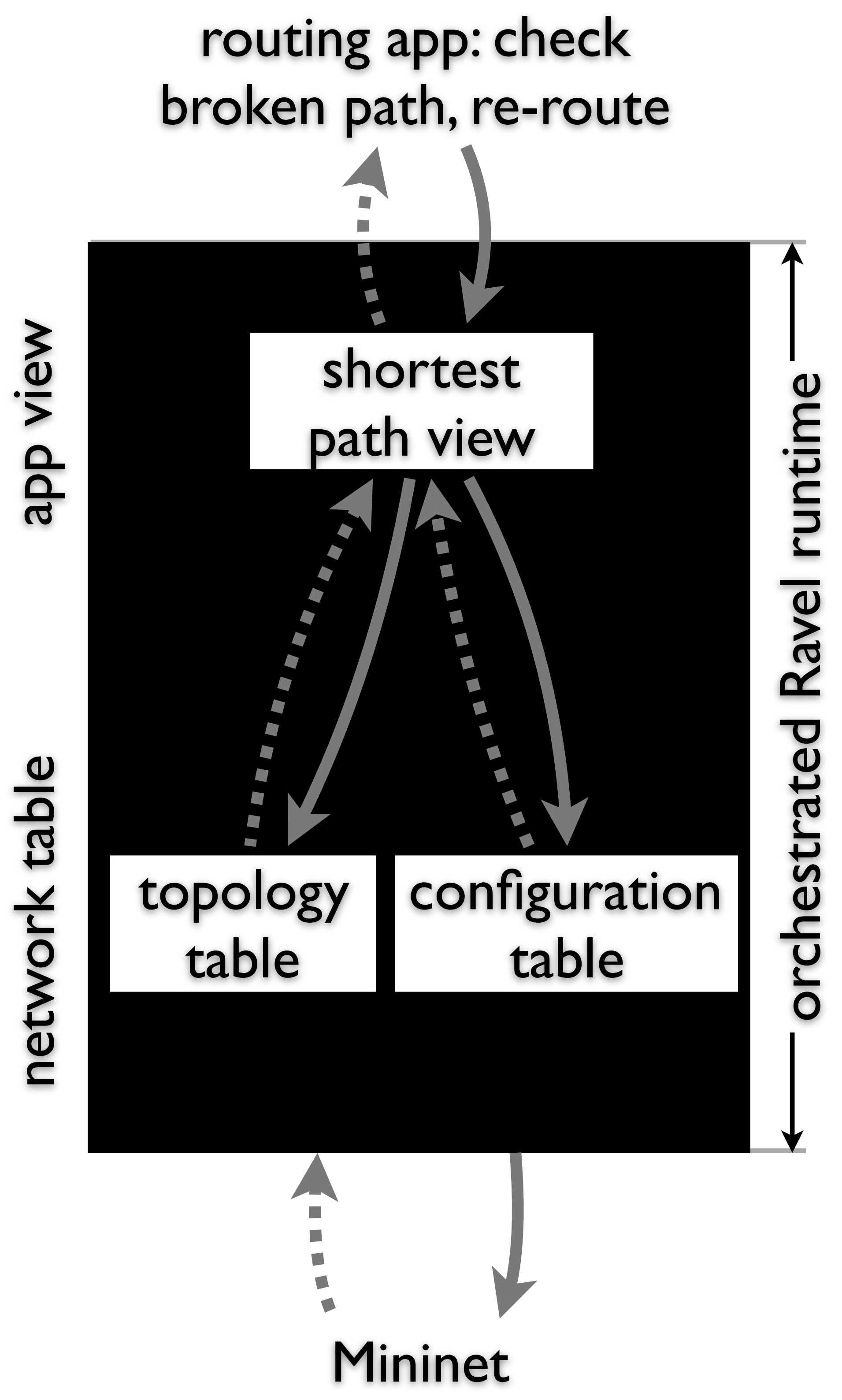
firewall control: repairing violation

```
CREATE RULE acl_repair AS
   ON DELETE TO acl_violation
   DO INSTEAD
         DELETE FROM rm WHERE fid = OLD.fid;
```

many more

- routing, stateful firewall, service chain policy between subdomains …

# orchestration across representations



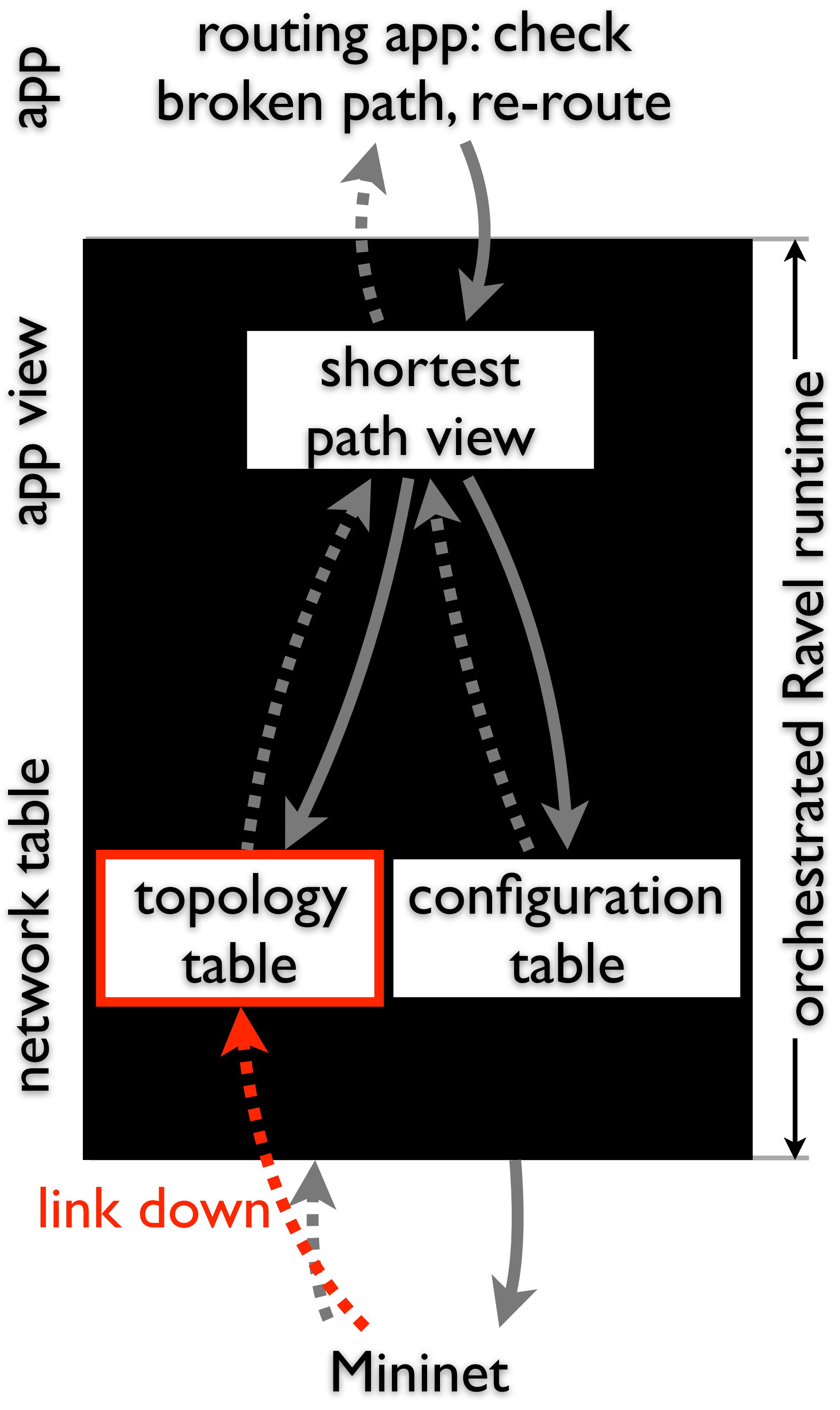
SQL rule:
upon broken path, re-route

| shortest path | |
|---|---|
| | |
| | |
| | |

| topology | | |
|---|---|---|
| | | |
| | | |
| | | |

| configuration | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

# orchestration across representations



SQL rule:
upon broken path, re-route

**shortest path**

| | |
|---|---|
| | |
| | |
| | |

**topology**

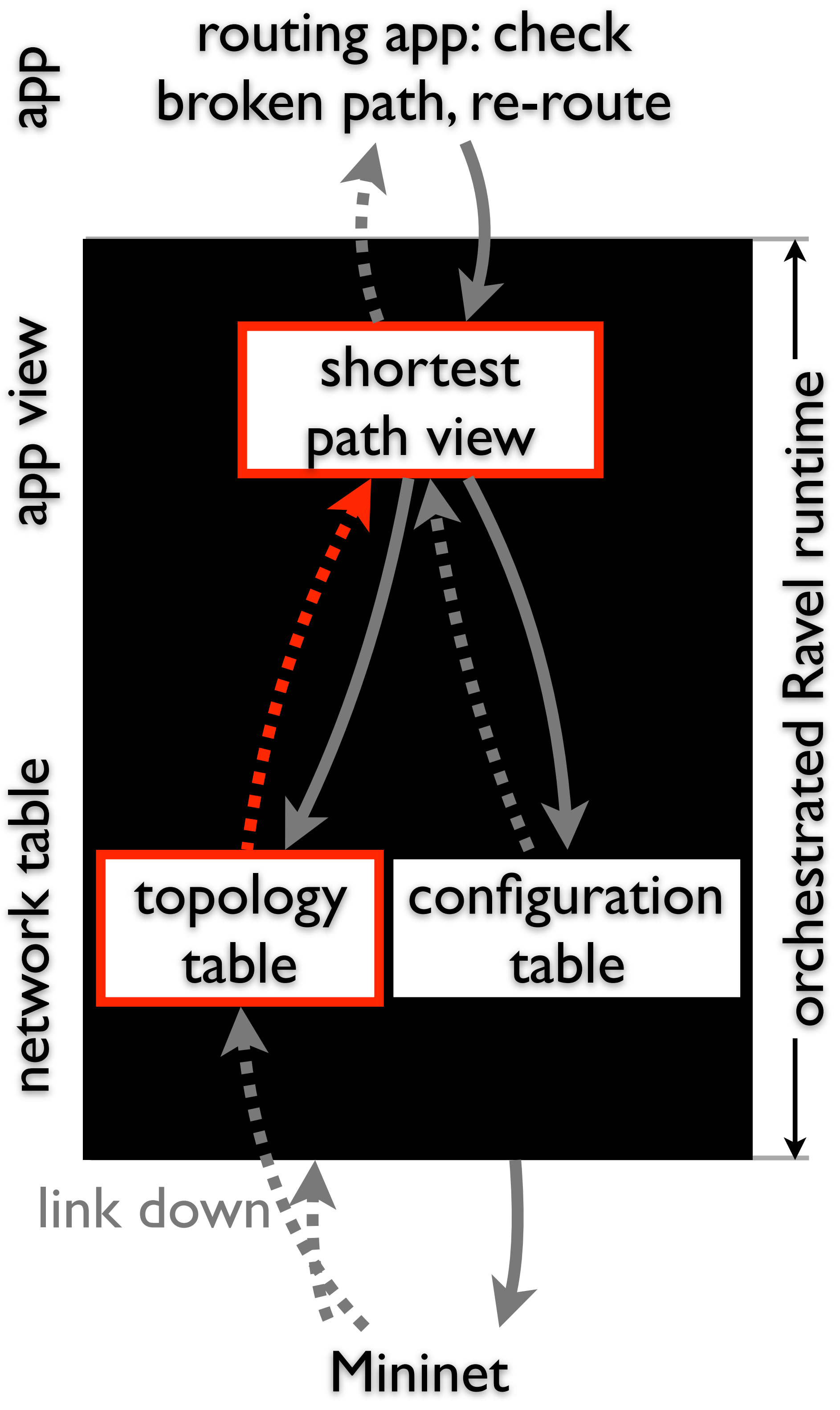
| | sid | nid | active |
|---|---|---|---|
| - | 172 | 39 | 1 |
| + | 172 | 39 | 0 |

Mininet link (172,39) down

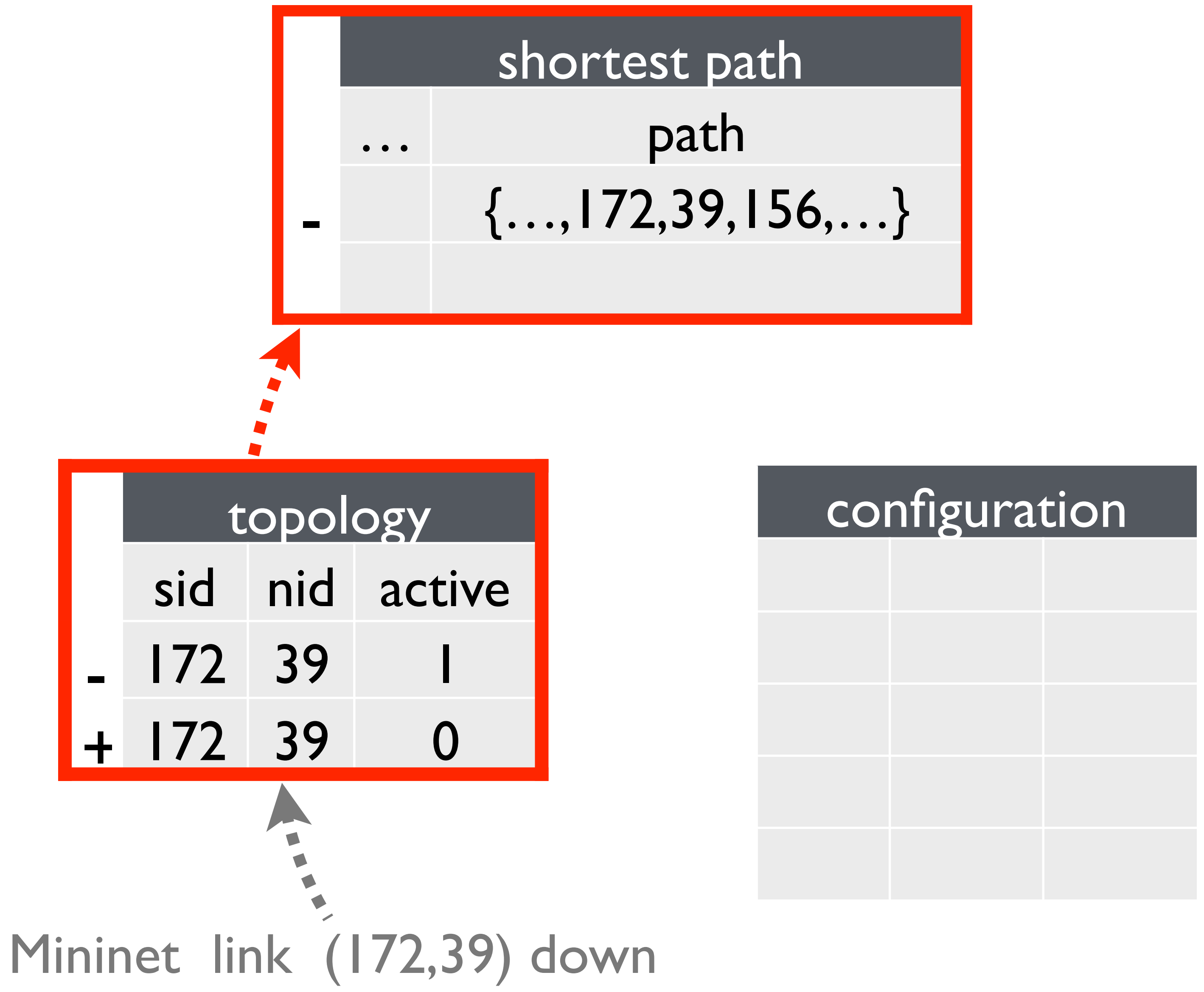
**configuration**

| | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

# orchestration across representations



SQL rule:
upon broken path, re-route



**shortest path**

| | ... | path |
|---|---|---|
| - | | {...,172,39,156,...} |
| | | |

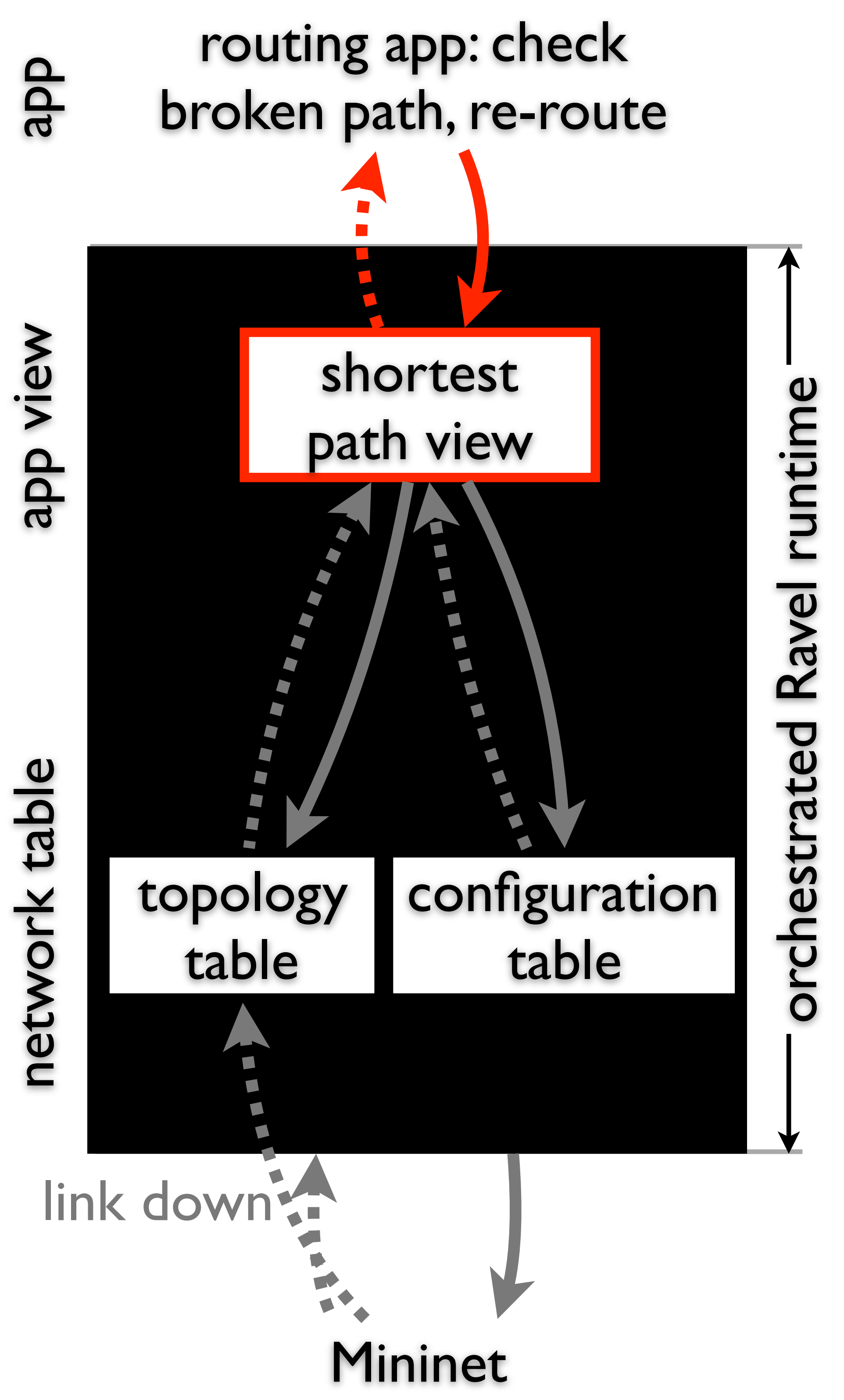
**topology**

| | sid | nid | active |
|---|---|---|---|
| - | 172 | 39 | 1 |
| + | 172 | 39 | 0 |

**configuration**

| | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

# orchestration across representations



SQL rule:
upon broken path, re-route

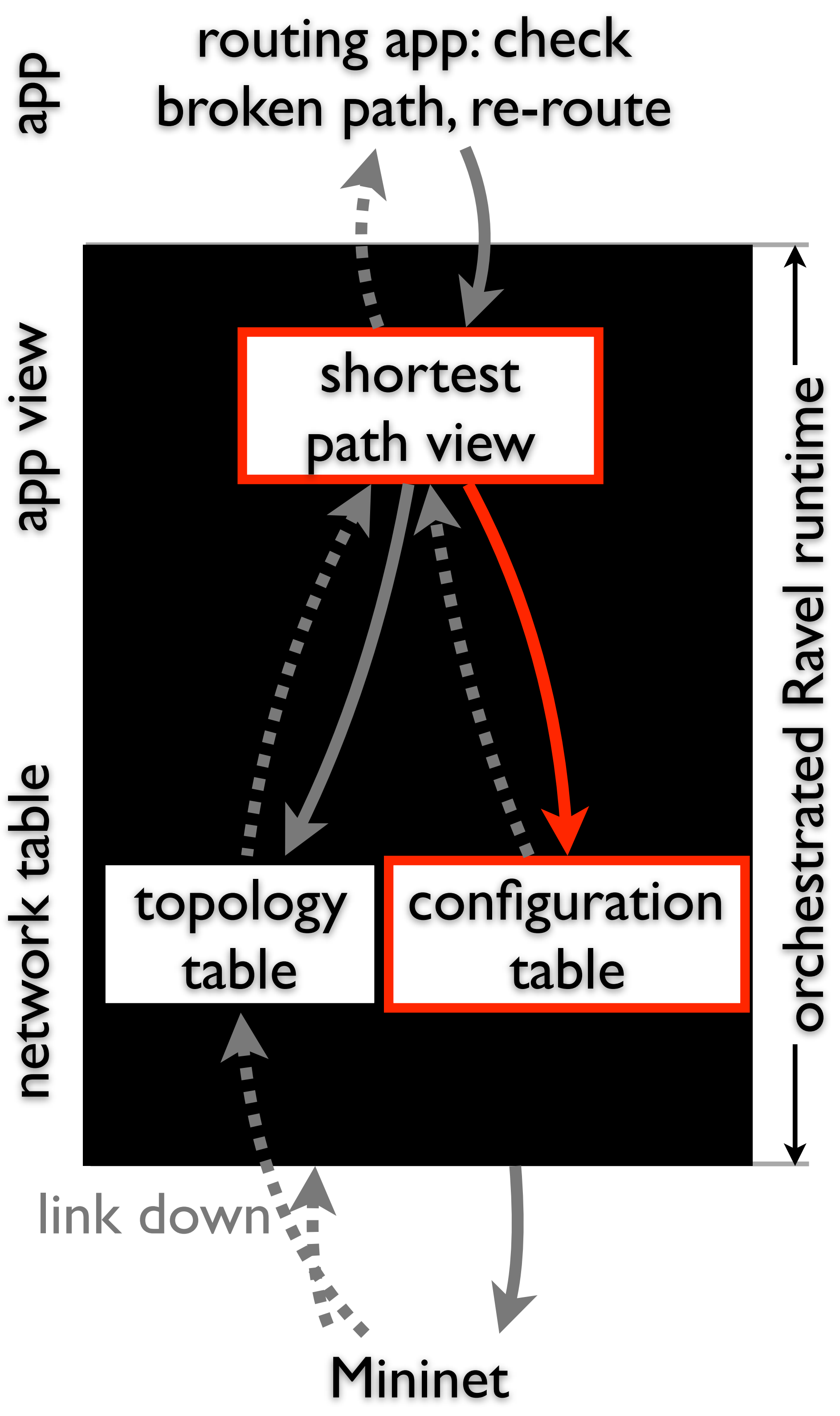
| | shortest path | |
|---|---|---|
| | … | path |
| - | | {…,172,39,156,…} |
| + | | {…,172,38,148,…} |

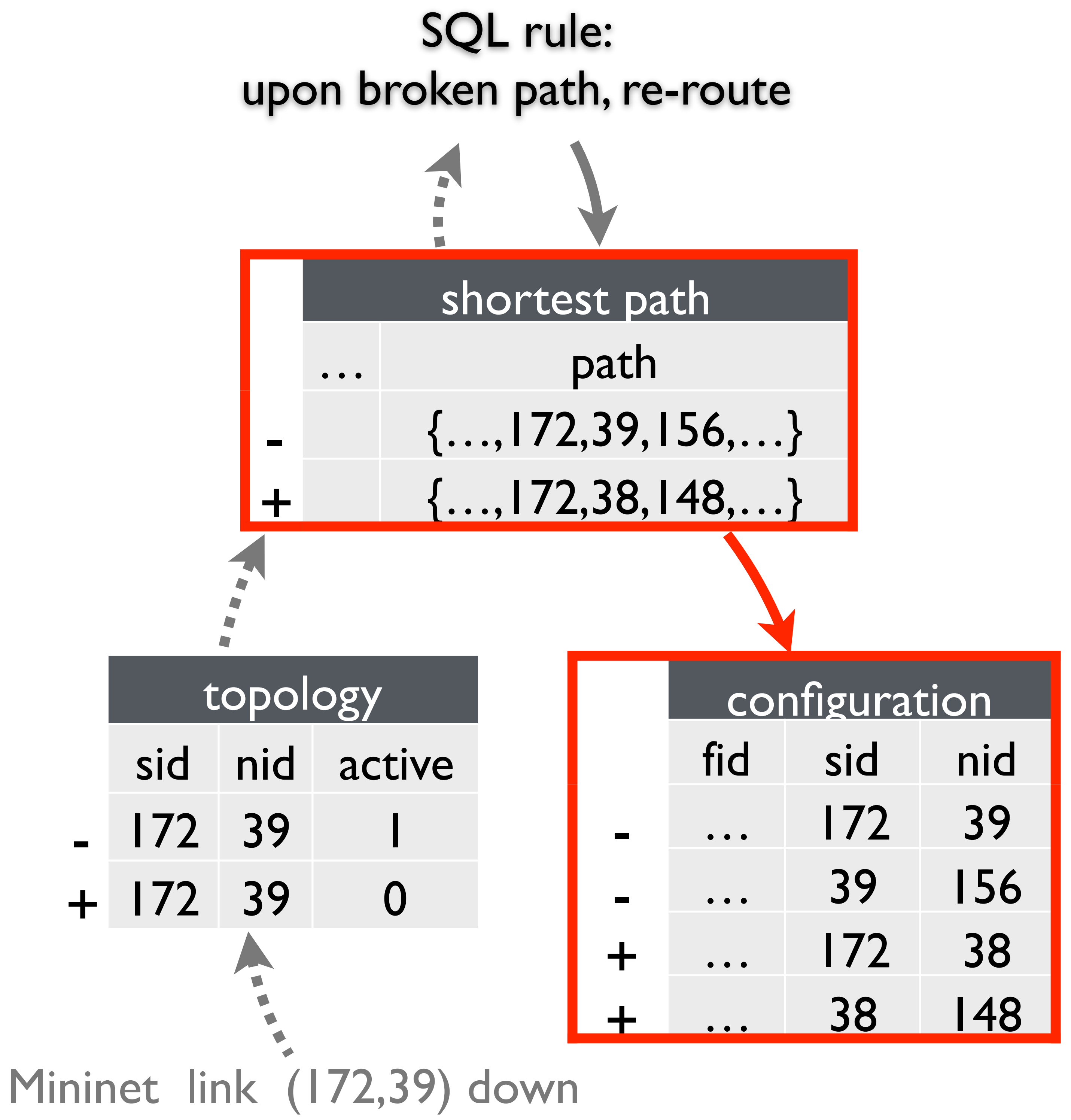
| | topology | | |
|---|---|---|---|
| | sid | nid | active |
| - | 172 | 39 | 1 |
| + | 172 | 39 | 0 |

| configuration | | |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

Mininet link (172,39) down

# orchestration across representations





shortest path

| | ... | path |
|---|---|---|
| - | | {...,172,39,156,...} |
| + | | {...,172,38,148,...} |

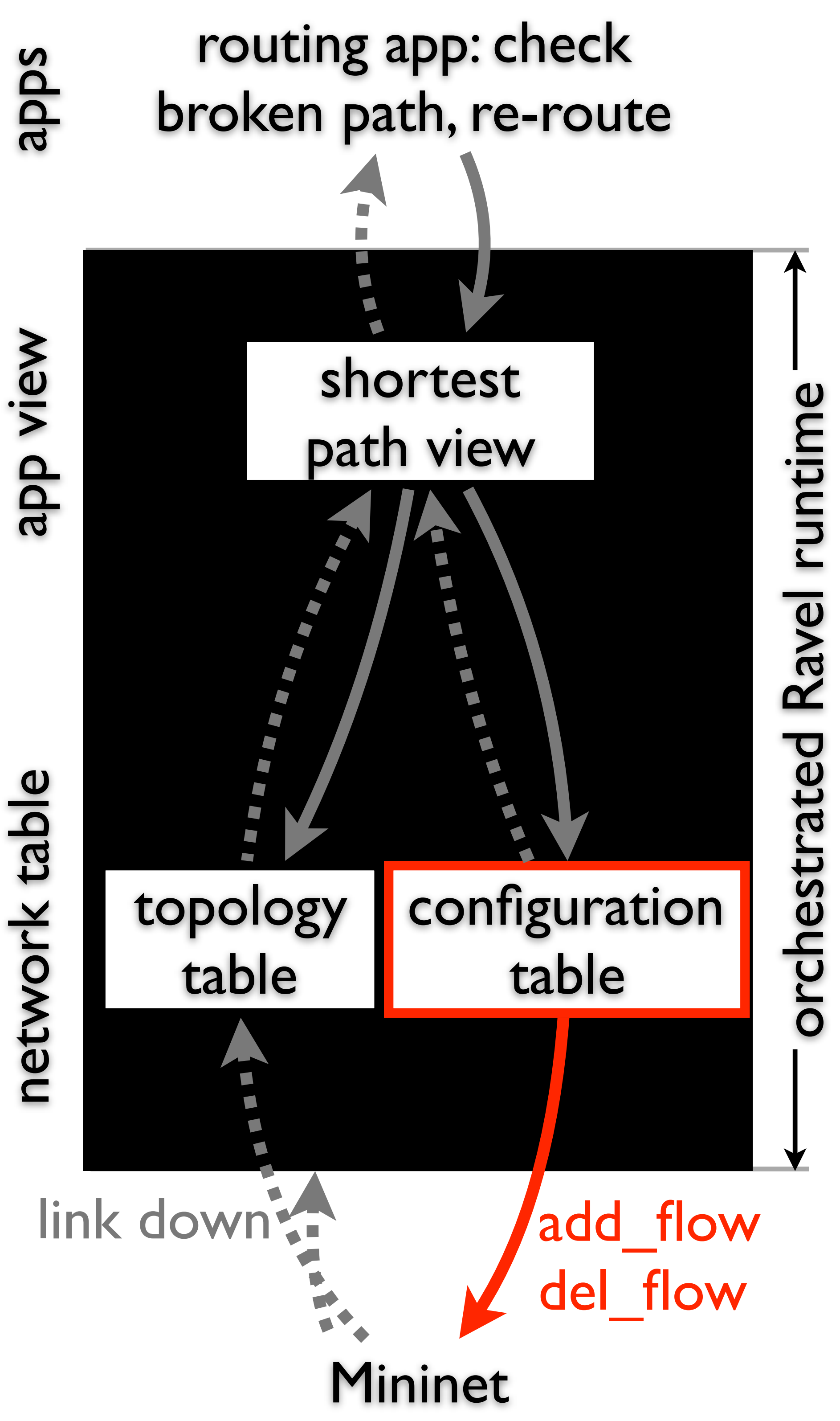
topology

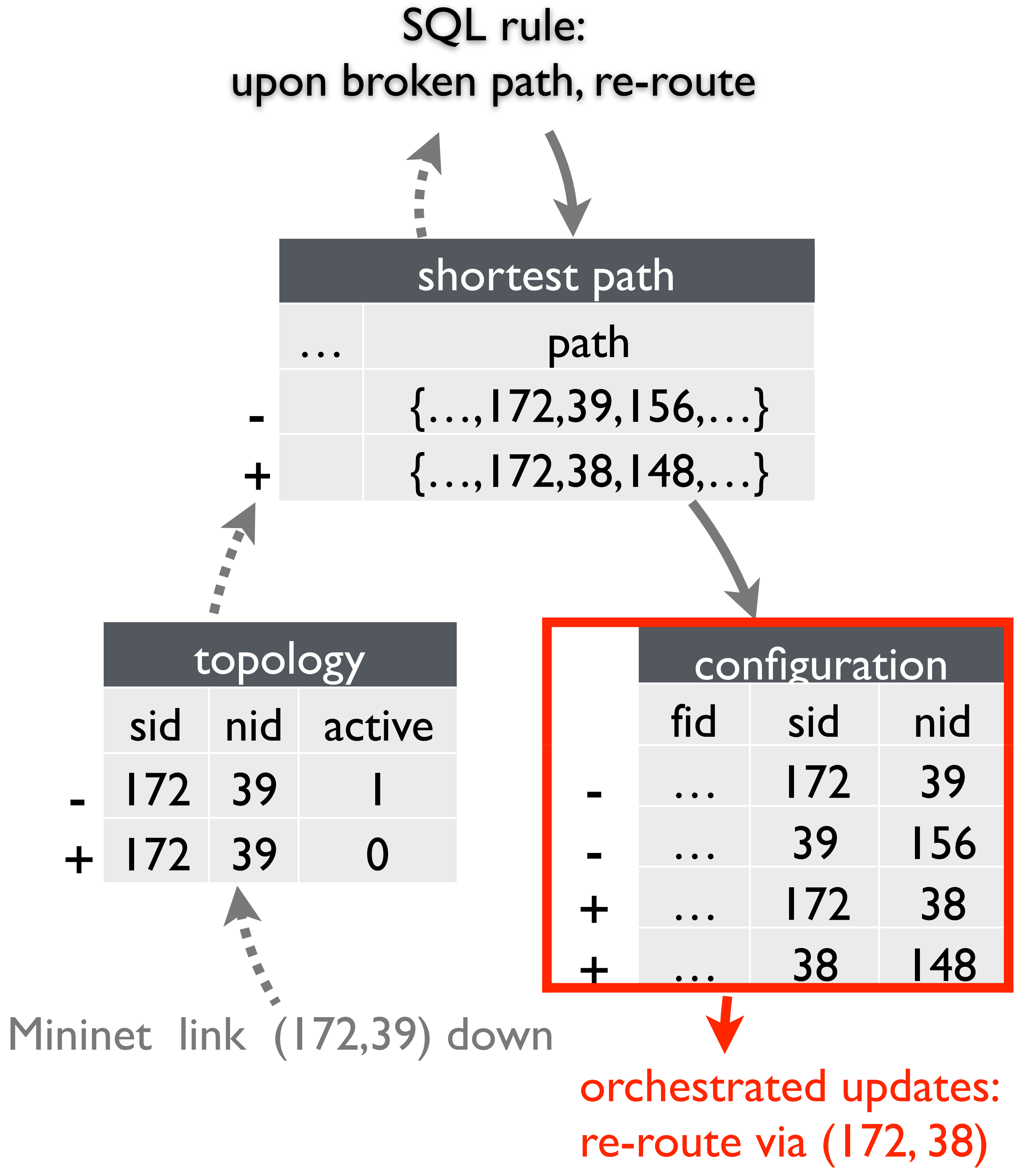
| | sid | nid | active |
|---|---|---|---|
| - | 172 | 39 | 1 |
| + | 172 | 39 | 0 |

configuration

| | fid | sid | nid |
|---|---|---|---|
| - | ... | 172 | 39 |
| - | ... | 39 | 156 |
| + | ... | 172 | 38 |
| + | ... | 38 | 148 |

# orchestration across representations





SQL rule: upon broken path, re-route
Mininet link (172,39) down
orchestrated updates: re-route via (172, 38)

shortest path

| | ... | path |
|---|---|---|
| - | | {...,172,39,156,...} |
| + | | {...,172,38,148,...} |

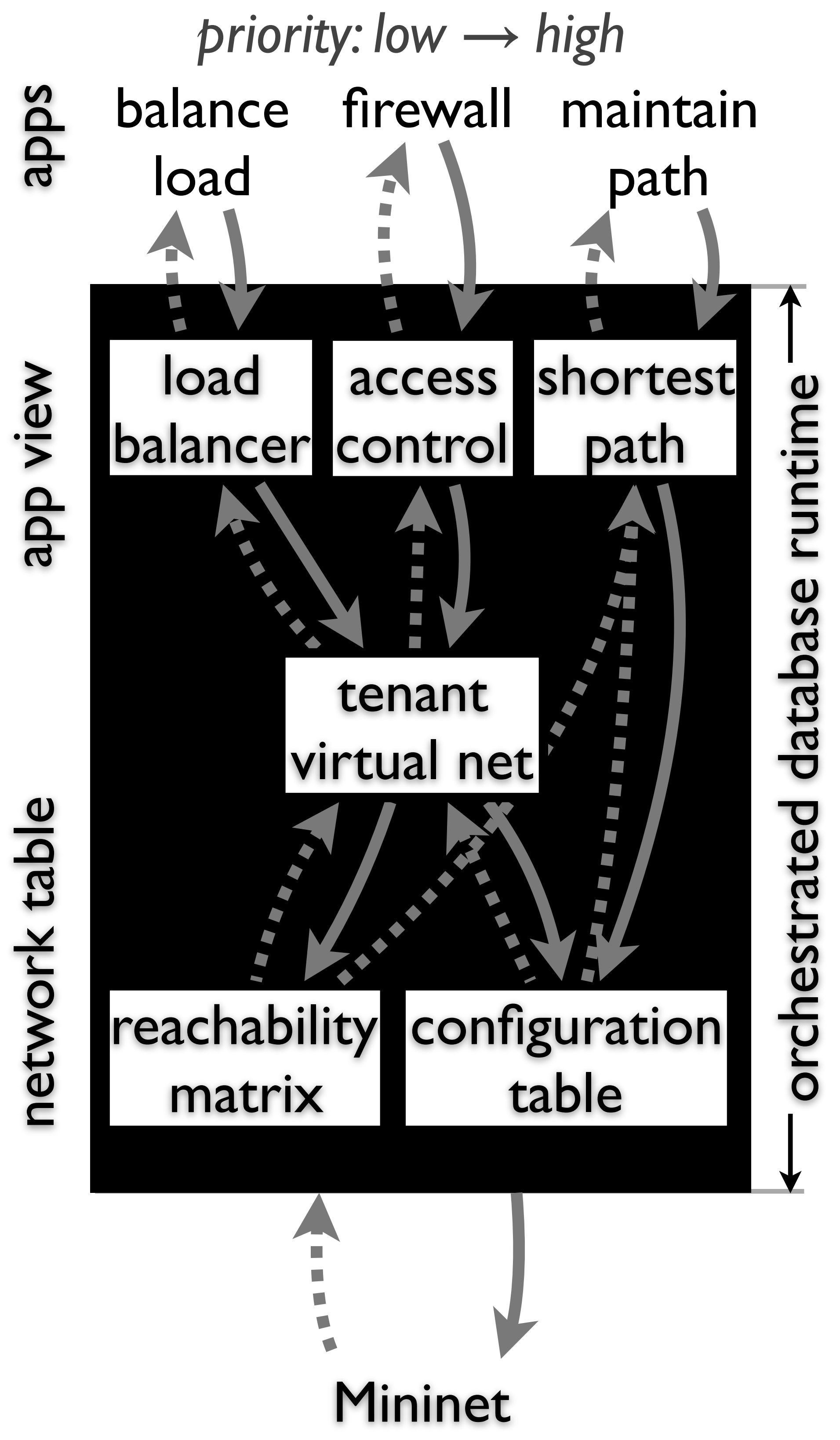
topology

| | sid | nid | active |
|---|---|---|---|
| - | 172 | 39 | 1 |
| + | 172 | 39 | 0 |

configuration

| | fid | sid | nid |
|---|---|---|---|
| - | ... | 172 | 39 |
| - | ... | 39 | 156 |
| + | ... | 172 | 38 |
| + | ... | 38 | 148 |

# orchestration across applications



| load balancer | |
|---|---|
| | |
| | |
| | |
| | |
| | |

| access control | | |
|---|---|---|
| | | |
| | | |
| | | |

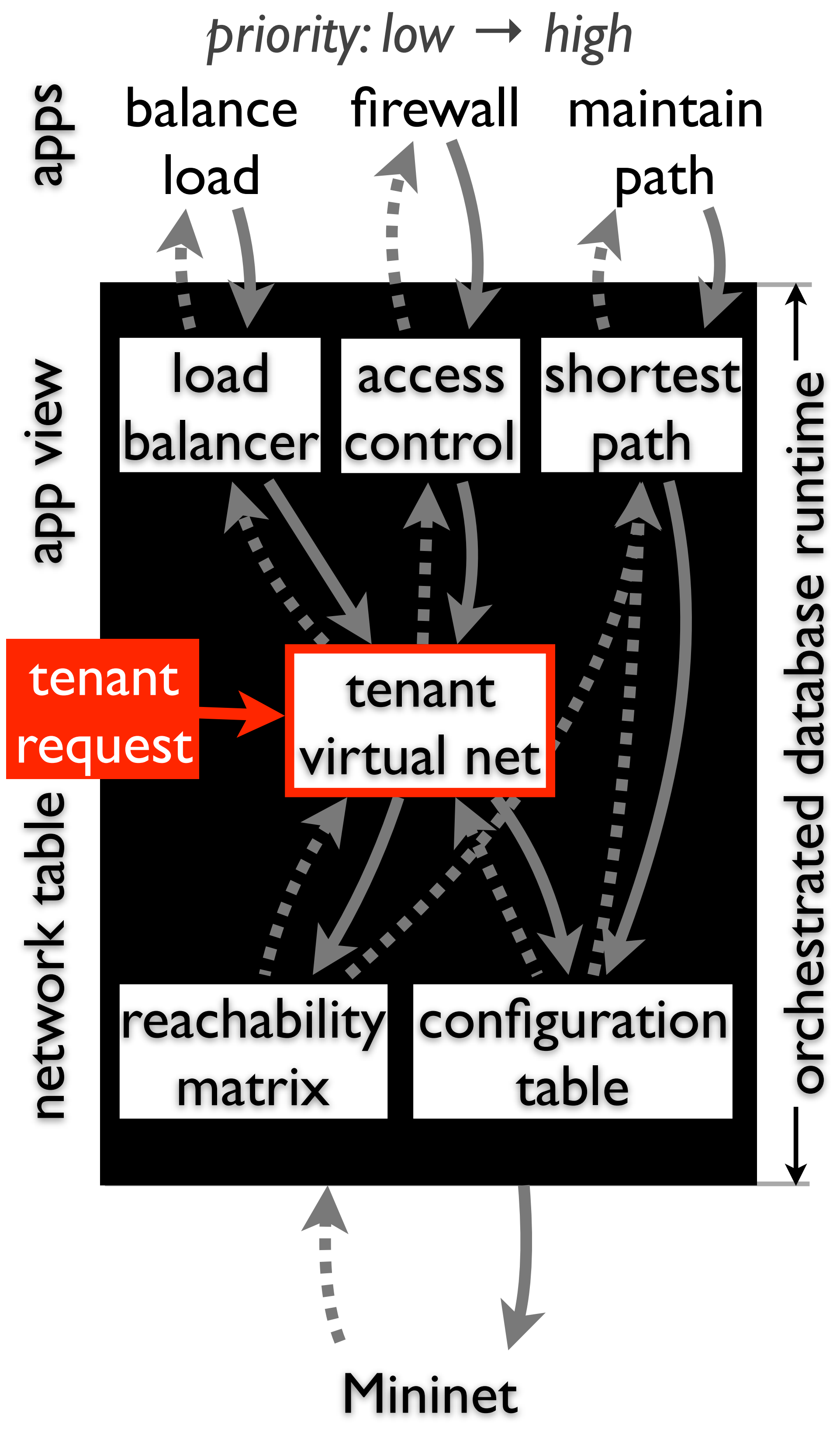
| shortest path | |
|---|---|
| | |
| | |

| tenant virtual net | | |
|---|---|---|
| | | |
| | | |
| | | |

| reachability matrix | | |
|---|---|---|
| | | |
| | | |

| configuration | | |
|---|---|---|
| | | |
| | | |

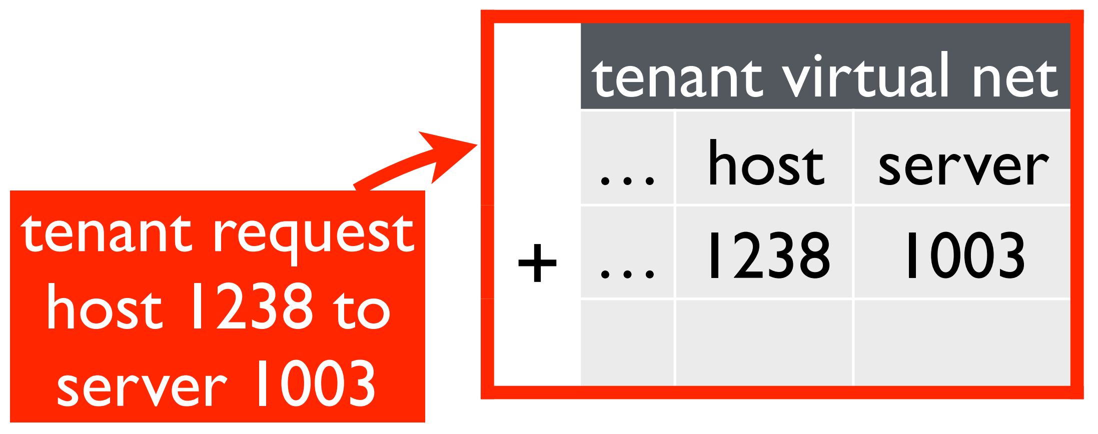
# orchestration across applications



| load balancer | |
|---|---|
| | |
| | |
| | |
| | |
| | |

| access control | | |
|---|---|---|
| | | |
| | | |
| | | |

| shortest path | |
|---|---|
| | |
| | |

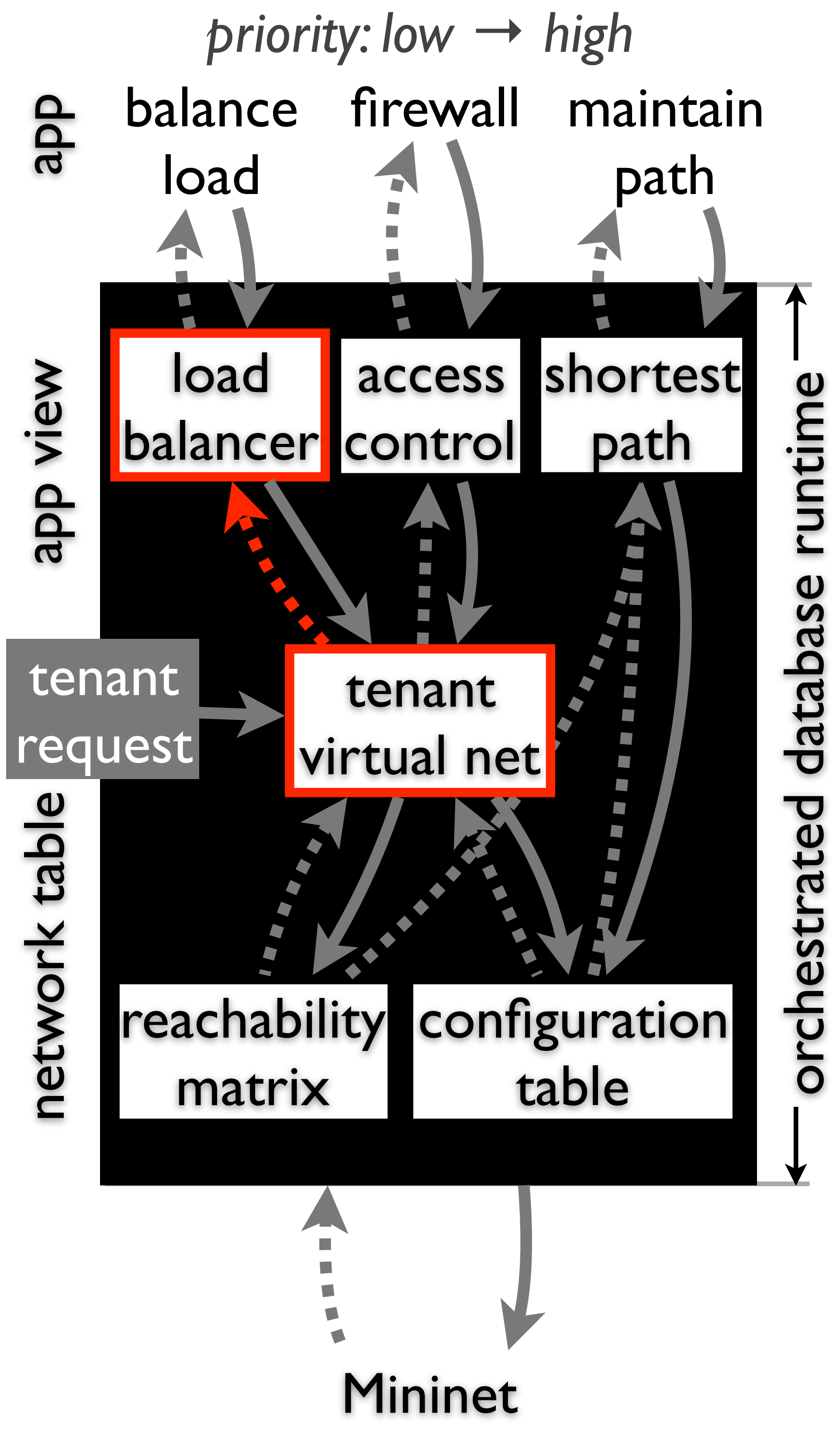


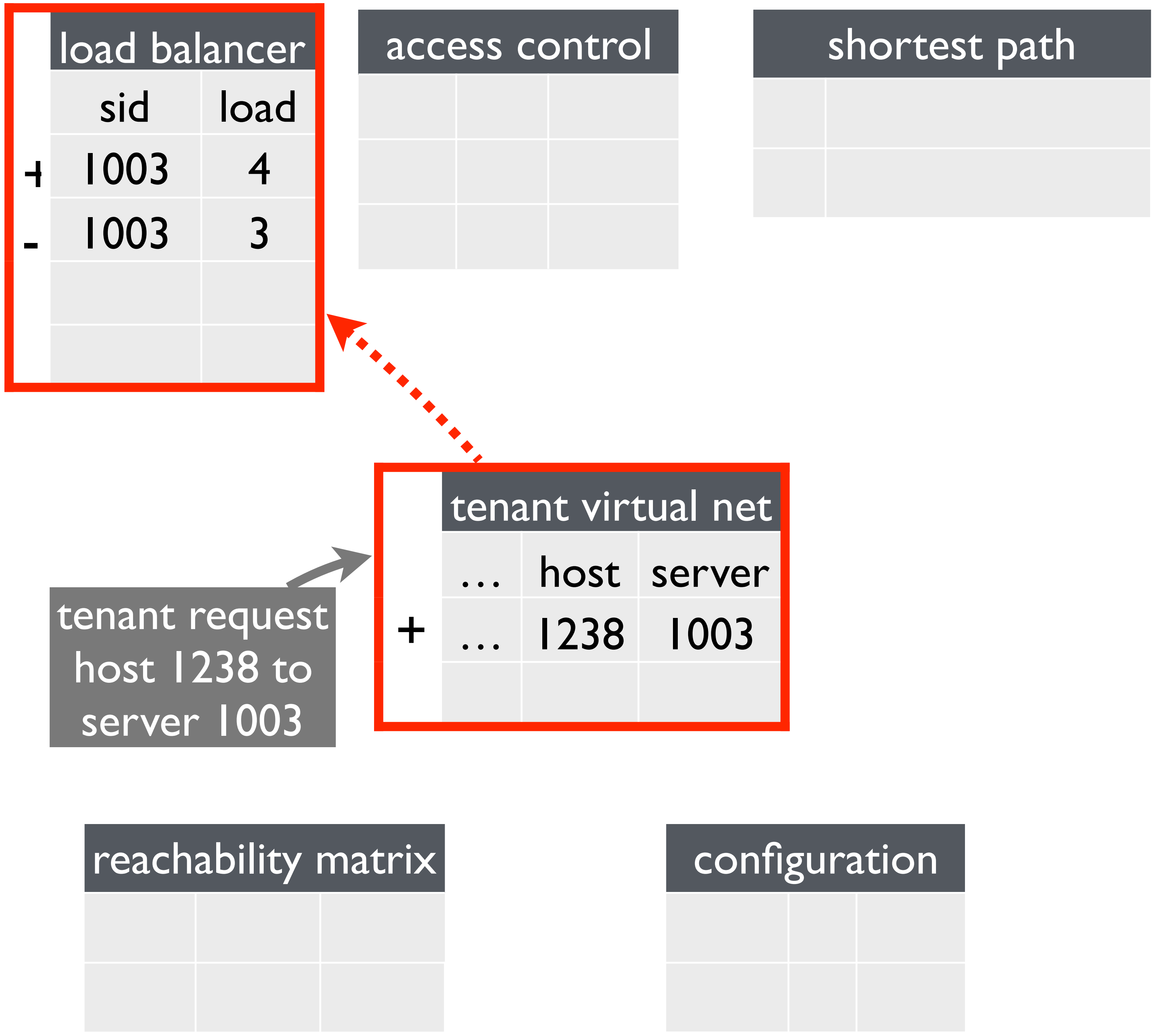
| | tenant virtual net | | |
|---|---|---|---|
| | … | host | server |
| + | … | 1238 | 1003 |
| | | | |

| reachability matrix | | |
|---|---|---|
| | | |
| | | |

| configuration | | |
|---|---|---|
| | | |
| | | |

# orchestration across applications





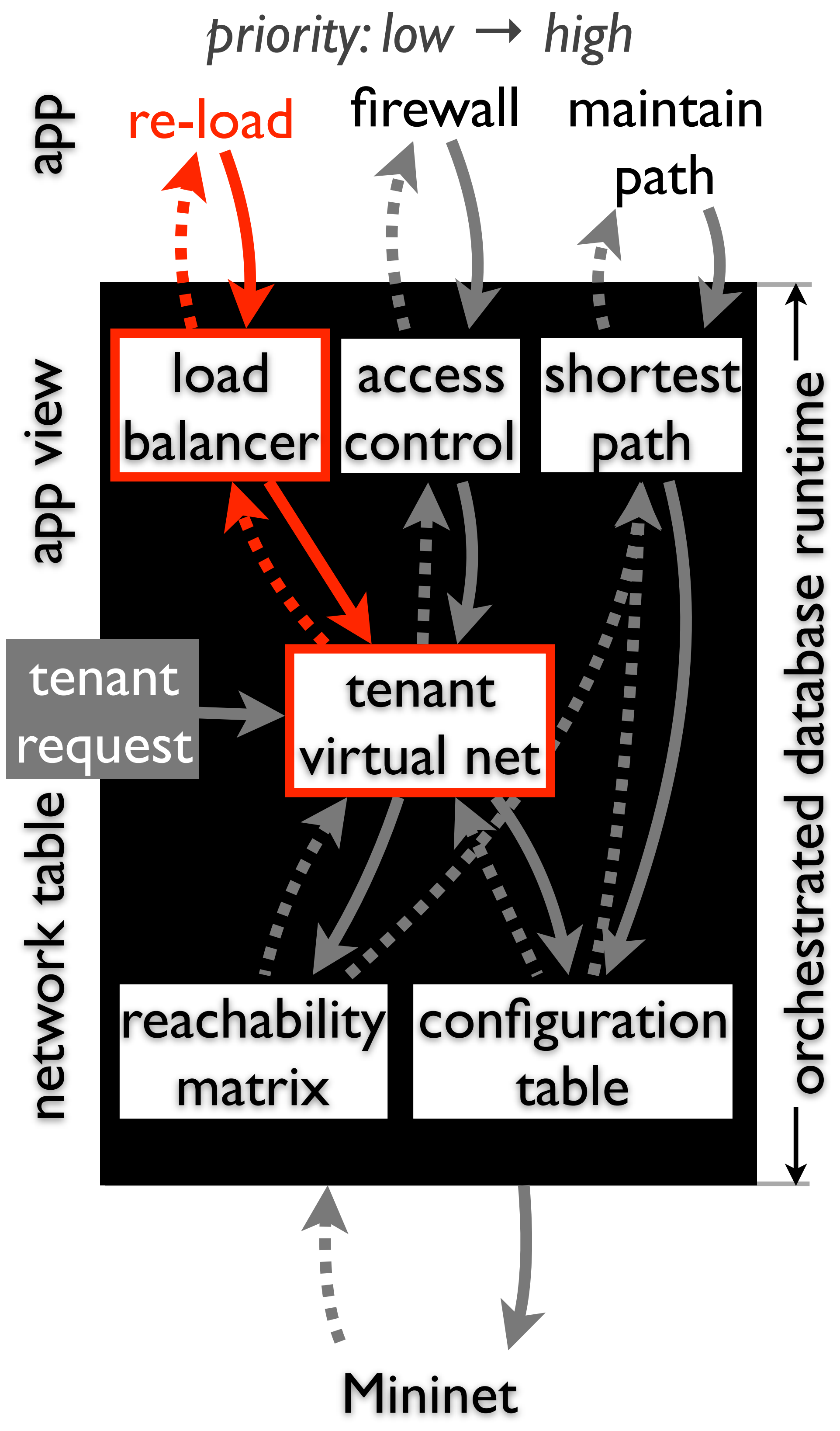
**load balancer**

| | sid | load |
|---|---|---|
| + | 1003 | 4 |
| - | 1003 | 3 |

**tenant virtual net**

| | … | host | server |
|---|---|---|---|
| + | … | 1238 | 1003 |

# orchestration across applications



| | load balancer | |
|---|---|---|
| | sid | load |
| + | ~~1003~~ | 4 |
| - | ~~1003~~ | ~~3~~ |
| - | 1034 | 1 |
| + | 1034 | 2 |

| access control | | |
|---|---|---|
| | | |
| | | |
| | | |

| shortest path | |
|---|---|
| | |
| | |

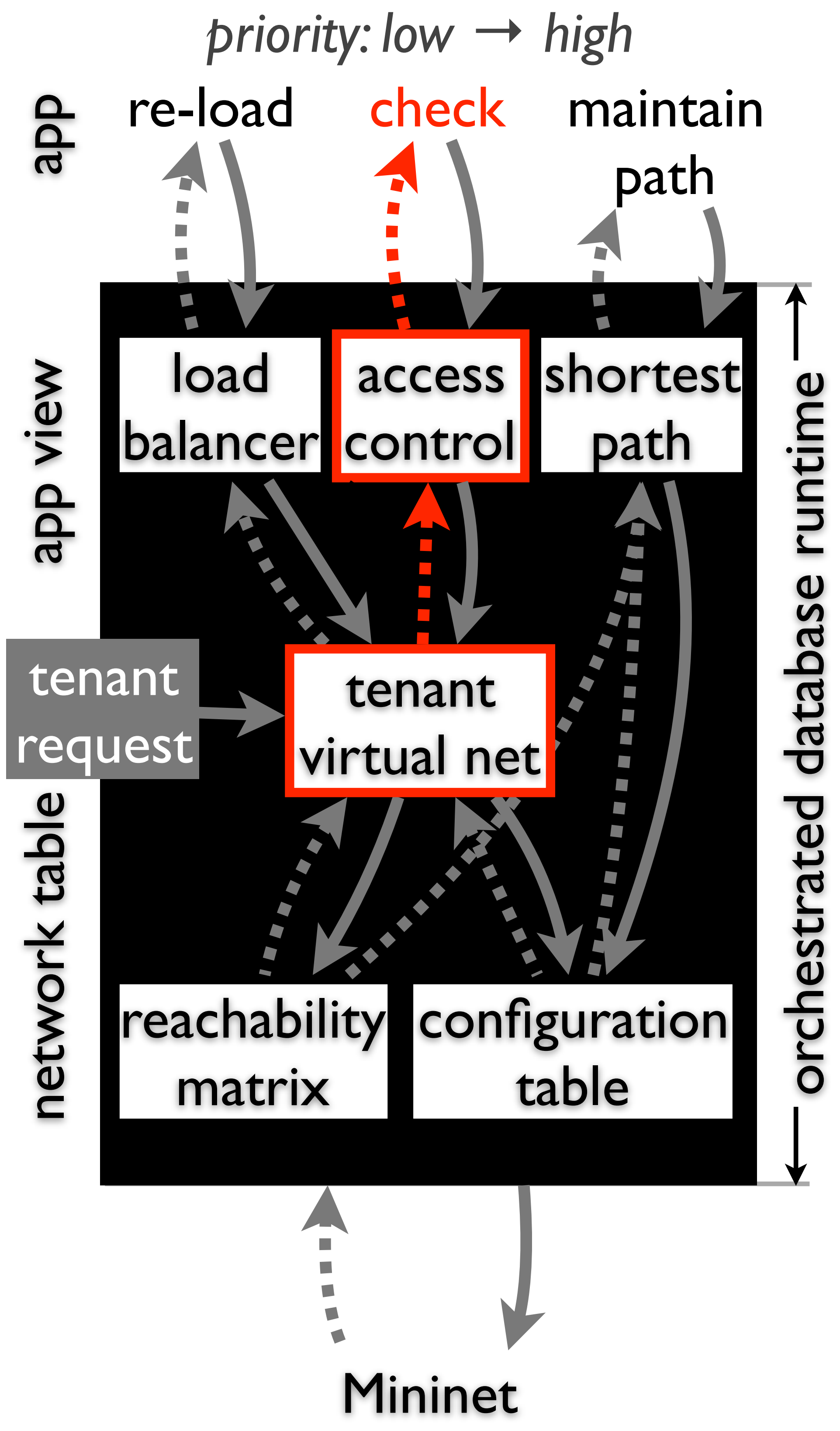
tenant request host 1238 to server 1003

| | tenant virtual net | | |
|---|---|---|---|
| | … | host | server |
| + | ~~…~~ | ~~1238~~ | ~~1003~~ |
| + | | 1238 | 1034 |

| reachability matrix | | |
|---|---|---|
| | | |
| | | |

| configuration | | |
|---|---|---|
| | | |
| | | |

# orchestration across applications



load balancer

| | sid | load |
|---|---|---|
| + | ~~1003~~ | 4 |
| - | ~~1003~~ | ~~3~~ |
| - | 1034 | 1 |
| + | 1034 | 2 |

access control

| src | dst | allow |
|---|---|---|
| 1238 | 1034 | 1 |
| 1238 | 1003 | 0 |

shortest path

| | |
|---|---|
| | |
| | |

tenant virtual net

| | … | host | server |
|---|---|---|---|
| + | ~~…~~ | ~~1238~~ | ~~1003~~ |
| + | | 1238 | 1034 |

tenant request host 1238 to server 1003

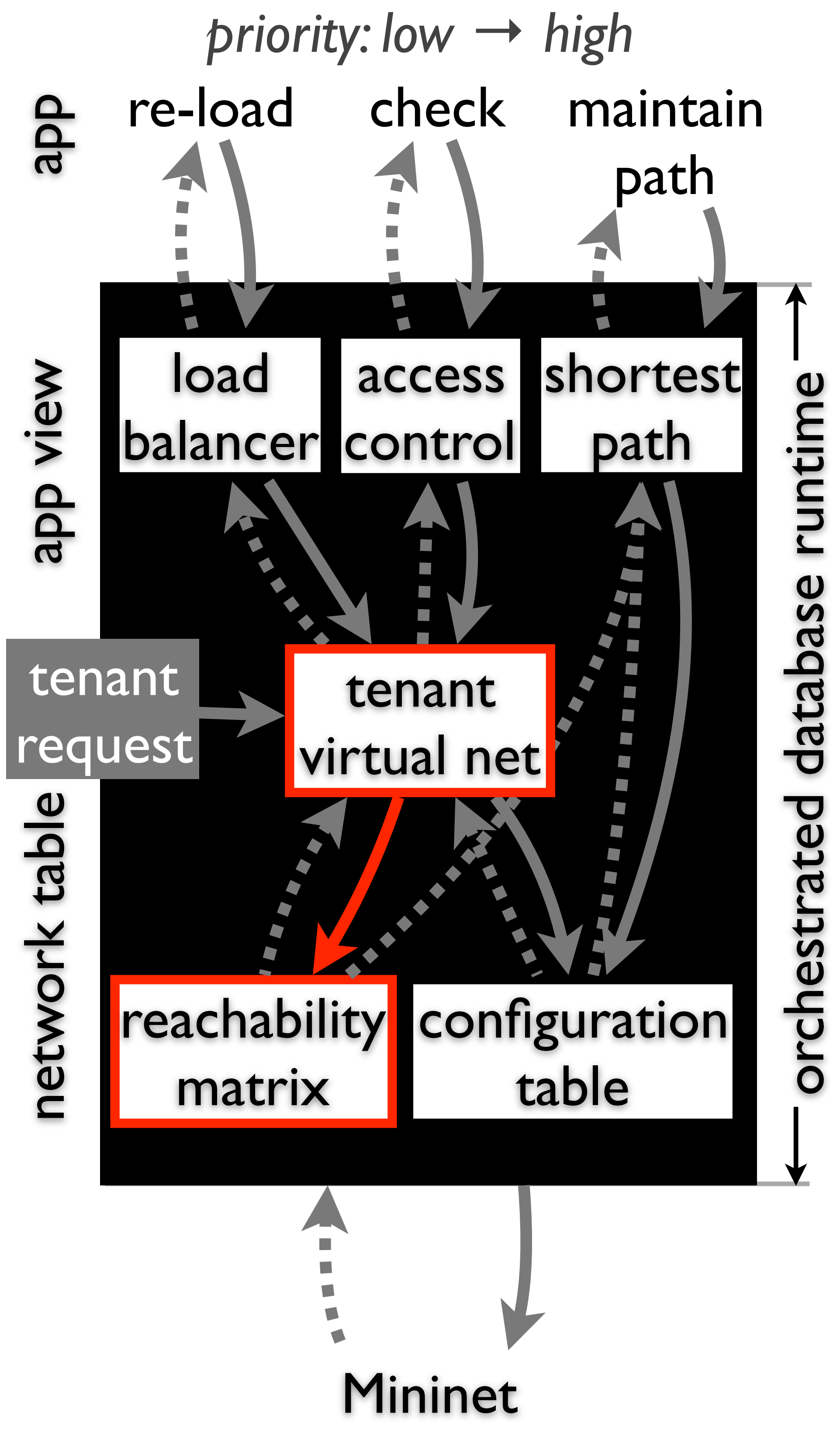
reachability matrix

| | | |
|---|---|---|
| | | |
| | | |

configuration

| | | |
|---|---|---|
| | | |
| | | |

# orchestration across applications



| | load balancer | |
|---|---|---|
| | sid | load |
| + | ~~1003~~ | 4 |
| - | ~~1003~~ | ~~3~~ |
| - | 1034 | 1 |
| + | 1034 | 2 |

| access control | | |
|---|---|---|
| src | dst | allow |
| 1238 | 1034 | 1 |
| 1238 | 1003 | 0 |

| shortest path | |
|---|---|
| | |
| | |

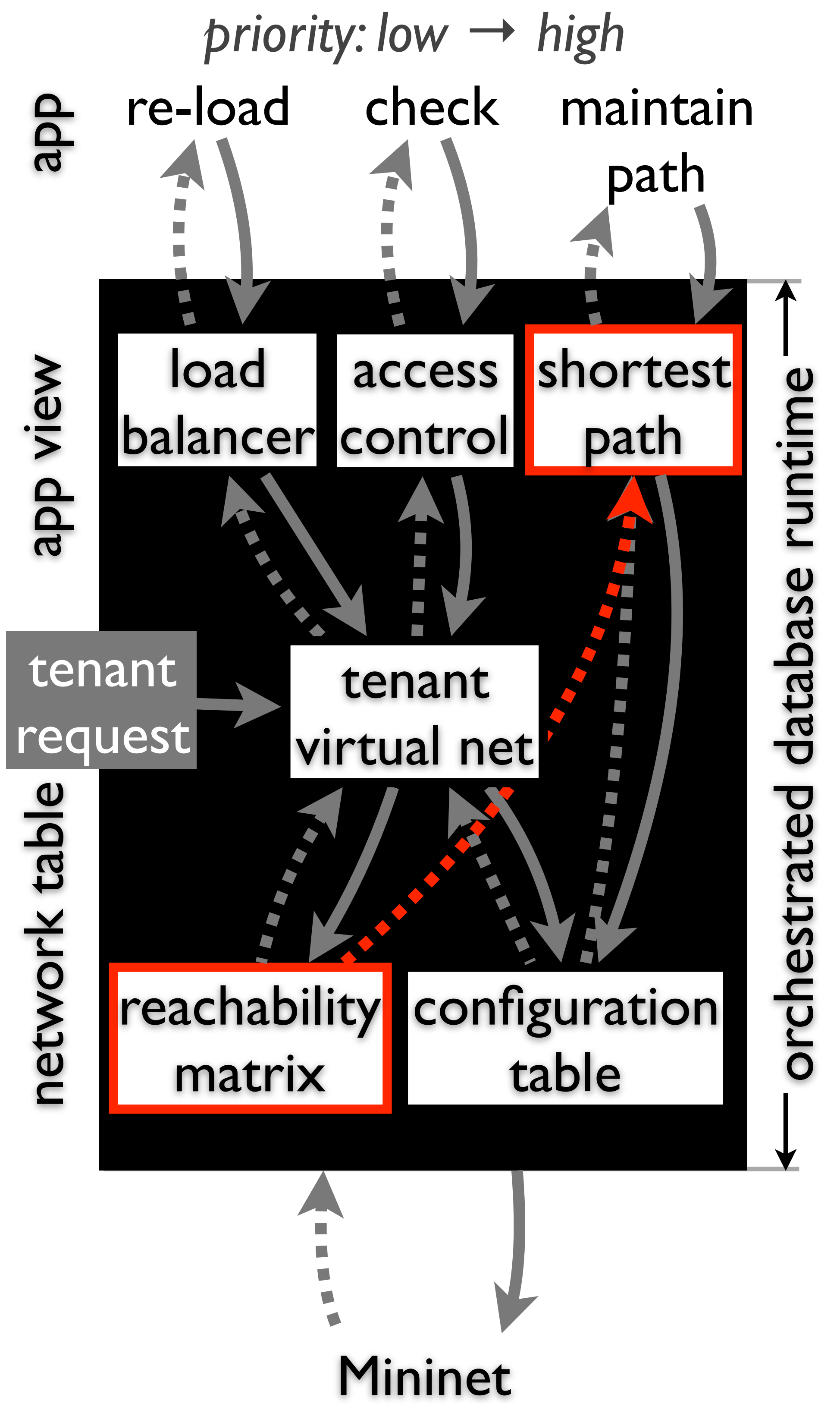
tenant request host 1238 to server 1003

| | tenant virtual net | | |
|---|---|---|---|
| | … | host | server |
| + | ~~…~~ | ~~1238~~ | ~~1003~~ |
| + | | 1238 | 1034 |

| | reachability matrix | | |
|---|---|---|---|
| | fid | sid | nid |
| + | … | 1238 | 1034 |

| configuration | | |
|---|---|---|
| | | |
| | | |

# orchestration across applications



| | load balancer | |
|---|---|---|
| | sid | load |
| + | ~~1003~~ | 4 |
| - | ~~1003~~ | ~~3~~ |
| - | 1034 | 1 |
| + | 1034 | 2 |

| access control | | |
|---|---|---|
| src | dst | allow |
| 1238 | 1034 | 1 |
| 1238 | 1003 | 0 |

| | shortest path | |
|---|---|---|
| | … | path |
| + | … | {1238,…,1034} |

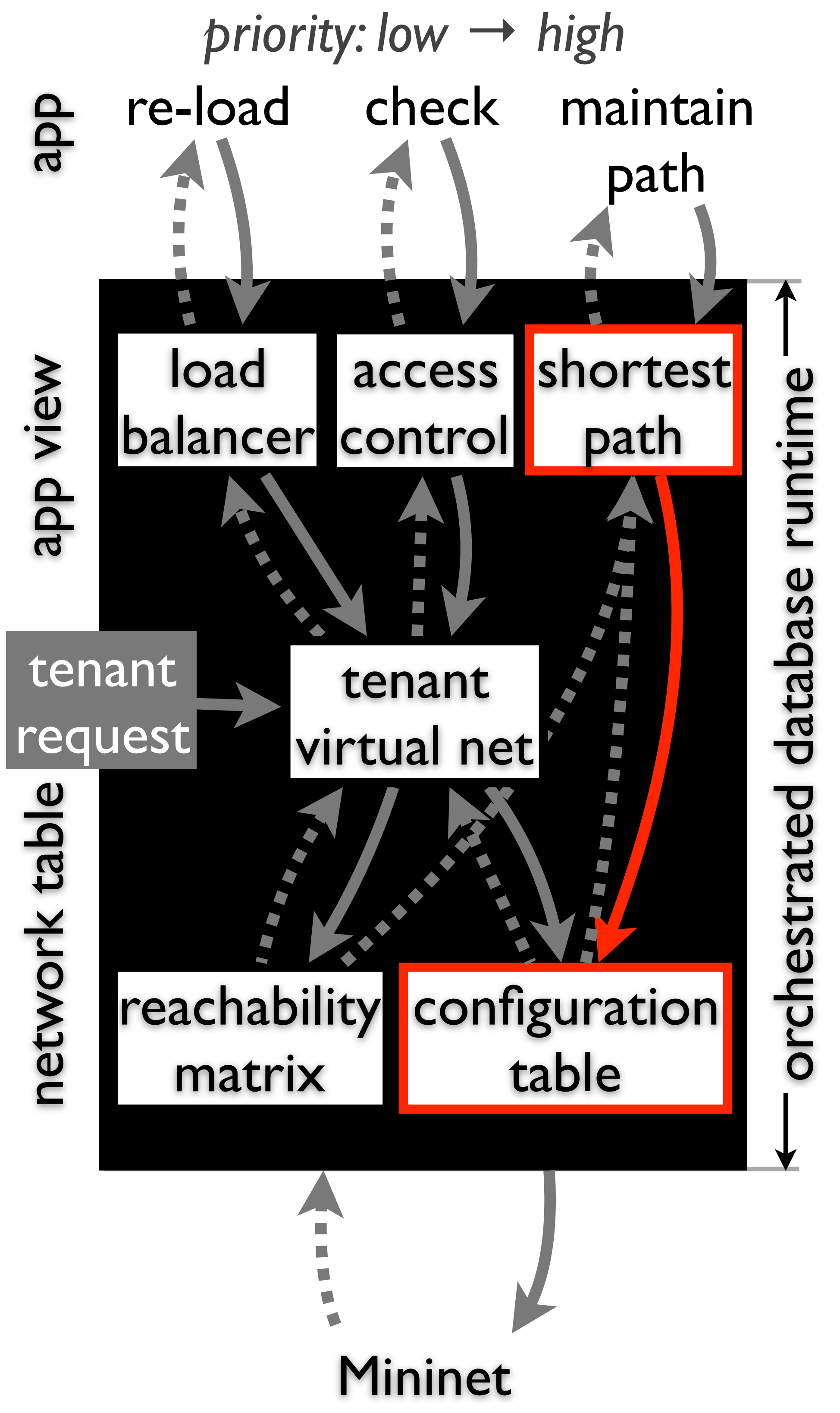
tenant request host 1238 to server 1003

| | tenant virtual net | | |
|---|---|---|---|
| | … | host | server |
| ~~+~~ | ~~…~~ | ~~1238~~ | ~~1003~~ |
| + | | 1238 | 1034 |

| | reachability matrix | | |
|---|---|---|---|
| | fid | sid | nid |
| + | … | 1238 | 1034 |

| configuration | | |
|---|---|---|
| | | |
| | | |

# orchestration across applications



**load balancer**

| | sid | load |
|---|---|---|
| + | ~~1003~~ | 4 |
| - | ~~1003~~ | ~~3~~ |
| - | 1034 | 1 |
| + | 1034 | 2 |

**access control**

| src | dst | allow |
|---|---|---|
| 1238 | 1034 | 1 |
| 1238 | 1003 | 0 |

**shortest path**

| | … | path |
|---|---|---|
| + | … | {1238,…,1034} |

**tenant virtual net**

| | … | host | server |
|---|---|---|---|
| + | ~~…~~ | ~~1238~~ | ~~1003~~ |
| + | | 1238 | 1034 |

tenant request host 1238 to server 1003

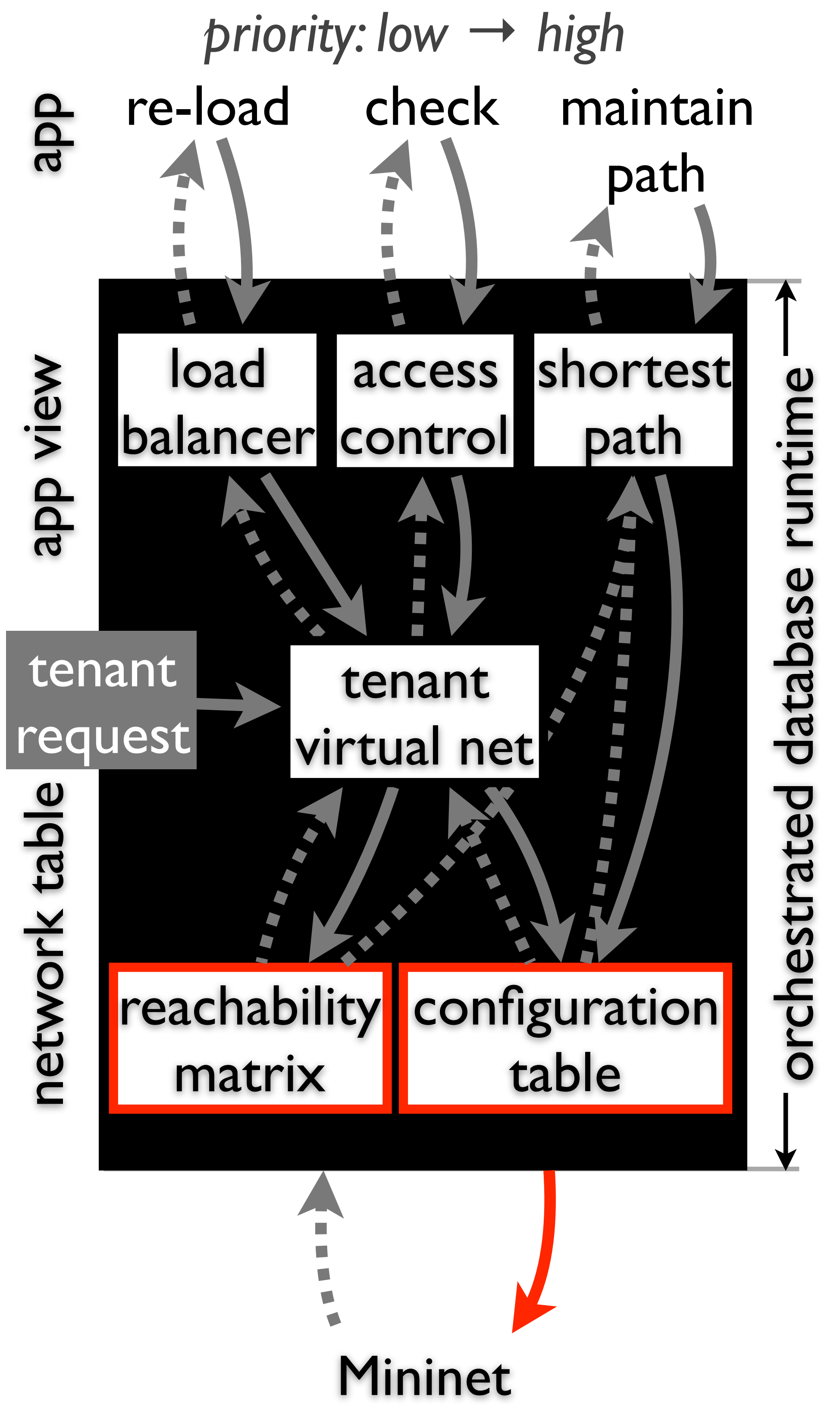
**reachability matrix**

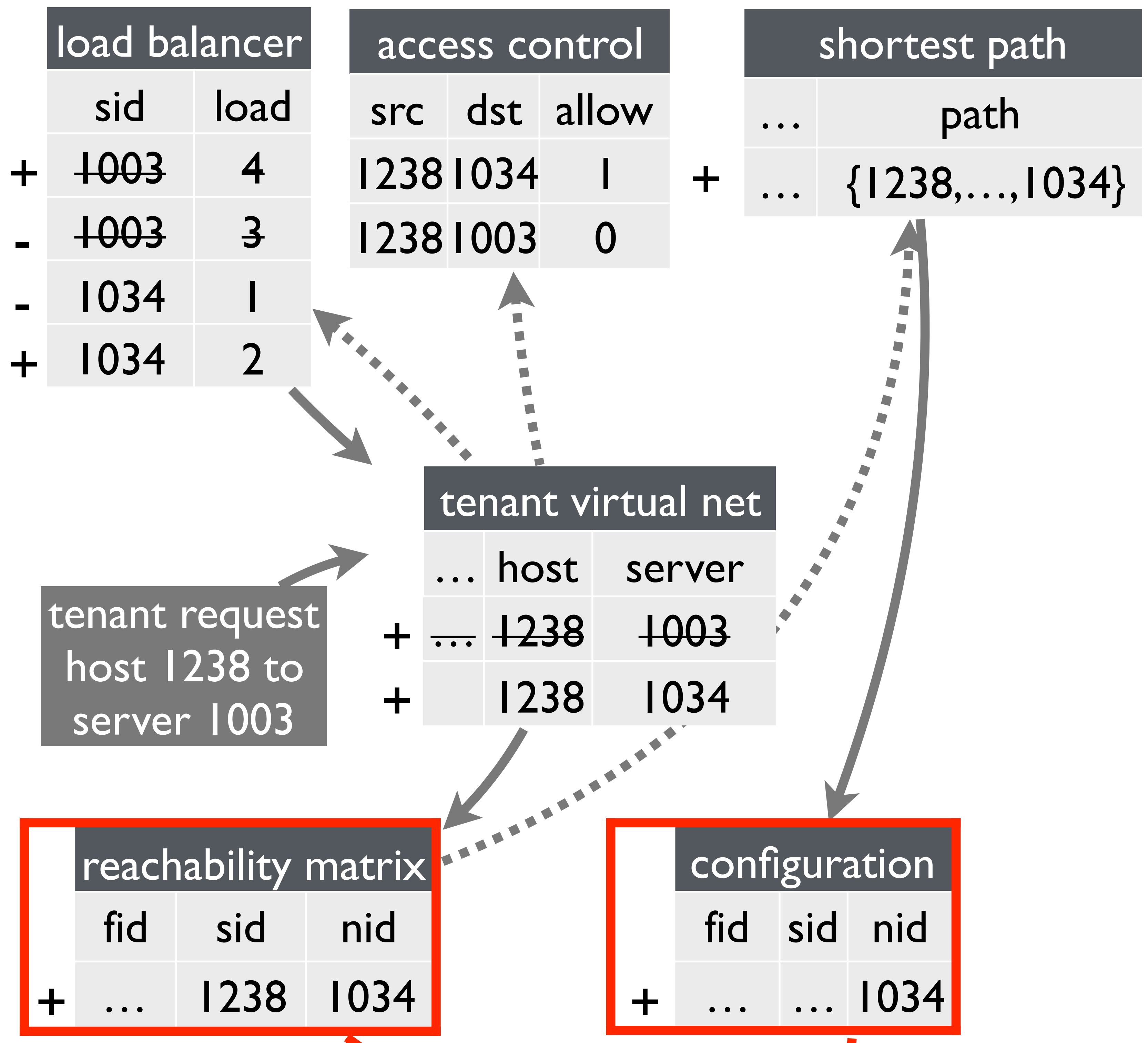
| | fid | sid | nid |
|---|---|---|---|
| + | … | 1238 | 1034 |

**configuration**

| | fid | sid | nid |
|---|---|---|---|
| + | … | … | 1034 |

# orchestration across applications





|  | load balancer |  |
|---|---|---|
|  | sid | load |
| + | ~~1003~~ | 4 |
| - | ~~1003~~ | ~~3~~ |
| - | 1034 | 1 |
| + | 1034 | 2 |

| access control |  |  |
|---|---|---|
| src | dst | allow |
| 1238 | 1034 | 1 |
| 1238 | 1003 | 0 |

|  | shortest path |  |
|---|---|---|
|  | … | path |
| + | … | {1238,…,1034} |

tenant request host 1238 to server 1003

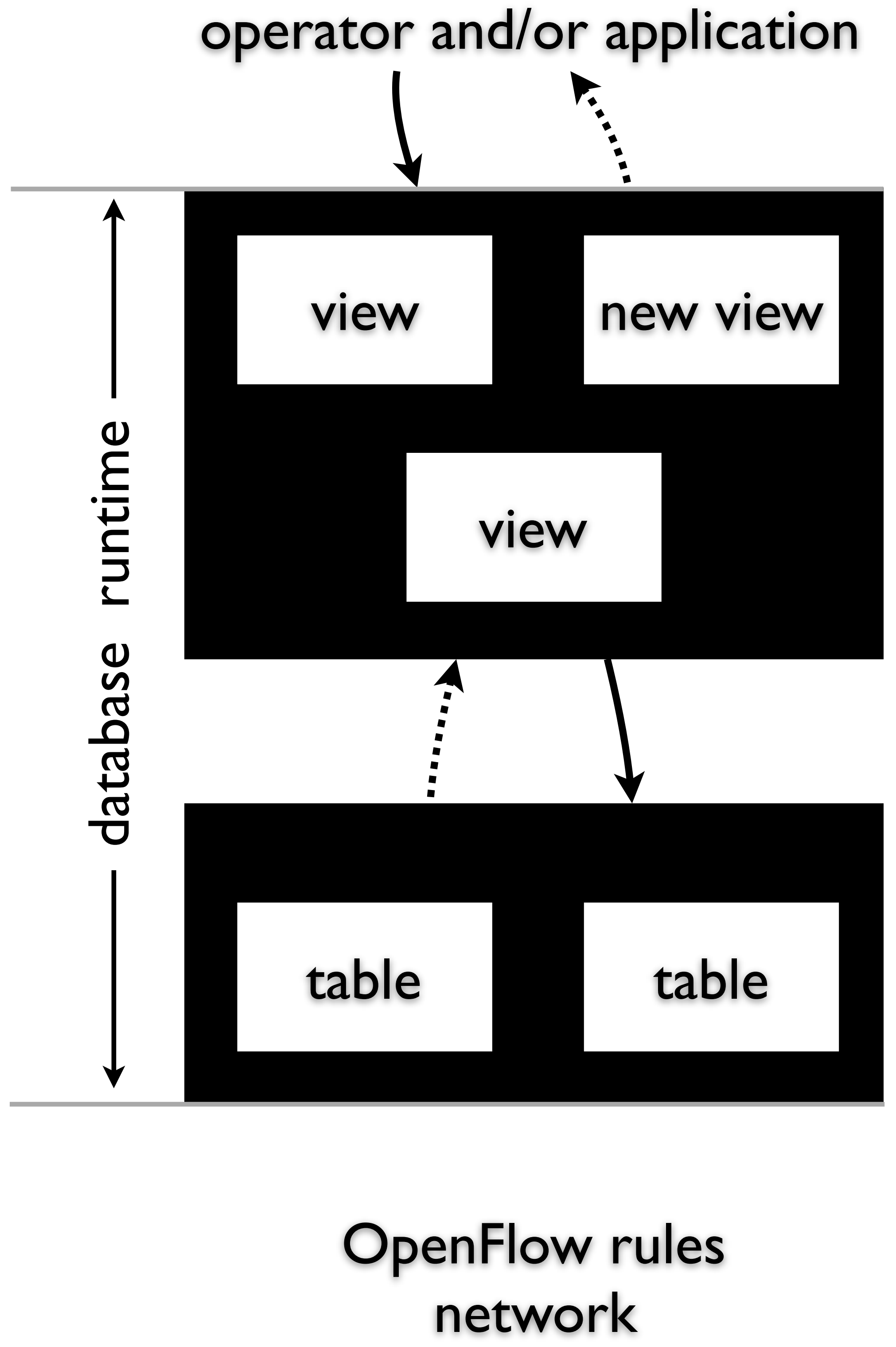
|  | tenant virtual net |  |  |
|---|---|---|---|
|  | … | host | server |
| + | ~~…~~ | ~~1238~~ | ~~1003~~ |
| + |  | 1238 | 1034 |

|  | reachability matrix |  |  |
|---|---|---|---|
|  | fid | sid | nid |
| + | … | 1238 | 1034 |

|  | configuration |  |  |
|---|---|---|---|
|  | fid | sid | nid |
| + | … | … | 1034 |

orchestrated updates: install alternative route that is load-balanced and safe

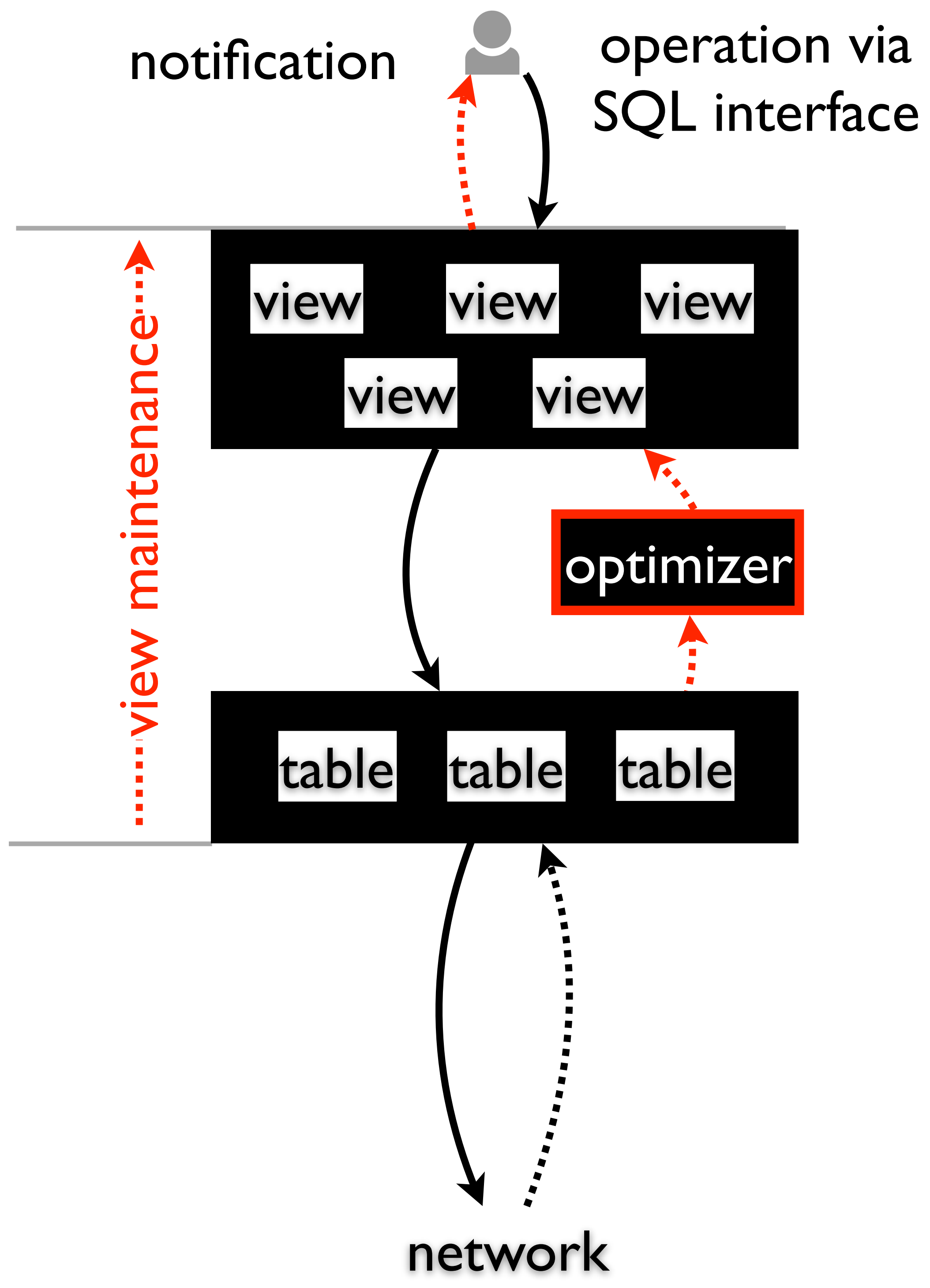
# achieving *Ravel* advantages



## attractive features

- ad-hoc programmable abstraction via views
- orchestration across abstractions via view mechanism
- orchestration across applications via data mediation
- network control via SQL

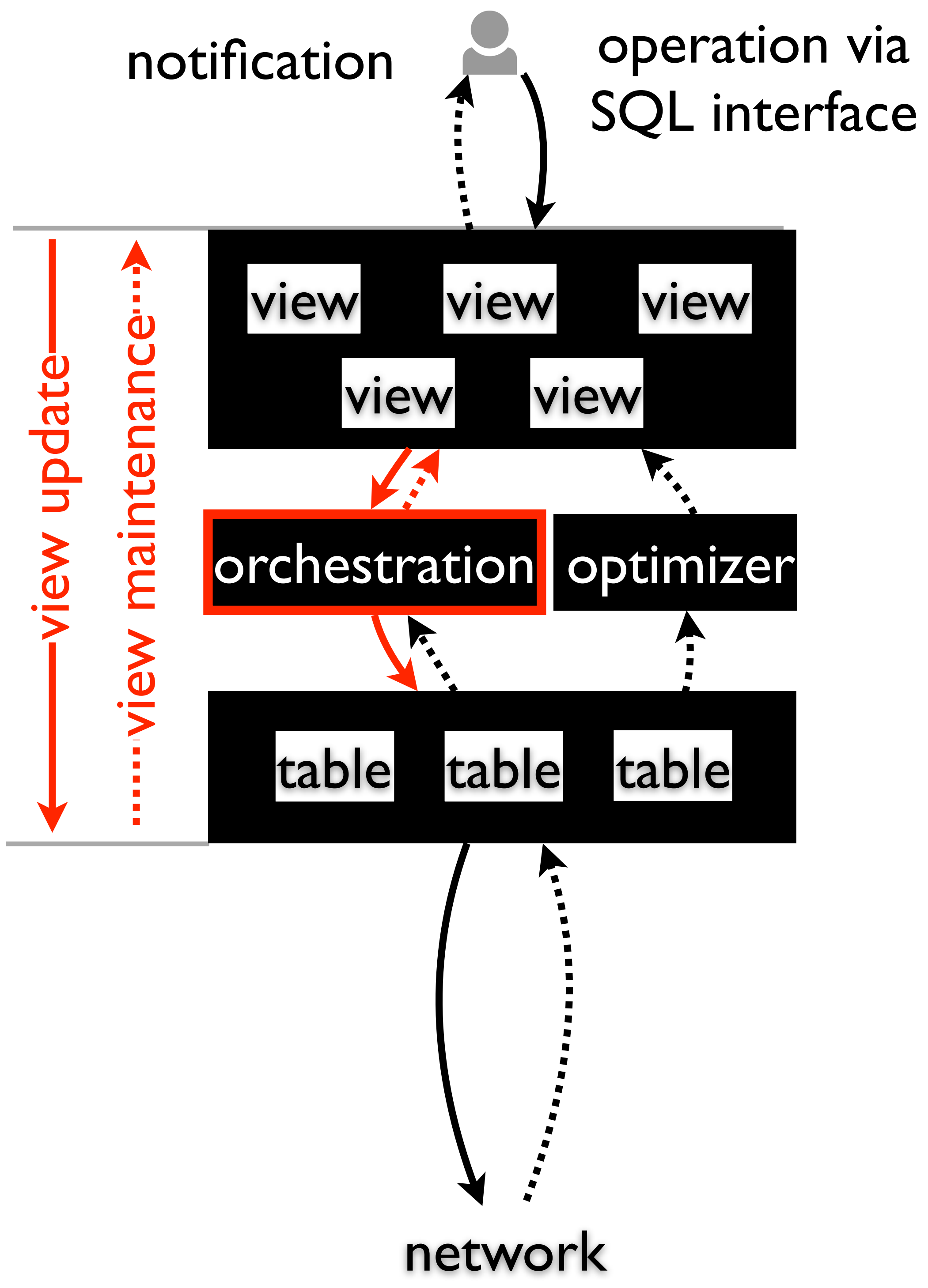
# runtime



## ad-hoc programmable abstraction via views

- challenge: inefficient user view
- solution: optimizer
  - materialize user view with fast maintenance algorithm
  - one order of magnitude faster access with small maintenance overhead — 0.01~10ms

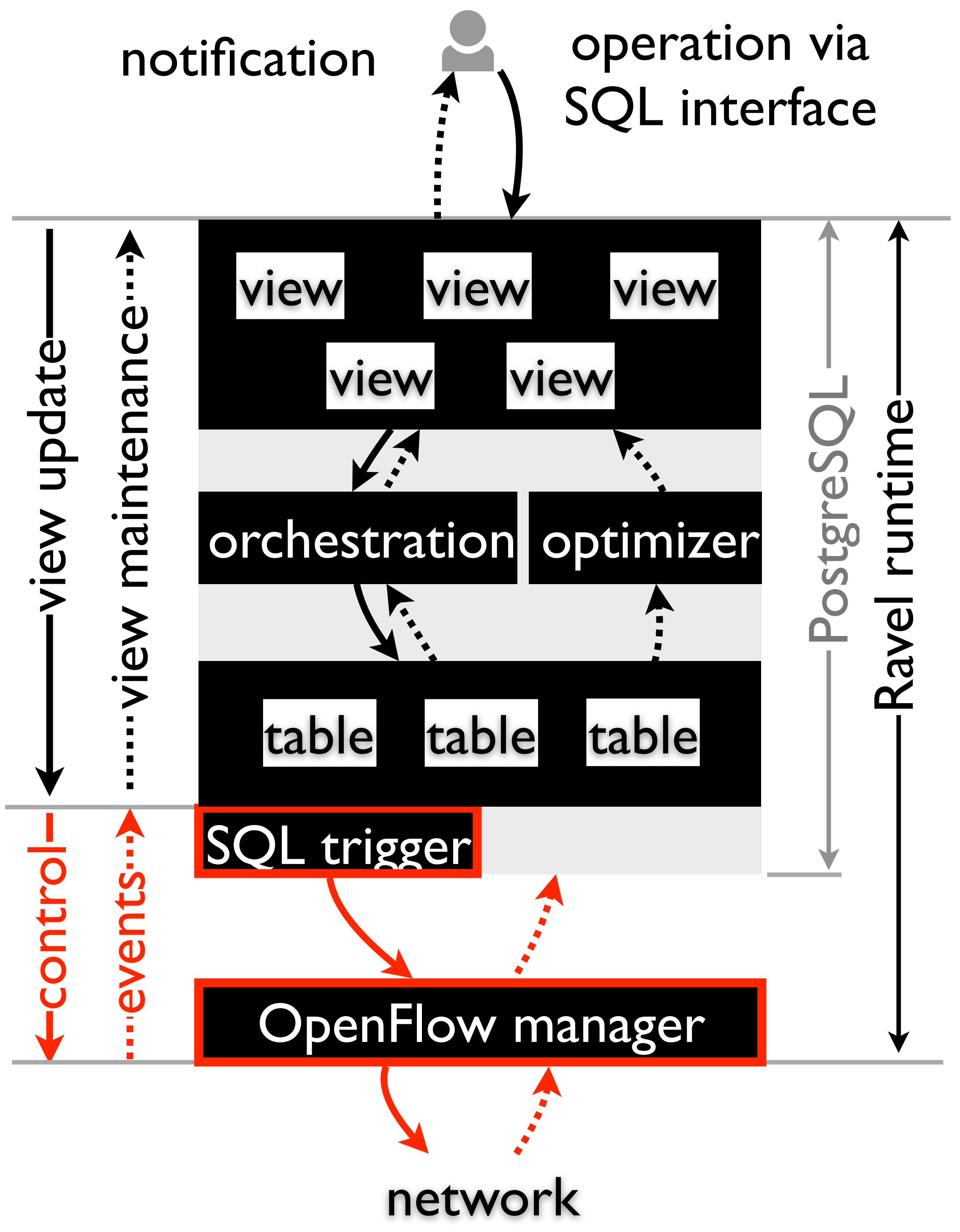
# runtime



## orchestration across applications

- challenge: database lacking inter-view support
- solution: mediation protocol
  - translate app priority into view updates that dynamically merge into a coherent data plane

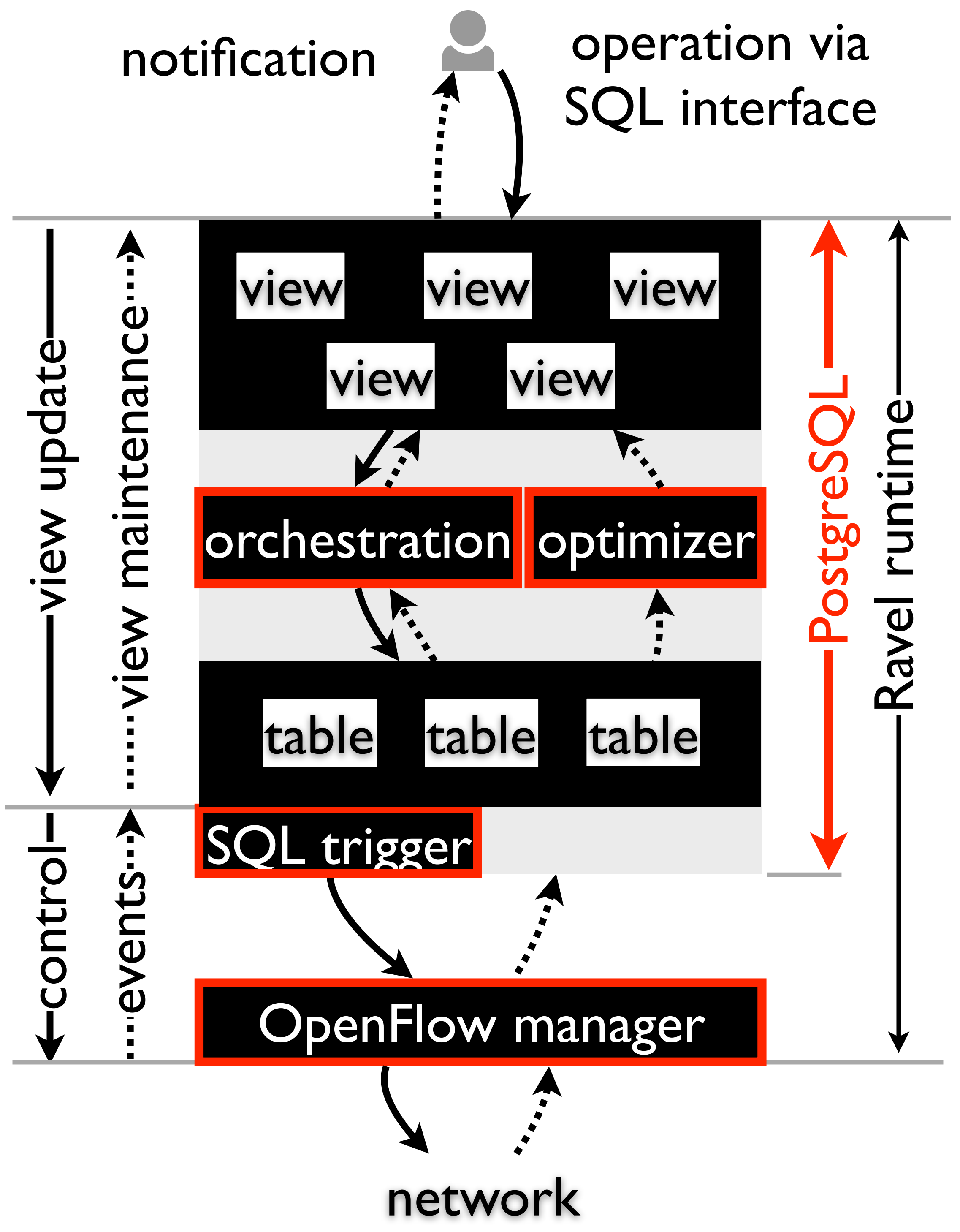
# runtime



## SDN control via SQL

- challenge: database lacks connection to network data plane
- solution: SQL trigger + OF manager

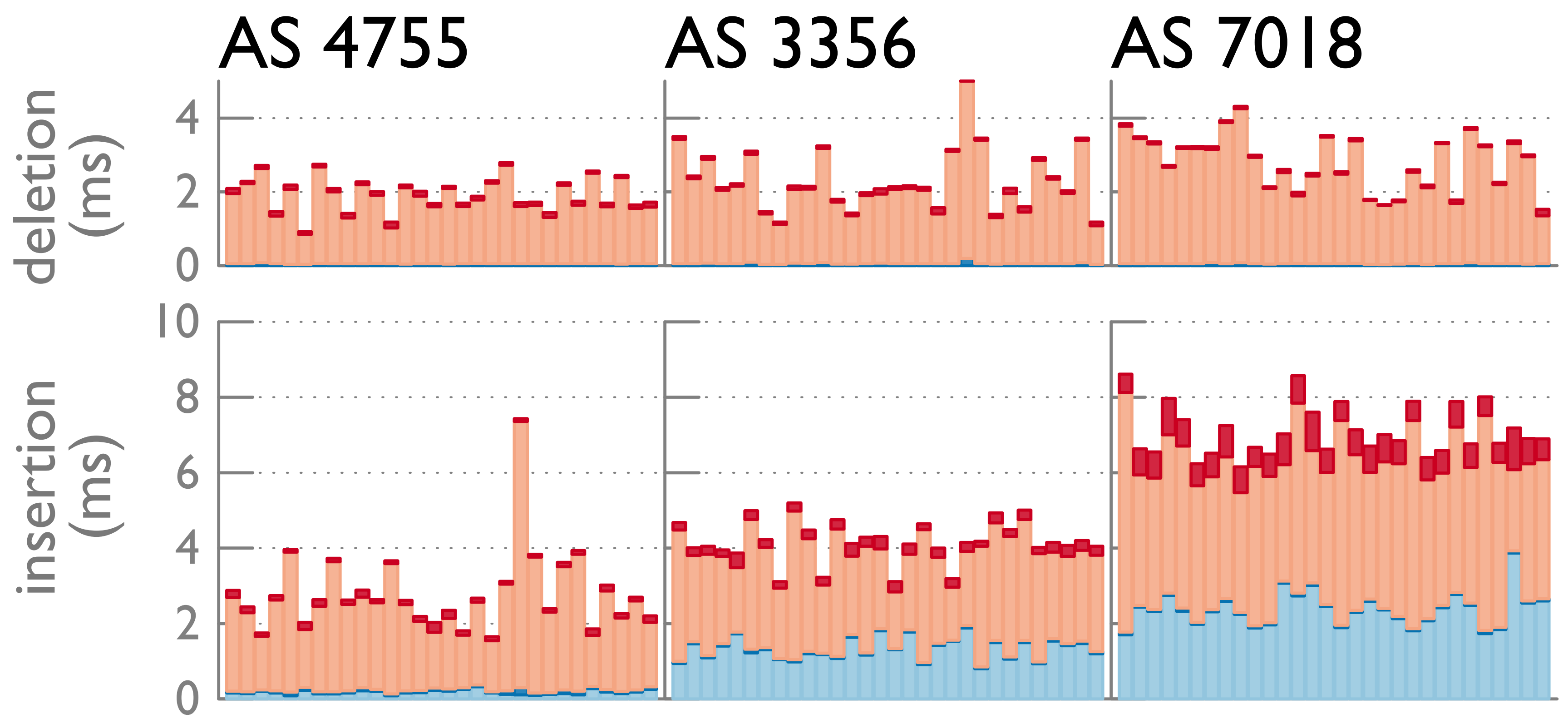
# runtime



a high-performance runtime

- PostgreSQL
- orchestration
- optimizer
- SQL trigger and OF manager

# evaluation



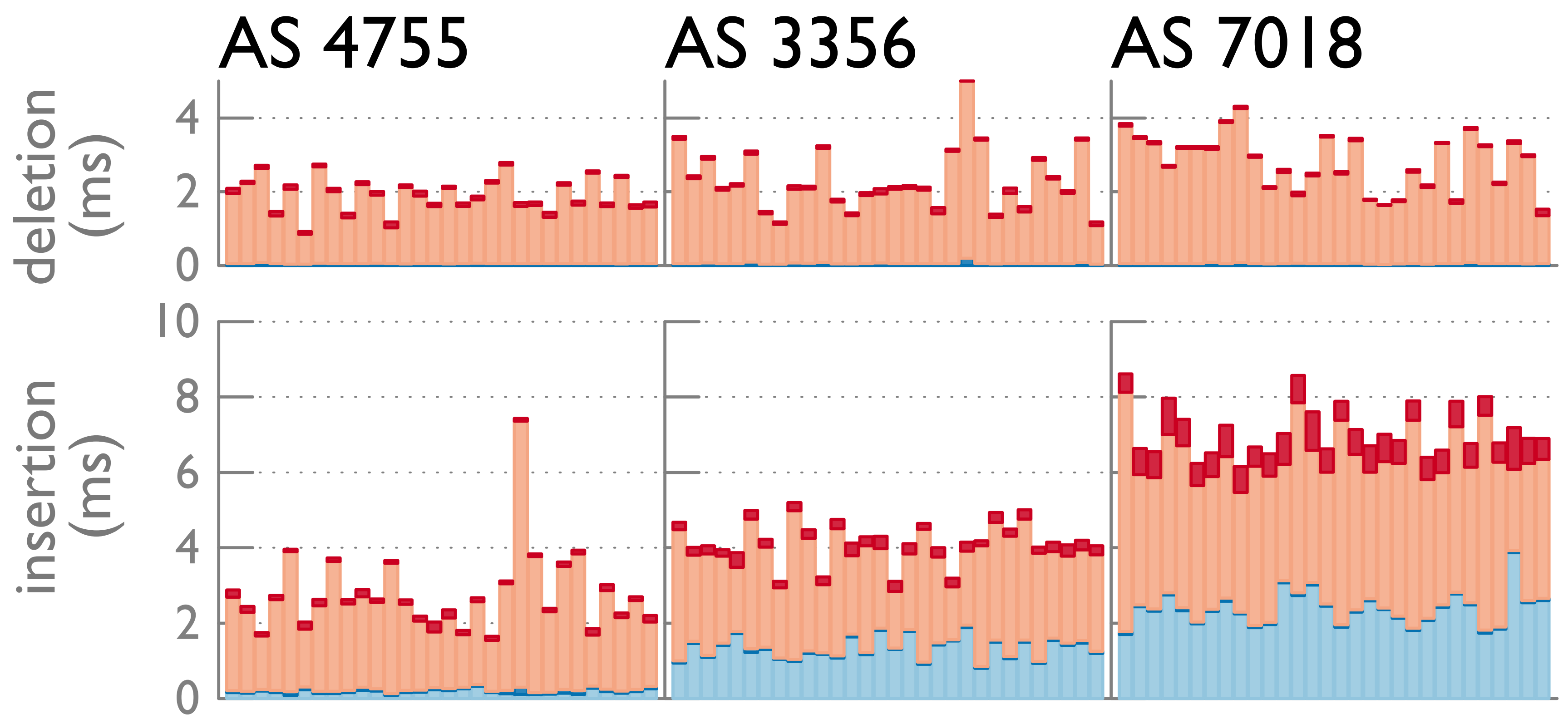
Rocketfuel ISP topology

| AS# | nodes | links |
|---|---|---|
| 4755 | 142 | 258 |
| 3356 | 1772 | 13640 |
| 7018 | 25382 | 11292 |

| | |
|---|---|
| compute path | 🟦 |
| lookup ports | 🟦 |
| write to table | 🟧 |
| trigger/rule | 🟥 |

profile end to end delay (normalized per-rule, 30 rounds) for route insertion and deletion

# evaluation



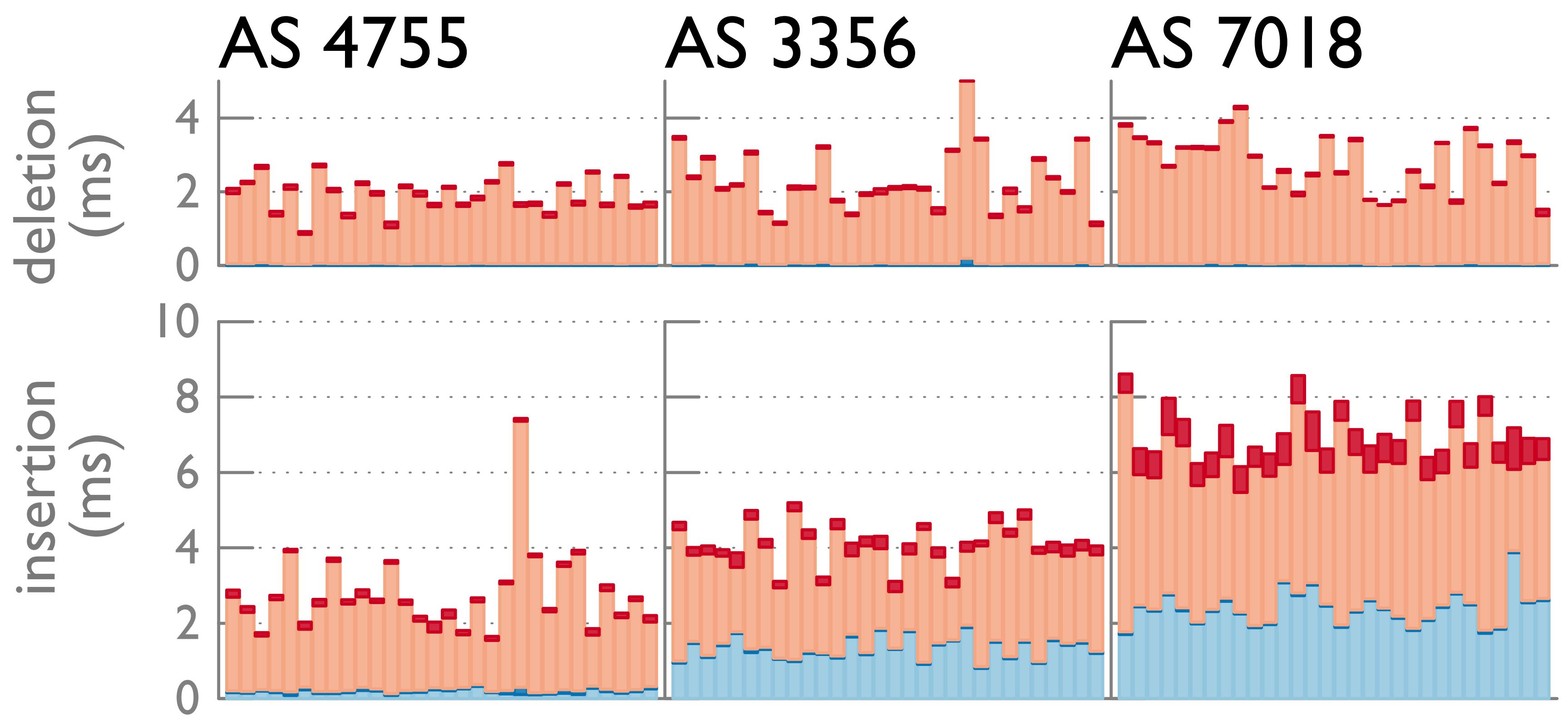
Rocketfuel ISP topology

| AS# | nodes | links |
|---|---|---|
| 4755 | 142 | 258 |
| 3356 | 1772 | 13640 |
| 7018 | 25382 | 11292 |

| | |
|---|---|
| compute path | 🟦 |
| lookup ports | 🟦 |
| write to table | 🟧 |
| trigger/rule | 🟥 |

profile end to end delay (normalized per-rule, 30 rounds) for route insertion and deletion

# evaluation



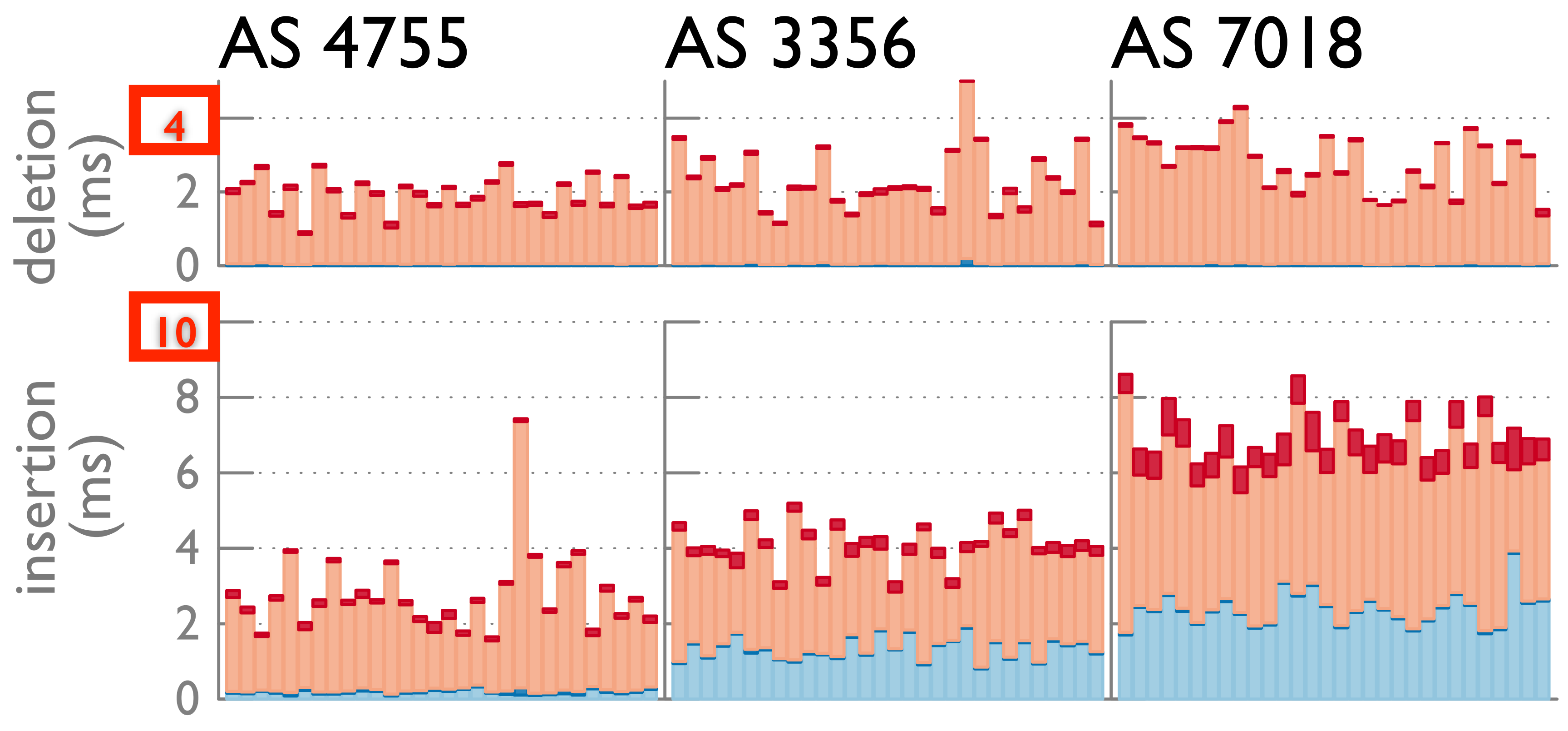
Rocketfuel ISP topology

| AS# | nodes | links |
|---|---|---|
| 4755 | 142 | 258 |
| 3356 | 1772 | 13640 |
| 7018 | 25382 | 11292 |

| | |
|---|---|
| compute path | 🟦 |
| lookup ports | 🟦 |
| write to table | 🟧 |
| trigger/rule | 🟥 |

profile end to end delay (normalized per-rule, 30 rounds) for route insertion and deletion

# evaluation



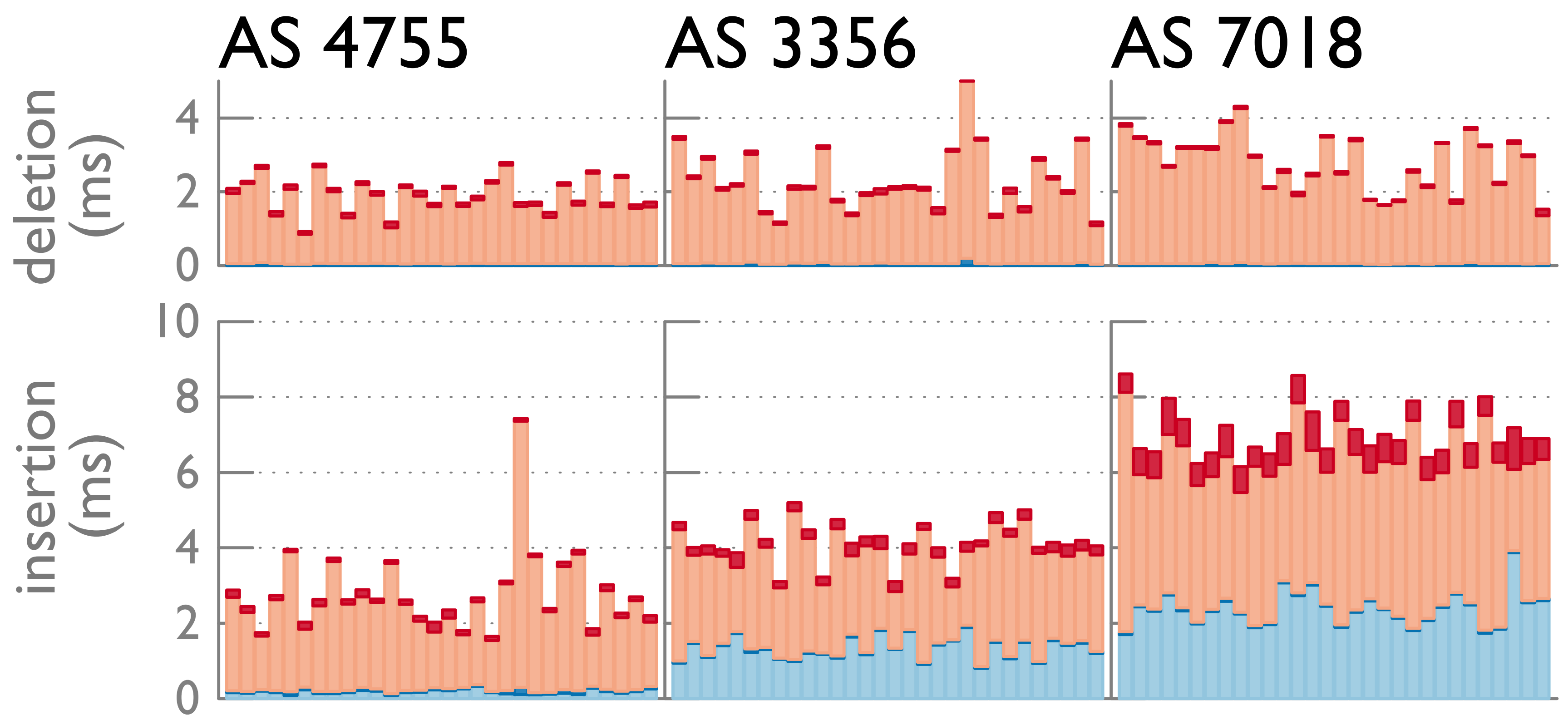
Rocketfuel ISP topology

| AS# | nodes | links |
|---|---|---|
| 4755 | 142 | 258 |
| 3356 | 1772 | 13640 |
| 7018 | 25382 | 11292 |

| | |
|---|---|
| compute path | 🟦 |
| lookup ports | 🟦 |
| write to table | 🟧 |
| trigger/rule | 🟥 |

profile end to end delay (normalized per-rule, 30 rounds) for route insertion and deletion

# evaluation



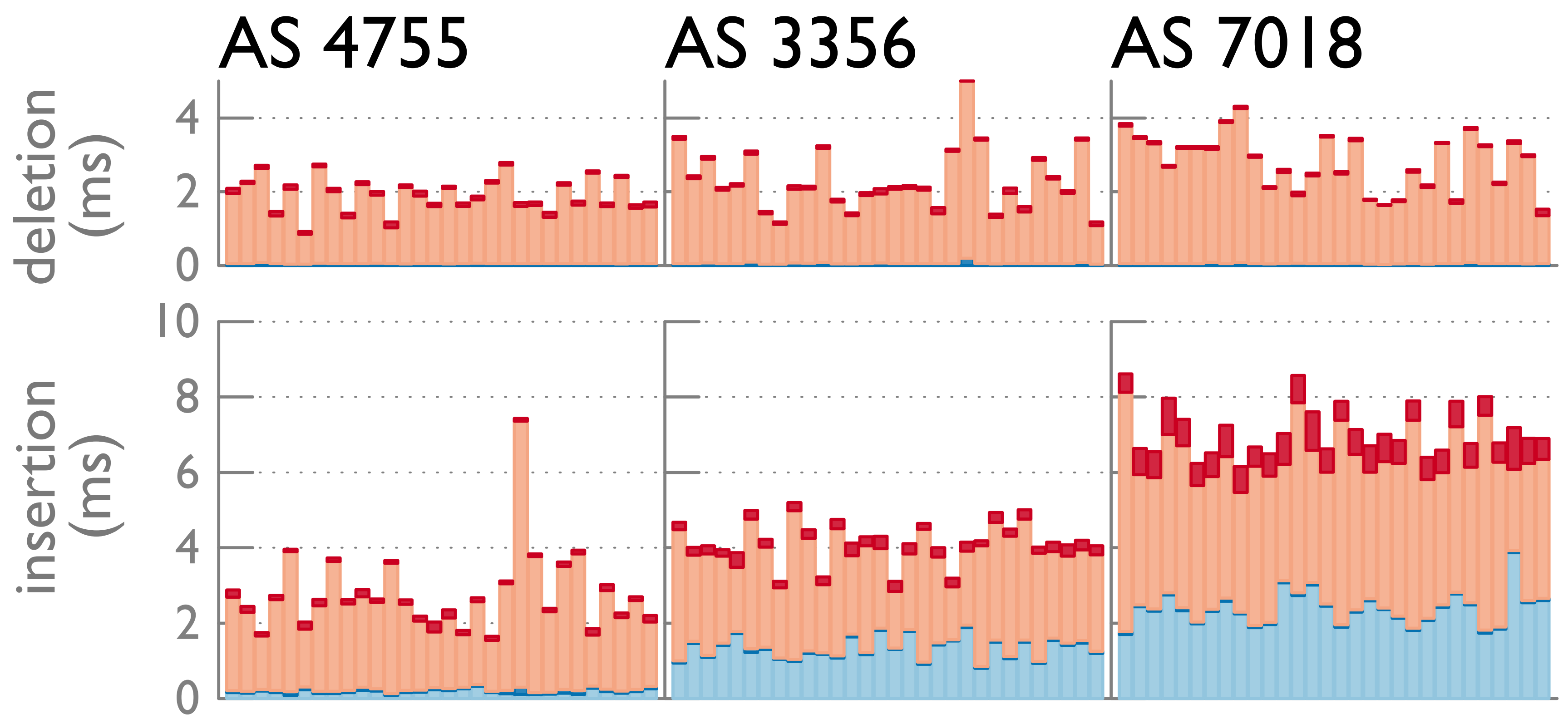
Rocketfuel ISP topology

| AS# | nodes | links |
|---|---|---|
| 4755 | 142 | 258 |
| 3356 | 1772 | 13640 |
| 7018 | 25382 | 11292 |

| | |
|---|---|
| compute path | 🟦 |
| lookup ports | 🟦 |
| write to table | 🟧 |
| trigger/rule | 🟥 |

profile end to end delay (normalized per-rule, 30 rounds) for route insertion and deletion

# evaluation



Rocketfuel ISP topology

| AS# | nodes | links |
|---|---|---|
| 4755 | 142 | 258 |
| 3356 | 1772 | 13640 |
| 7018 | 25382 | 11292 |

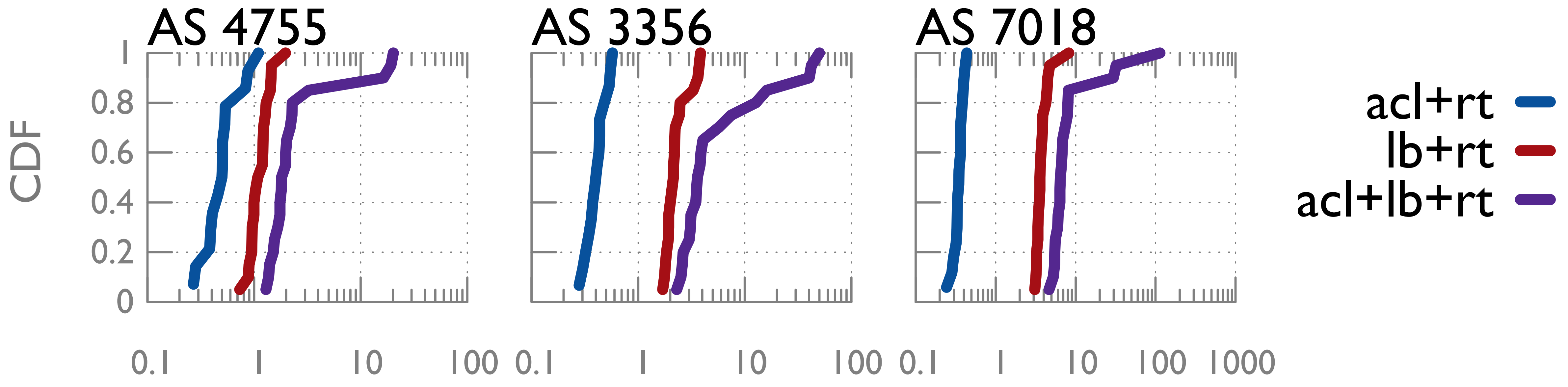
| | |
|---|---|
| compute path | 🟦 |
| lookup ports | 🟦 |
| write to table | 🟧 |
| trigger/rule | 🟥 |

profile end to end delay (normalized per-rule, 30 rounds) for route insertion and deletion

similar profile on fat-tree topology (fewer nodes, more links)

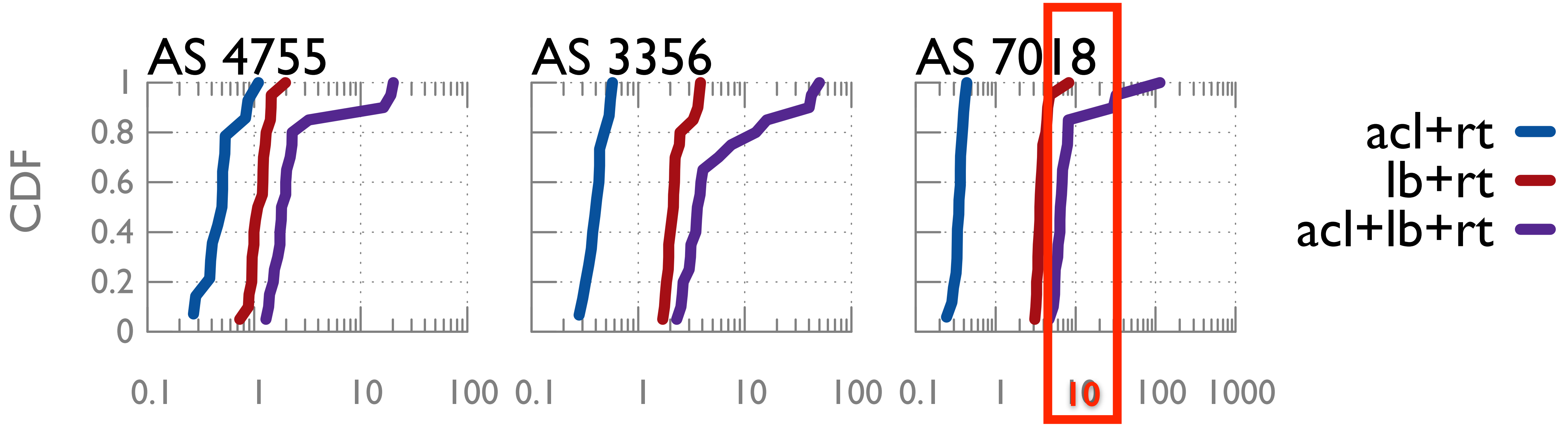
- total delay < 30ms for fat-tree with 5120 switches and 196608 links

# evaluation



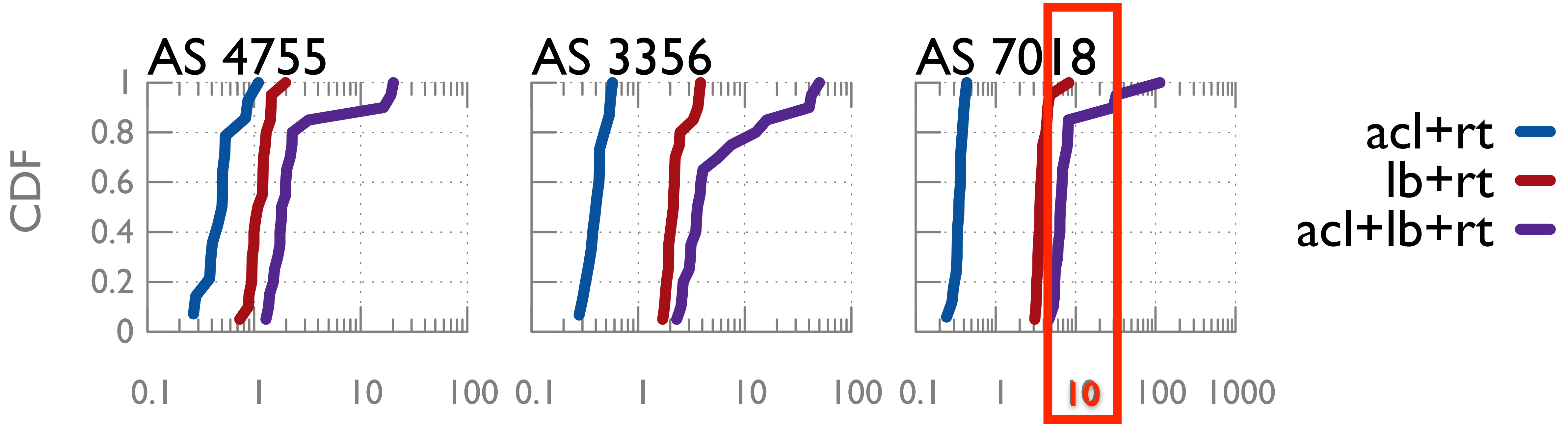
orchestration delay (ms) normalized per-rule for 3 scenarios:
access control and routing (acl+rt), load balancing and routing (lb+rt), access control, load balancing, and routing (acl+lb+rt)

# evaluation



orchestration delay (ms) normalized per-rule for 3 scenarios:
access control and routing (acl+rt), load balancing and routing (lb+rt), access control, load balancing, and routing (acl+lb+rt)

# evaluation



orchestration delay (ms) normalized per-rule for 3 scenarios:
access control and routing (acl+rt), load balancing and routing (lb+rt), access control, load balancing, and routing (acl+lb+rt)

orchestration also scales gracefully on fat-tree

- < 30ms for fat-tree with 5120 switches and 196608 links demo

```
[ravel@ravelvm ravel]$
```

demo

```
[ravel@ravelvm ravel]$
```

# towards a secure Ravel

improper modification of data

- unauthorized modification
- one-directional information flow

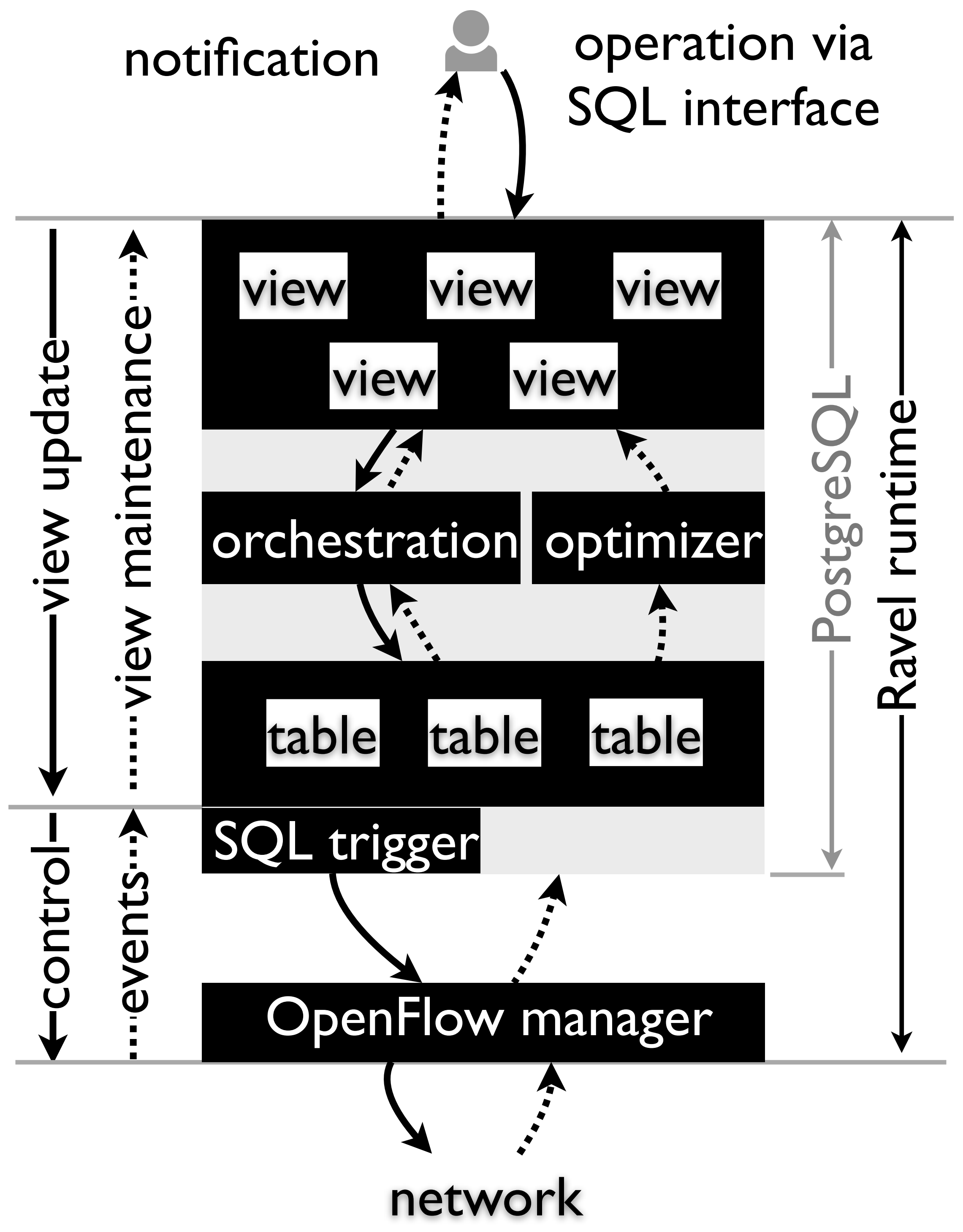
# towards a secure Ravel

expectation of data quality

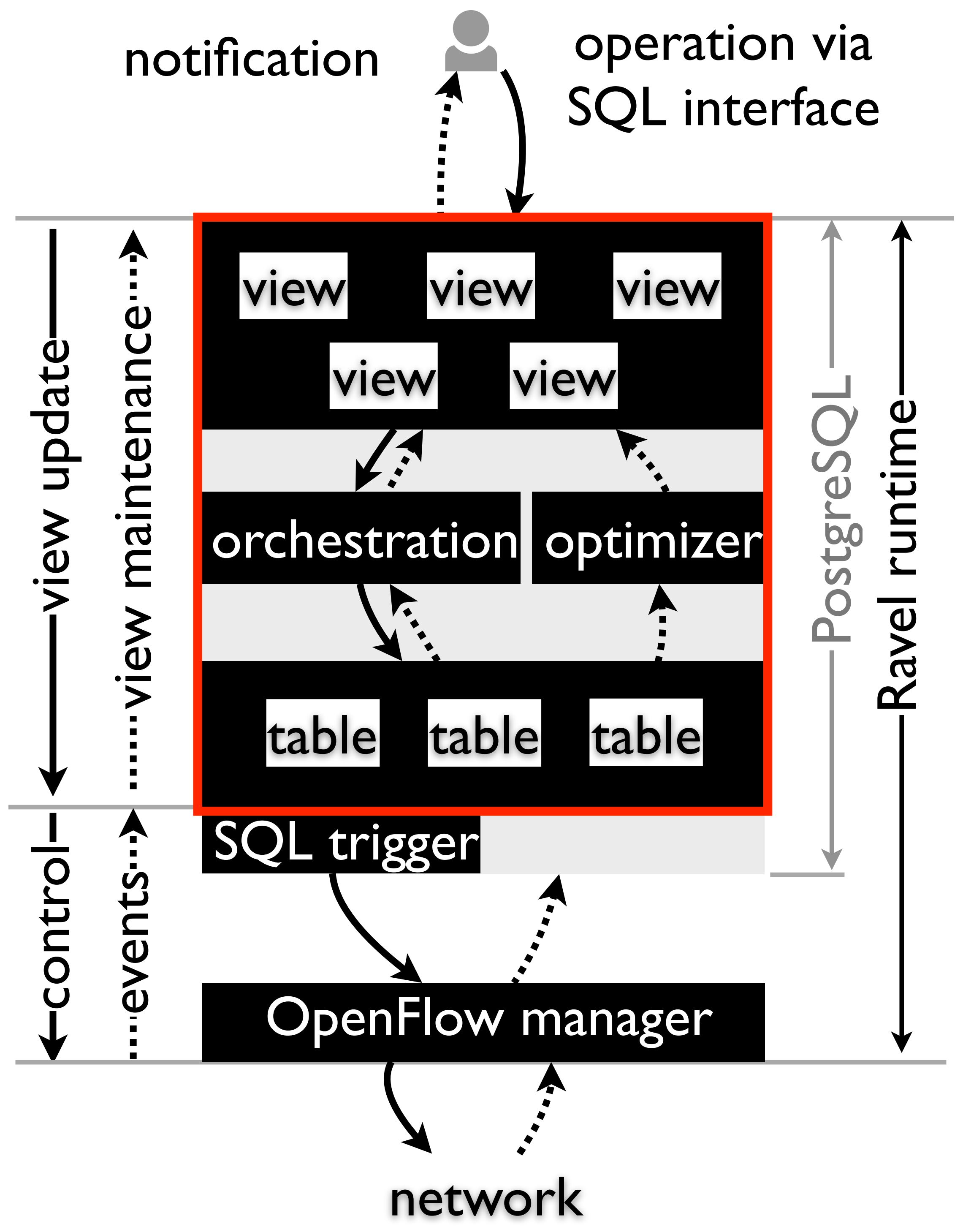
improper medication of data

- unauthorized modification — access control (ACL)
- one-directional information flow

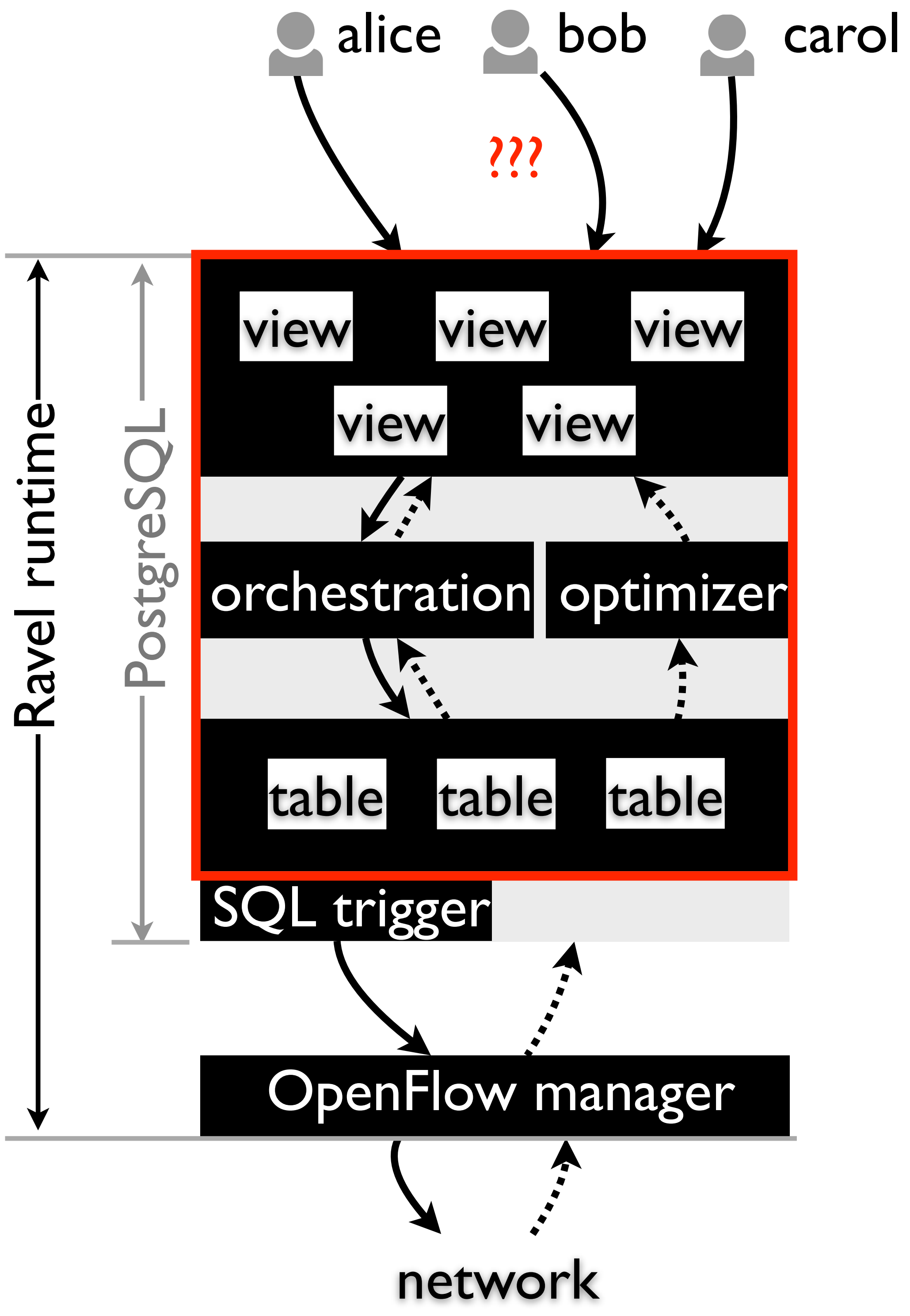
# ACL in Ravel


notification
operation via SQL interface
view
view
view
view
view
orchestration
optimizer
table
table
table
SQL trigger
OpenFlow manager
network
view update
view maintenance
control
events
PostgreSQL
Ravel runtime

# ACL in Ravel


notification
operation via SQL interface
view
view
view
view
view
orchestration
optimizer
table
table
table
SQL trigger
OpenFlow manager
network
view update
view maintenance
control
events
PostgreSQL
Ravel runtime

# ACL in Ravel


alice
bob
carol
???
view
view
view
view
view
orchestration
optimizer
table
table
table
SQL trigger
OpenFlow manager
network
Ravel runtime
PostgreSQL

# example scenario

## a SDN network and multiple tenants

- admin can see/modify all resources, see/modify the network
- tenants can only see the resources they pay
- tenants can only manage their portions of network under contract

SLA (service level agreement)

| tenant | switches | rate limit | connectivity |
|---|---|---|---|
| alice | {1,2,3,4} | 20 | {alice} |
| bob | {51,52,53,…} | 50 | {bob, alice} |
| carol | {100,101,…} | 10 | {carol, alice} |

# explicit access control list (ACL)

## <principal, subject, operation>

ACL on topology

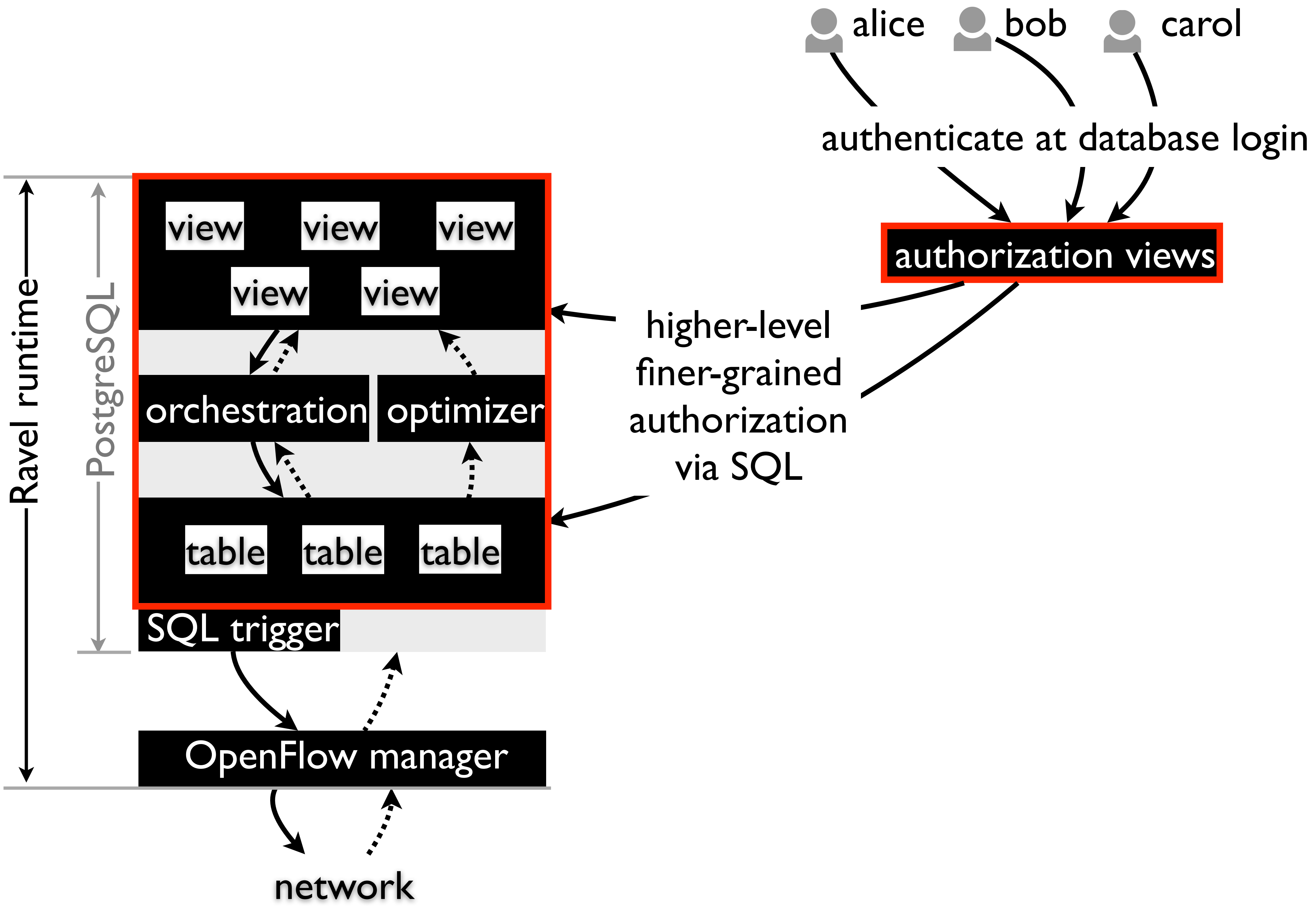
| users | switches | privilege |
|---|---|---|
| alice | 1 | read |
| alice | 2 | read |
| alice | … | read |
| bob | … | read |
| carol | … | read |
| admin | … | read,write |
| … | … | … |

ACL on configuration

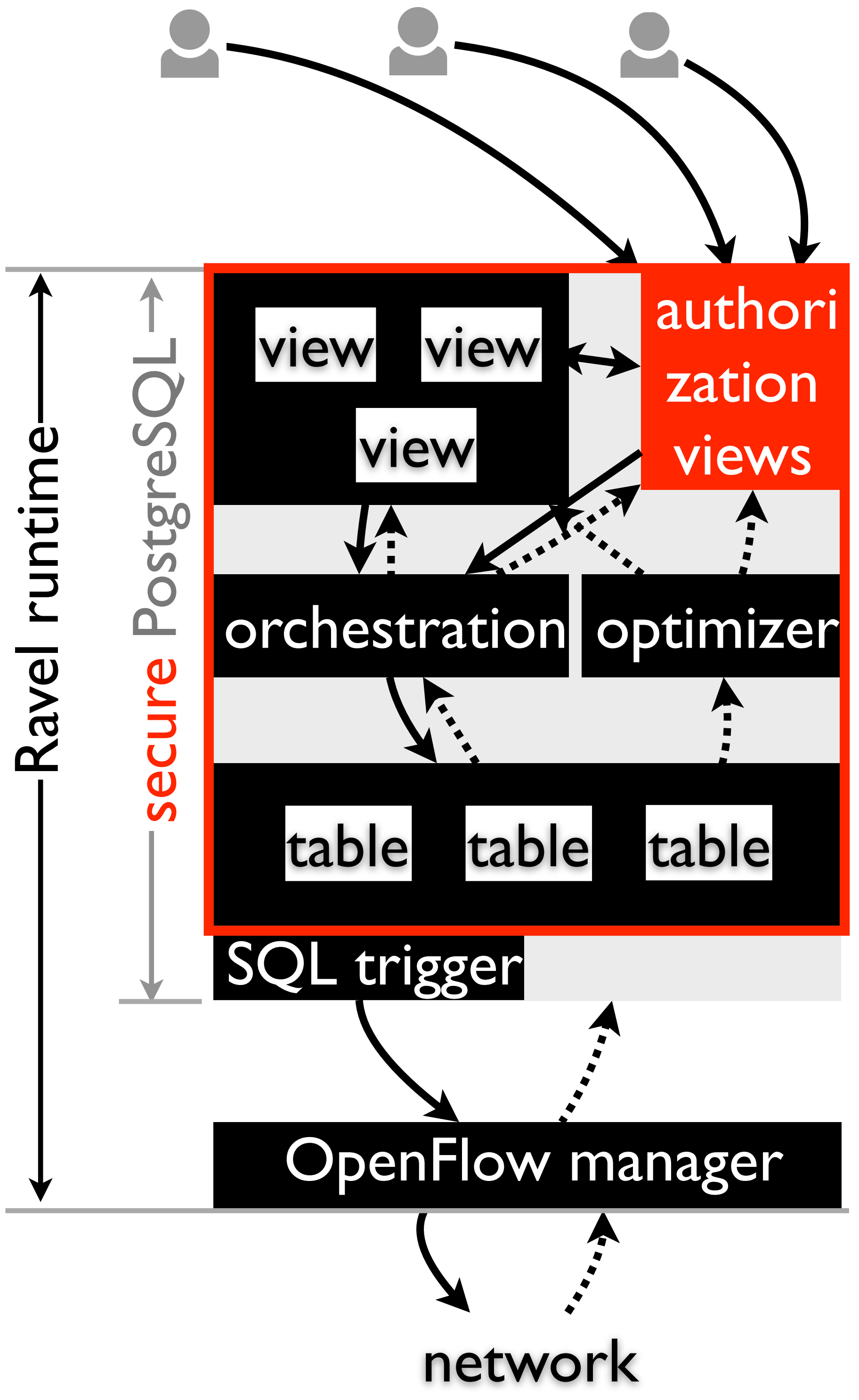
| users | flows (source, destination, rate) | privilege |
|---|---|---|
| alice | (1,2,<20) | read,write |
| alice | (2,3,<20) | read,write |
| alice | … | … |
| bob | … | … |
| … | … | … |

- very low-level
- update ACL as tenant contract evolves

# ACL in Ravel


alice
bob
carol
authenticate at database login
authorization views
higher-level finer-grained authorization via SQL
Ravel runtime
PostgreSQL
view
view
view
view
view
orchestration
optimizer
table
table
table
SQL trigger
OpenFlow manager
network

# ACL in Ravel



Ravel runtime
secure PostgreSQL
view
view
view
authorization views
orchestration
optimizer
table
table
table
SQL trigger
OpenFlow manager
network

## authorization views: a strawman solution

associate each table with an ACL

- <principal, allowed operation>

create a separate view

- if only a portion of a table is granted to a principal
- benefit: dynamic, content-based

# authorization views: a strawman solution

```
-- admin policy
GRANT SELECT, UPDATE, INSERT, DELETE ON topology TO admin;
GRANT SELECT, UPDATE, INSERT, DELETE ON configuration TO admin;
```

```
-- alice policy
CREATE OR REPLACE VIEW topology_alice AS (
       SELECT sid, nid FROM topology
       WHERE (topology.sid = 1 OR topology.sid = 2 OR …);

CREATE OR REPLACE VIEW configuration_alice AS (
       SELECT fid, sid, nid FROM configuration
       WHERE ((topology.sid = 1 AND topology.nid = 2) OR
              (topology.sid = 1 AND topology.nid = 2) OR …) AND
              rate < 20);

GRANT SELECT ON topology_alice TO alice;
GRANT SELECT, INSERT, DELETE, UPDATE ON configuration_alice TO alice;
```

```
-- bob policy, carol policy ...
```

# limitations

many tenants

- for each tenant, create a separate view?

dynamic tenant membership

- add/remove views?

SLAs evolving

- update tenant views?

more examples:

- tenants can only access the resources the pay
- raise tenant rate limit to100

# finer-grained, higher-level ACL

capture the intent rather than extent

dynamic, context-based

$$\begin{tikzcd}[column sep=huge]
\begin{array}{c}\text{a network table of arity n}\\ p(\_,\_,\ldots,\_)\end{array} \arrow[r, "\begin{array}{c}\text{SQL query over data}\\ \text{in p \textit{and other parts} of}\\ \text{the network database}\end{array}"] & \begin{array}{c}\text{access control view of n+1 arity}\\ p\_acl\ (principal,\ \_,\_,\ldots,\_)\end{array}
\end{tikzcd}$$

# finer-grained, higher-level ACL

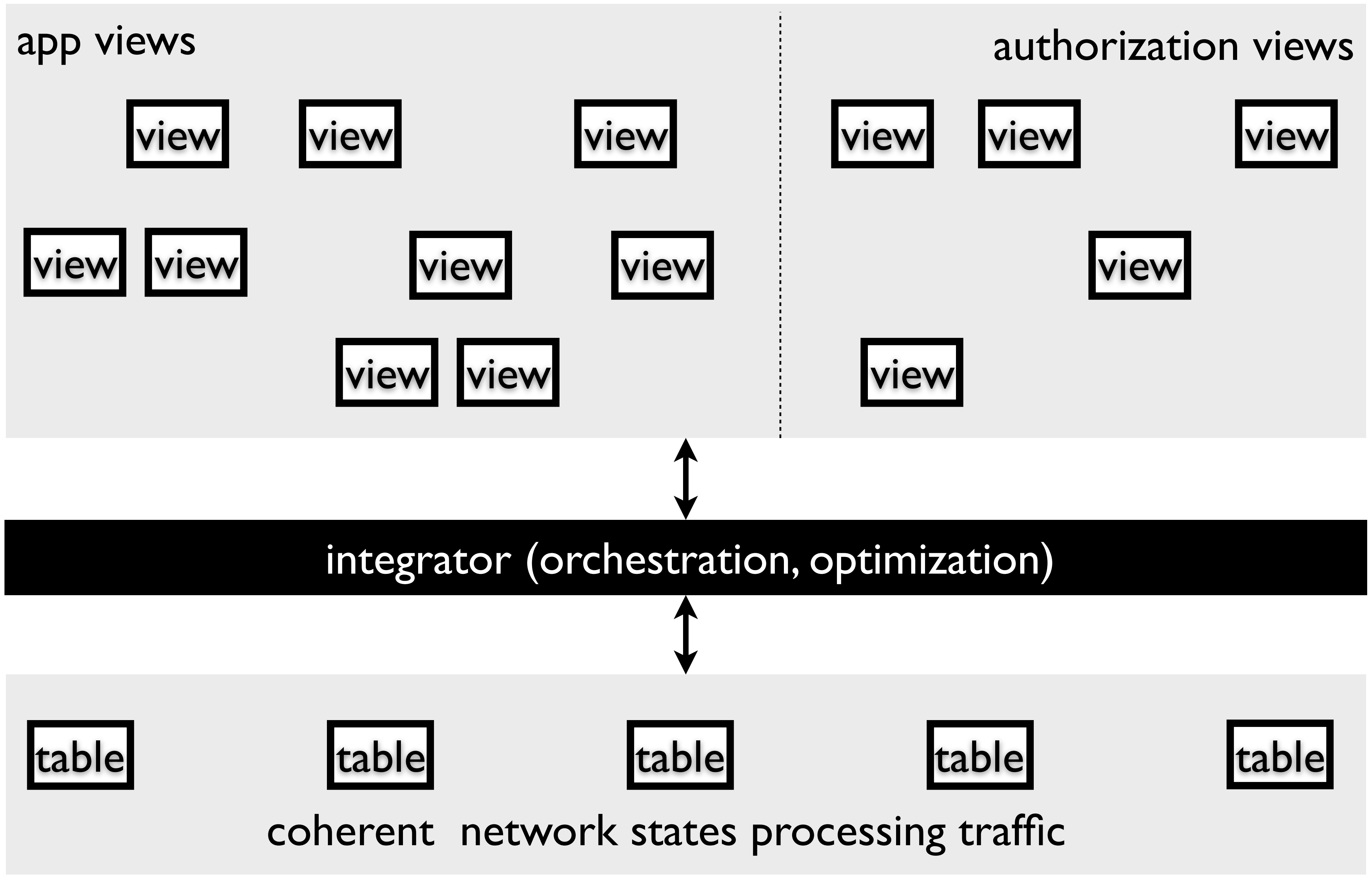
- a tenant can only access the leased network topology
- admin can access the whole topology

```
CREATE VIEW topology_acl AS (
       -- admin policy
       (SELECT 'admin' as principal,
        sid, nid
        FROM topology)
       UNION

       -- tenant policy
       (SELECT tenant as principal,
              sid, nid
        FROM topology, SLA
        WHERE topology.sid IN SLA.switches
              AND topology.nid IN SLA.switches));
```

```
CREATE VIEW topology_public AS (
       SELECT sid, nid FROM topology_acl
       WHERE principal = 'current_user')

GRANT SELECT ON topology_public TO public;
```

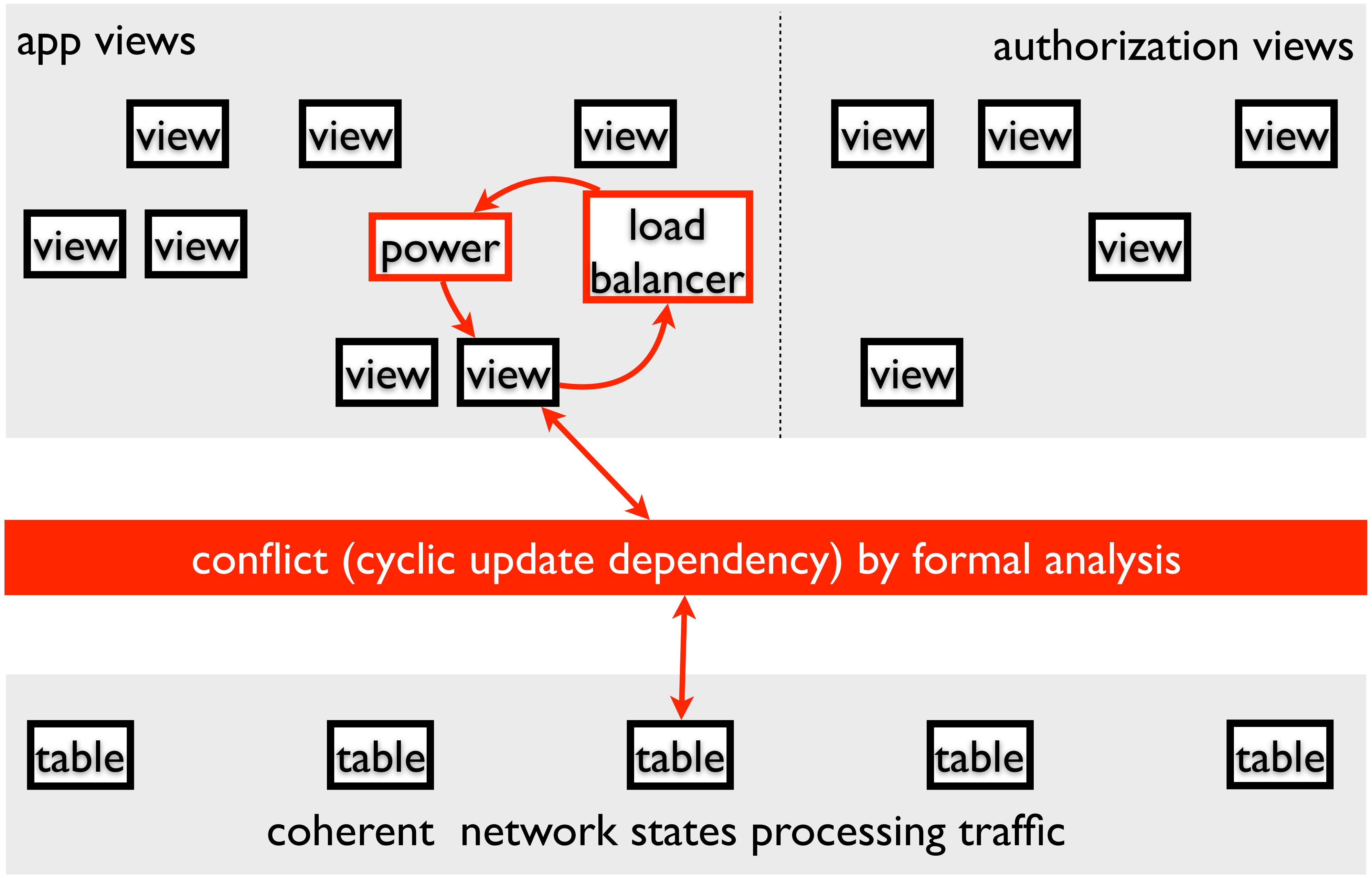
# looking forward

## data integration as a networking service



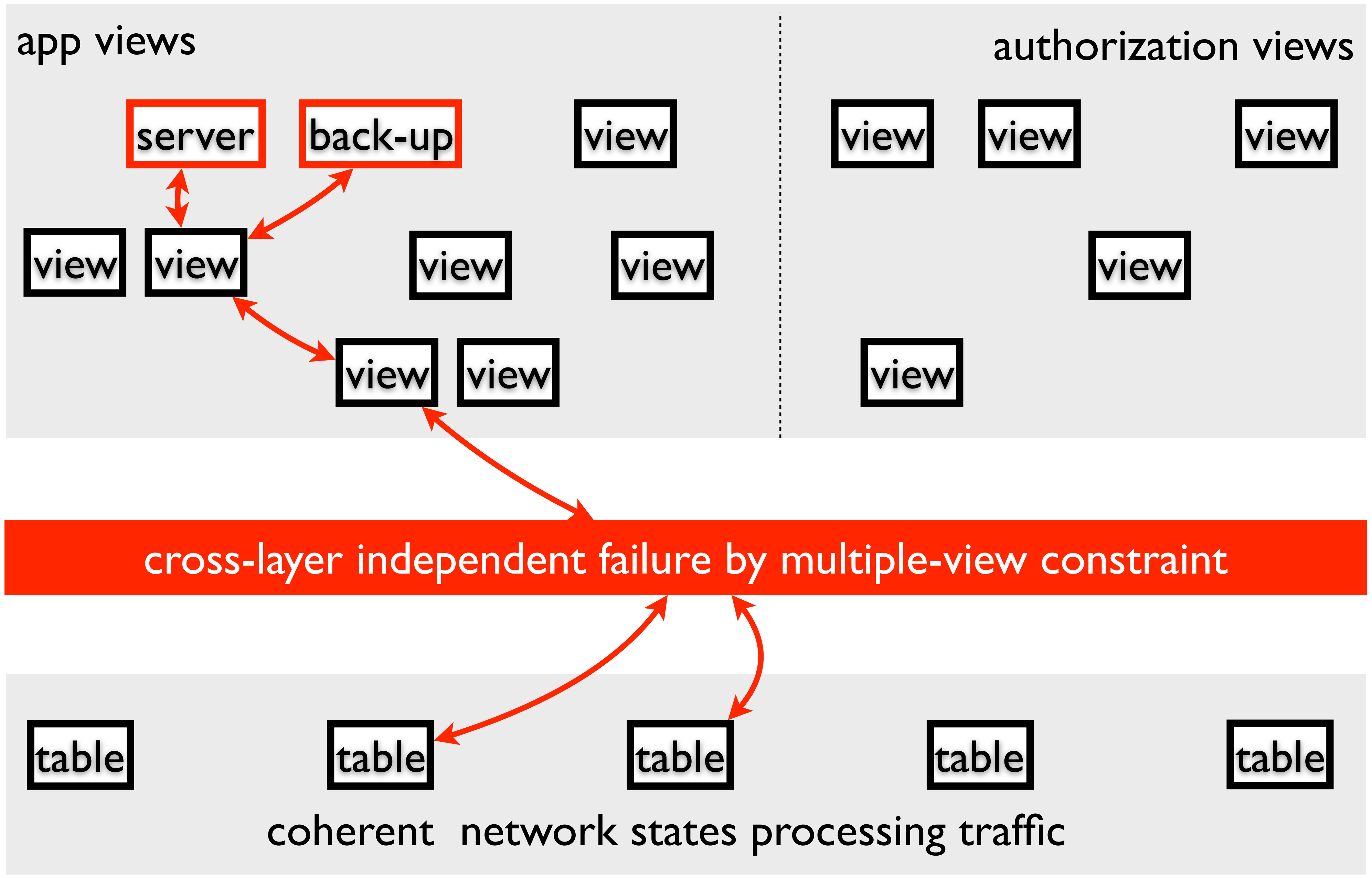
# looking forward

## data integration as a networking service



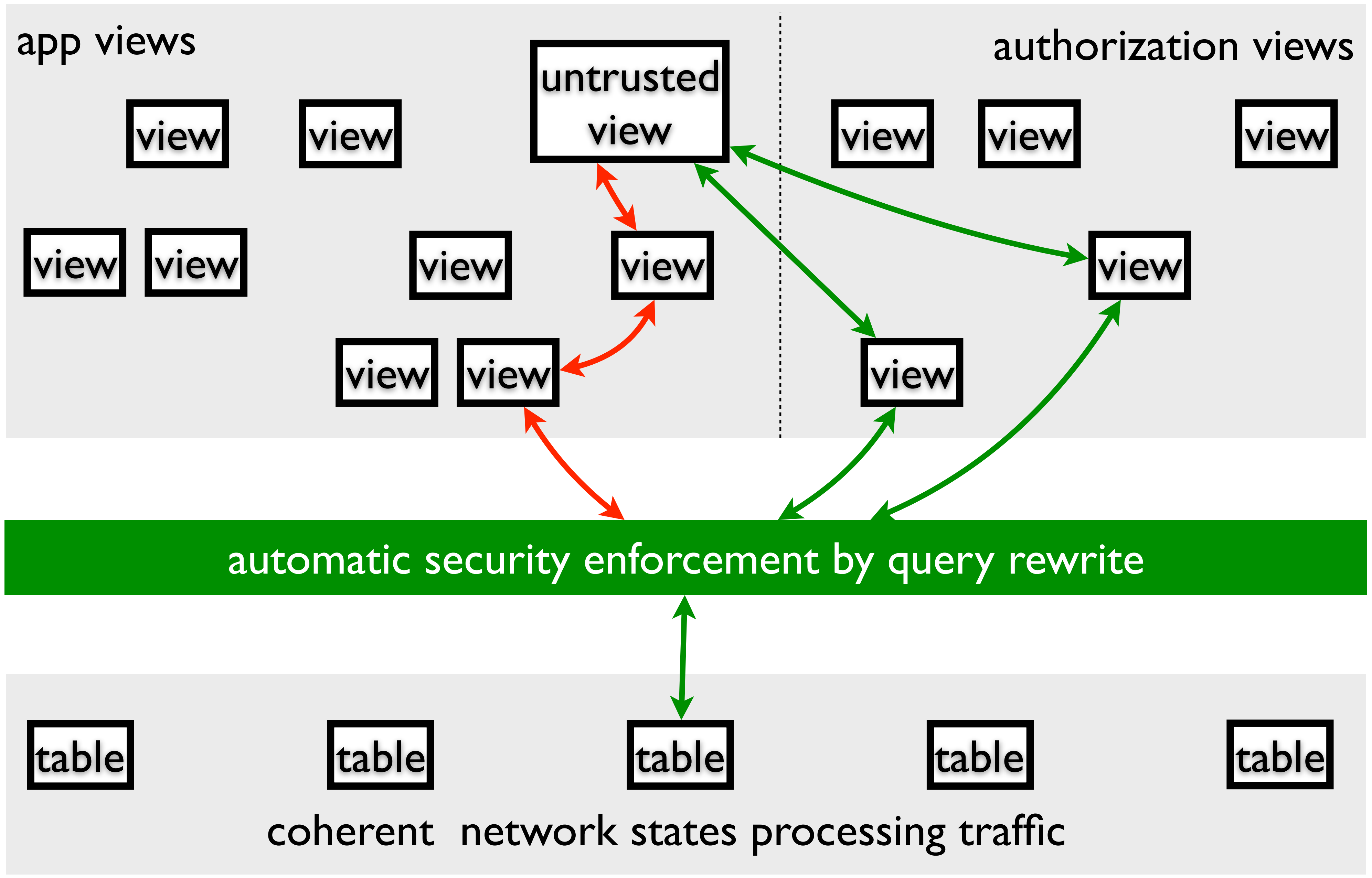
# looking forward

## data integration as a networking service

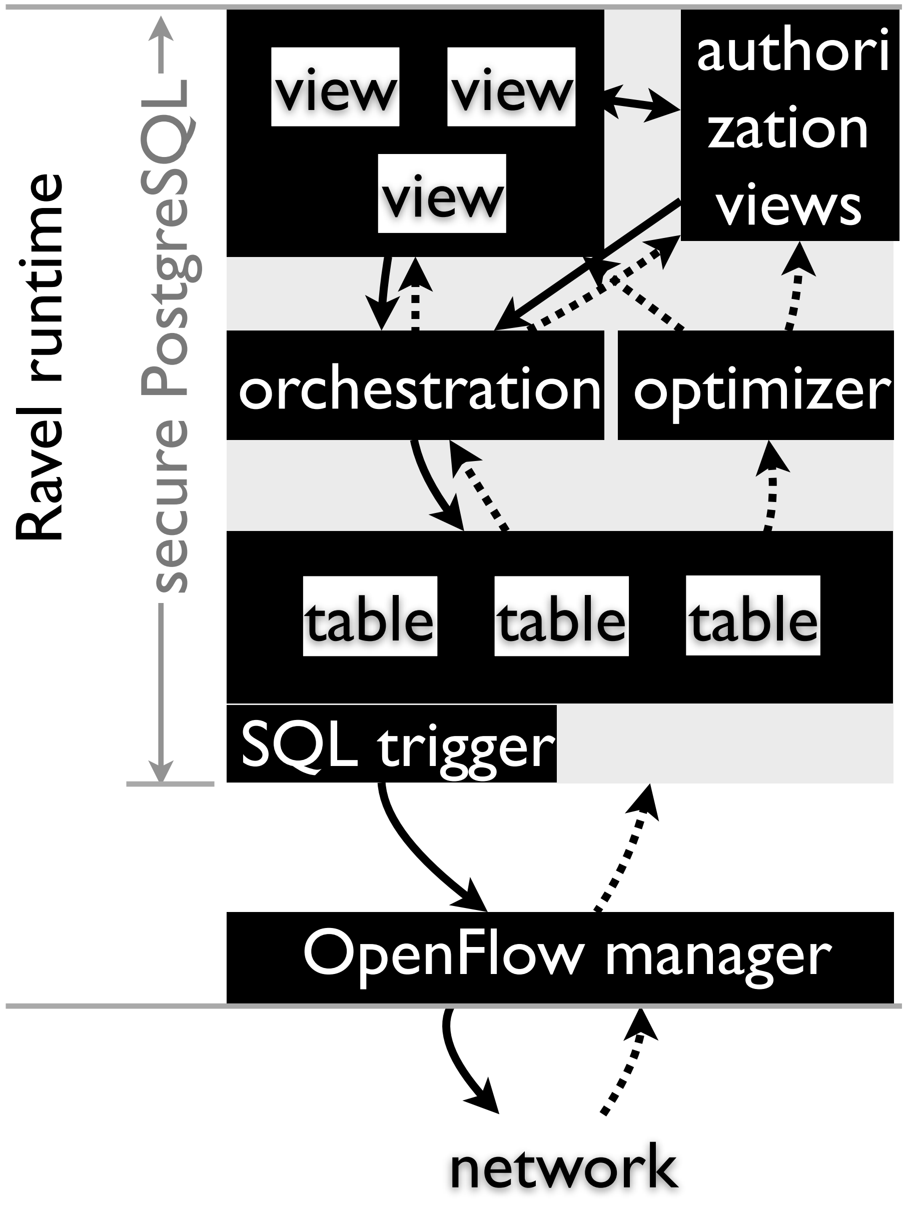


# looking forward

## data integration as a networking service



# conclusion



this talk: via SQL

- orchestratable abstraction
- finer-grained access control

looking forward

- data integration as a networking service

# playtime

download *Ravel*

[ravel-net.org/download]

start playing: tutorials, add your own app

[ravel-net.org]

explore more

[github.com/ravel-net]