Ravel: a database-defined network

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Matthew Caesar† Brighten Godfrey†

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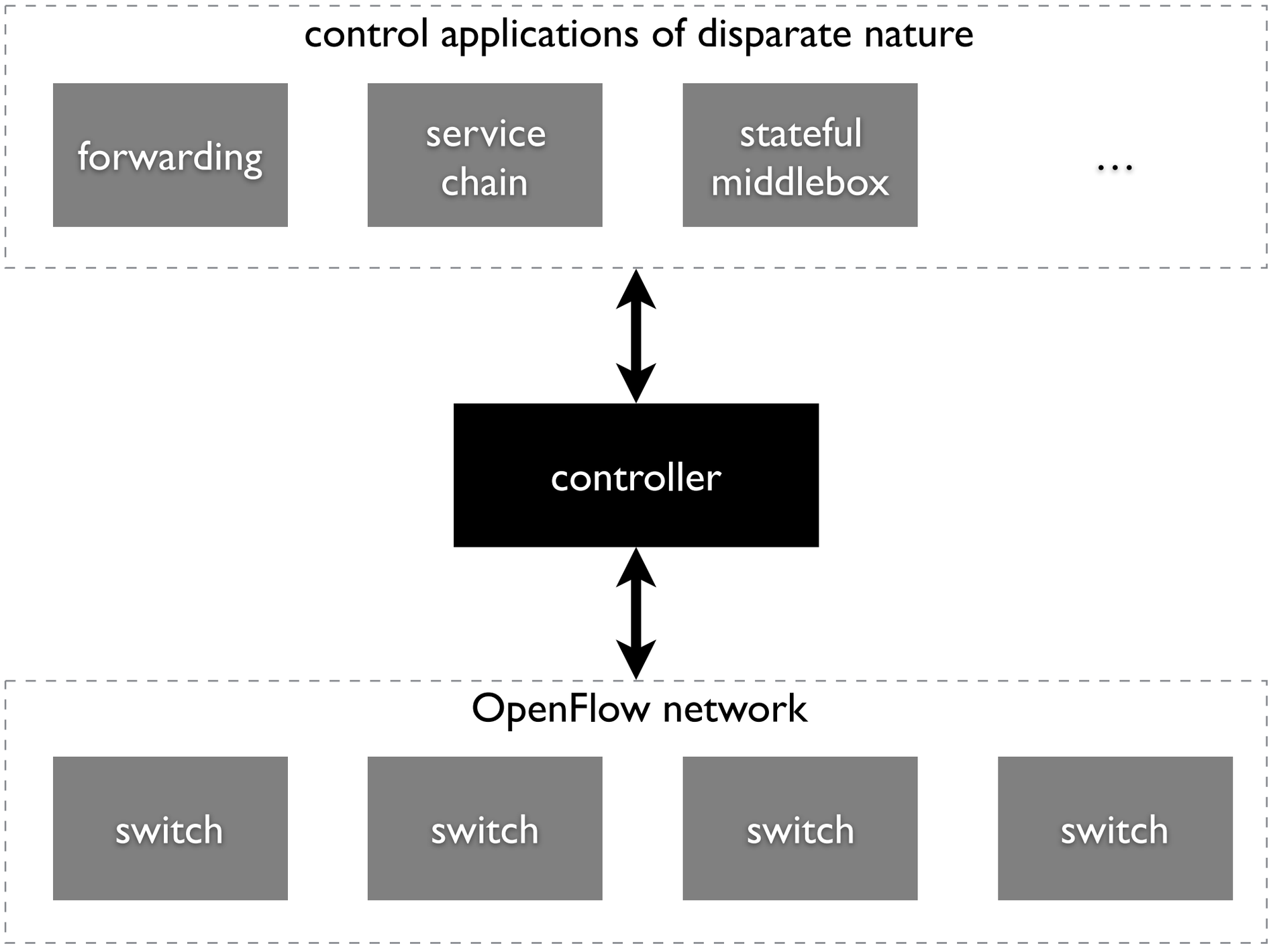
software-defined network



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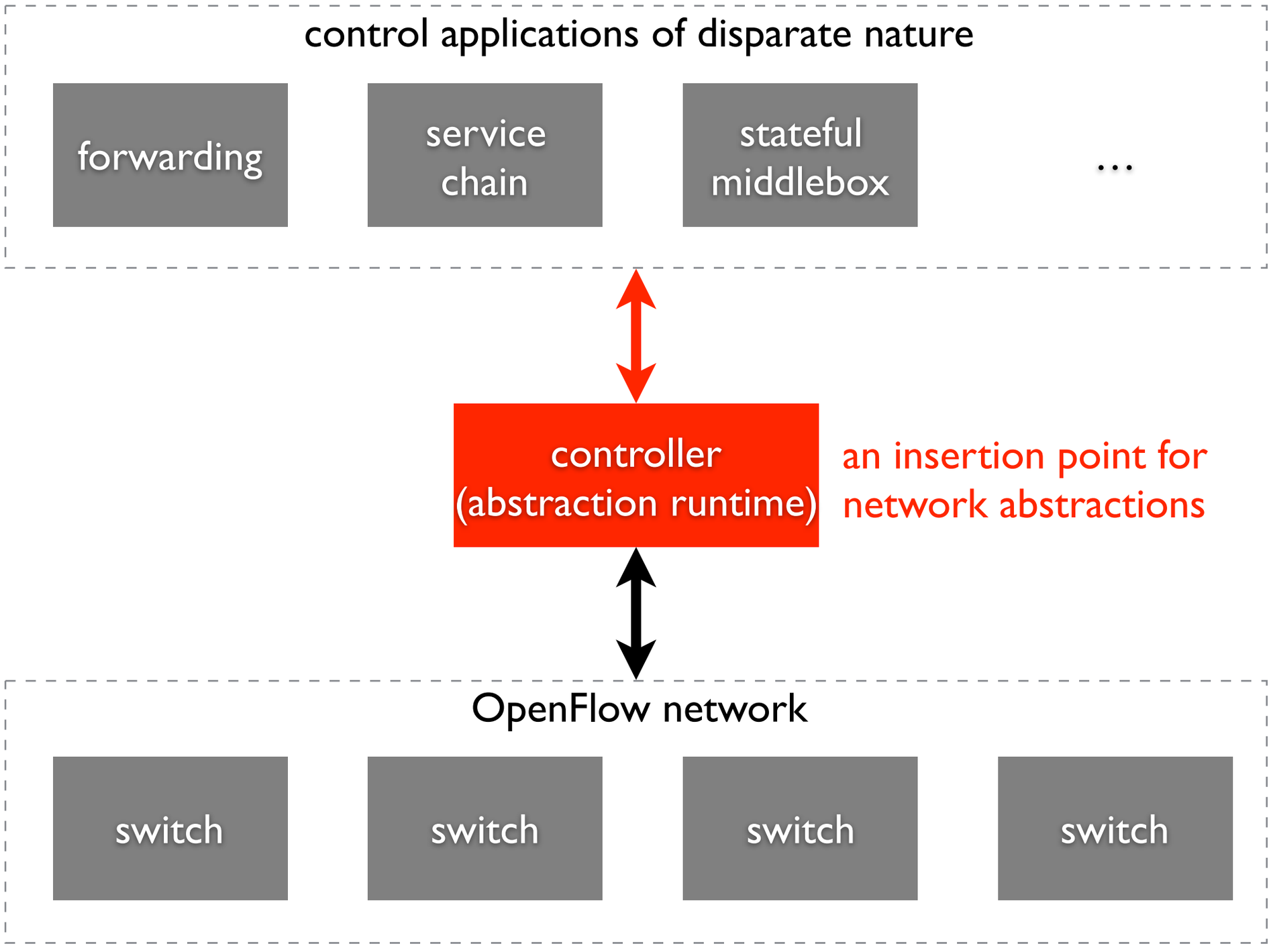
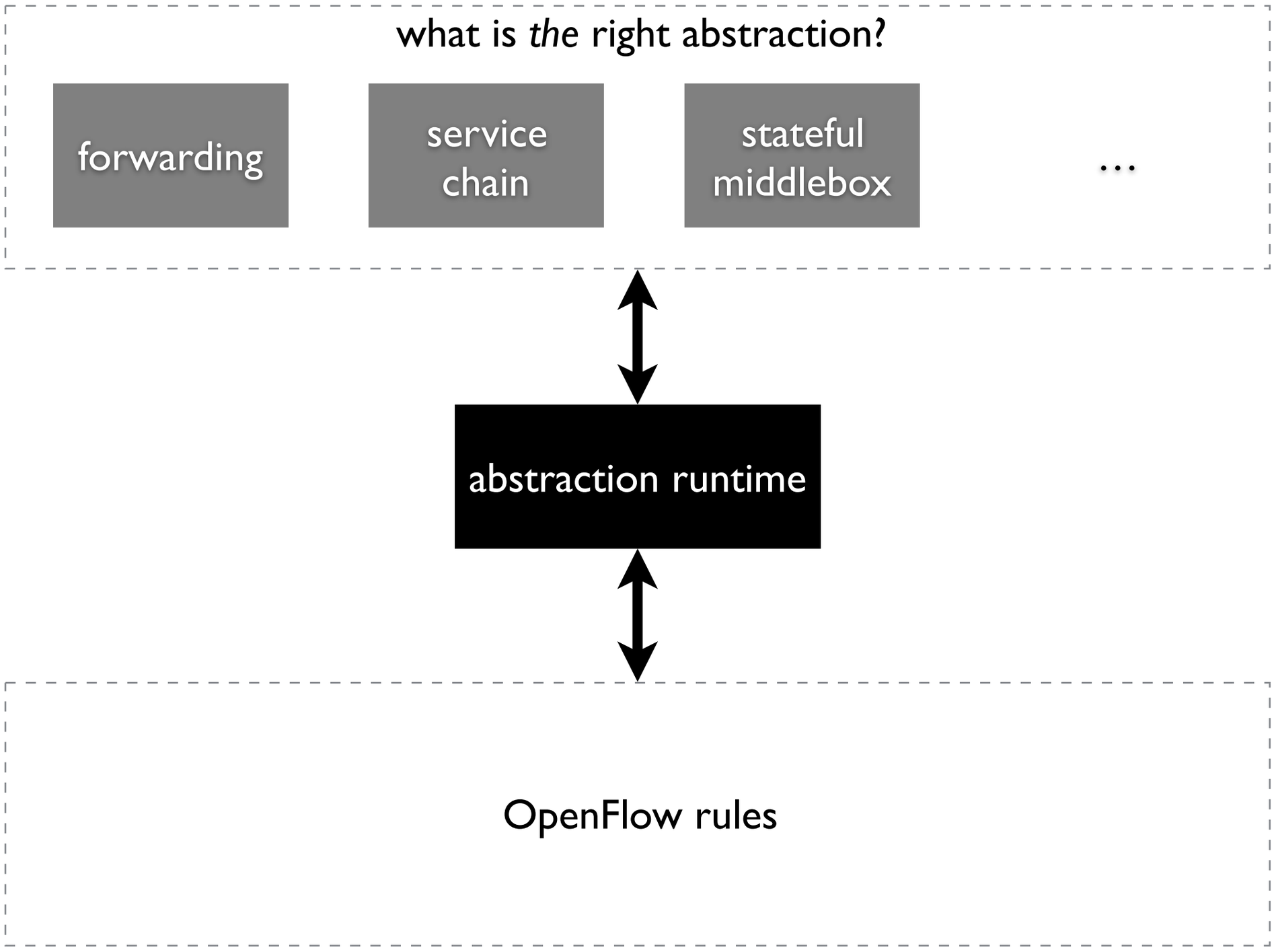


abstractions



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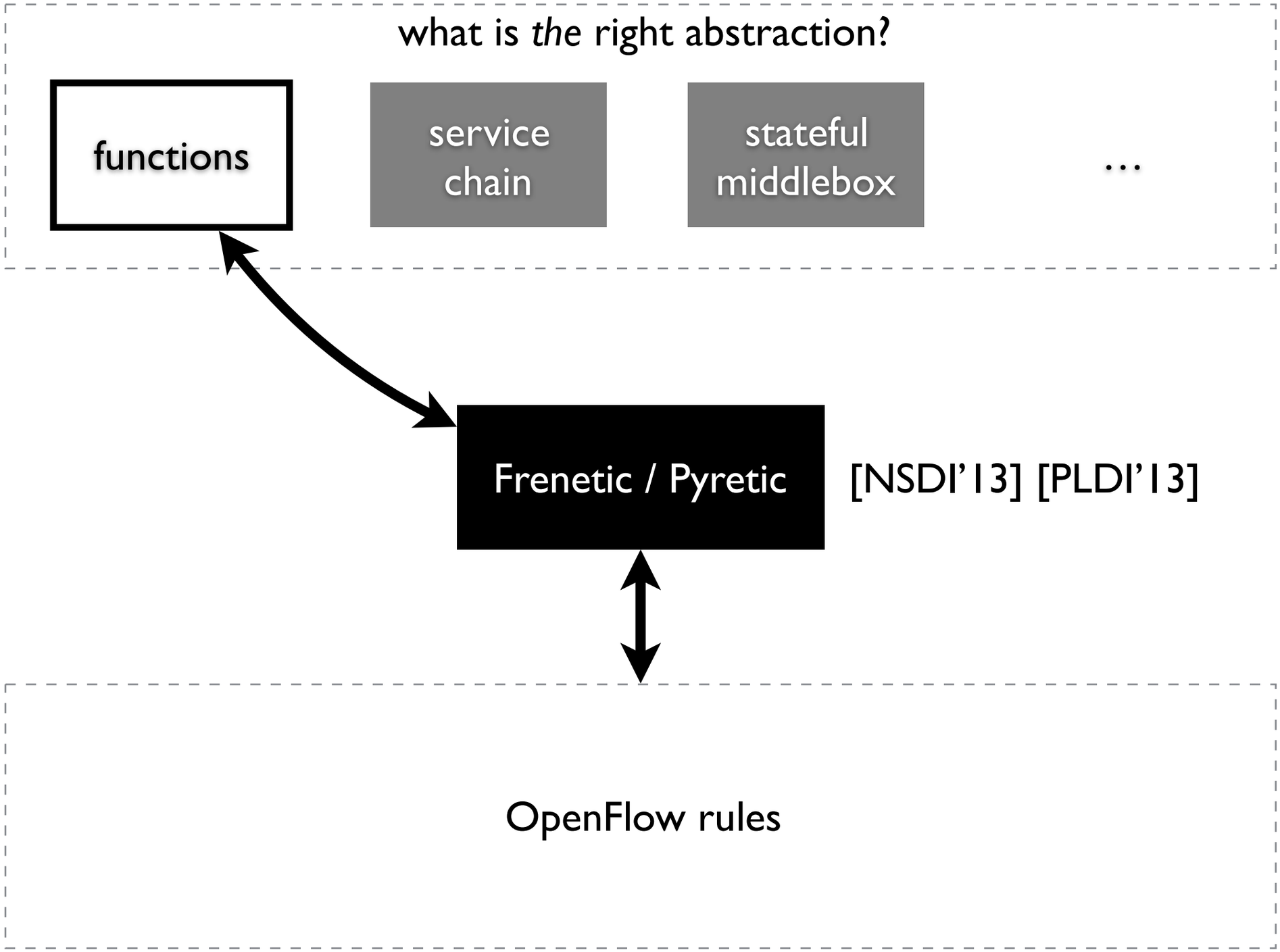

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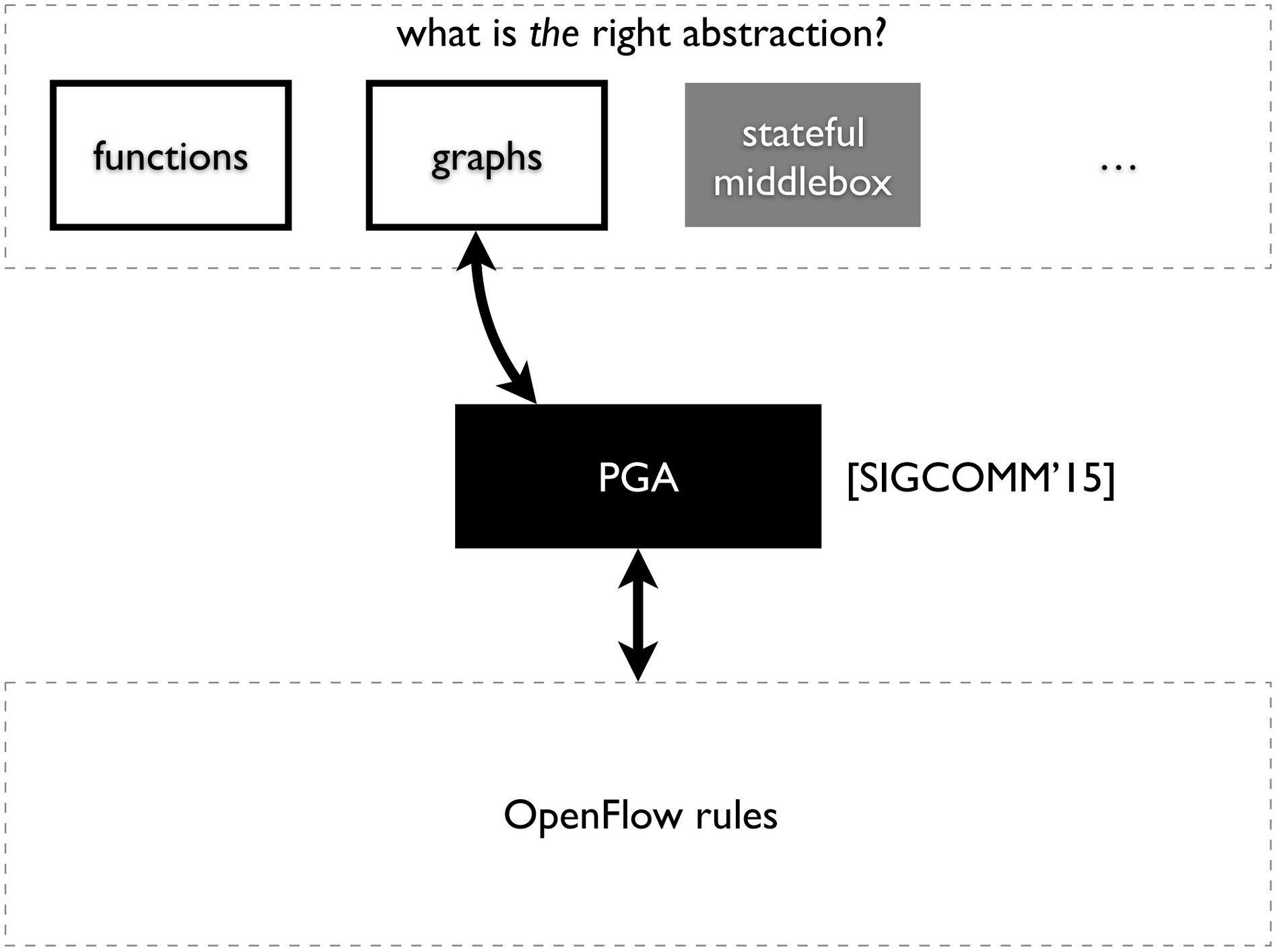

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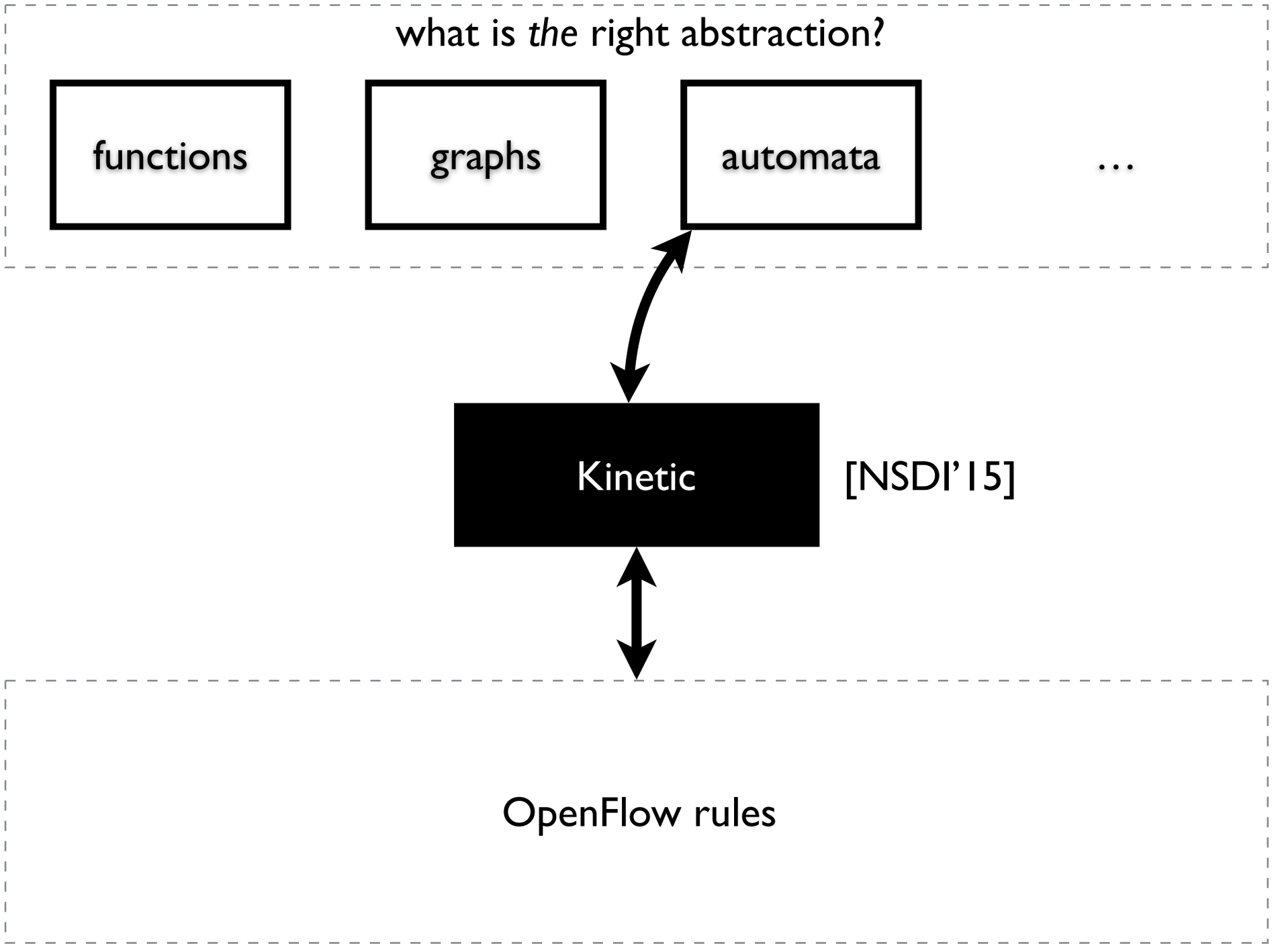

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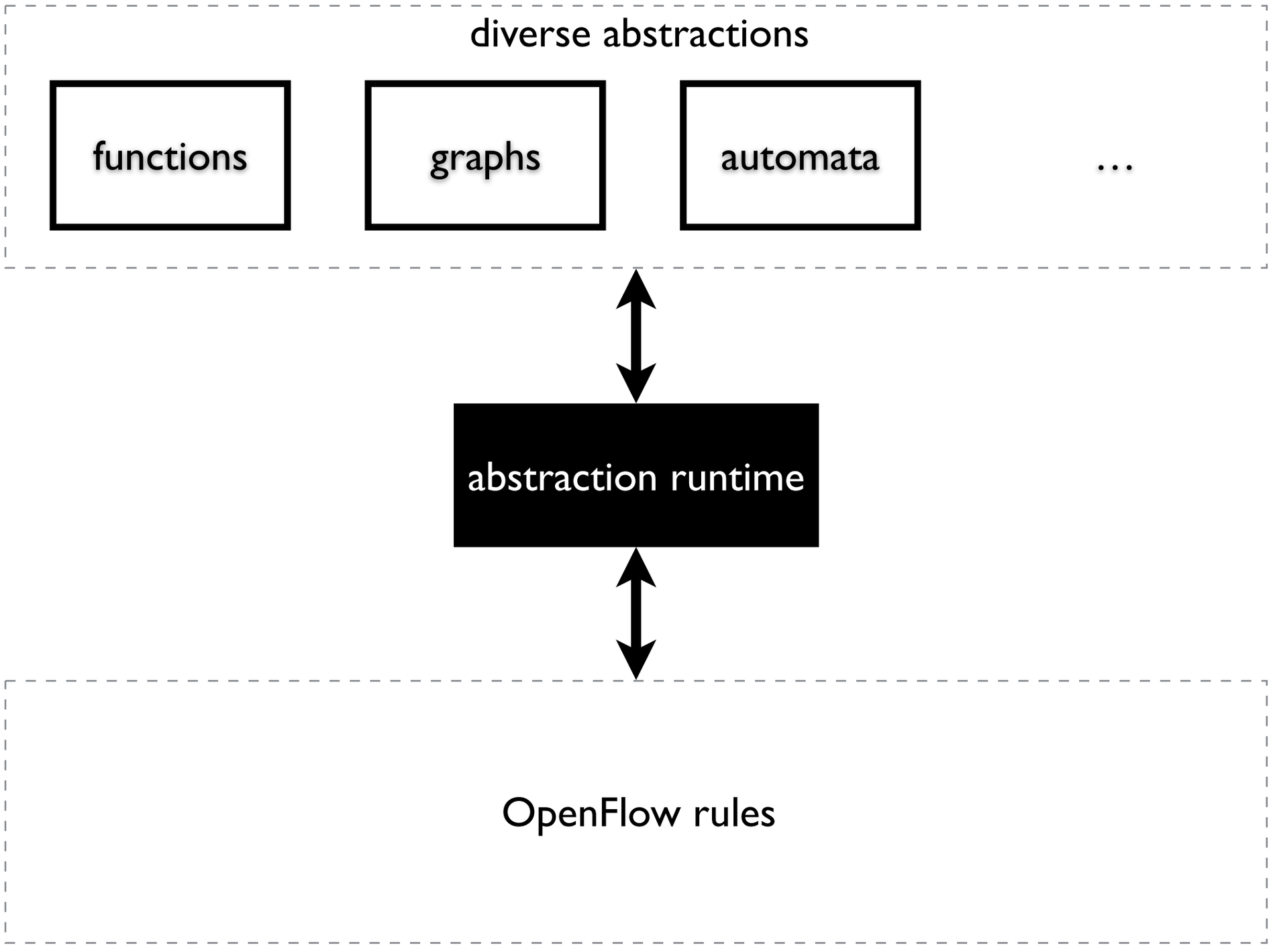
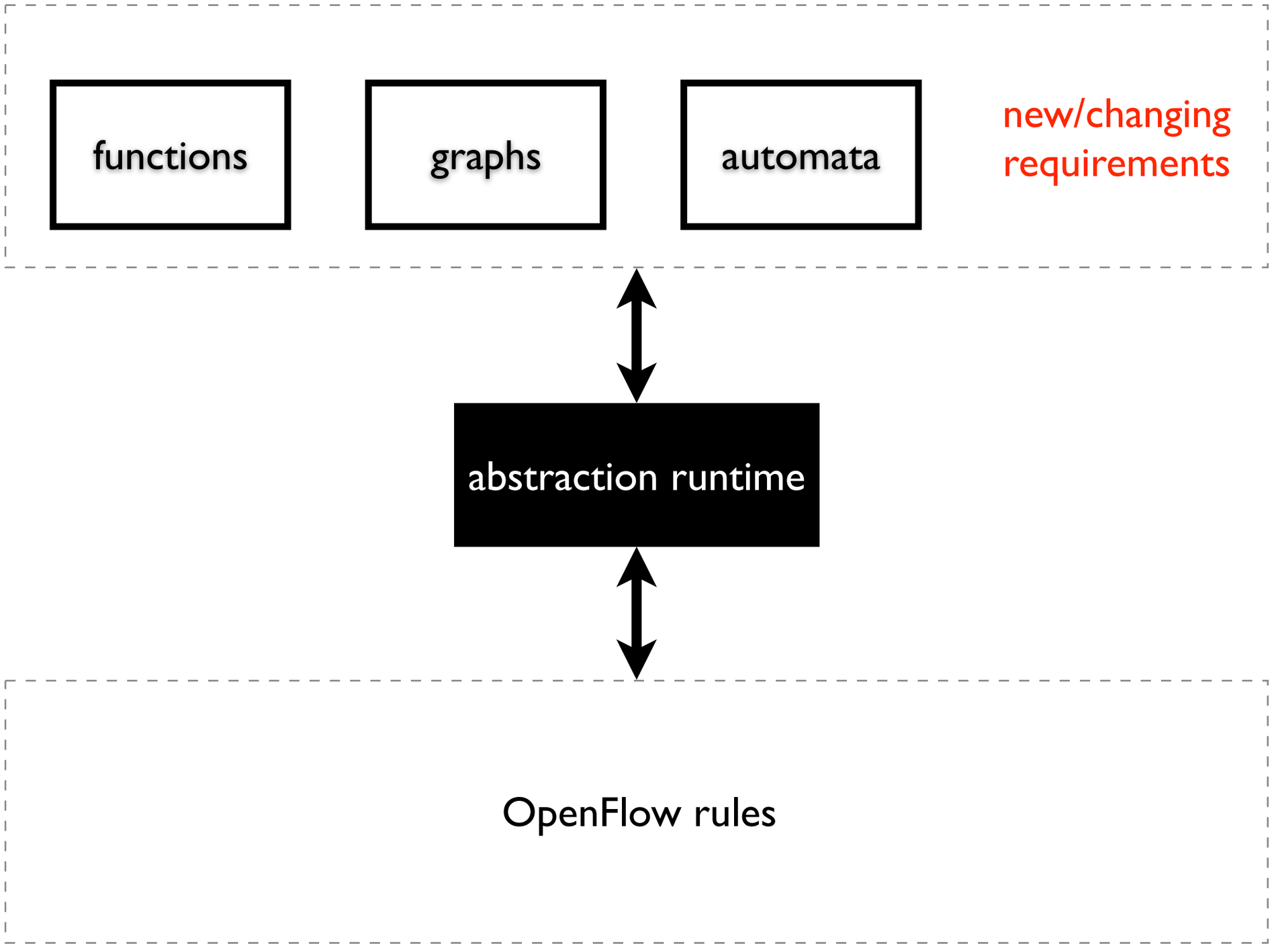


but network keeps evolving



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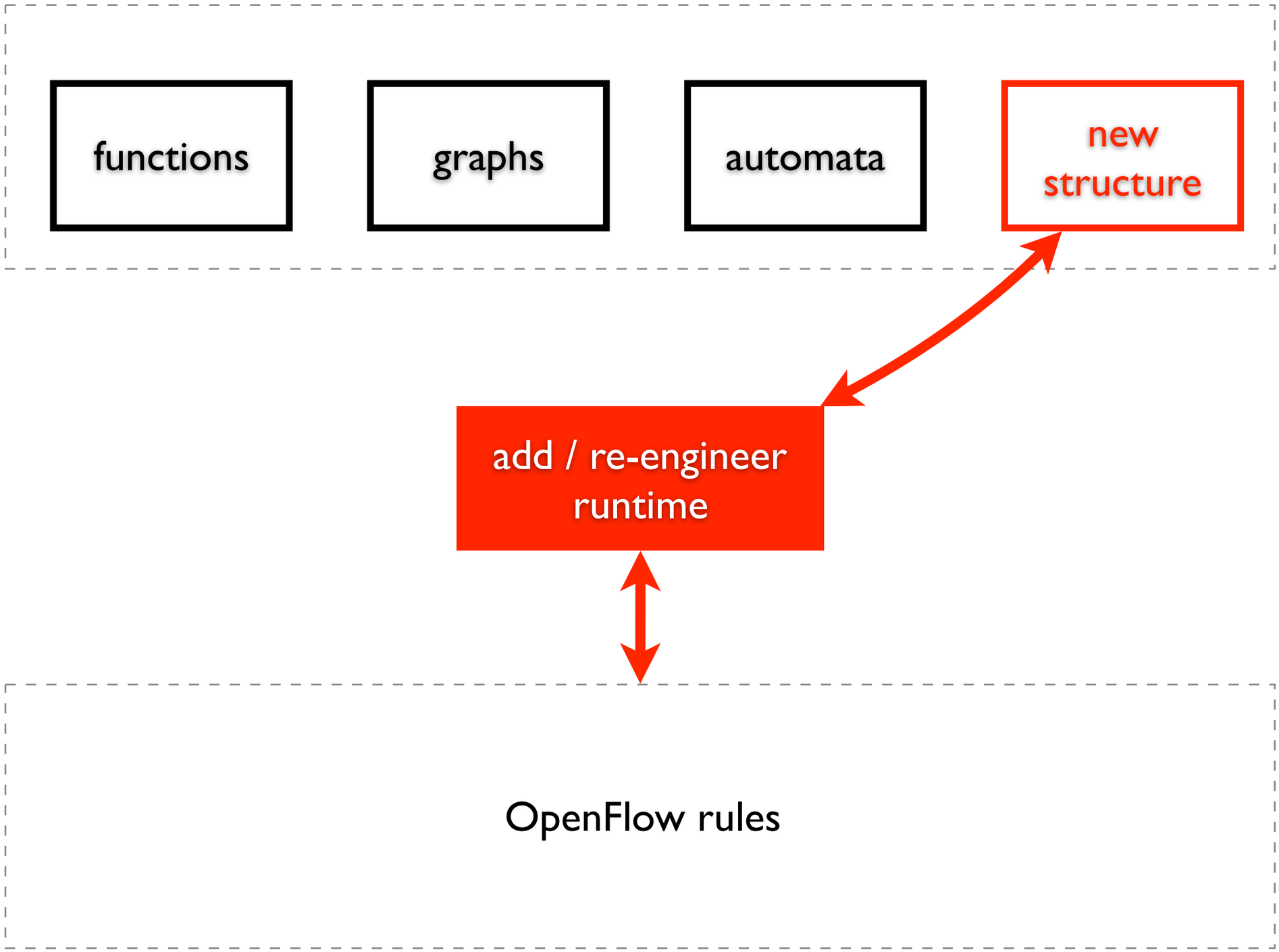
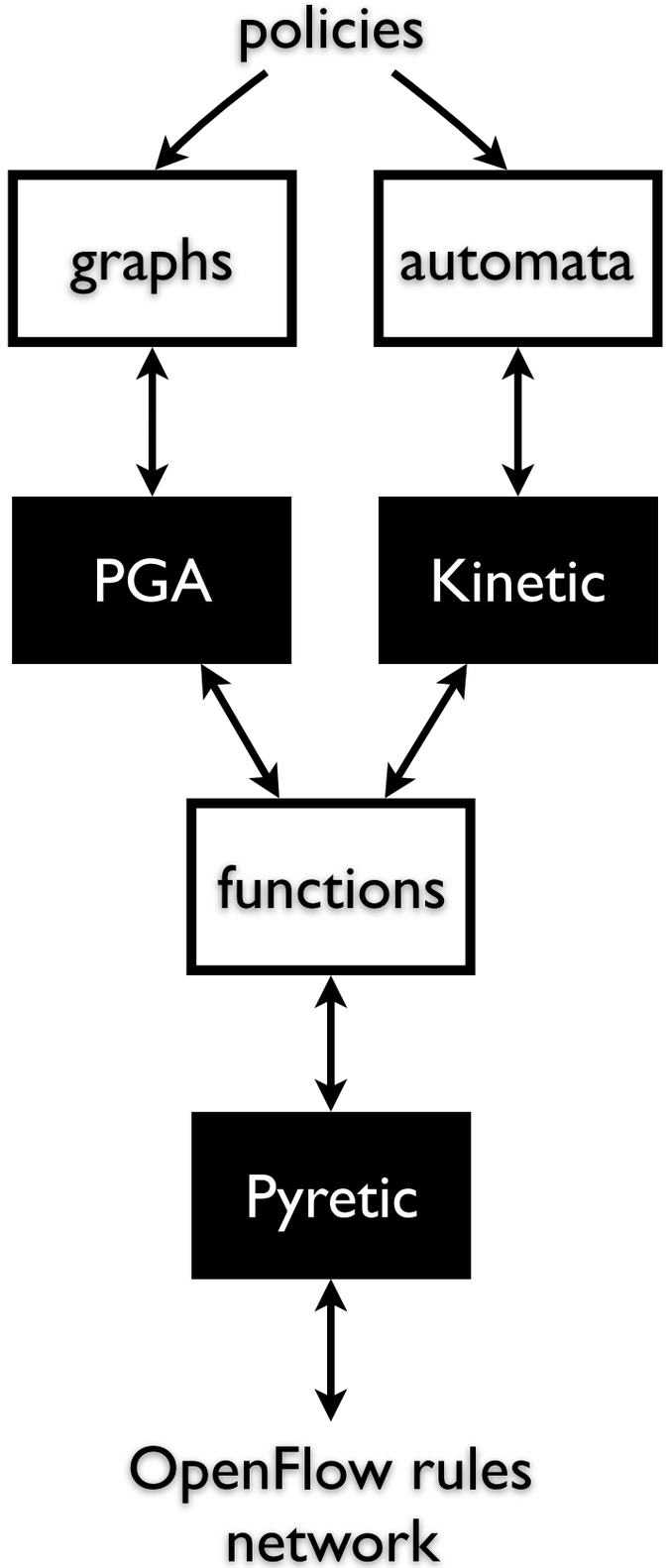


and applications (components) interact



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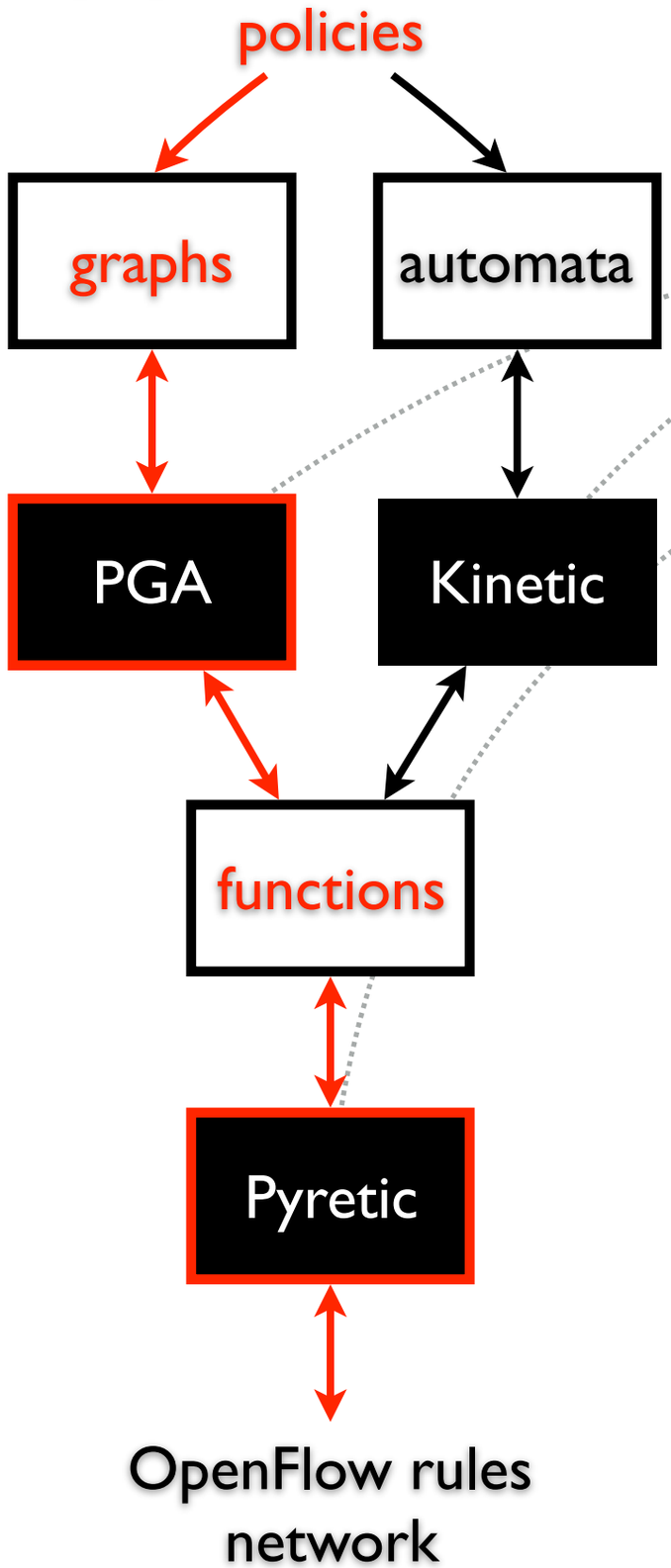
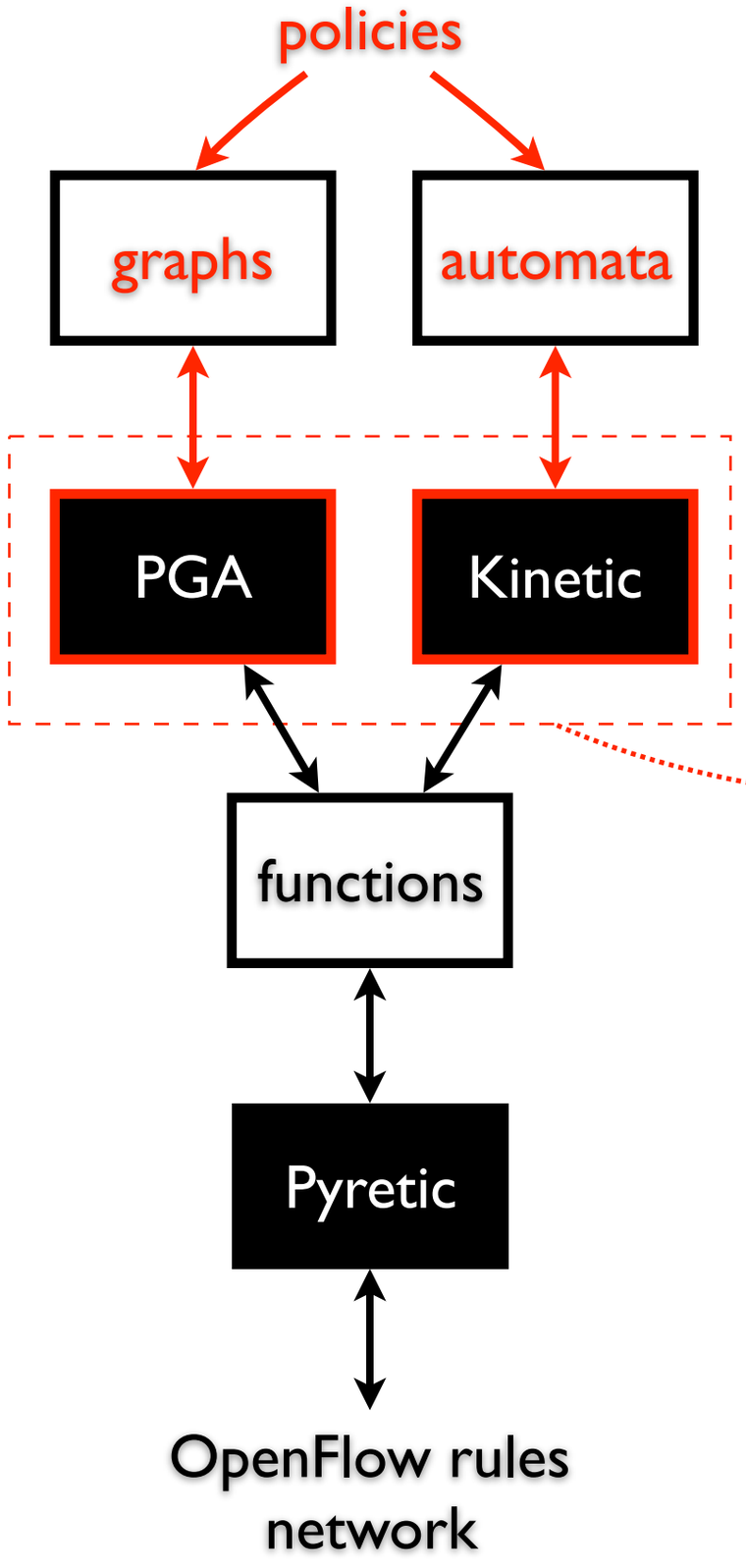


language-level orchestration restricted to each abstraction

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

and applications (components) interact

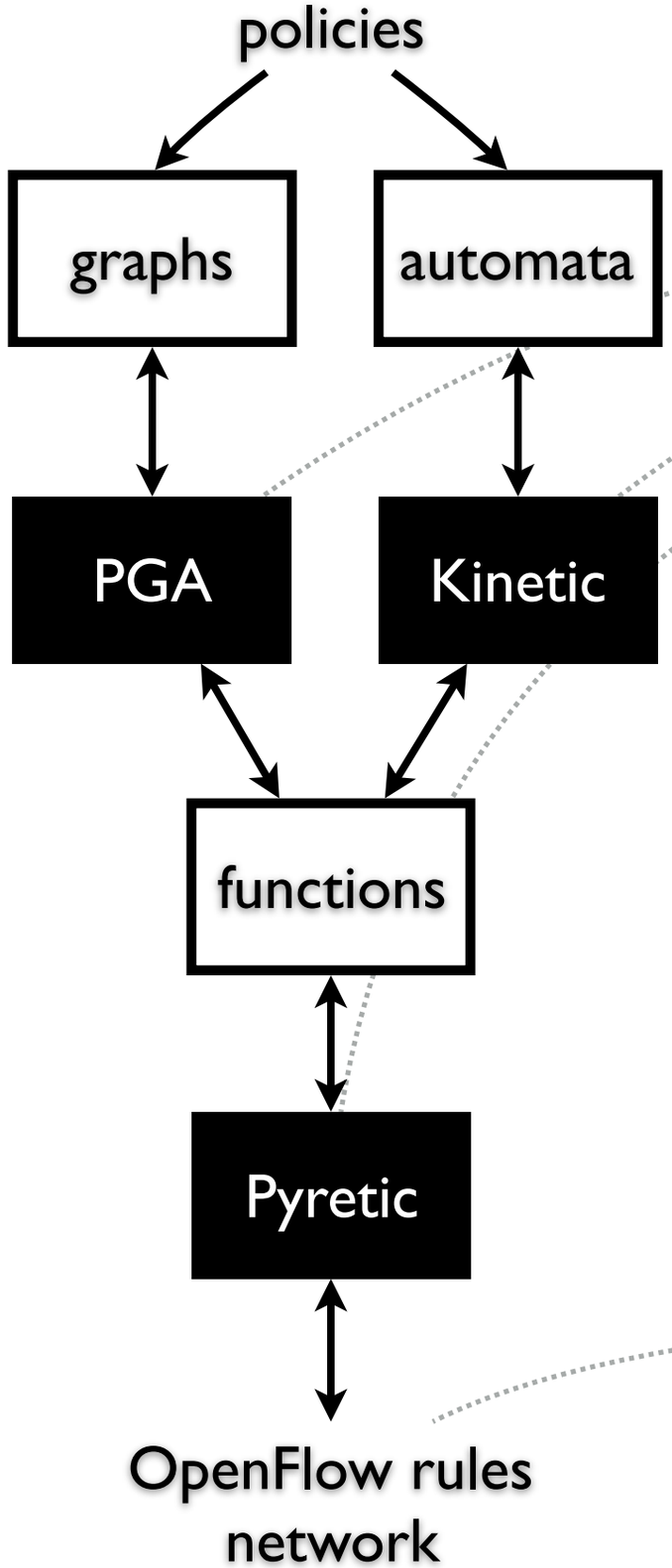


language-level orchestration restricted to each abstraction

composing (+) policy
→ graph +? automata

how to integrate the runtime?
hard-wiring internals?

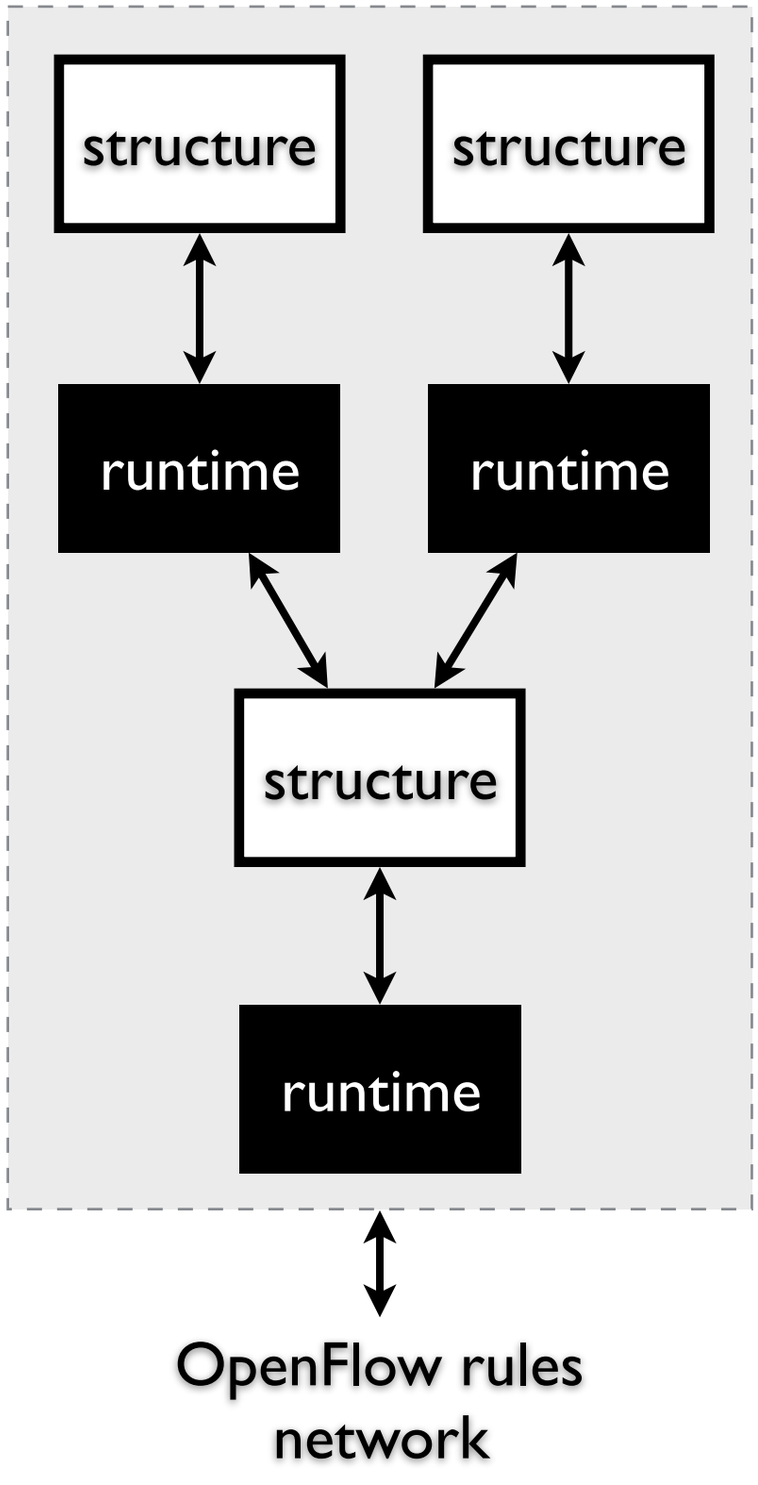
and applications (components) interact



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



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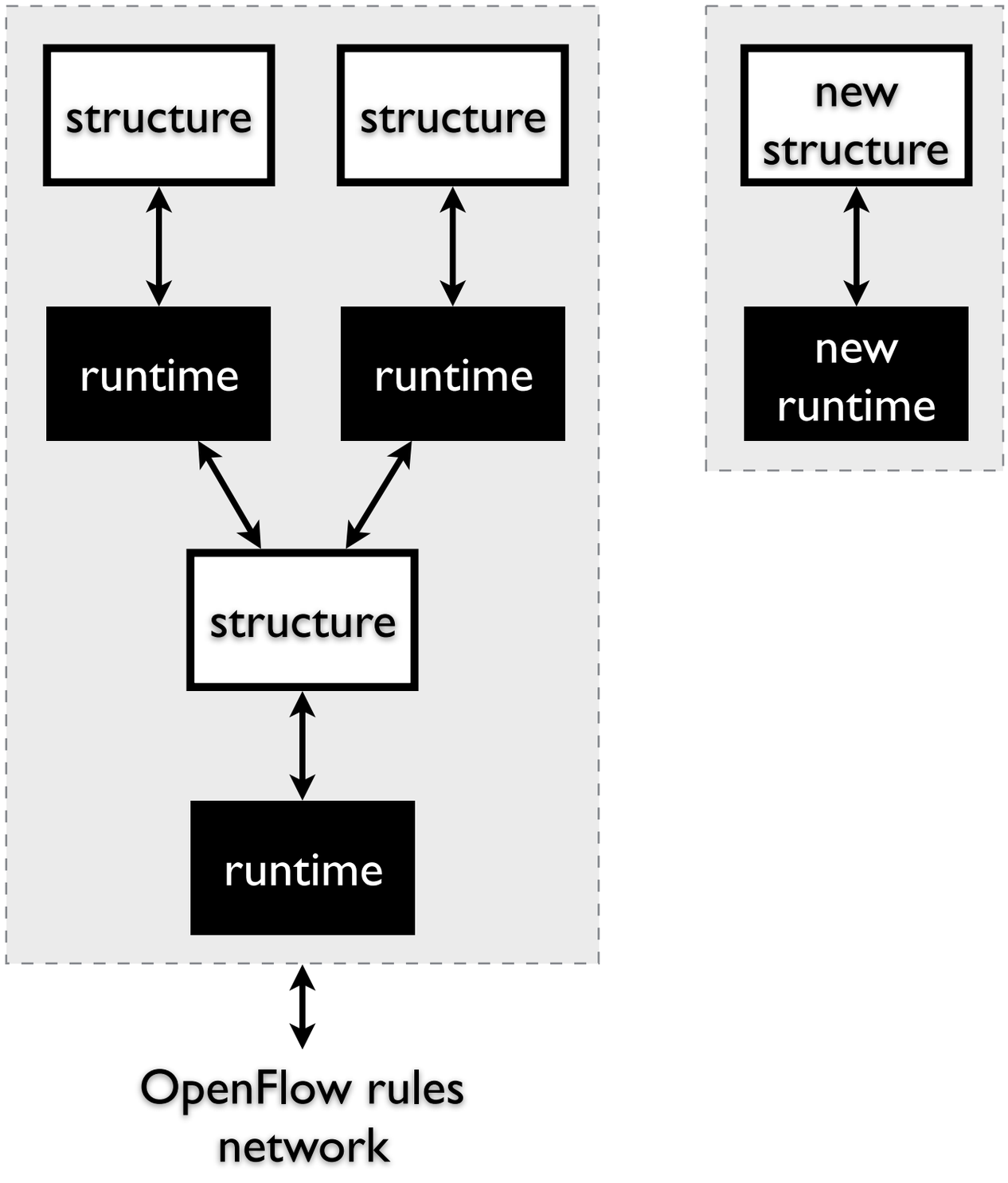
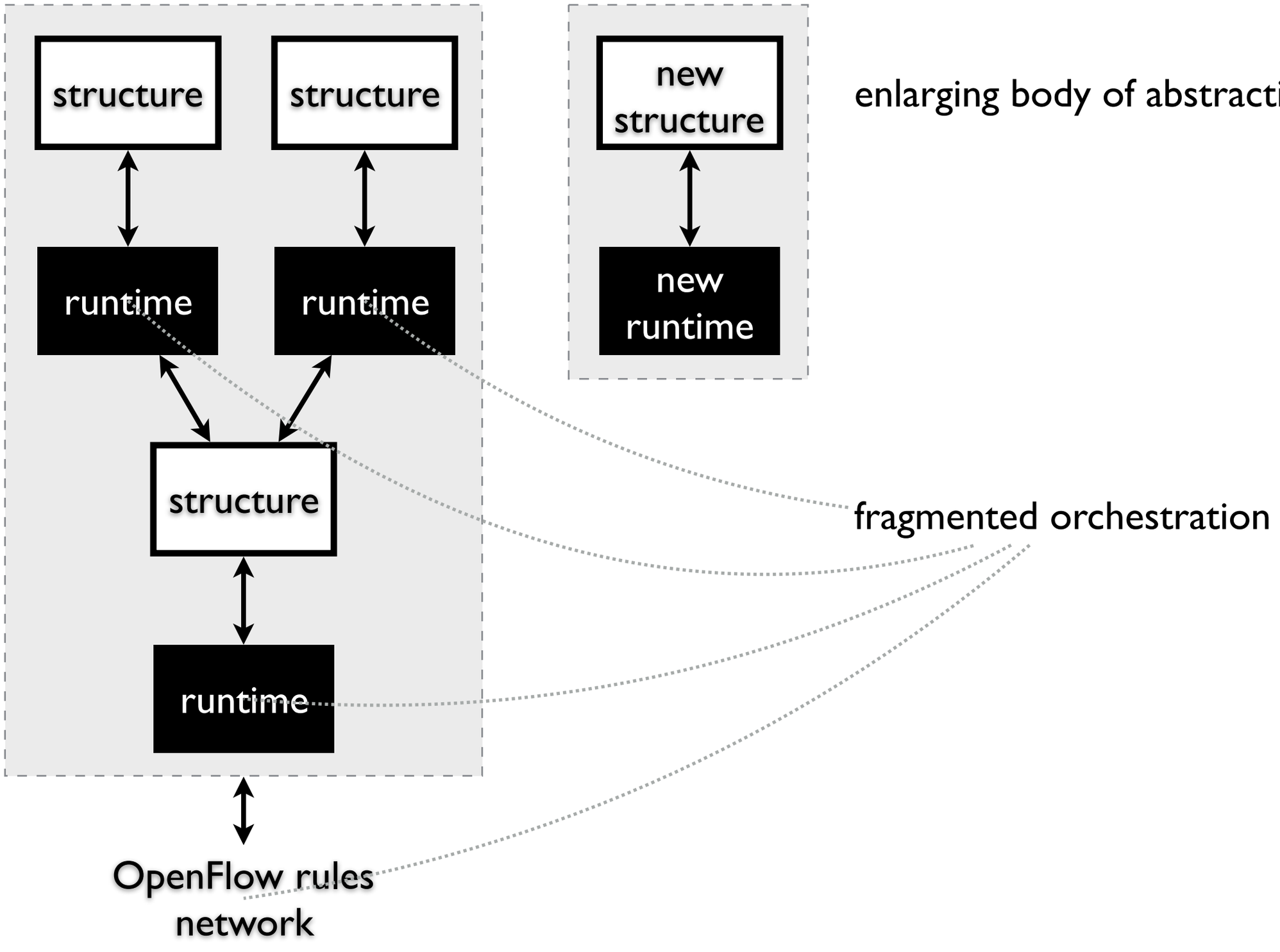
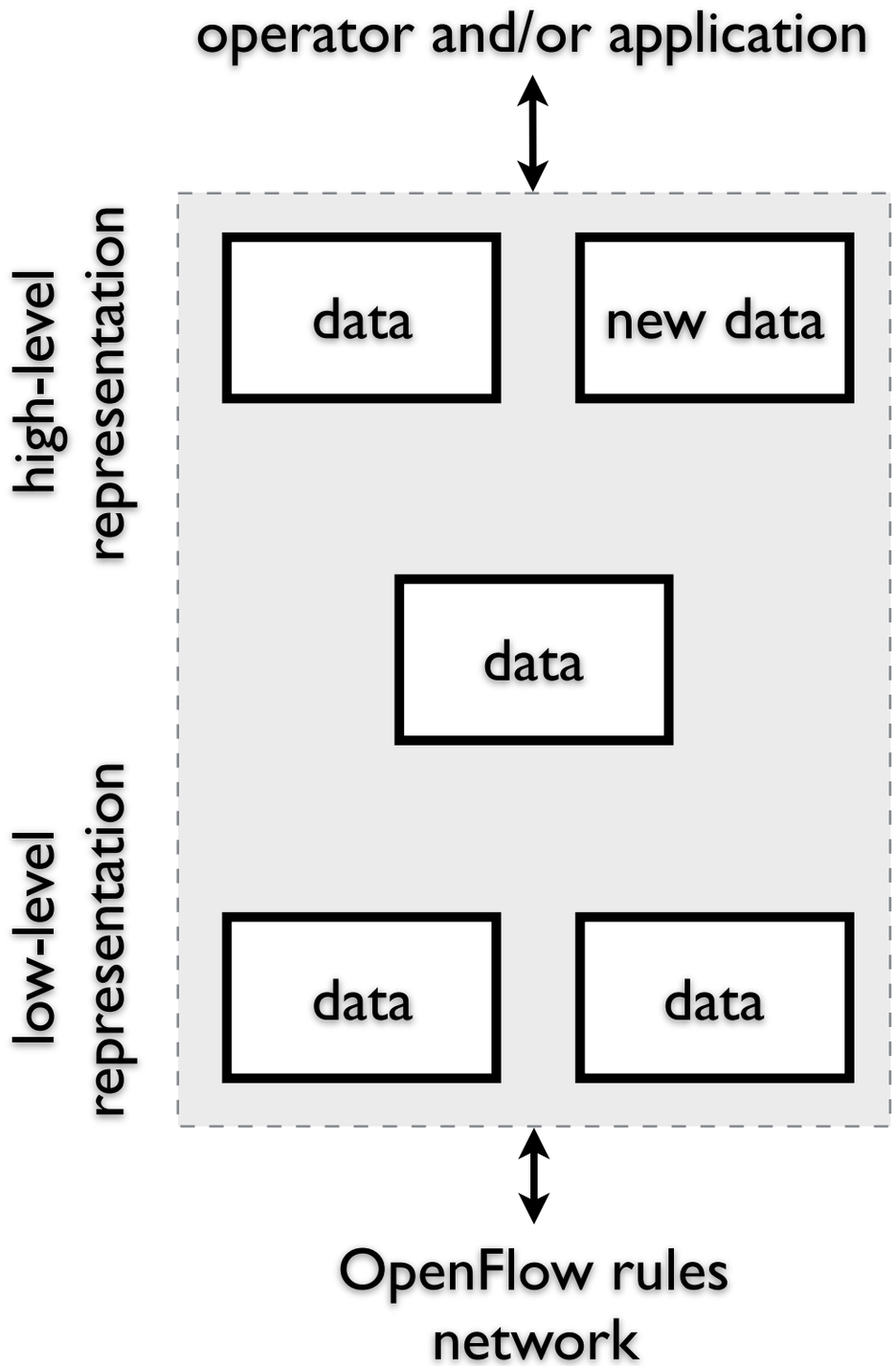


enlarging body of abstractions

current state of abstraction research



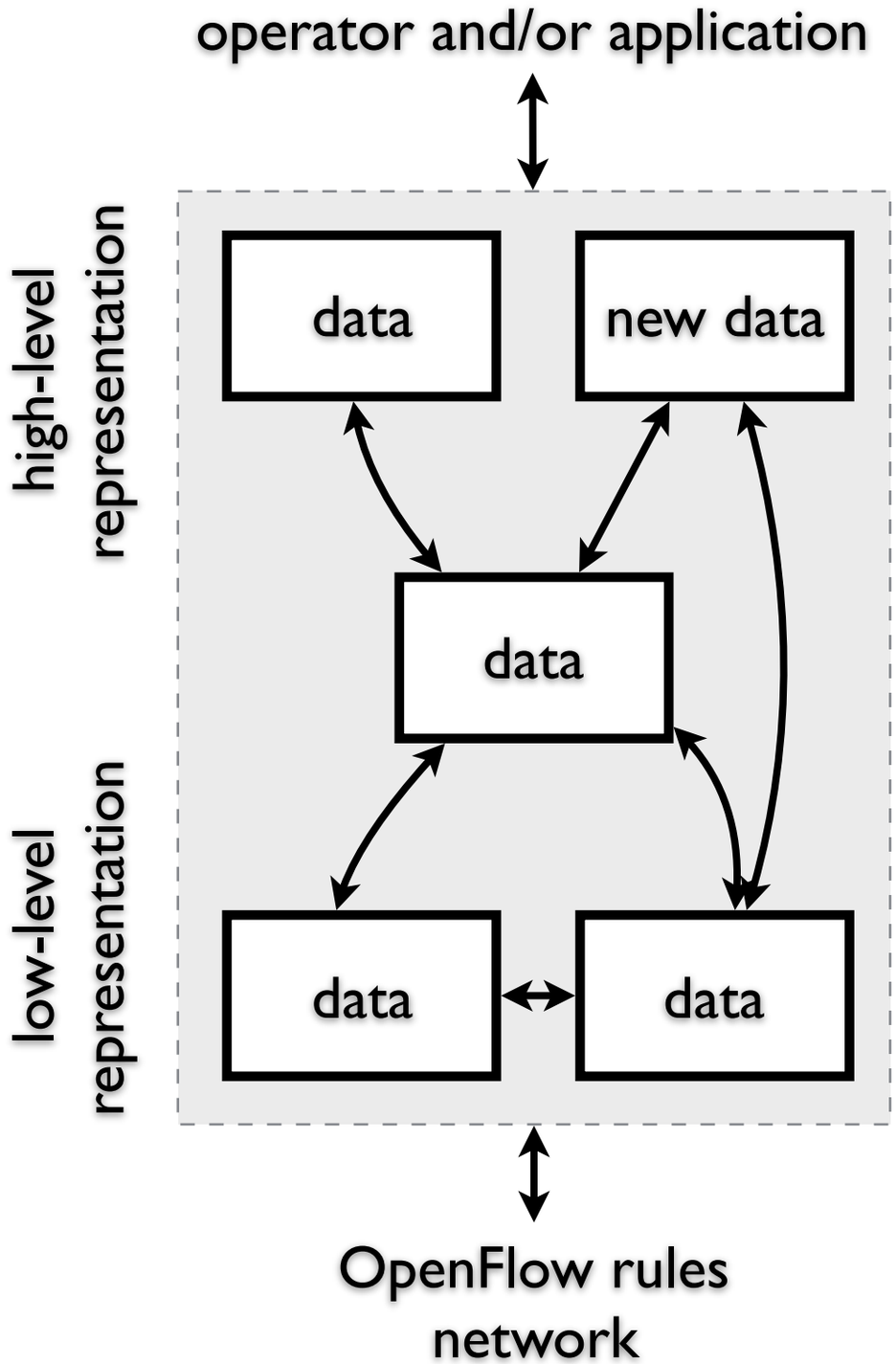
our perspective



SDN control revolves around data representation

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

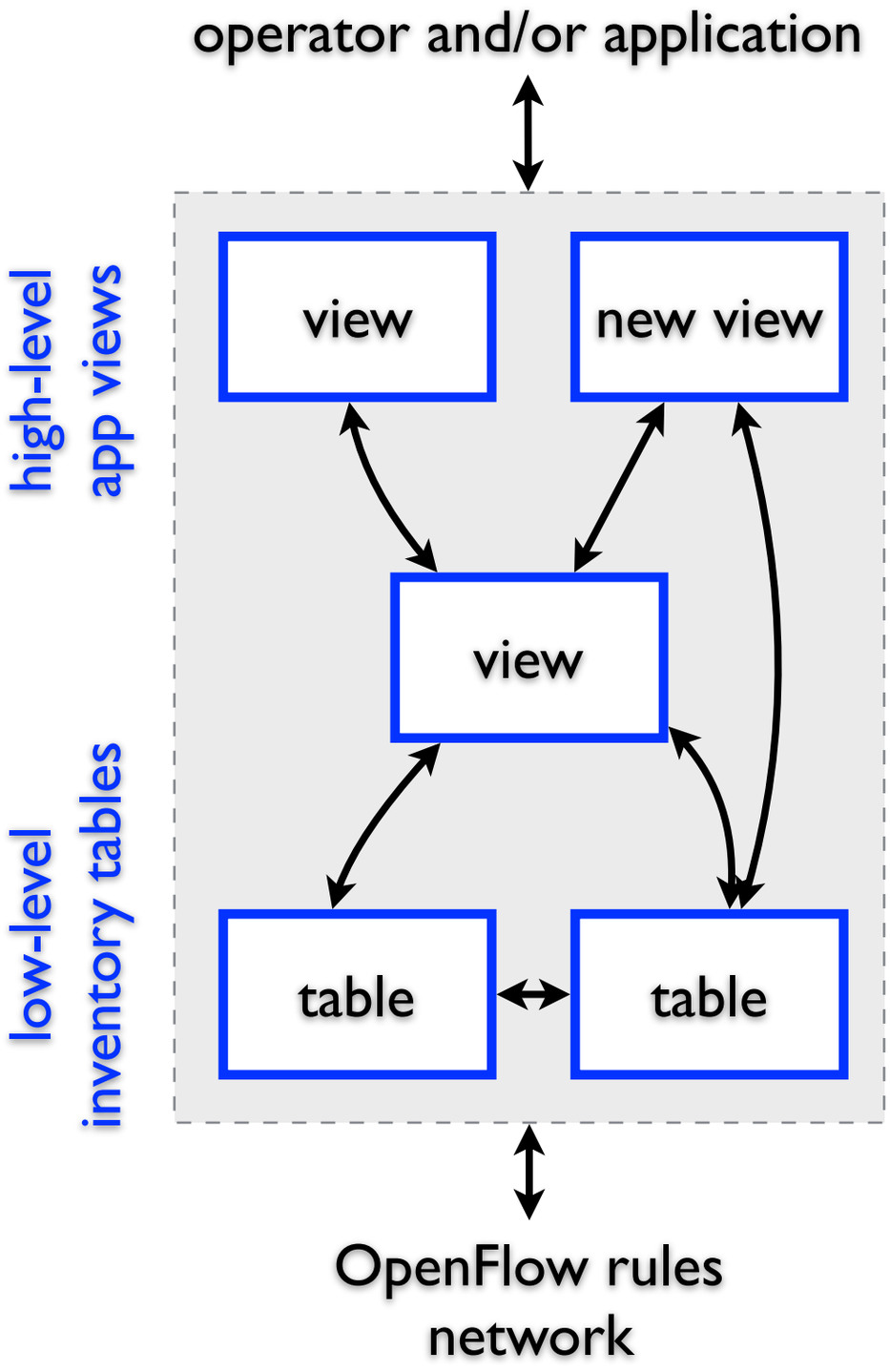
our perspective



SDN control revolves around data representation

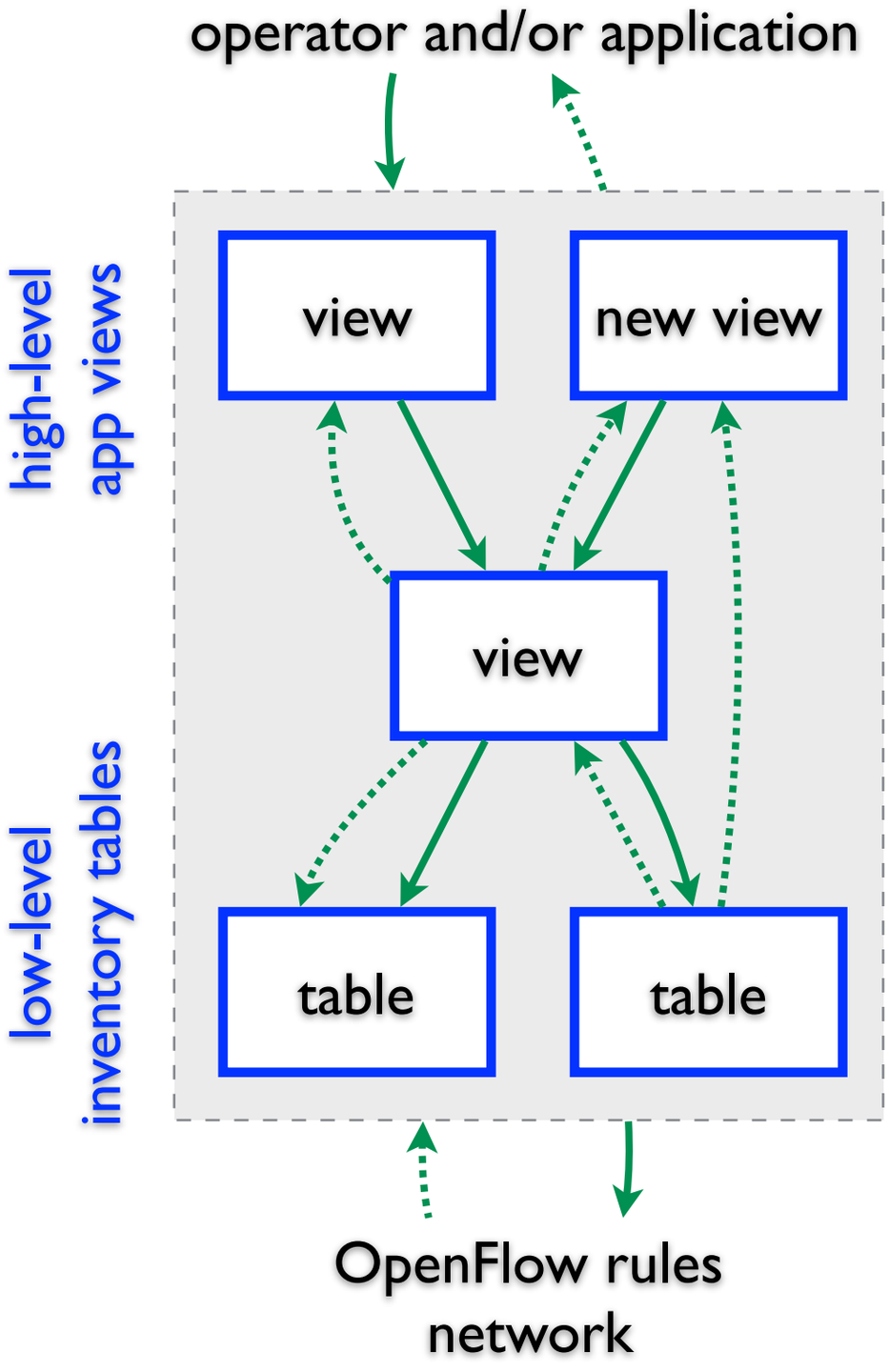
- discard specialized, pre-compiled, fixed structures
- adopt a *plain data representation*
- use a *universal data language*

a database-defined network



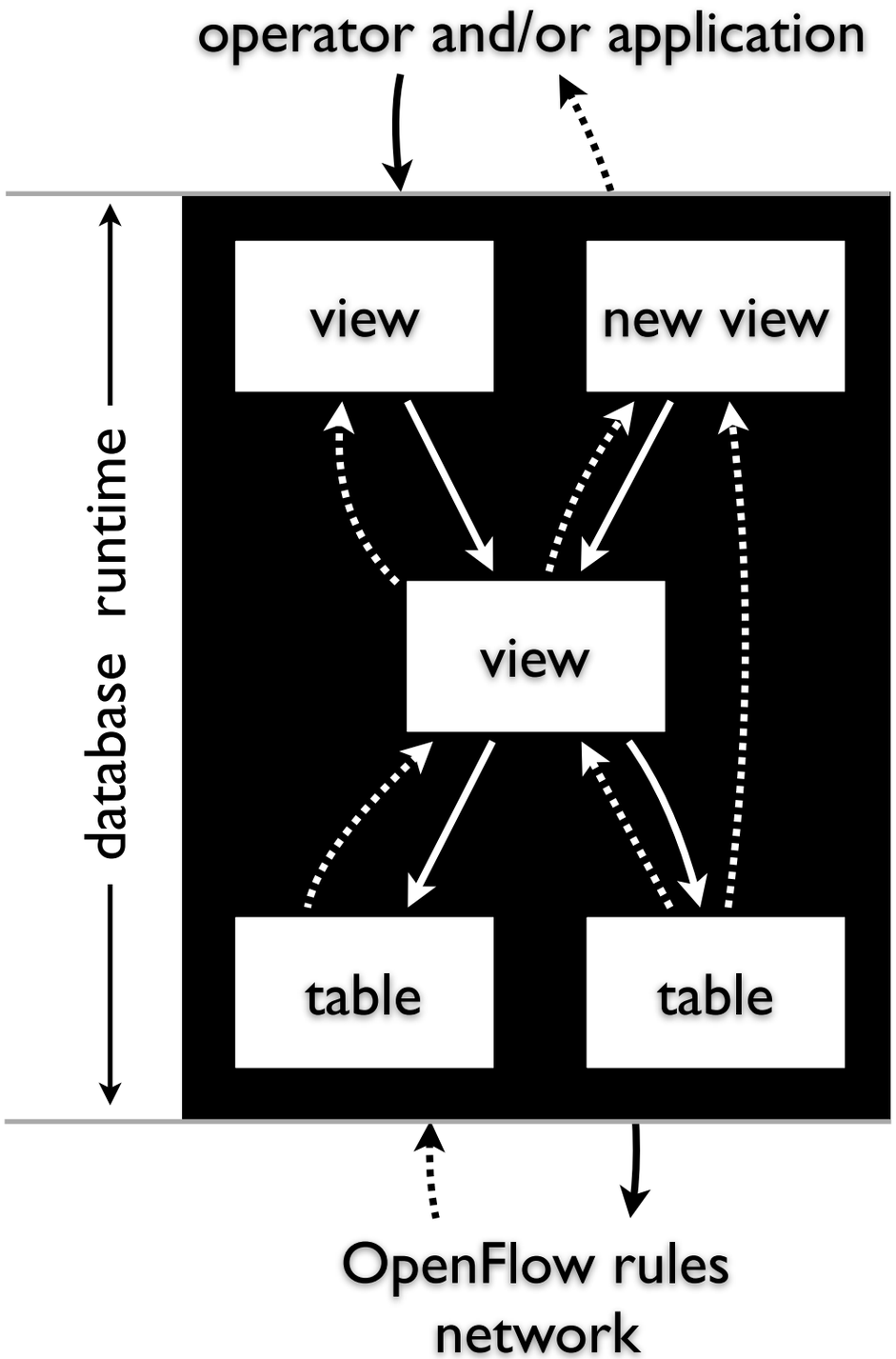
- relation — the plain data representation
  - table — stored relation
  - view — virtual relation

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

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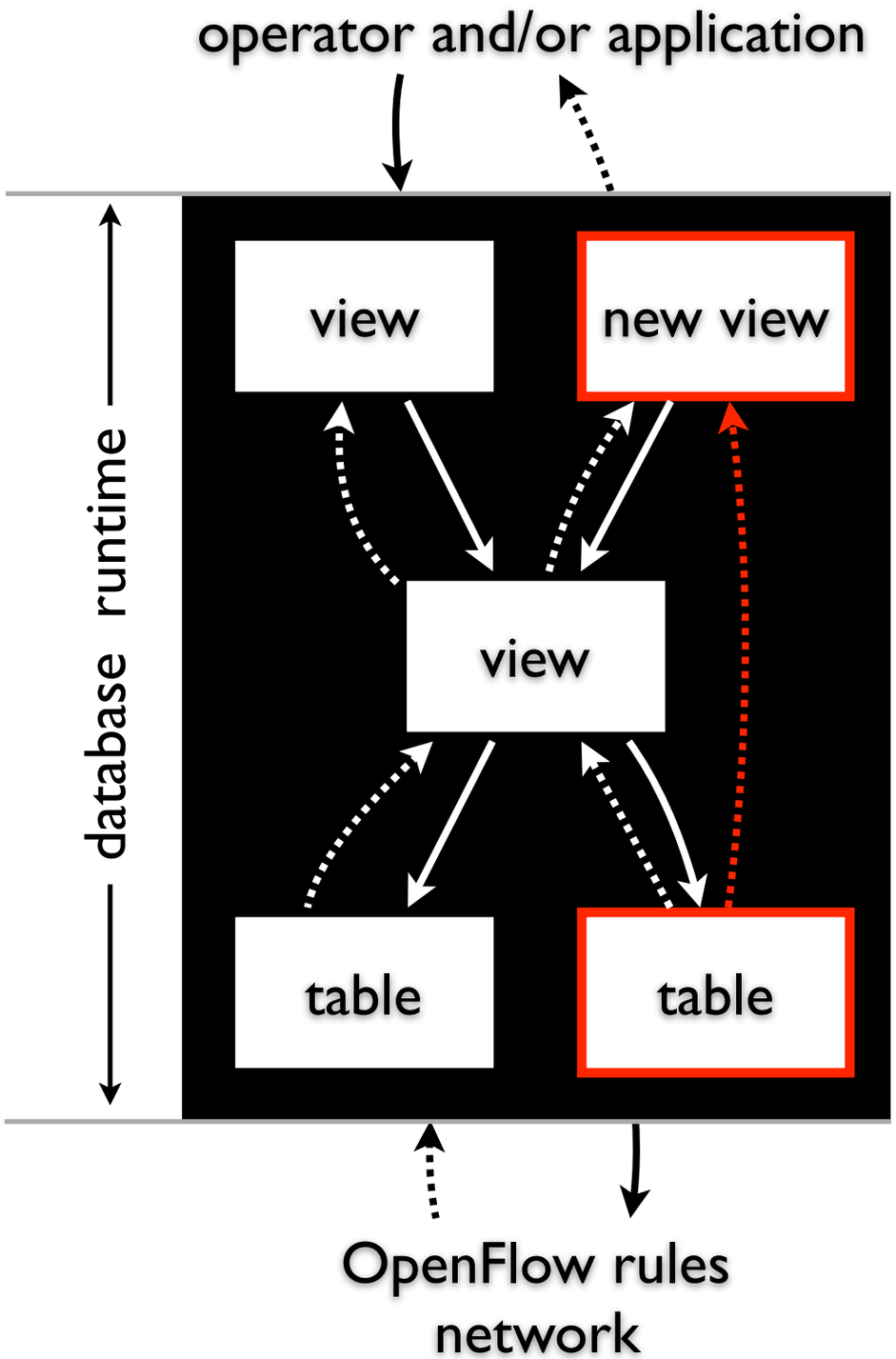

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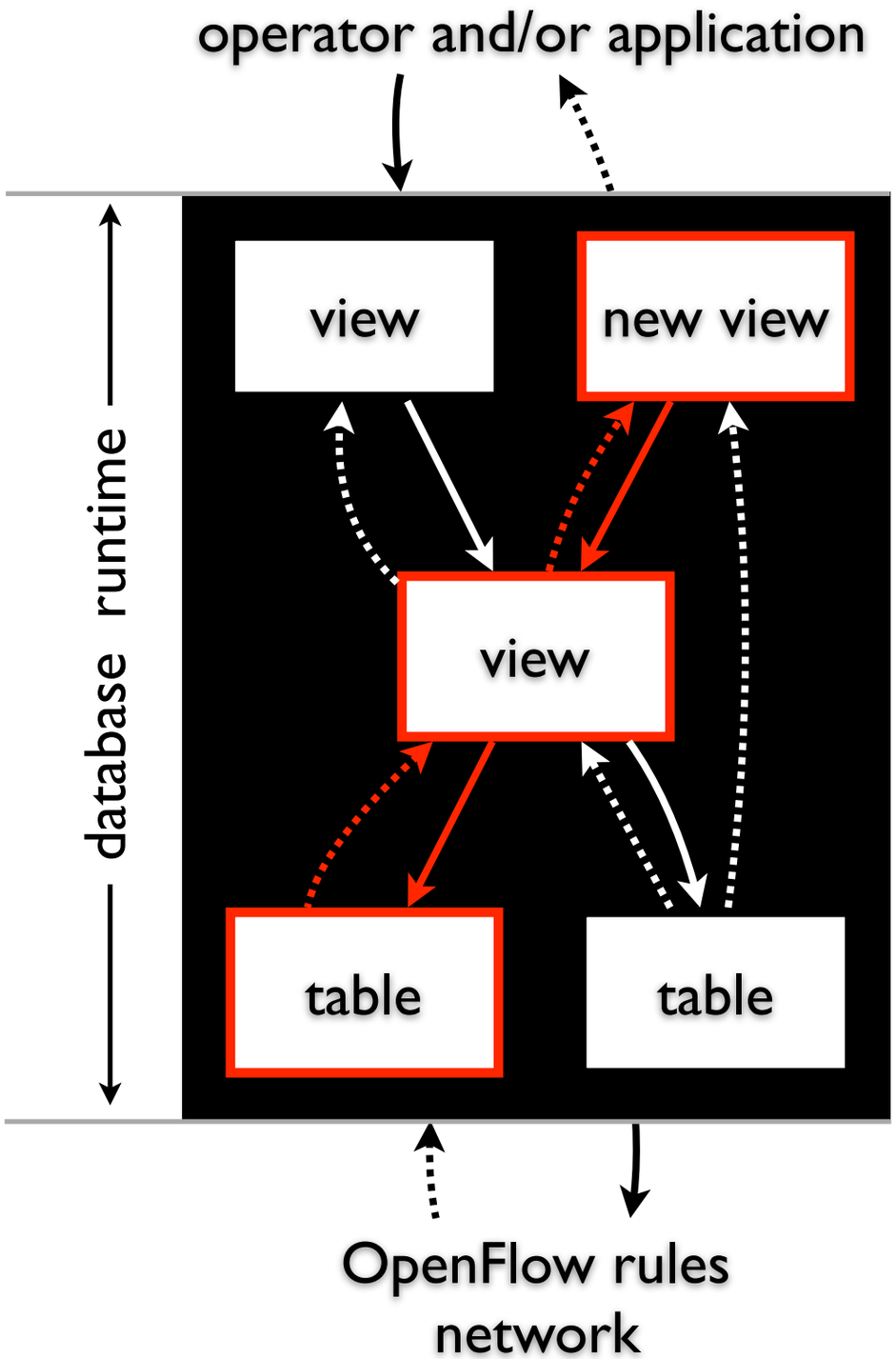

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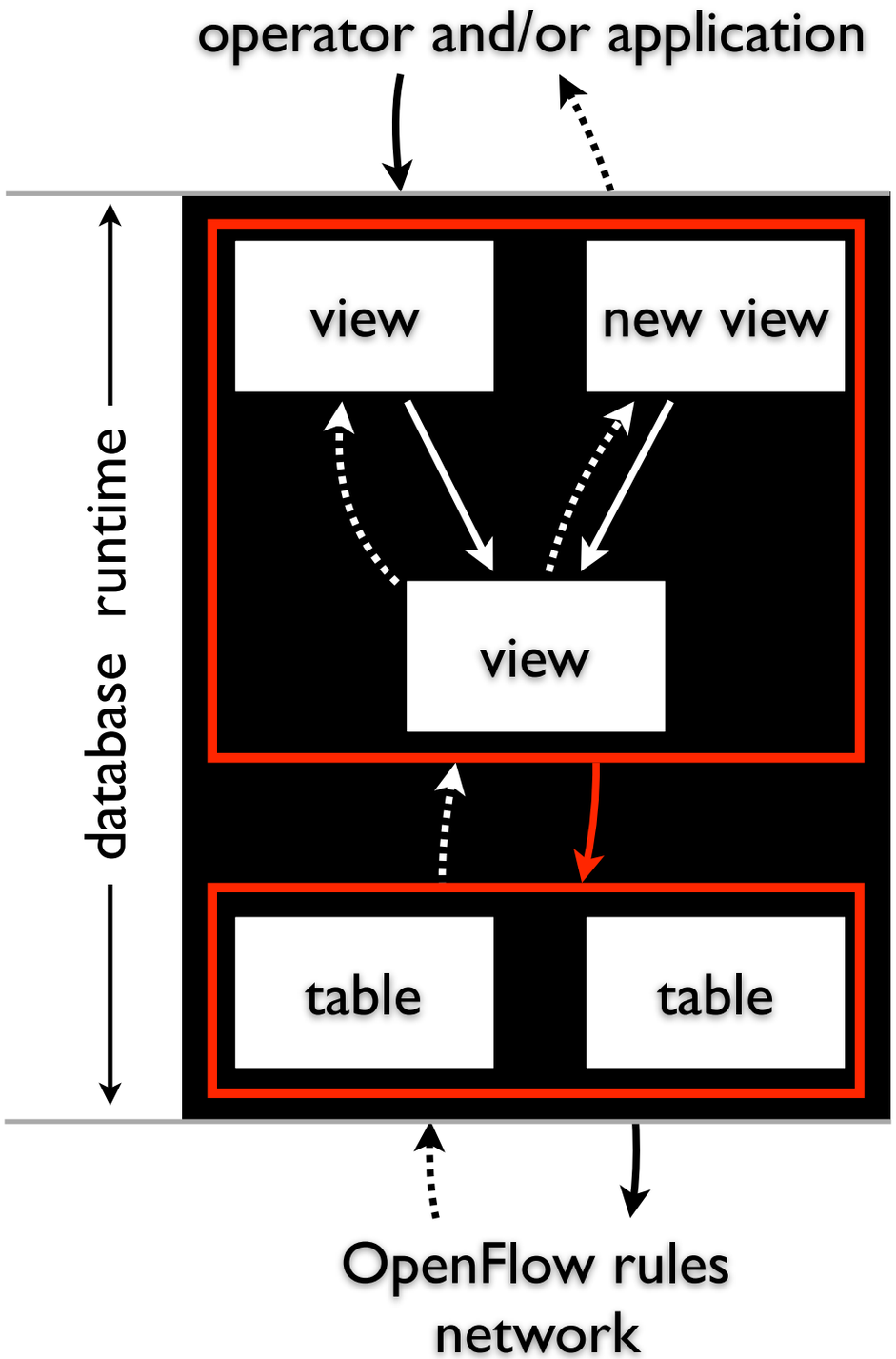

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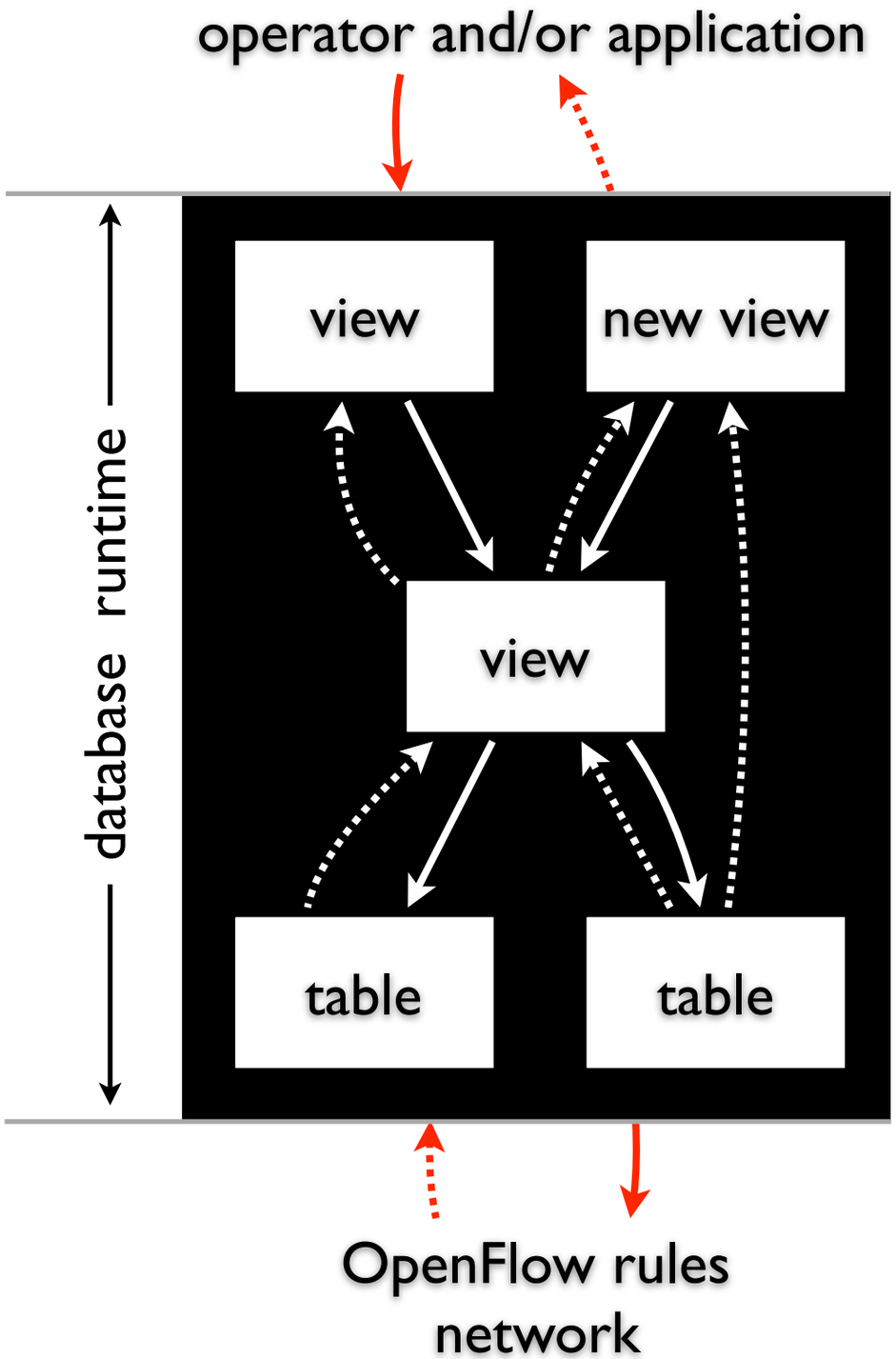

attractive features

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abstraction: network tables

reachability matrix

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

…

topology

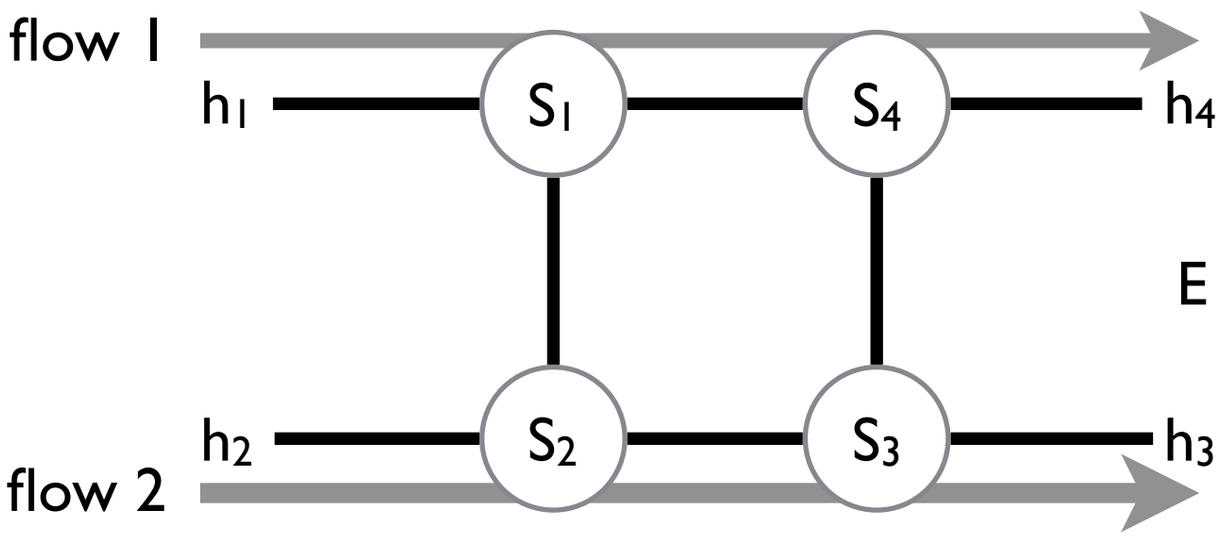
sid	nid
S_1	S_2
S_1	S_3
S_1	h_1

…

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)
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```

```
CREATE TABLE acl (
  end1 integer, end2 integer, allow integer
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firewall control: repairing violation

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CREATE RULE acl_repair AS
   ON DELETE TO acl_violation
   DO INSTEAD
         DELETE FROM rm WHERE fid = OLD.fid;
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abstraction: application view

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

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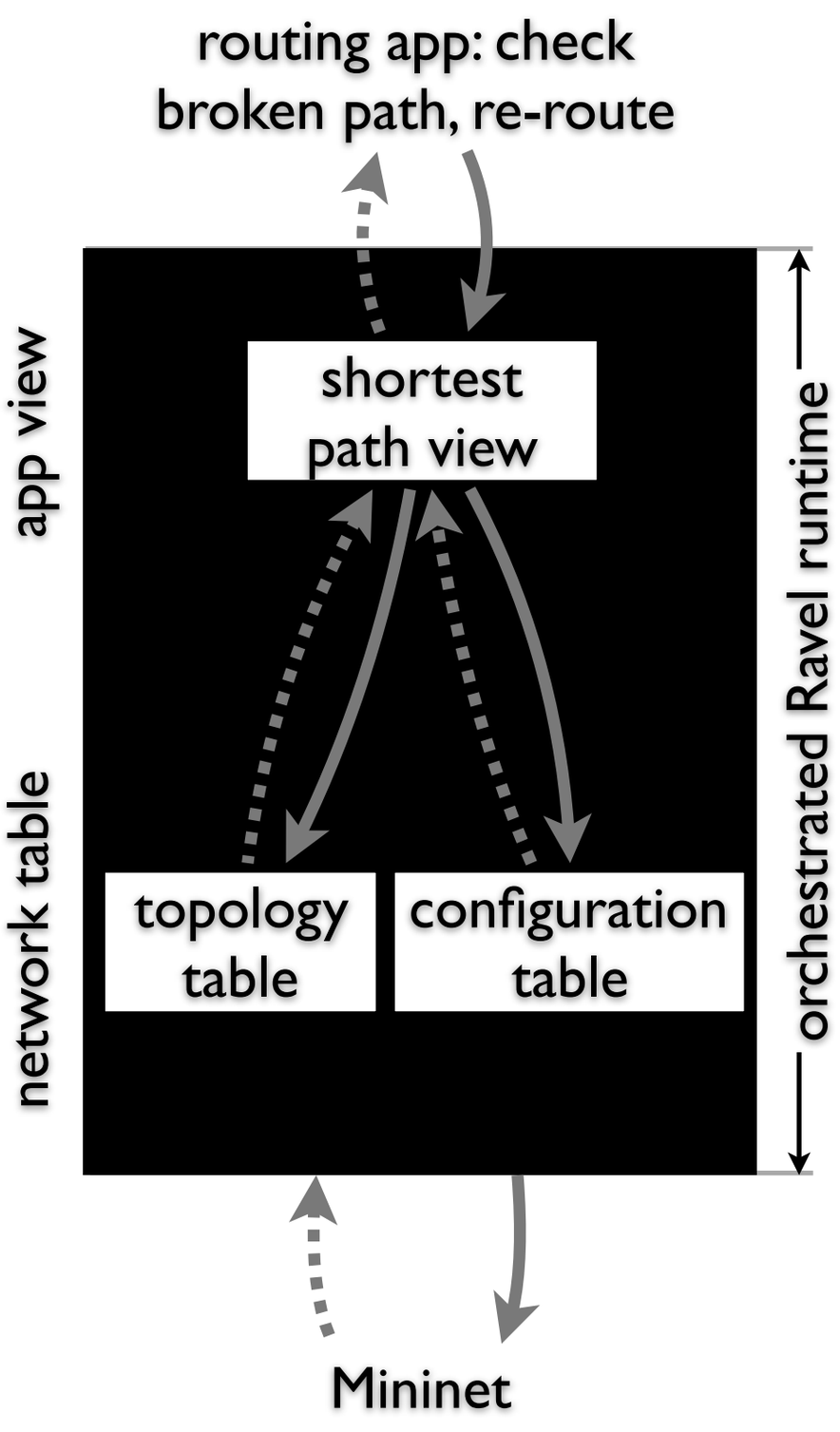
- many more
  - routing, stateful firewall, service chain policy between subdomains …
- optimizing application by materializing views
  - (one order of magnitude) faster access with small maintenance overhead (.01~10ms)

orchestration across representations



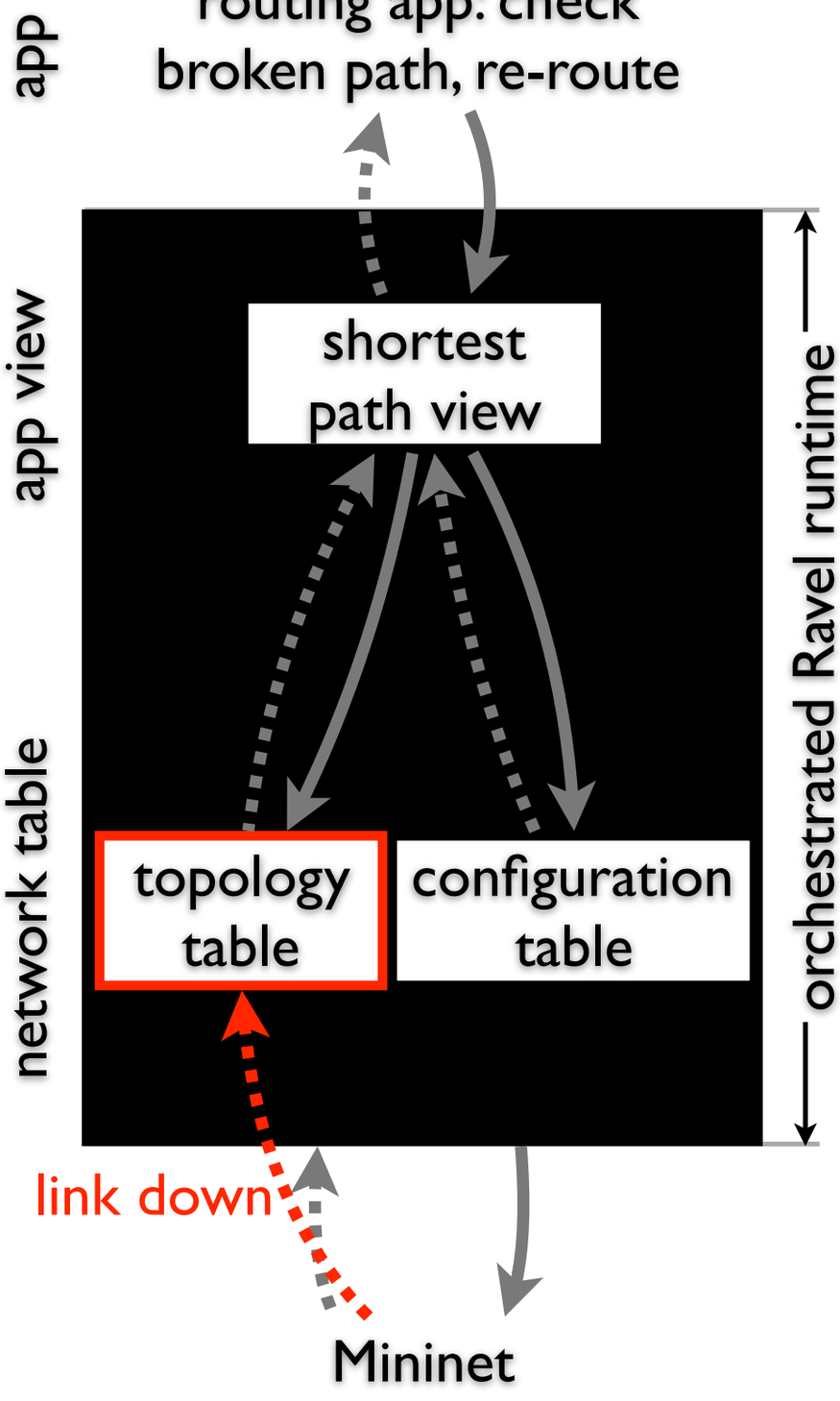
SQL rule:
upon broken path, re-route

shortest path	

topology		

configuration		

orchestration across representations



SQL rule:
upon broken path, re-route

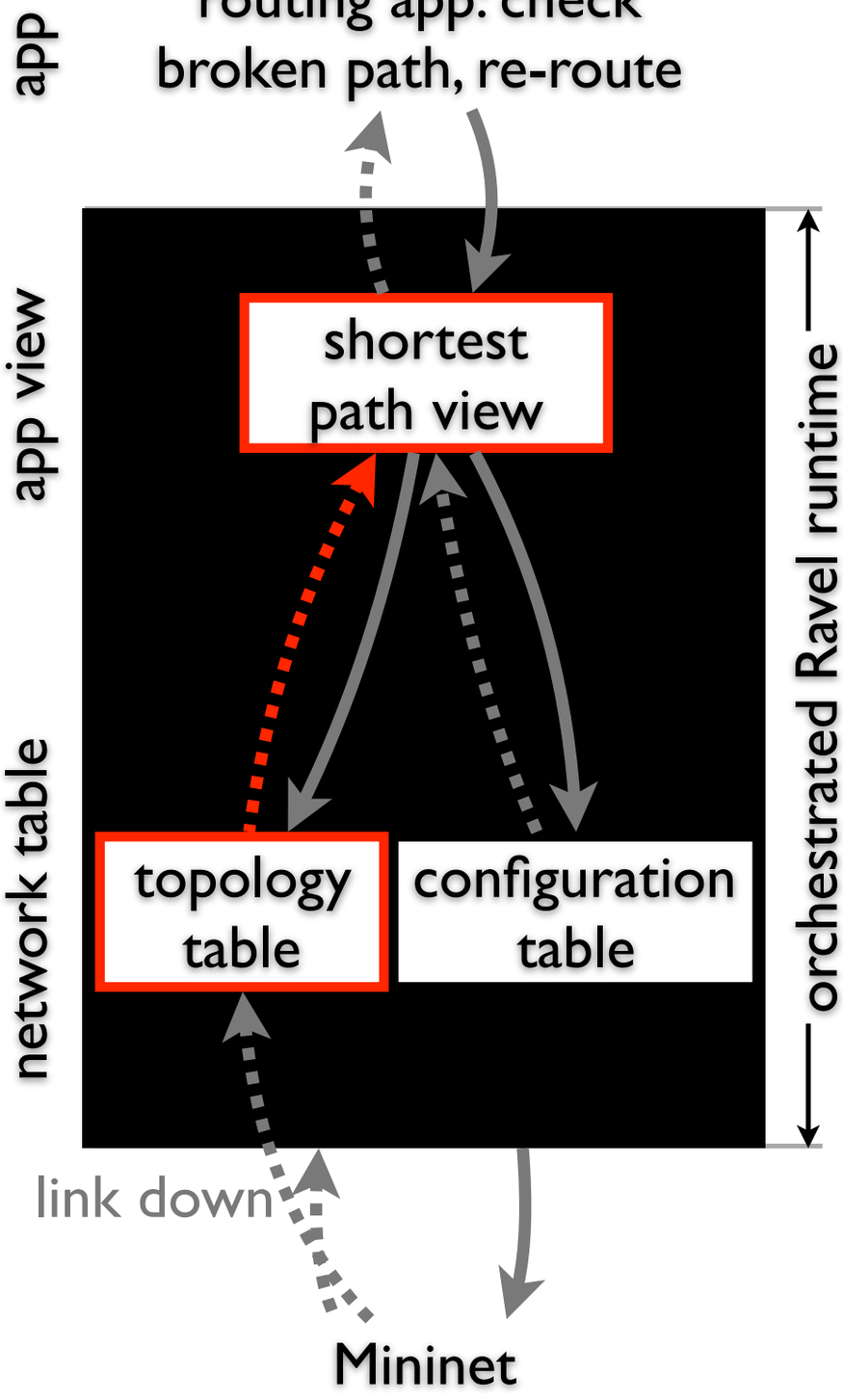
shortest path	

	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

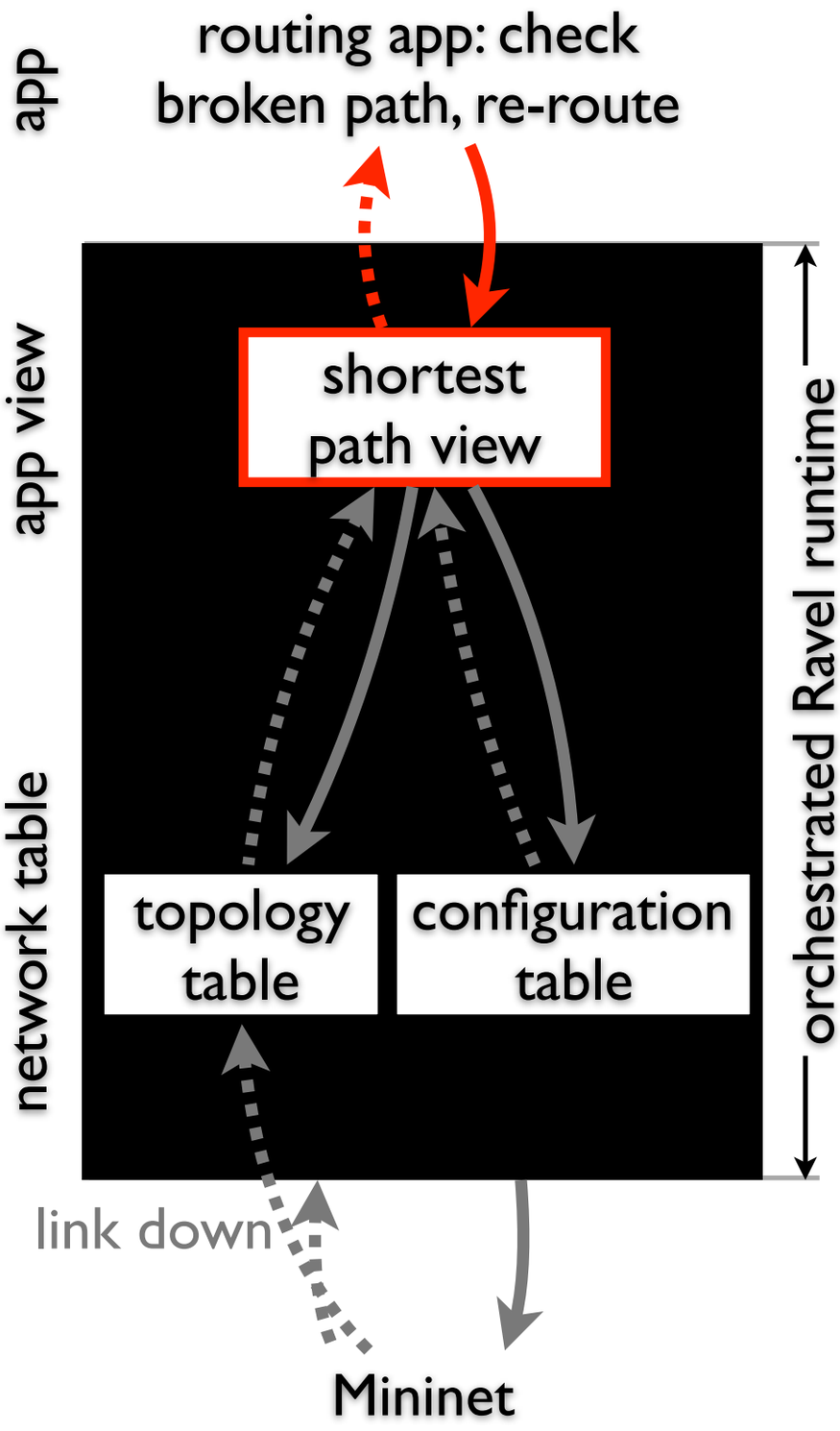
	shortest path	
	…	path
-		{…,172,39,156,…}

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

configuration		

Mininet link (172,39) down

orchestration across representations



SQL rule:
upon broken path, re-route

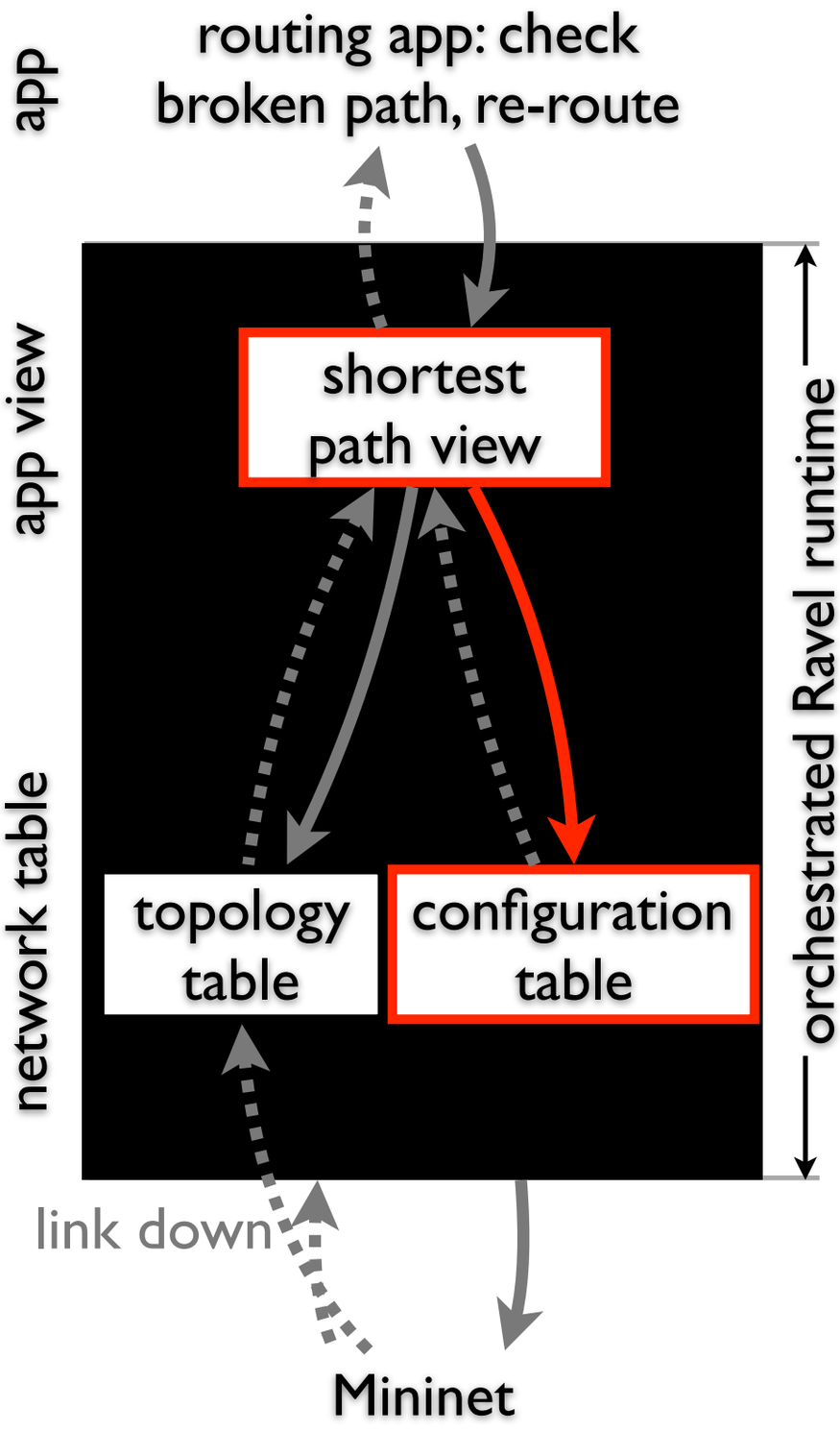
		shortest path
	…	path
-		{…,172,39,156,…}
+		{…,172,38,148,…}

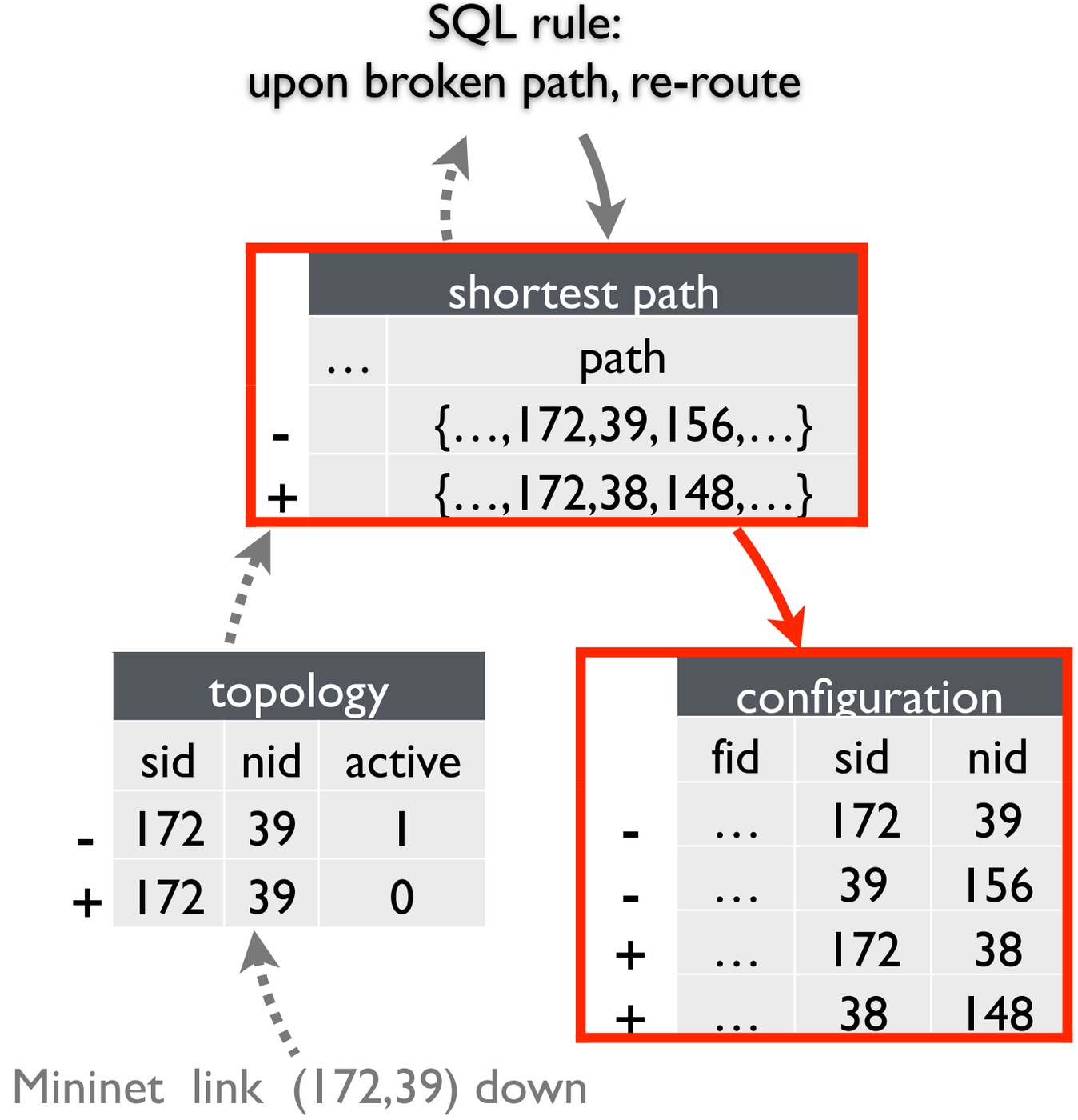
	topology		
	sid	nid	active
-	172	39	1
+	172	39	0

configuration		

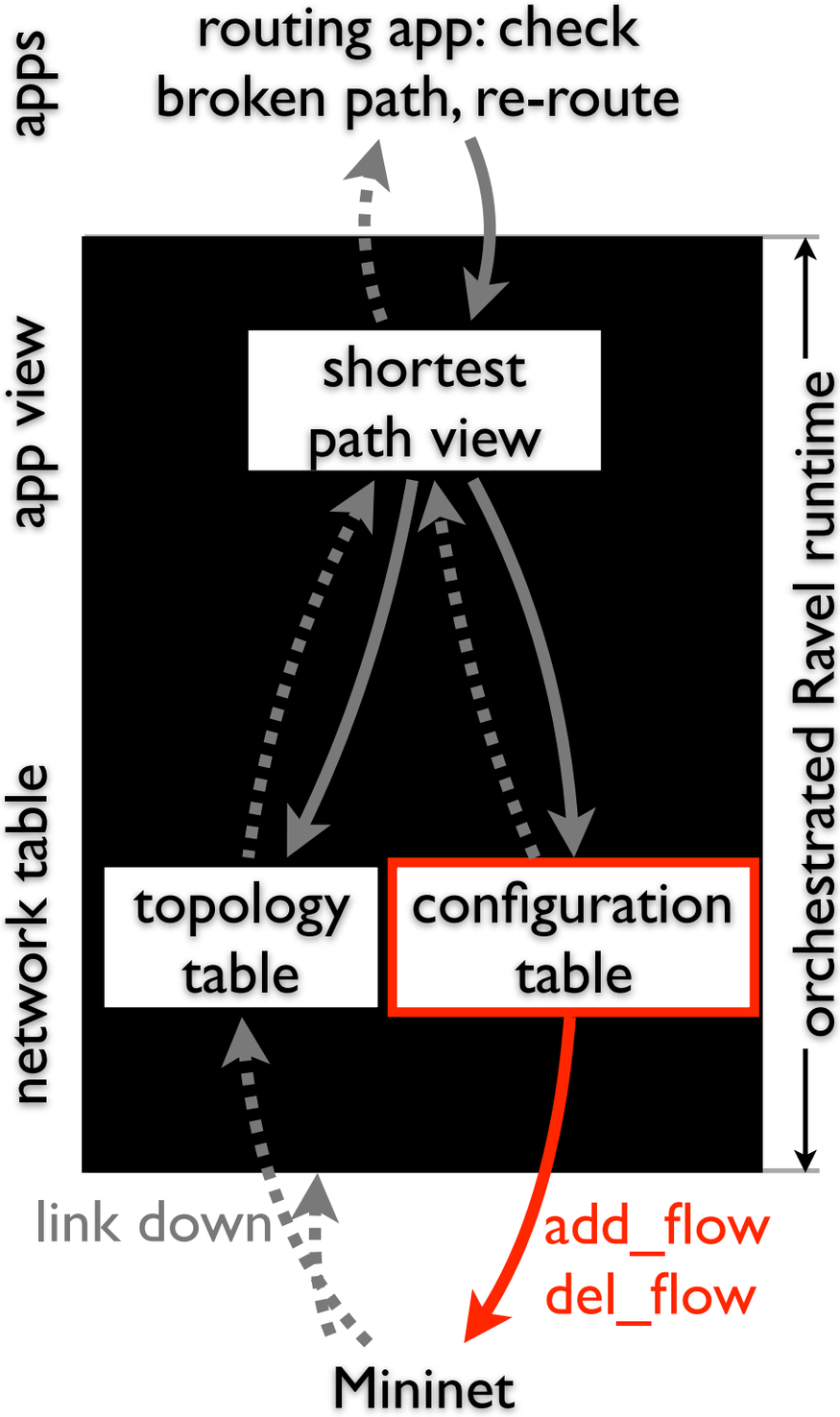
Mininet link (172,39) down

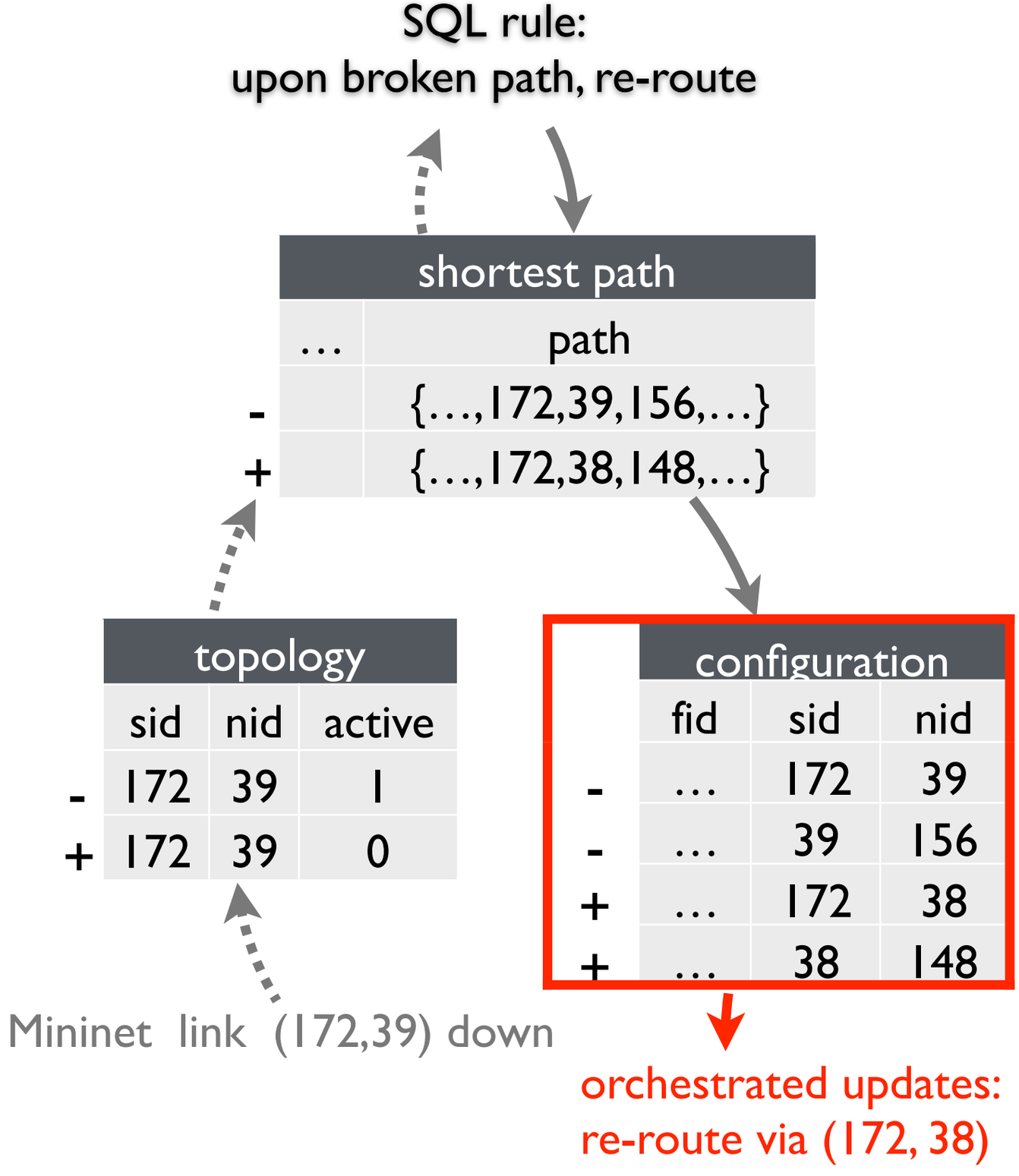
orchestration across representations



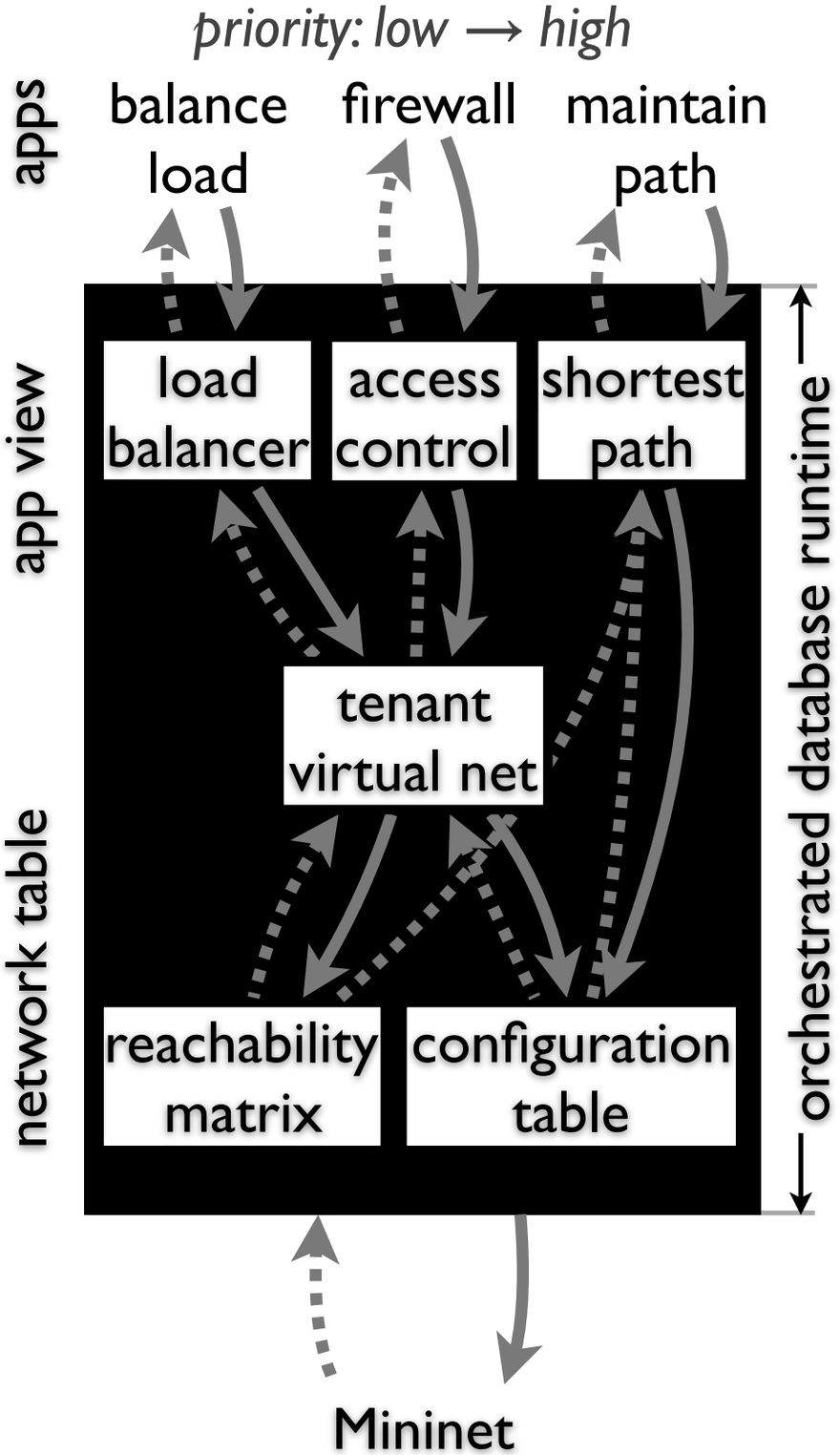


orchestration across representations





orchestration across applications



load balancer		

access control		

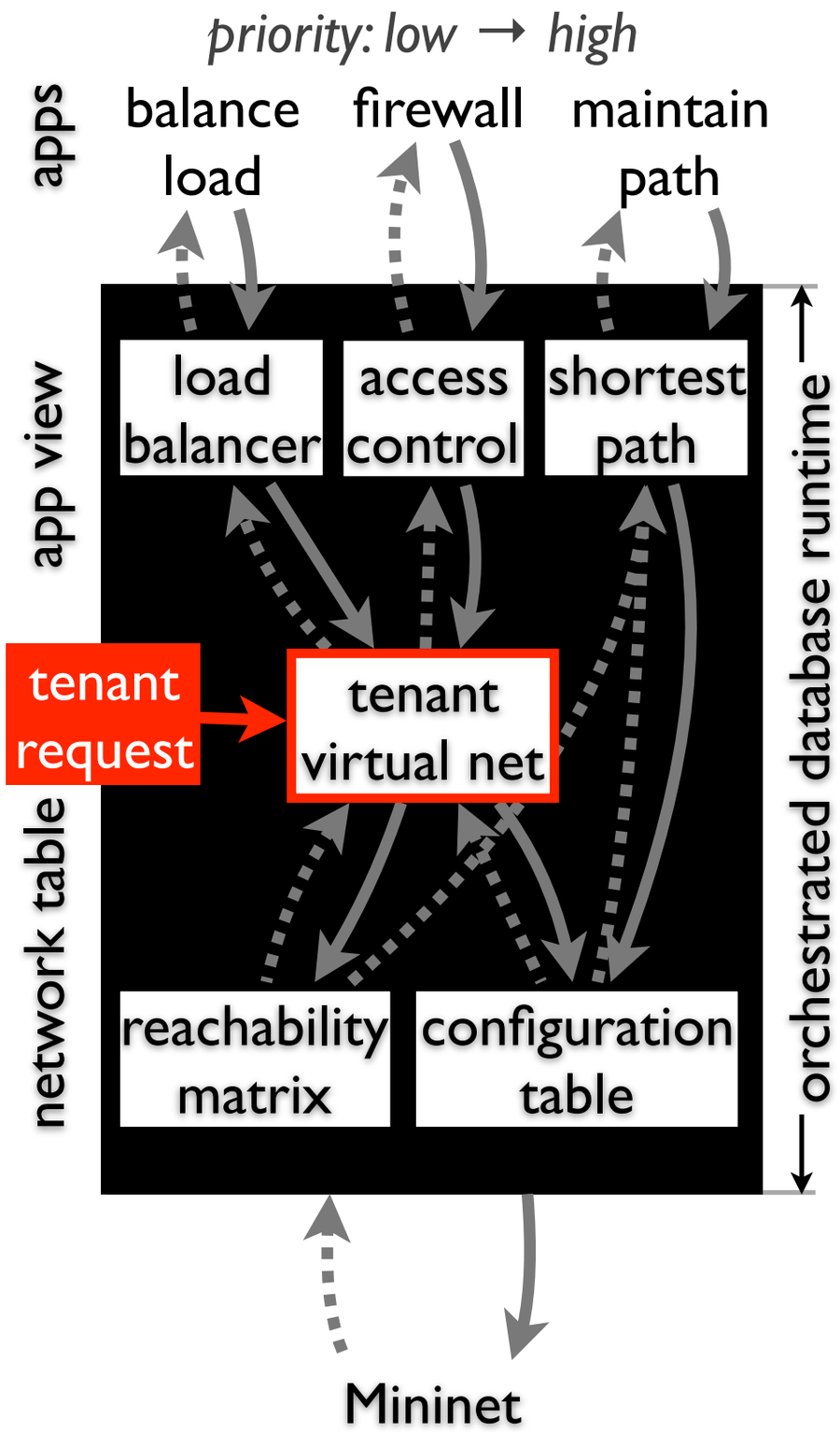
shortest path	

tenant virtual net		

reachability matrix		

configuration		

orchestration across applications



load balancer		

access control		

shortest path	

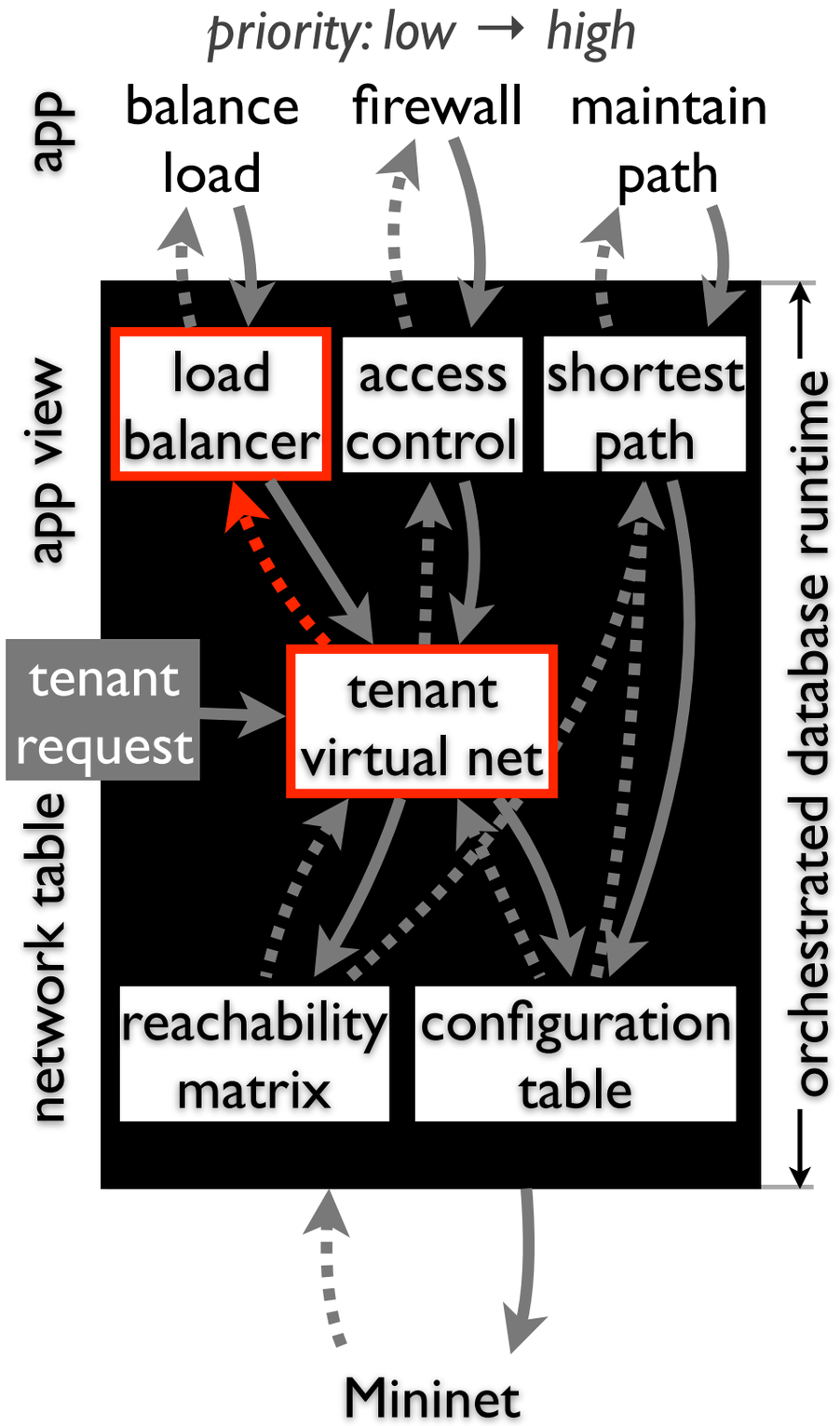
tenant request host 1238 to server 1003

	tenant virtual net		
	…	host	server
+	…	1238	1003

reachability matrix		

configuration		

orchestration across applications



	load	
	sid	load
+	1003	4
-	1003	3

access control		

shortest path	

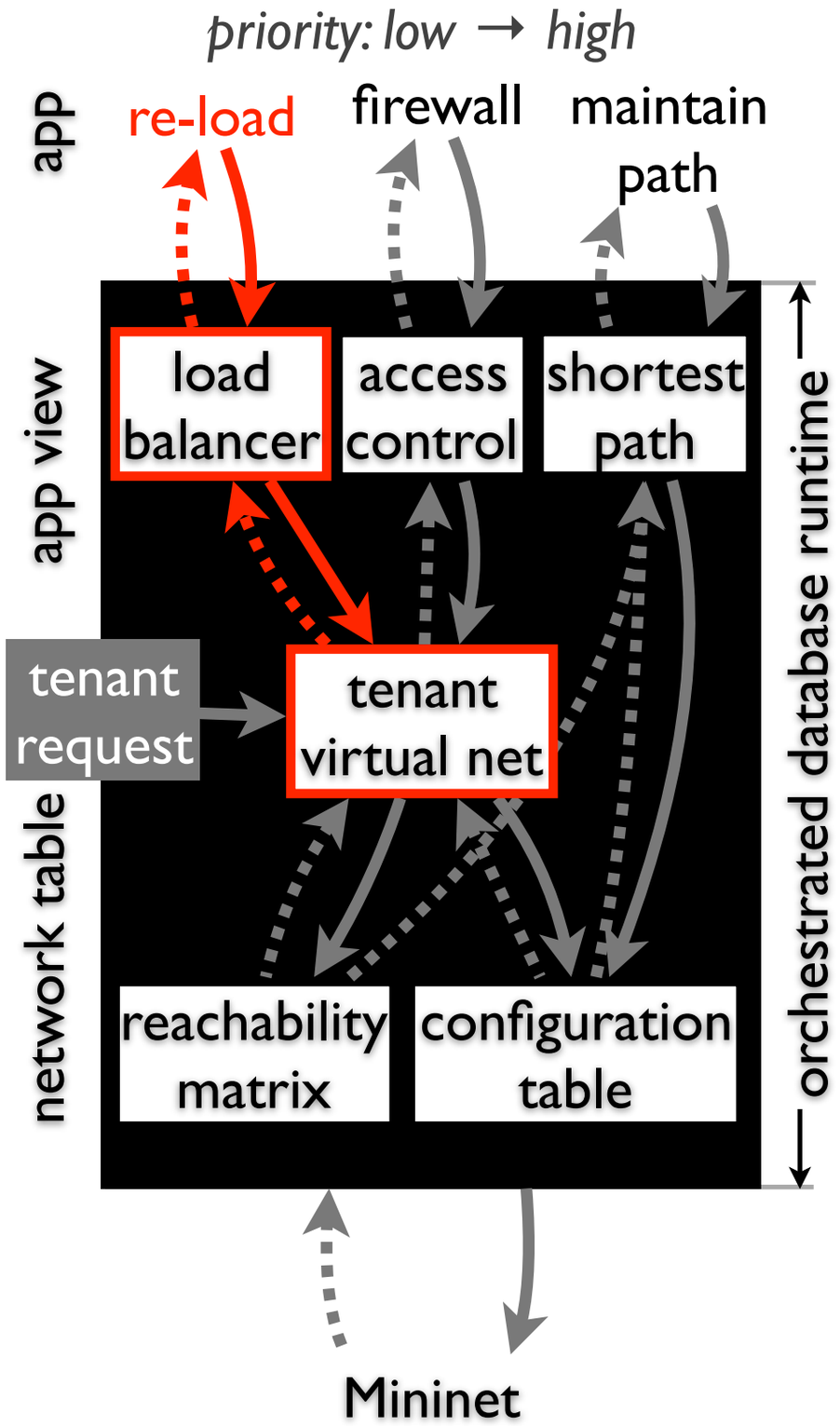
tenant request host 1238 to server 1003

	tenant virtual net		
	…	host	server
+	…	1238	1003

reachability matrix		

configuration		

orchestration across applications



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-	~~1003~~	~~3~~
-	1034	1
+	1034	2

access control		

shortest path	

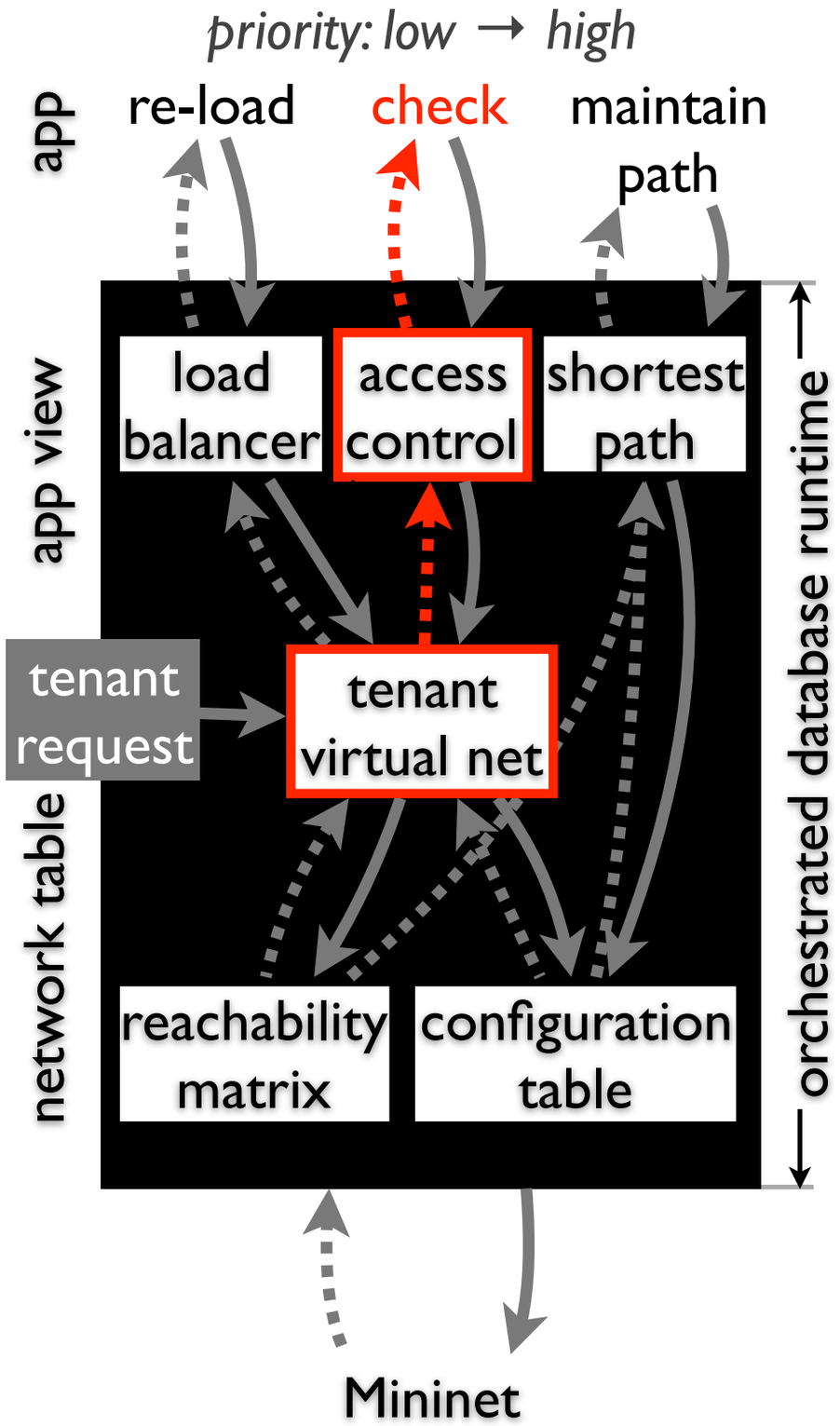
tenant request host 1238 to server 1003

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

reachability matrix		

configuration		

orchestration across applications



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	sid	load
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+	1034	2

access control		
src	dst	allow
1238	1034	1
1238	1003	0

shortest path	

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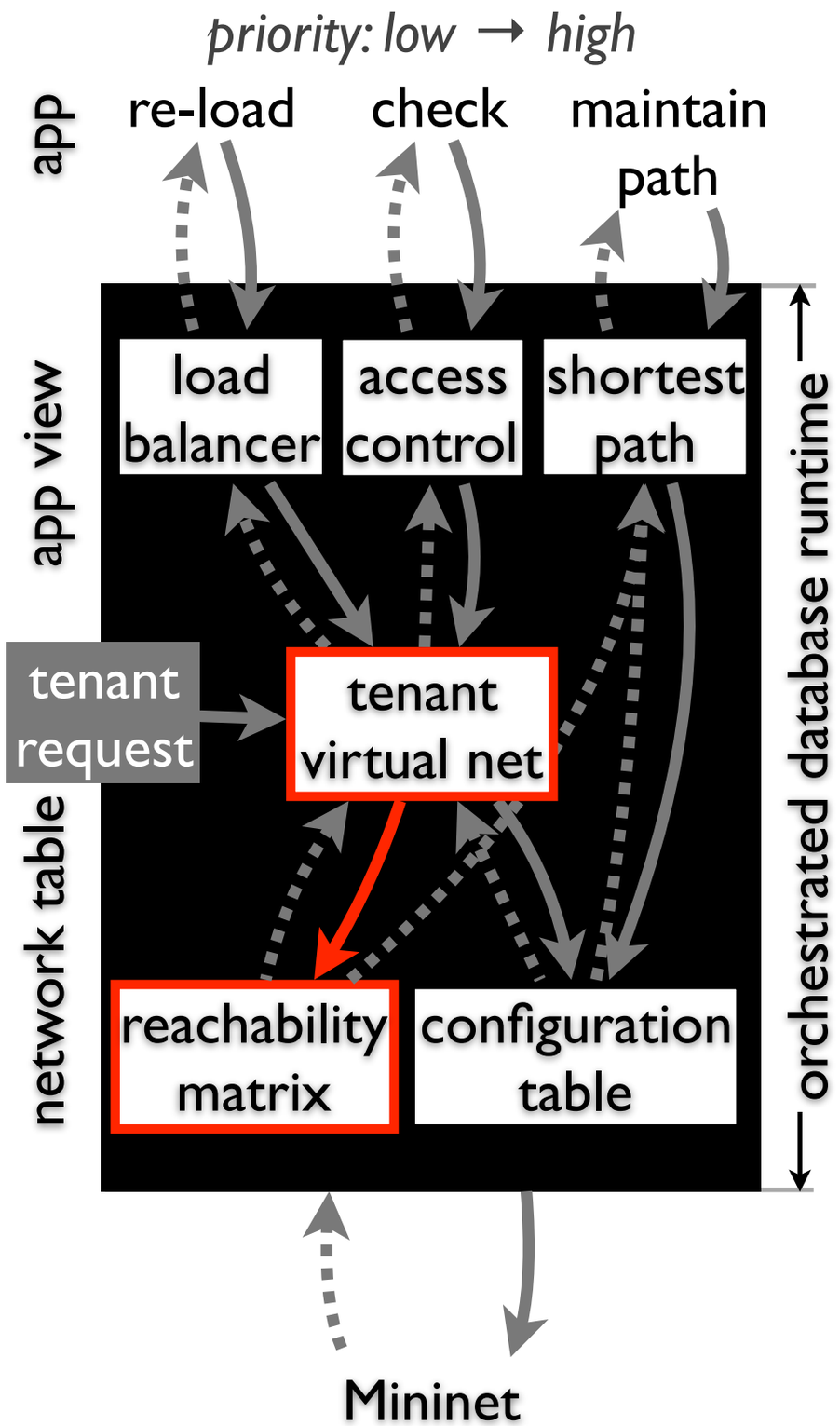
reachability matrix		

configuration		

orchestration across applications



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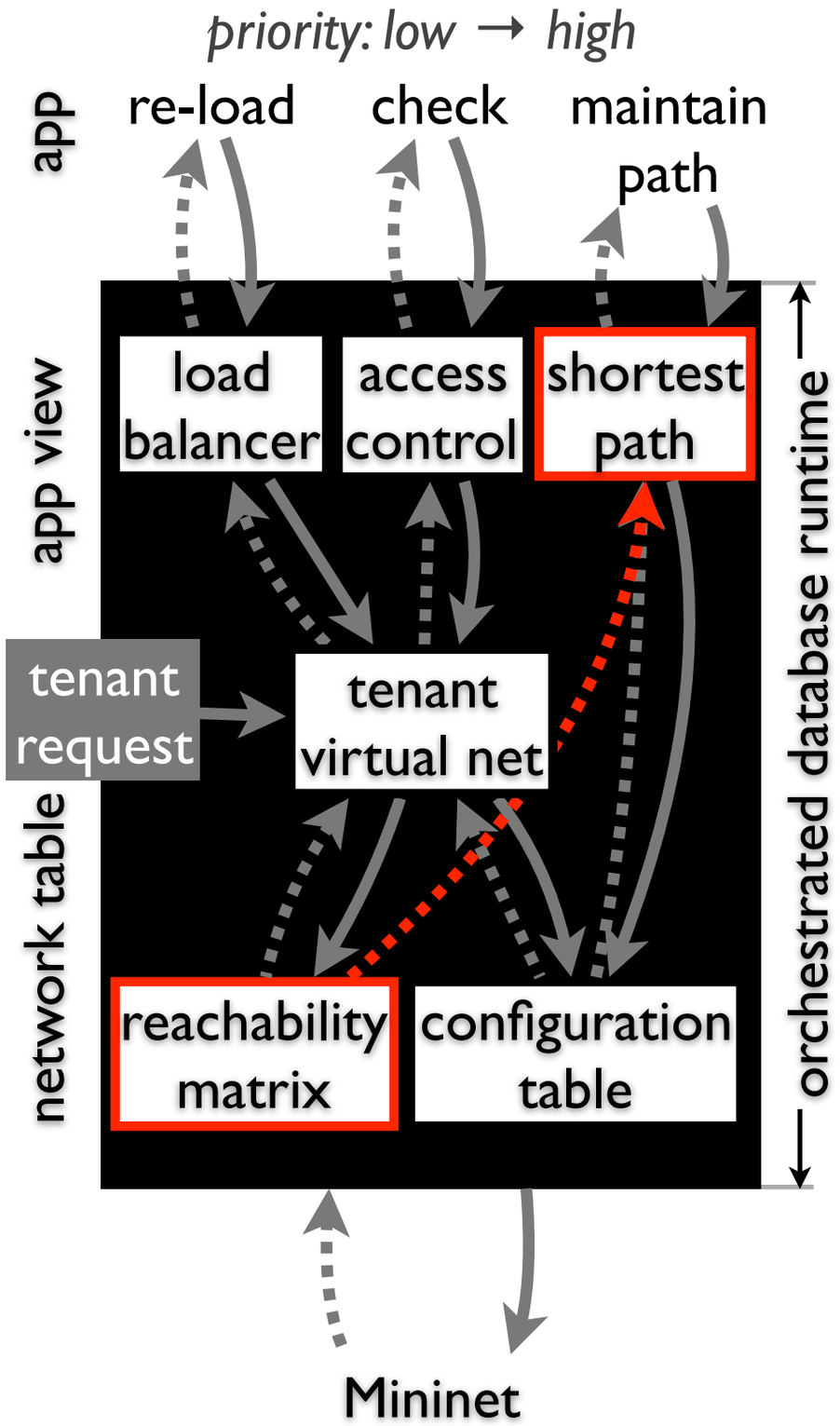
	reachability matrix		
	fid	sid	nid
+	…	1238	1034

configuration		

orchestration across applications



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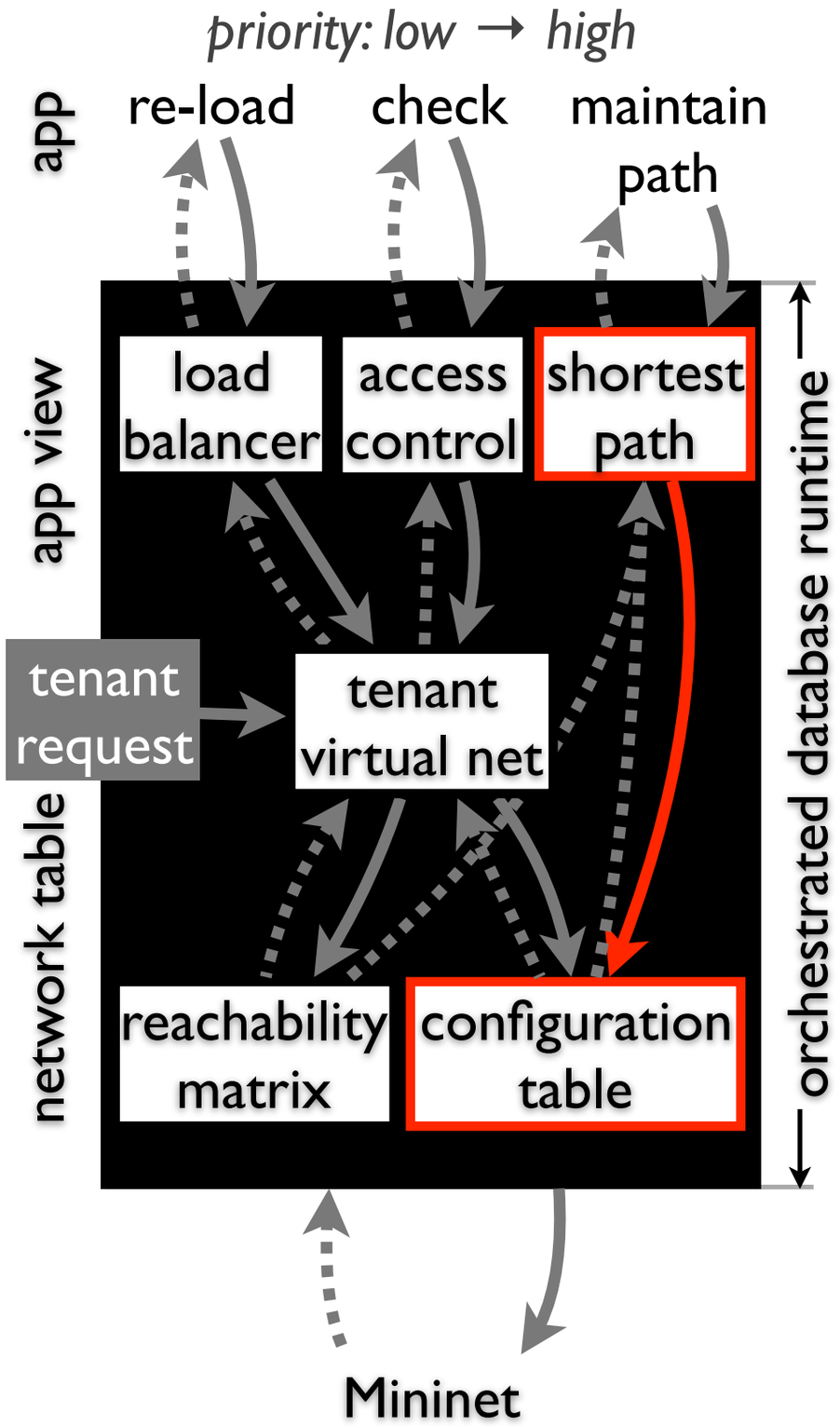
configuration		

orchestration across applications



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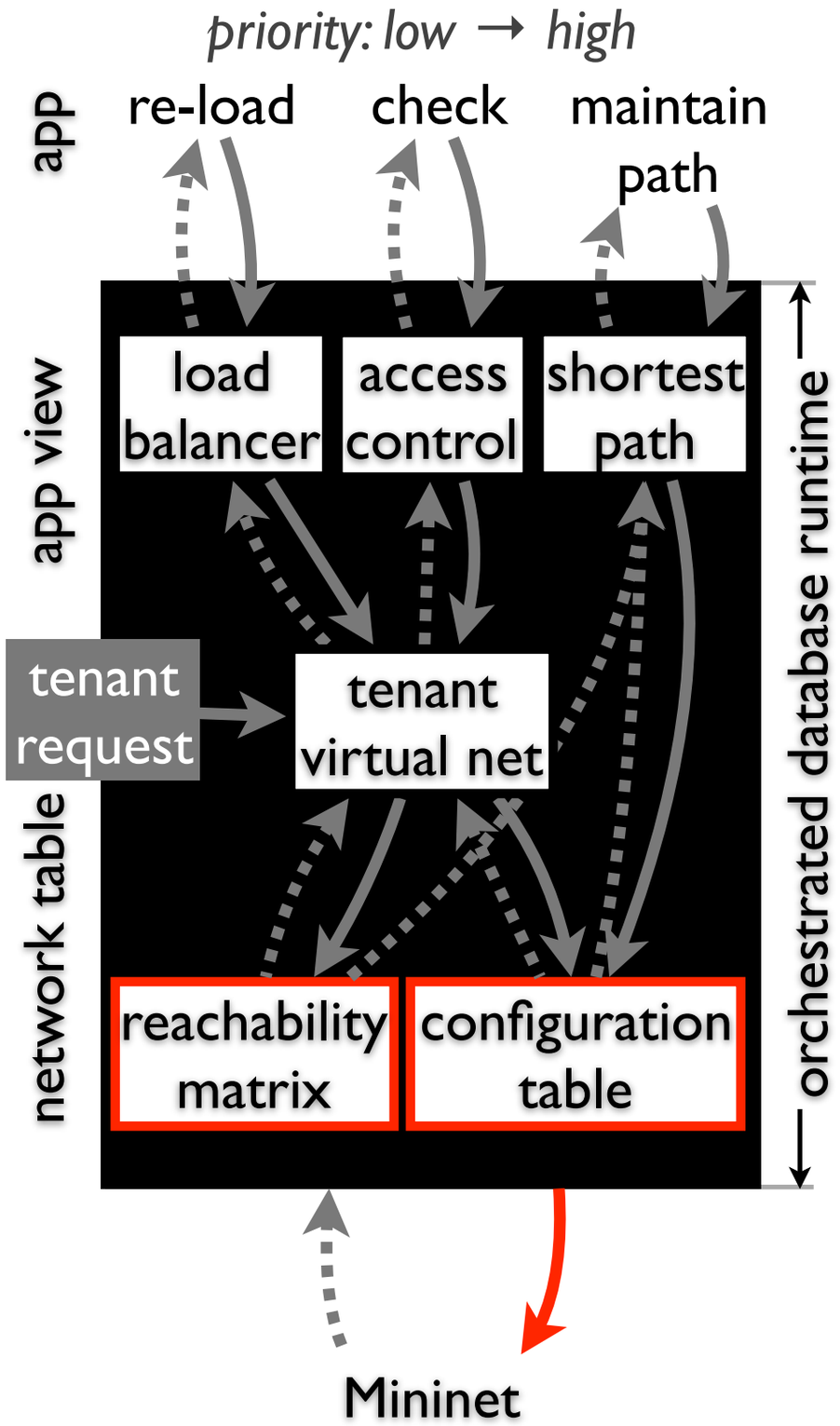
orchestration across applications



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	configuration		
	fid	sid	nid
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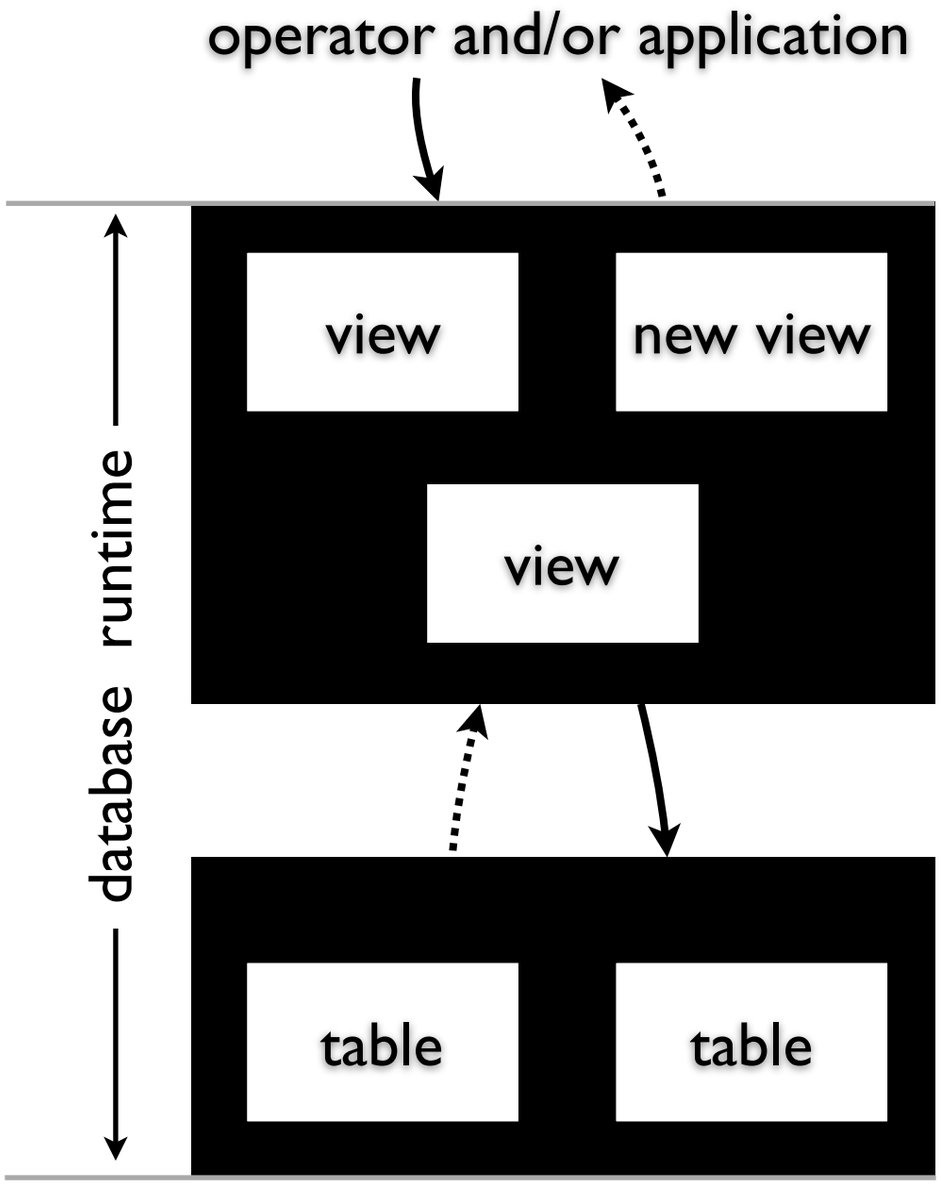
orchestrated updates: install alternative route that is load-balanced and safe

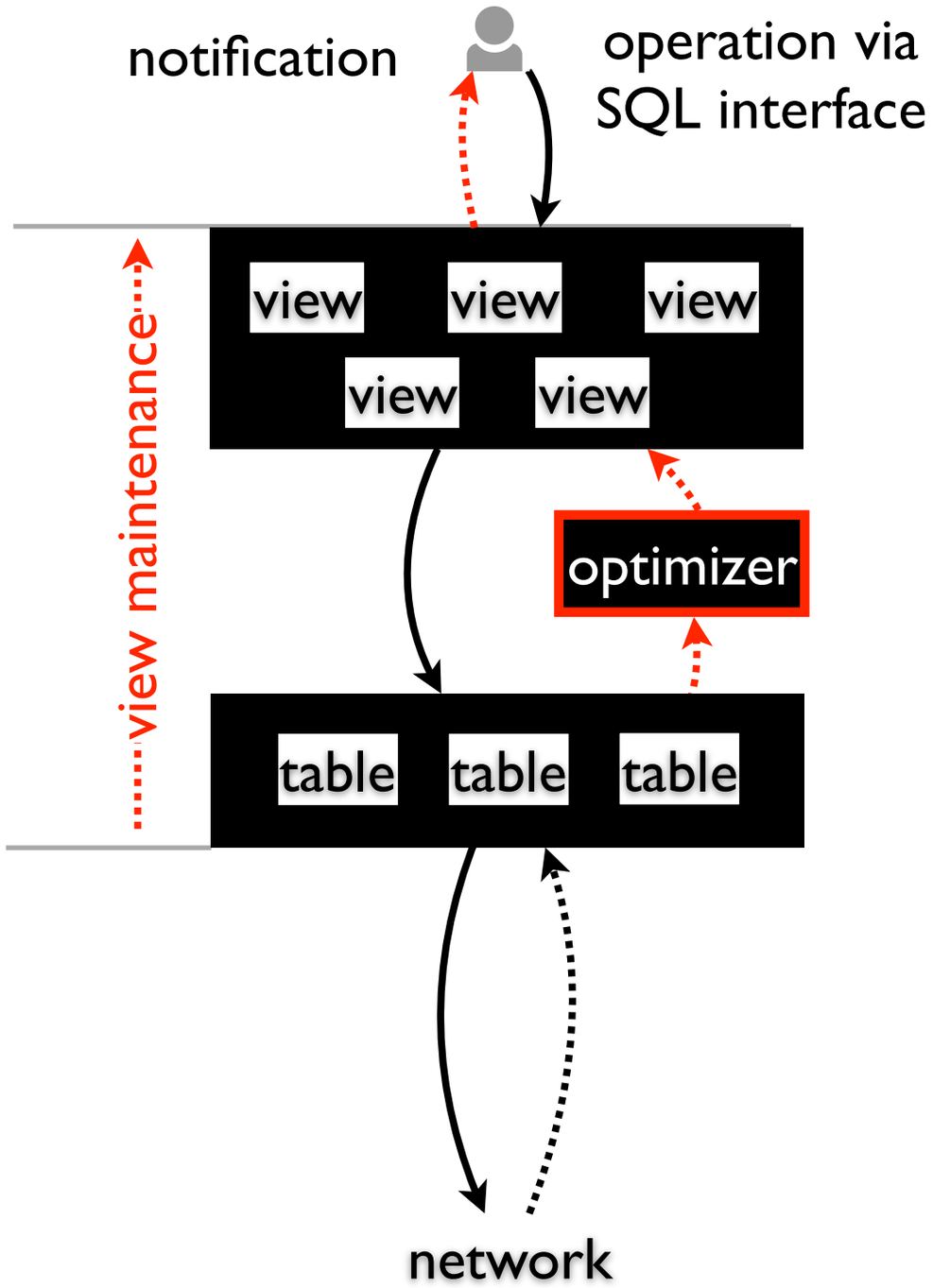
achieving *Ravel* advantages



attractive features

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

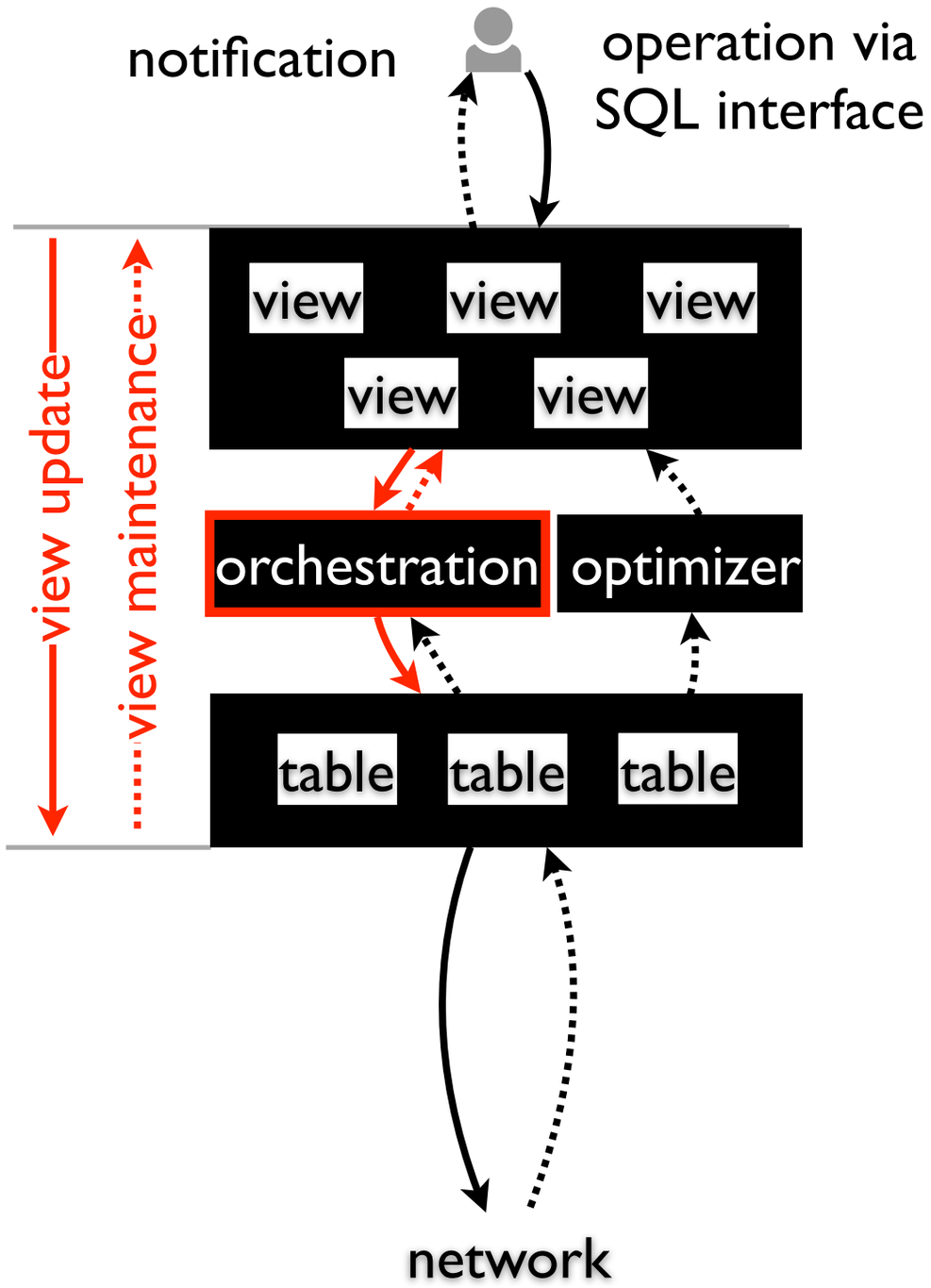
runtime



ad-hoc programmable abstraction via views

- challenge: inefficient user view
- solution: optimizer
- materialize user view with fast maintenance algorithm

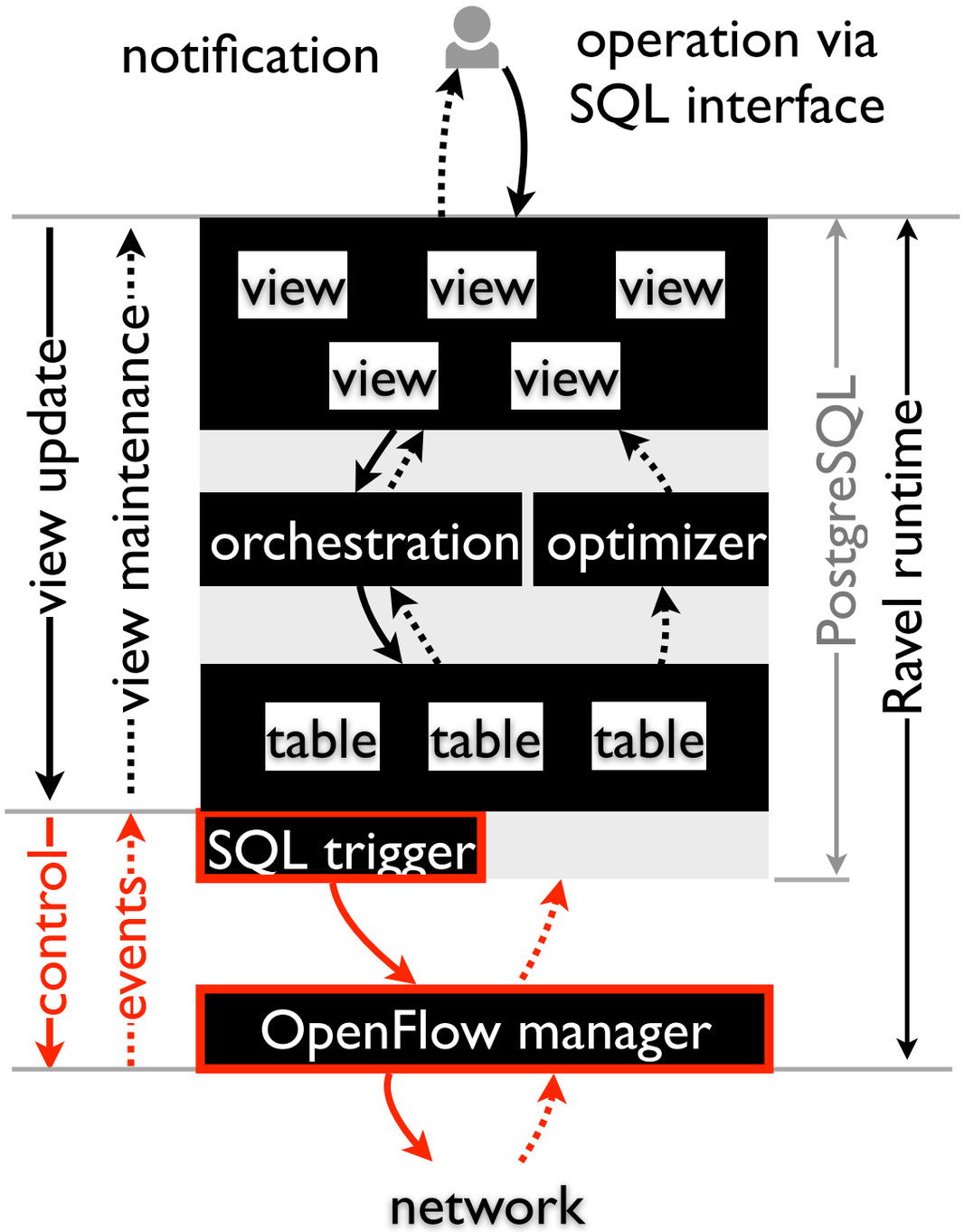
runtime



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

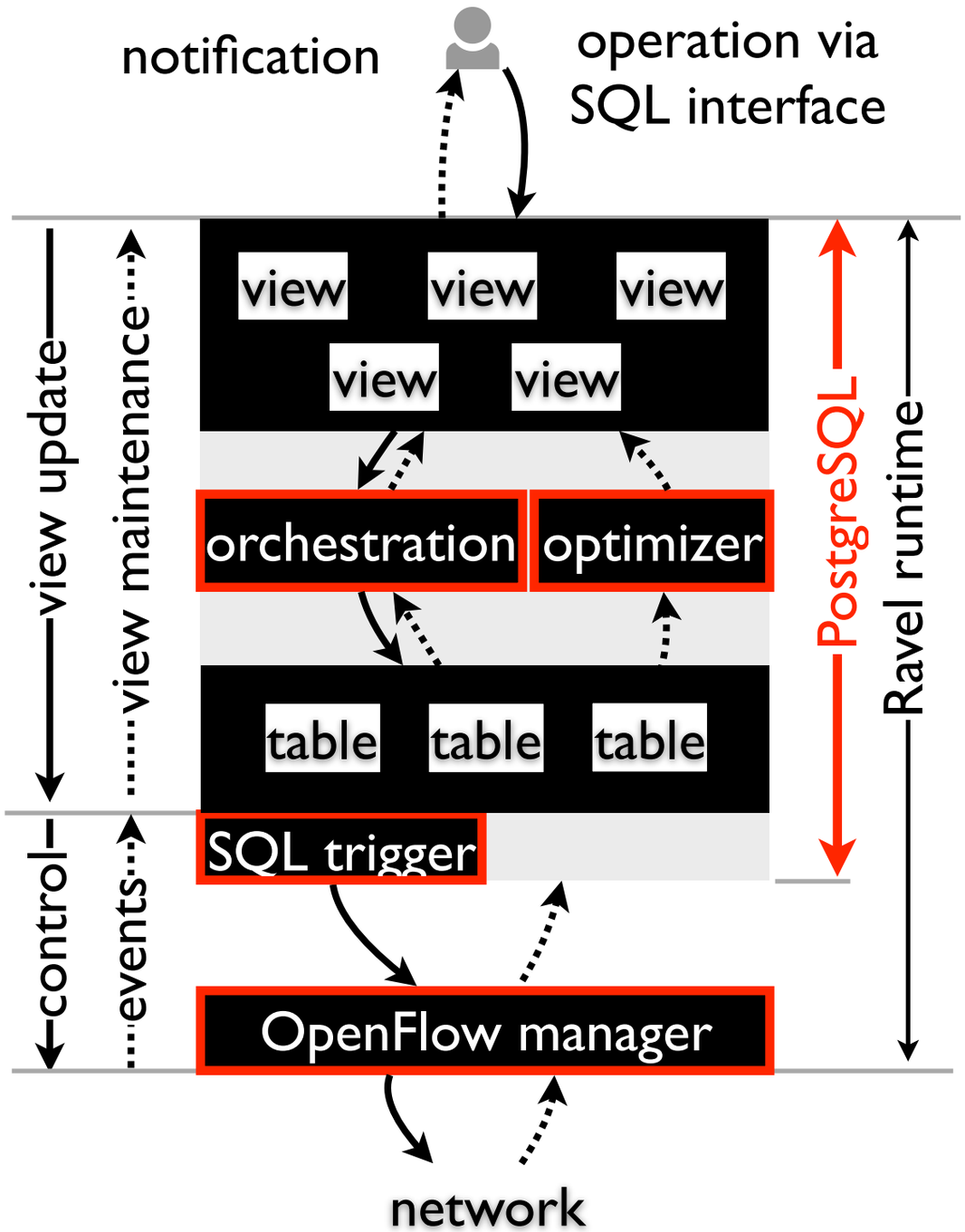
runtime



SDN control via SQL

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

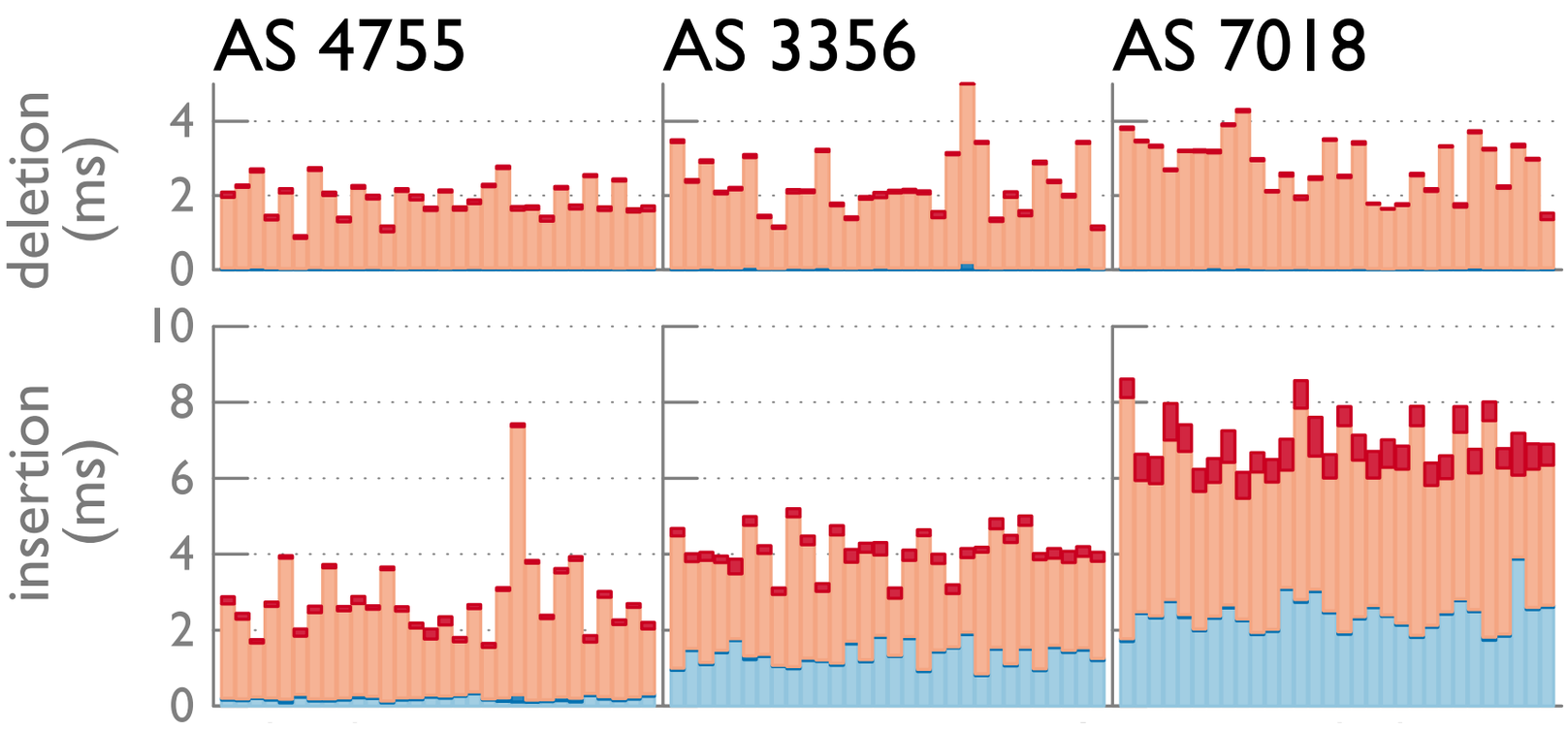
runtime



a high-performance runtime

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

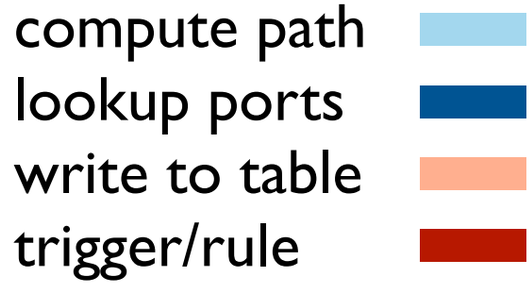
evaluation



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

Rocketfuel ISP topology

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



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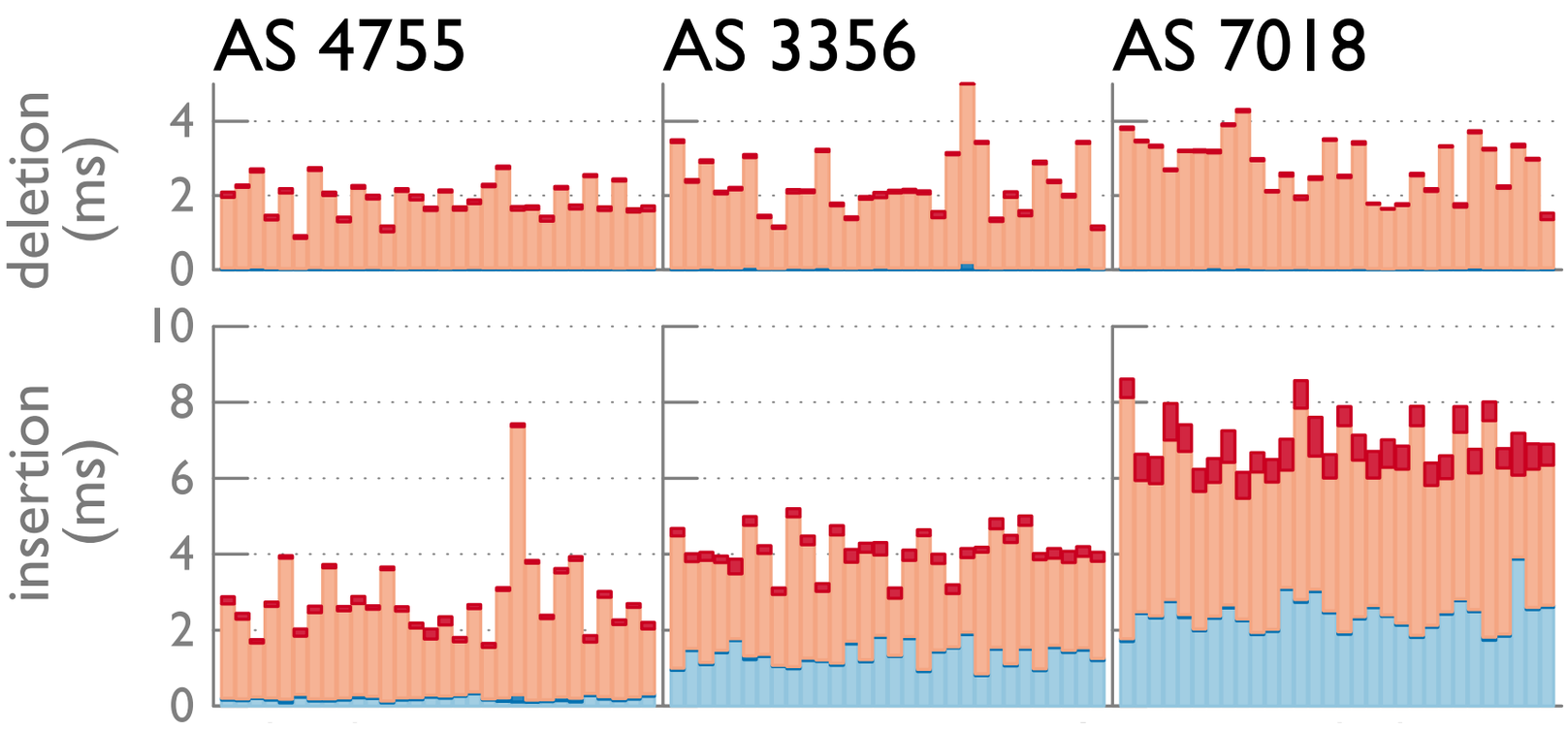

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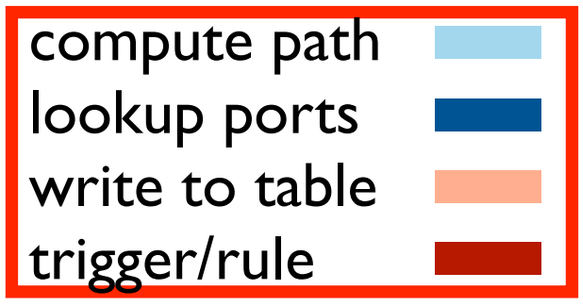

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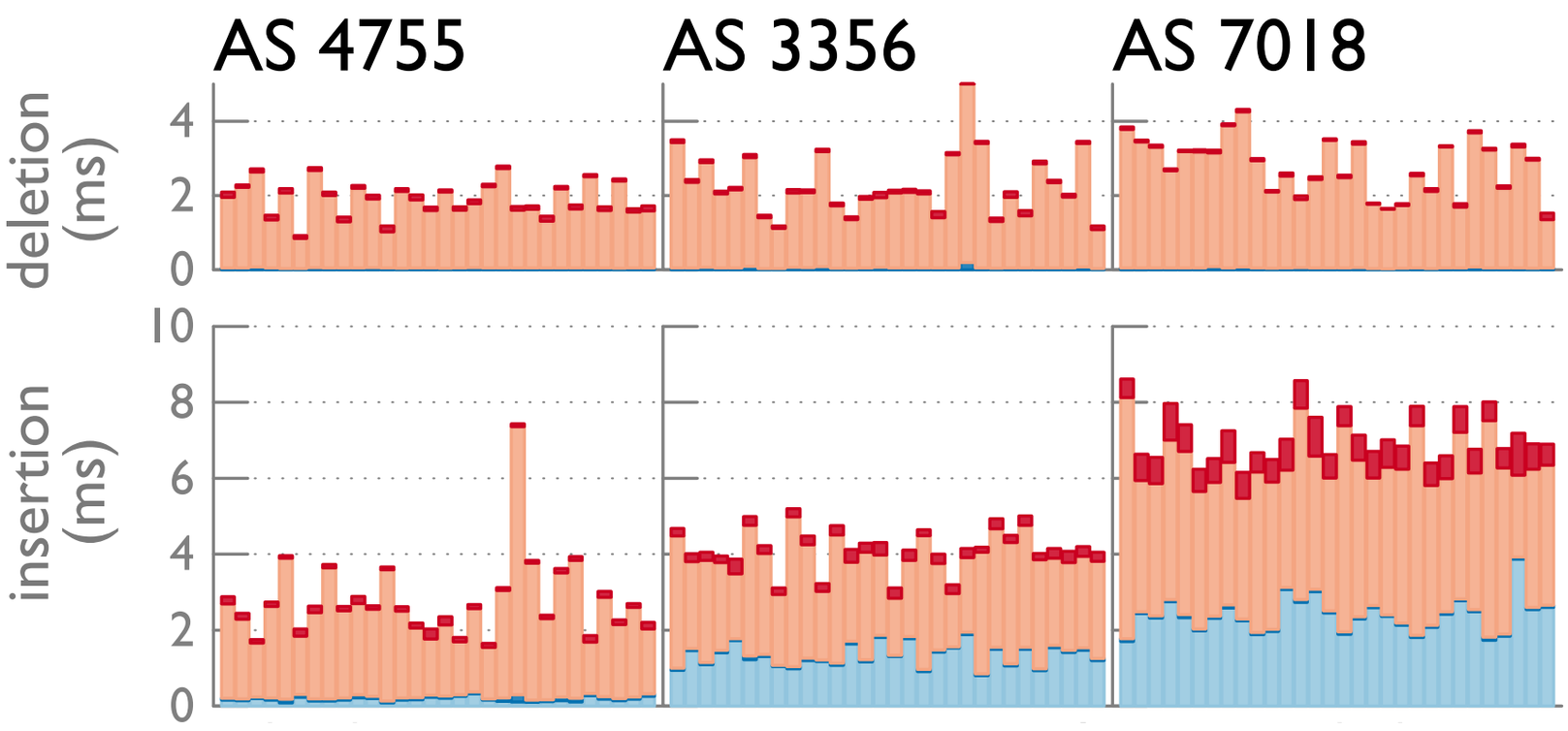

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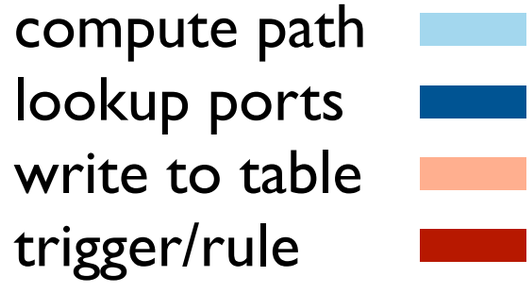

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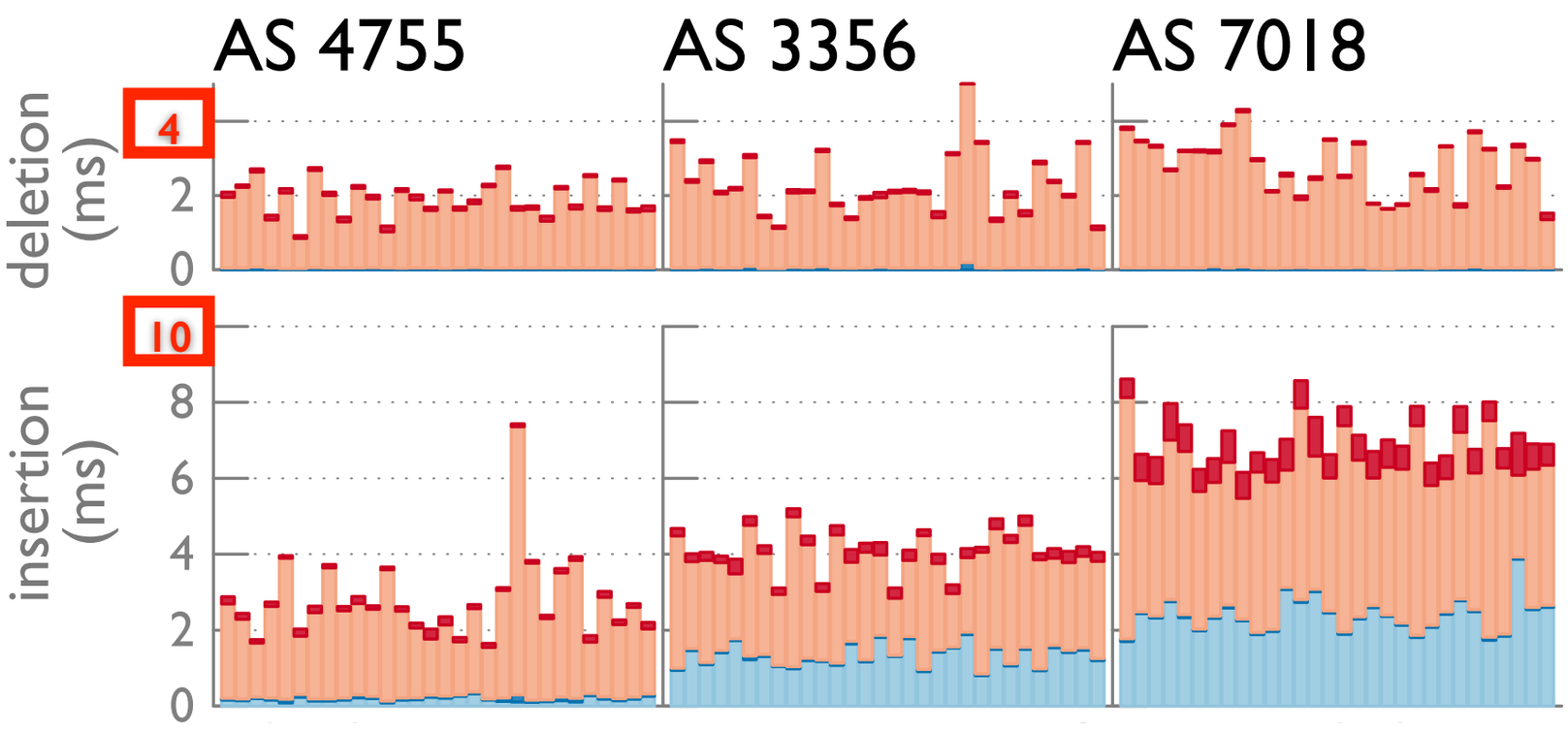

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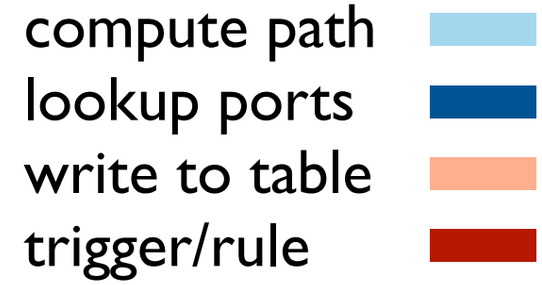

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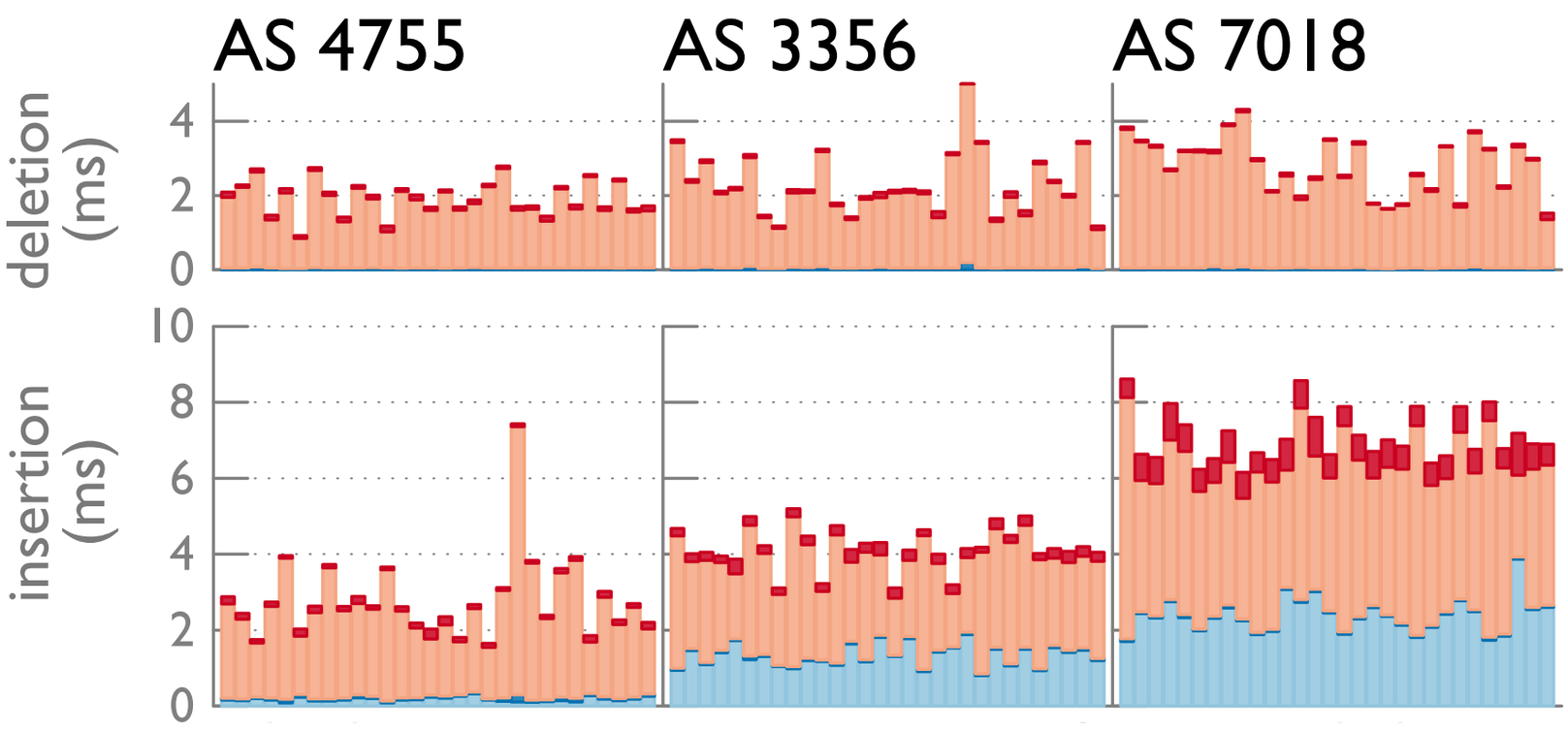

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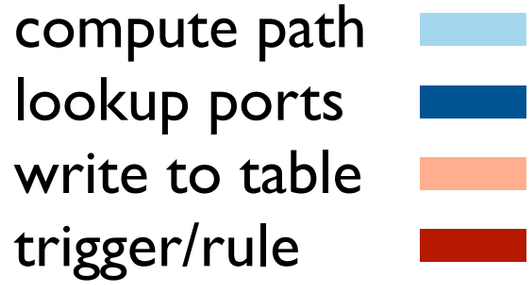

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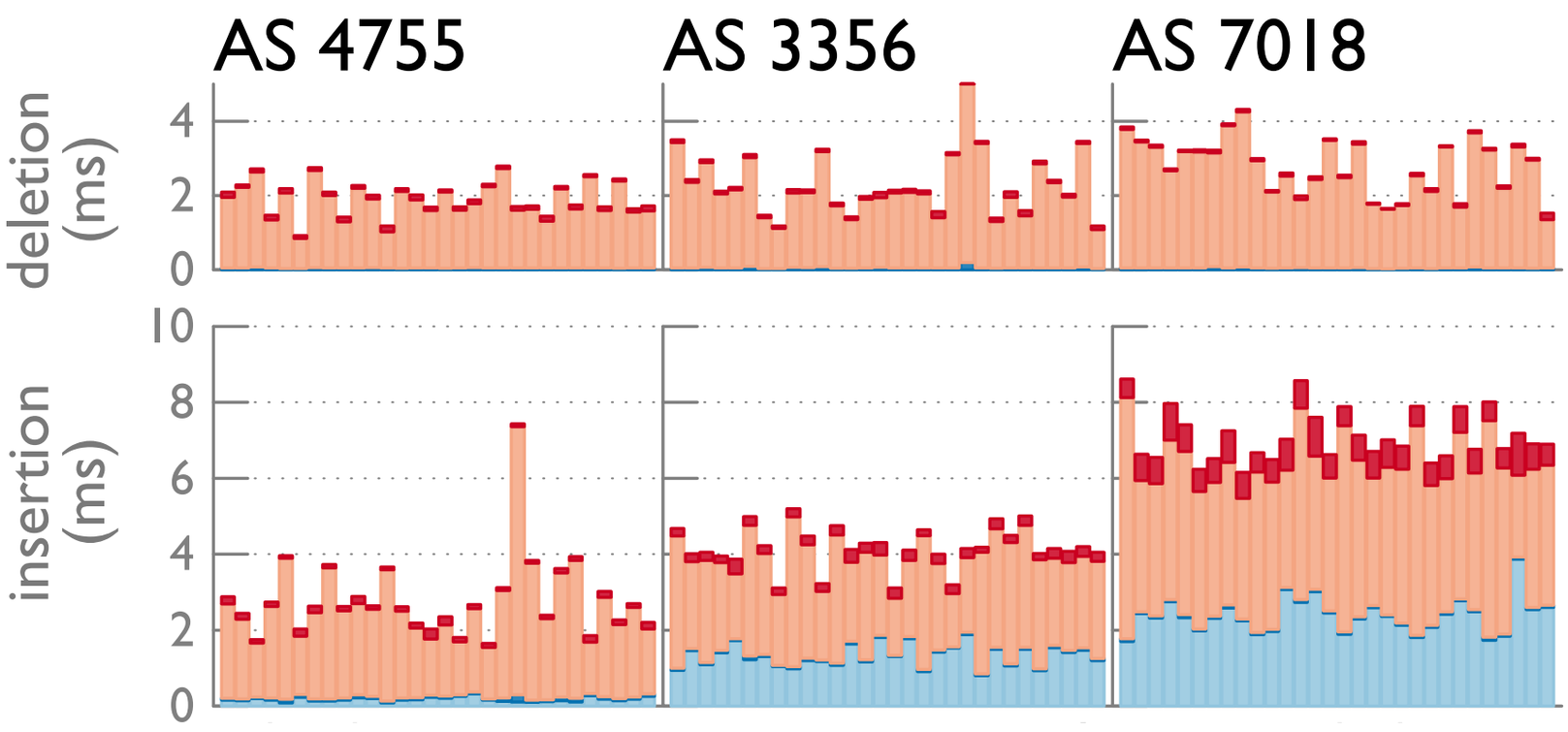

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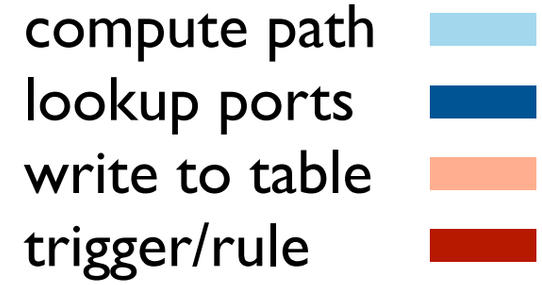
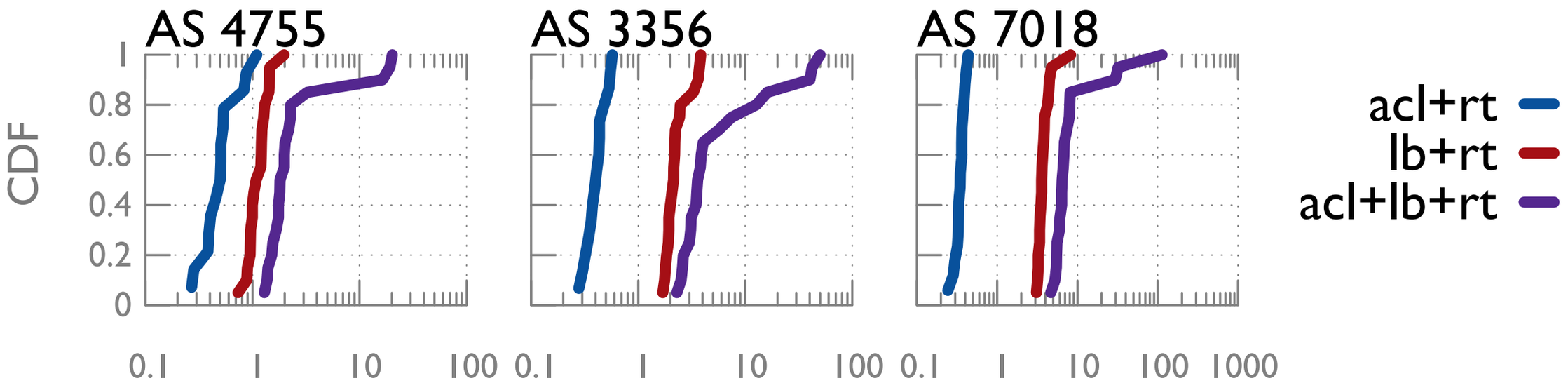


similar profile on fat-tree topology (fewer nodes, more links)

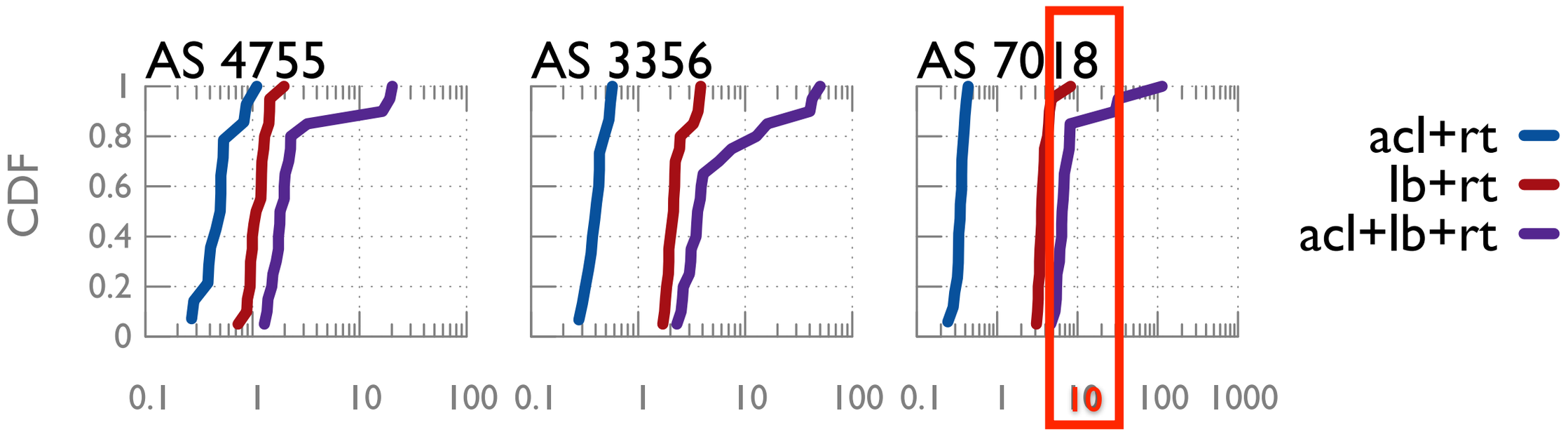
- total delay < 30ms for fat-tree with 5120 switches and 196608 links

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



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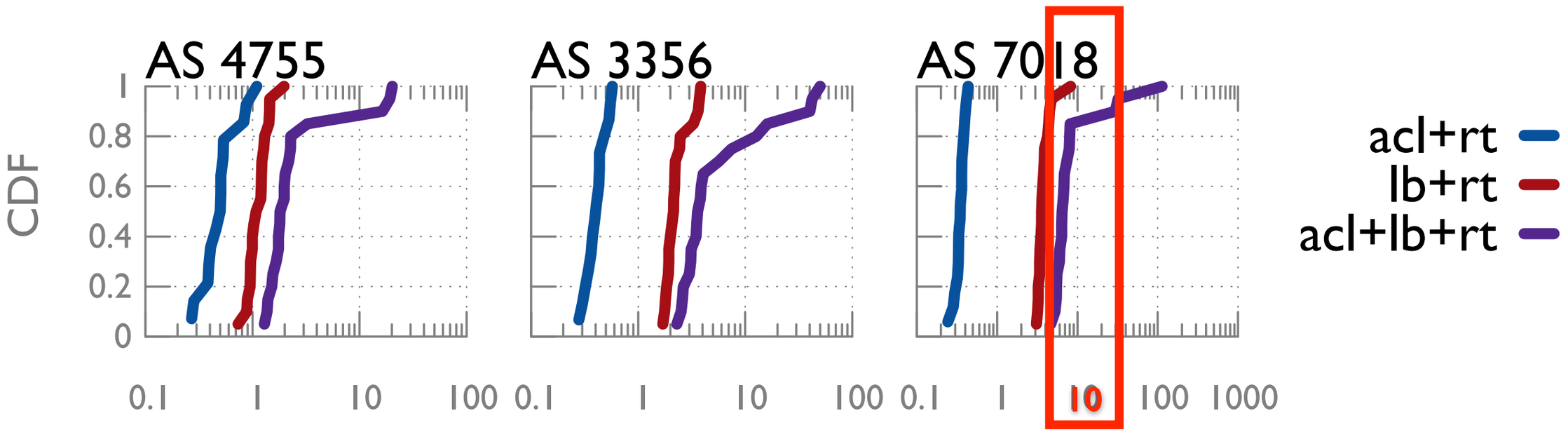
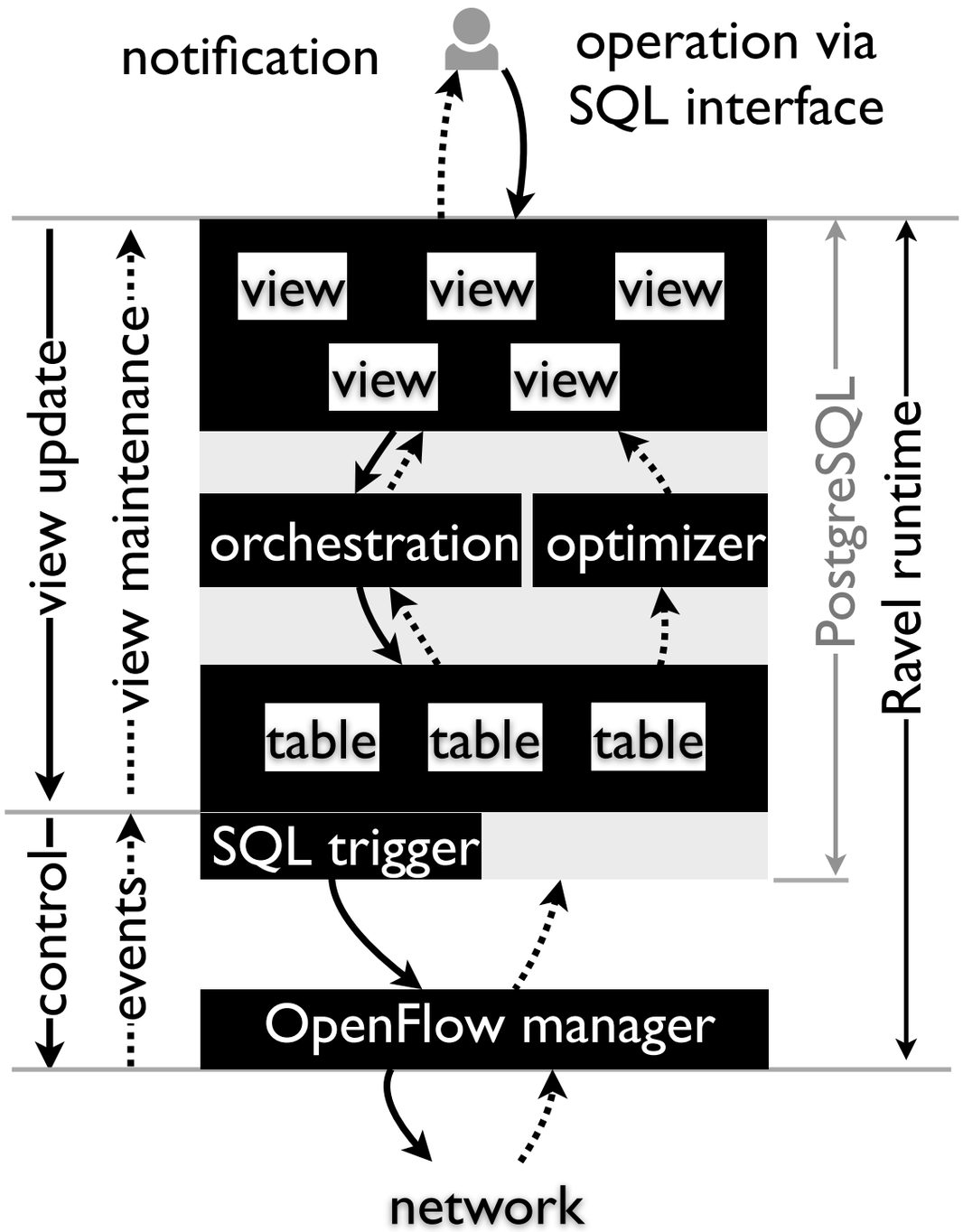


orchestration delay (ms) normalized per-rule for 3 scenarios:
access control and routing (acl+rt), load balancing and routing (lb+rt), access control, load balancing, and routing (acl+lb+rt)

orchestration also scales gracefully on fat-tree

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

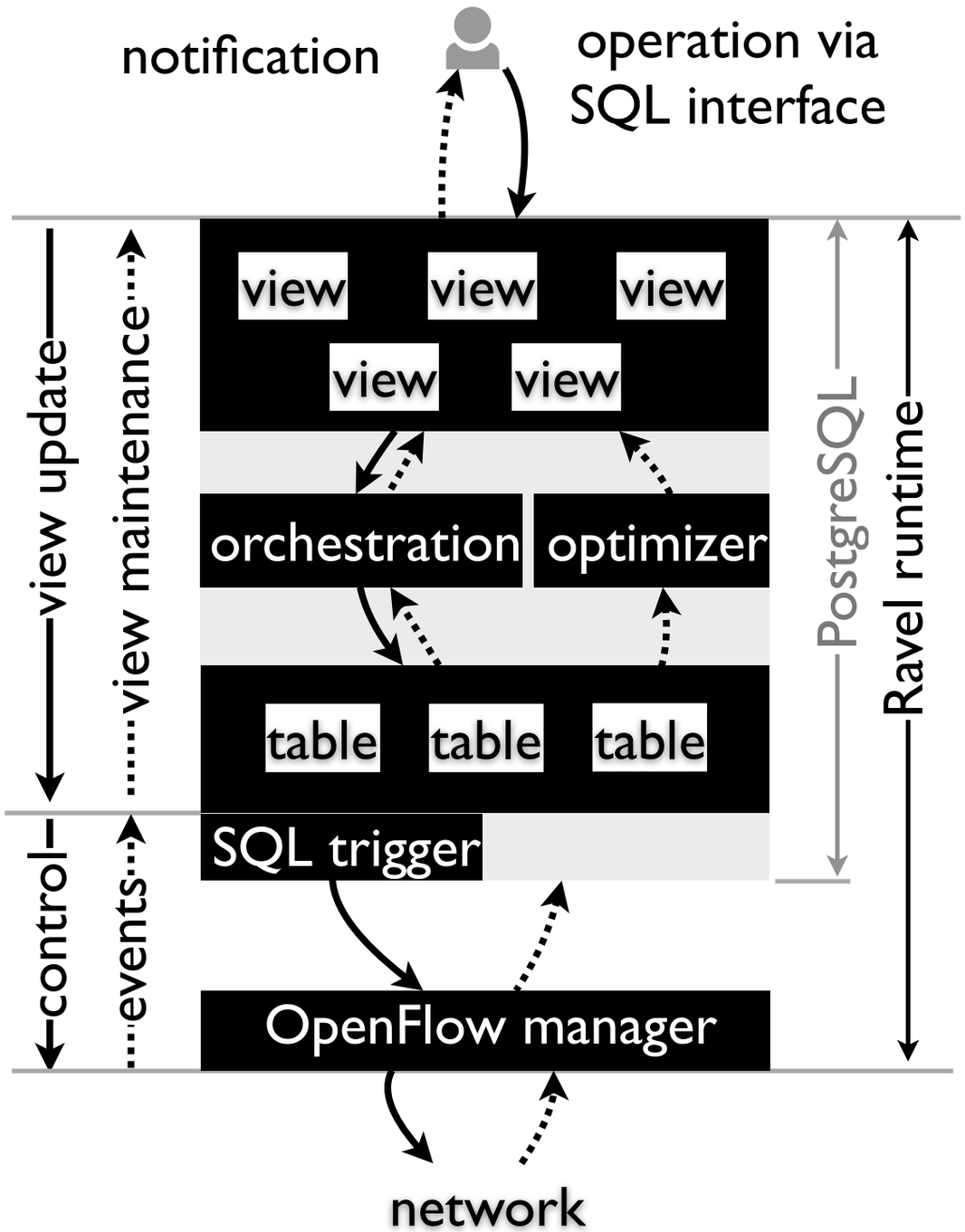
conclusion



this talk

- flexible abstraction via SQL:
  ad-hoc extensible, orchestratable
  promising performance

conclusion



this talk

- flexible abstraction via SQL:
  ad-hoc extensible, orchestratable
  promising performance

looking forward

- application of database features
  - network-wide transaction
  - bootstrapping legacy networks
- enhancing database
  - better runtime: orchestration
  - better control decision: view analysis
- interpretability
  - integrate foreign applications, plug-n-play
    3rd party solvers

demo

demo

playtime

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explore more

github.com/ravel-net