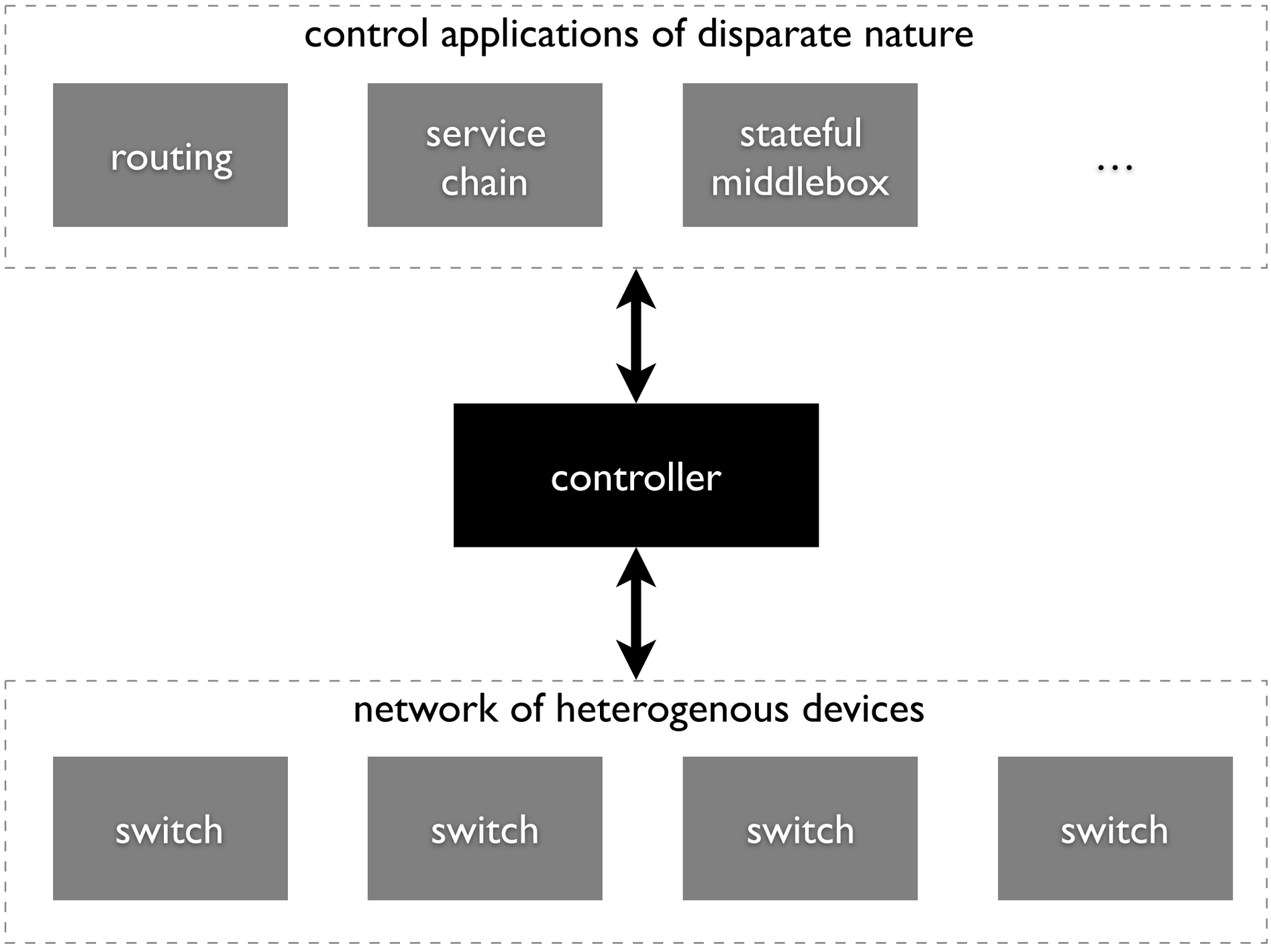
Ravel: a database-defined network

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

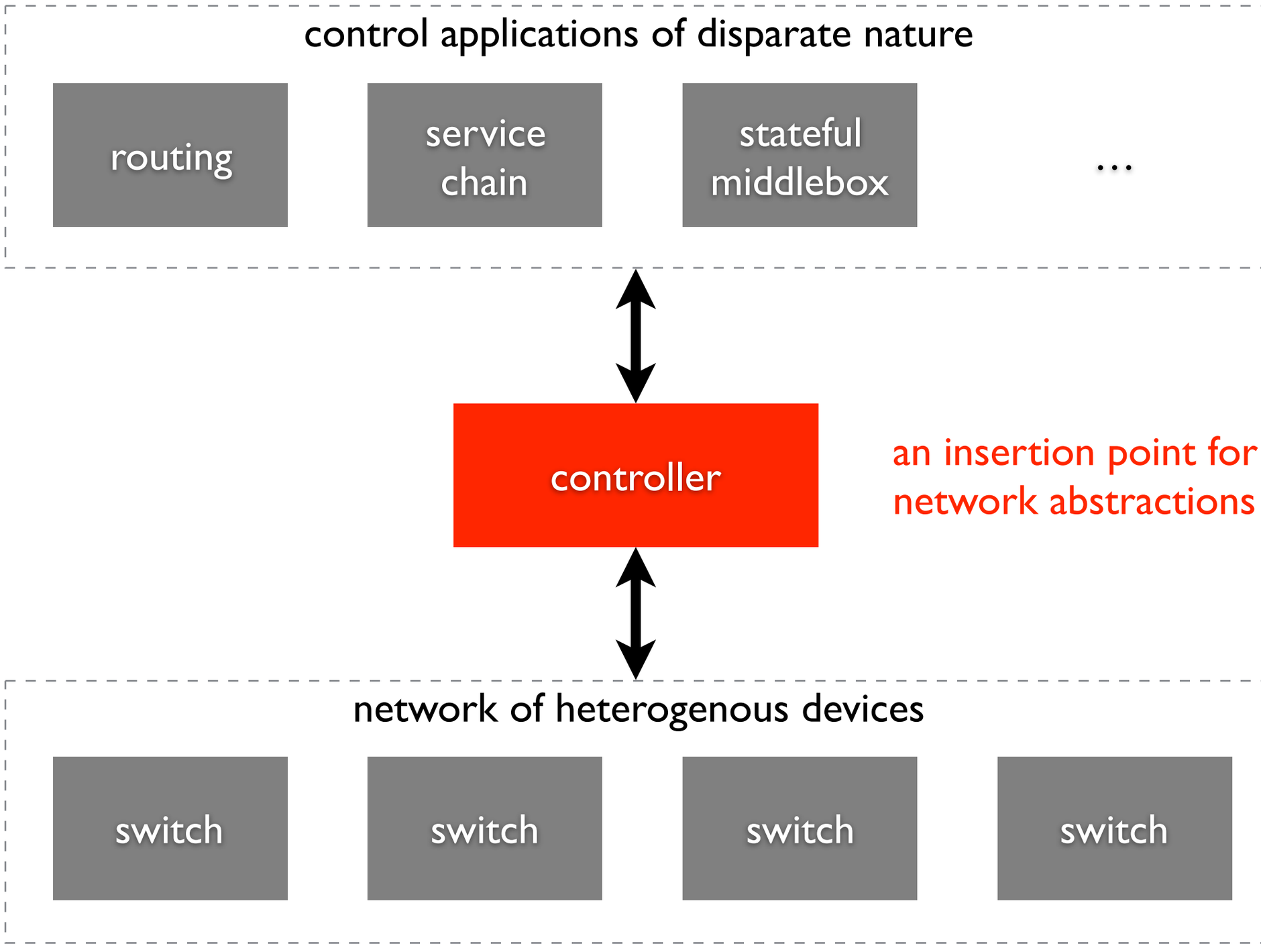
**Temple University* †*University of Illinois Urbana-Champaign*

March 14, 2016 SOSR'16

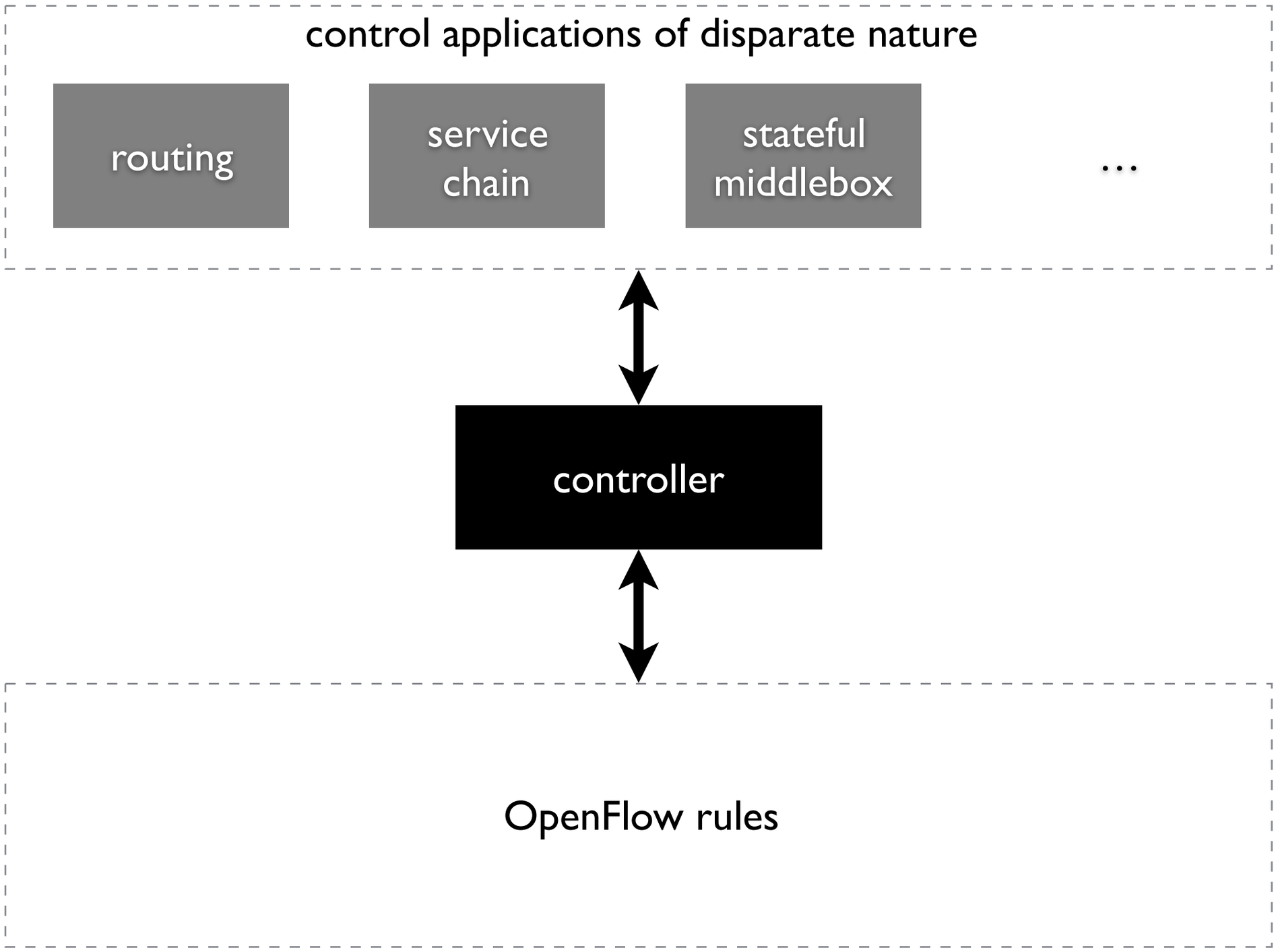
software-defined network



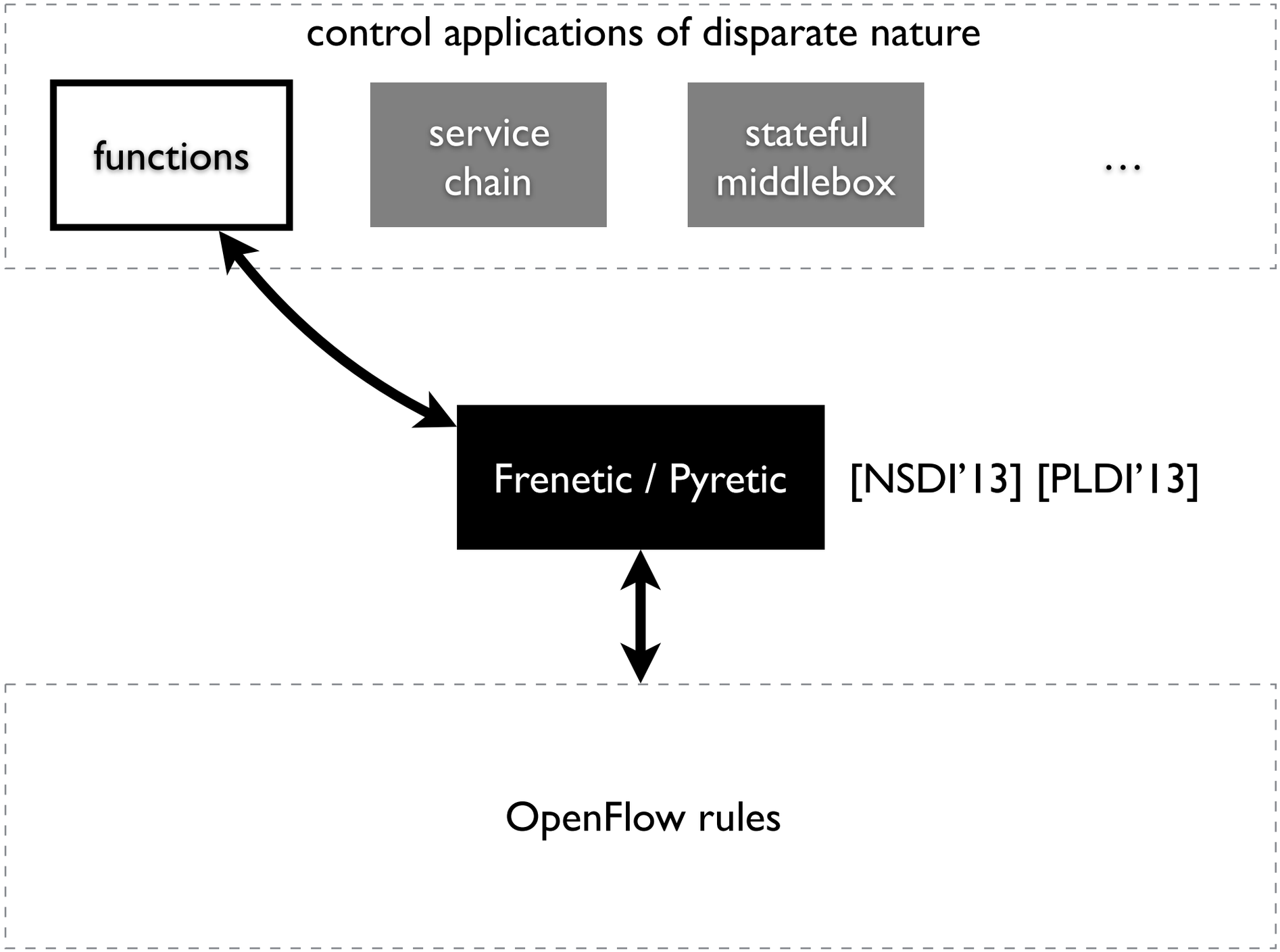
software-defined network



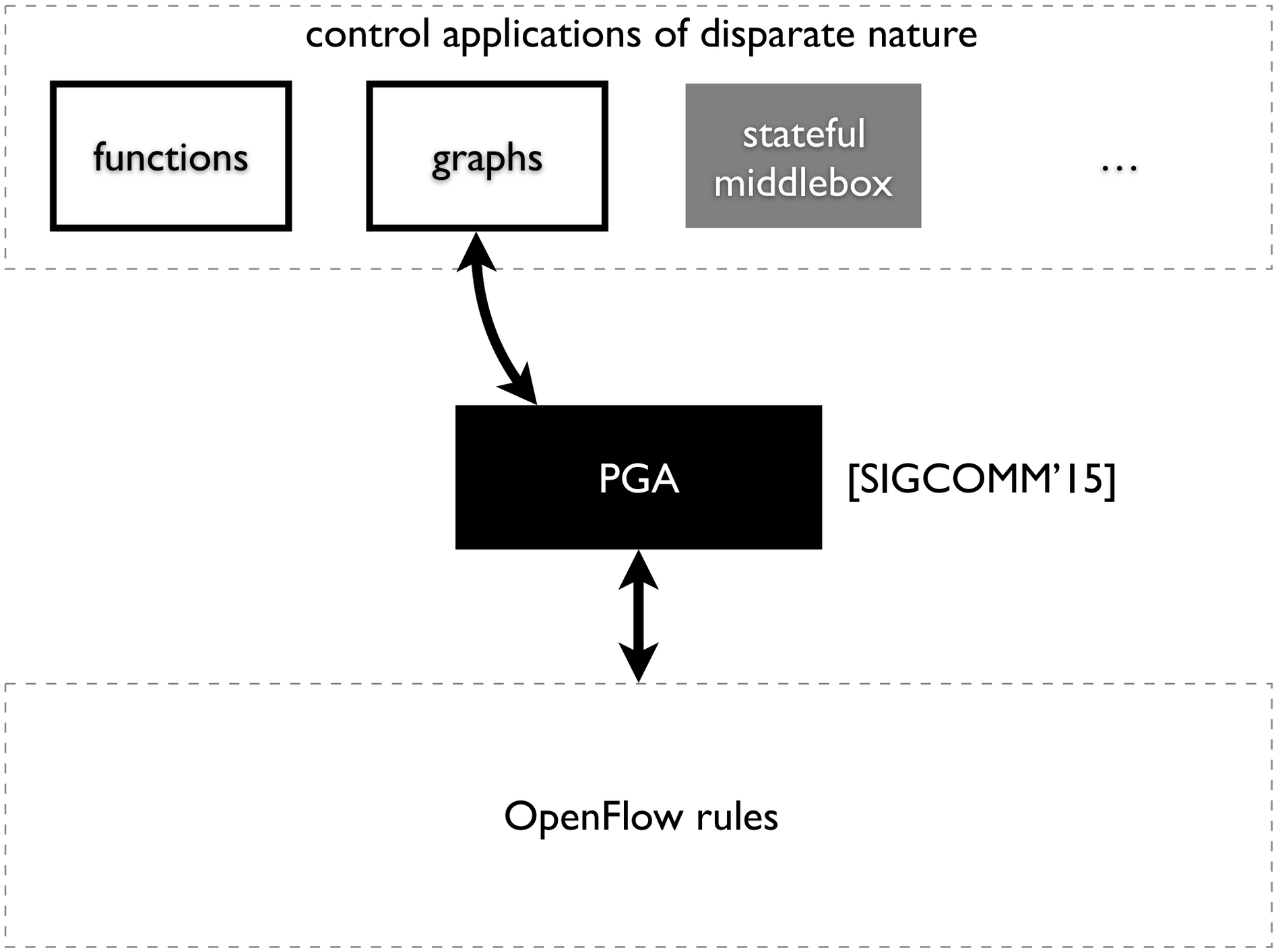
abstractions



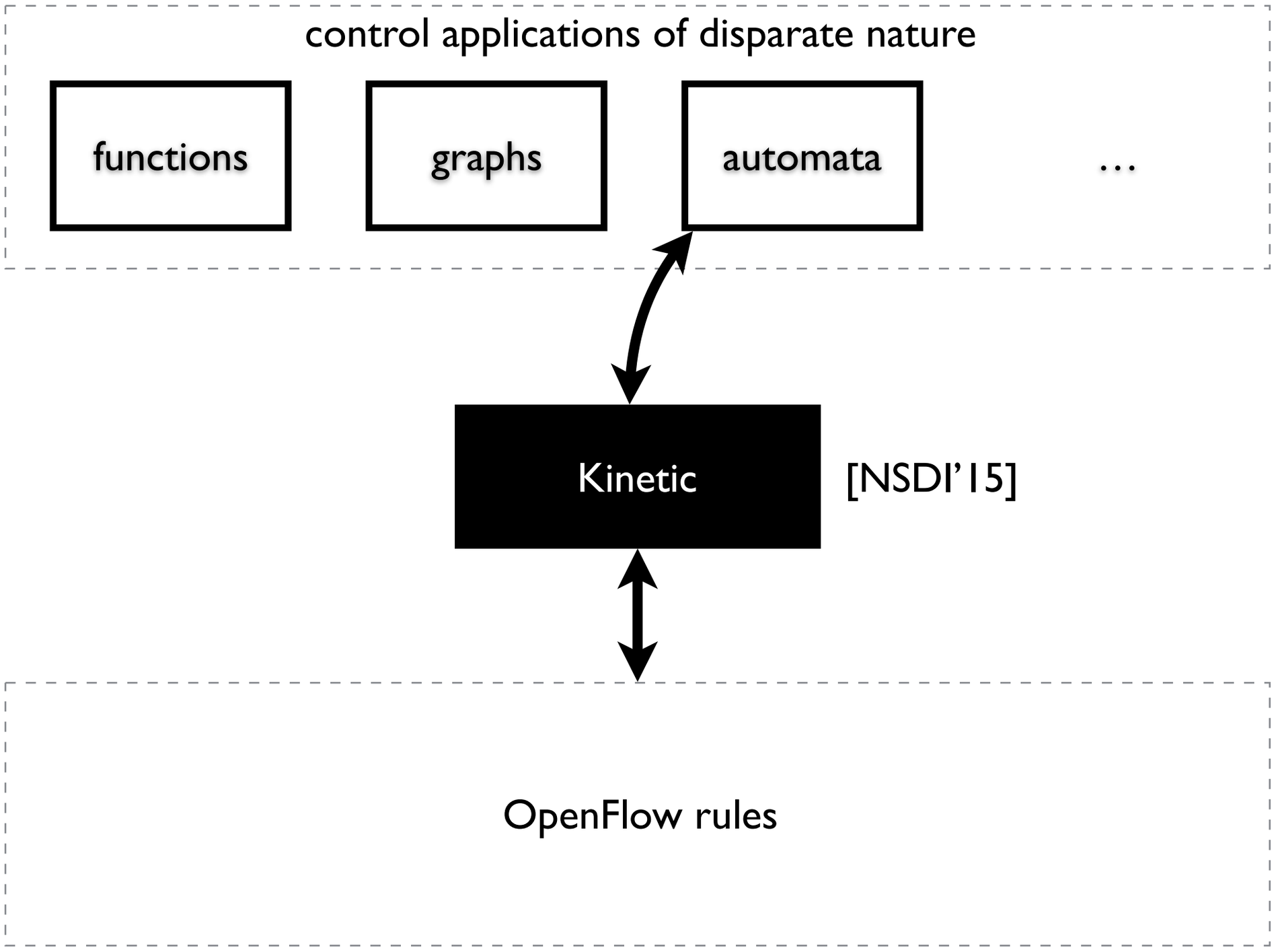
abstractions



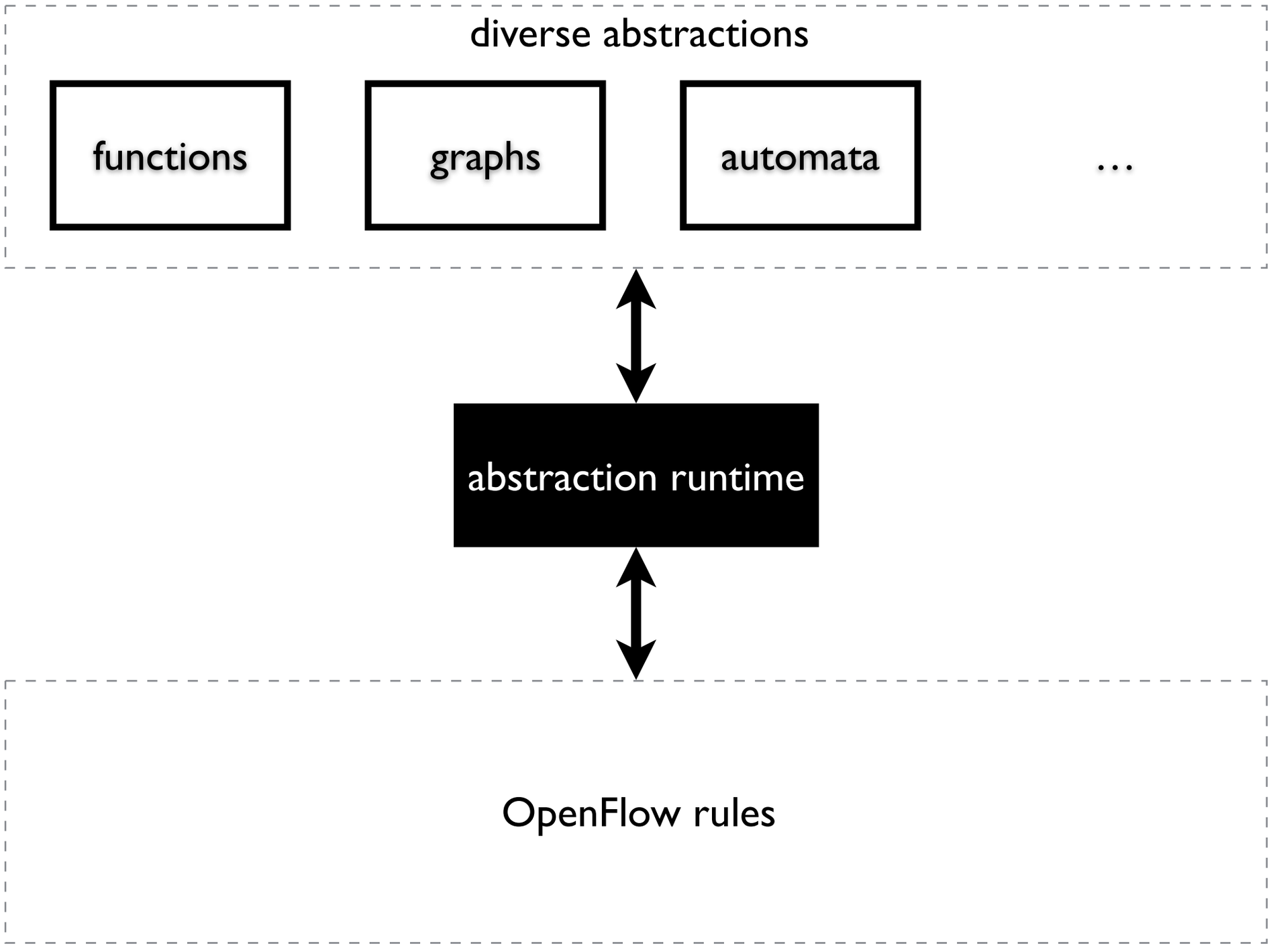
abstractions



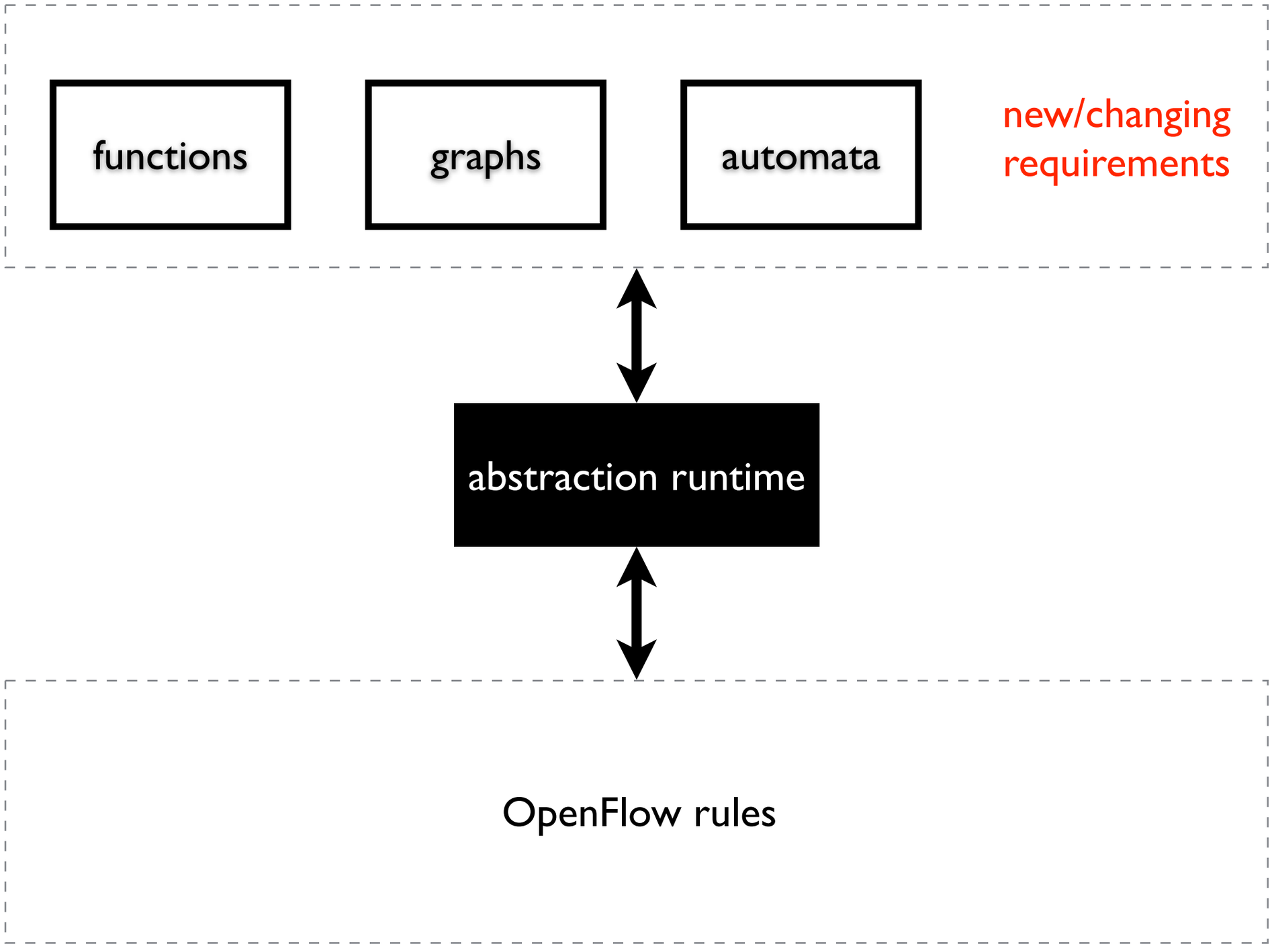
abstractions



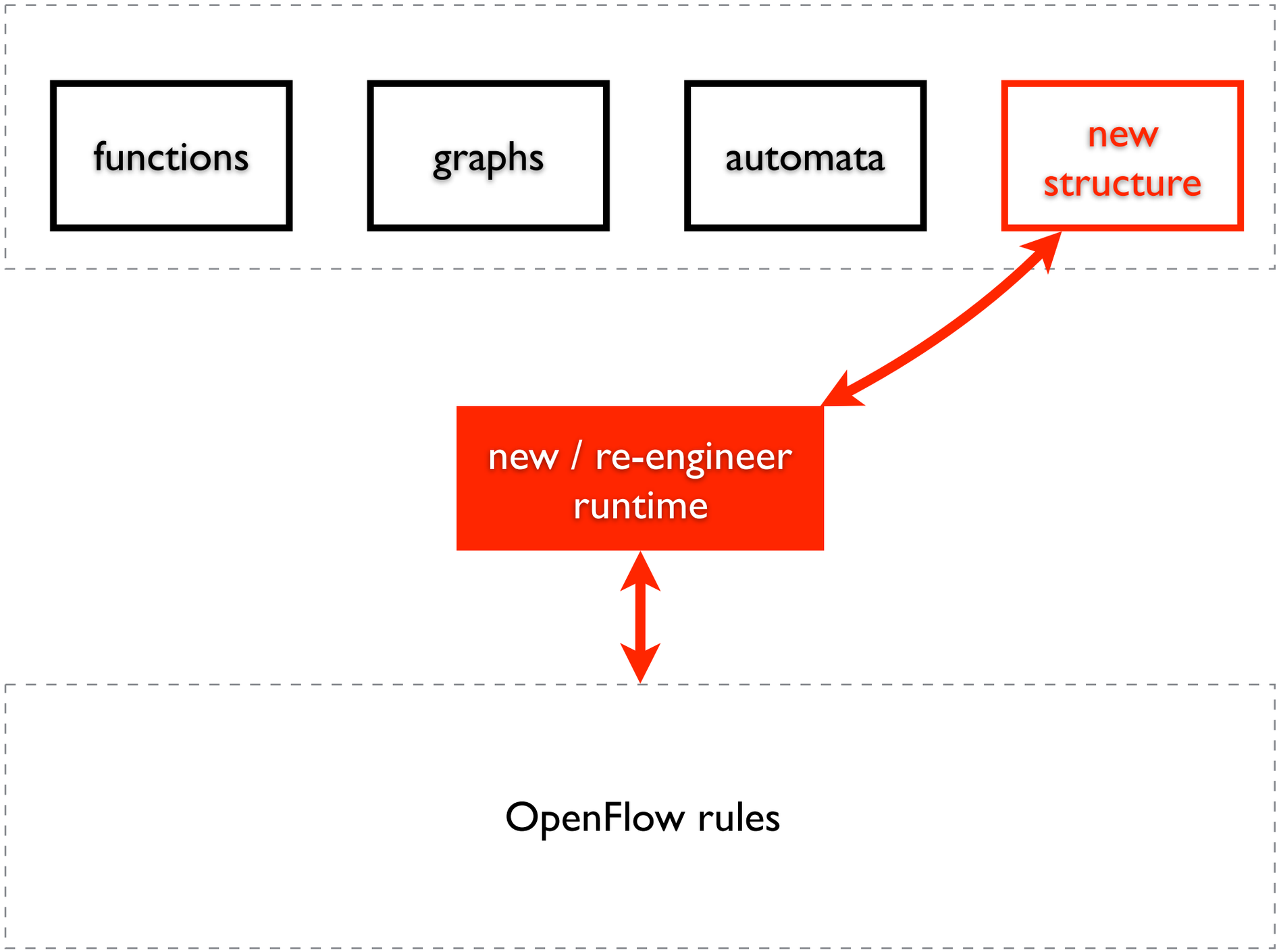
abstractions



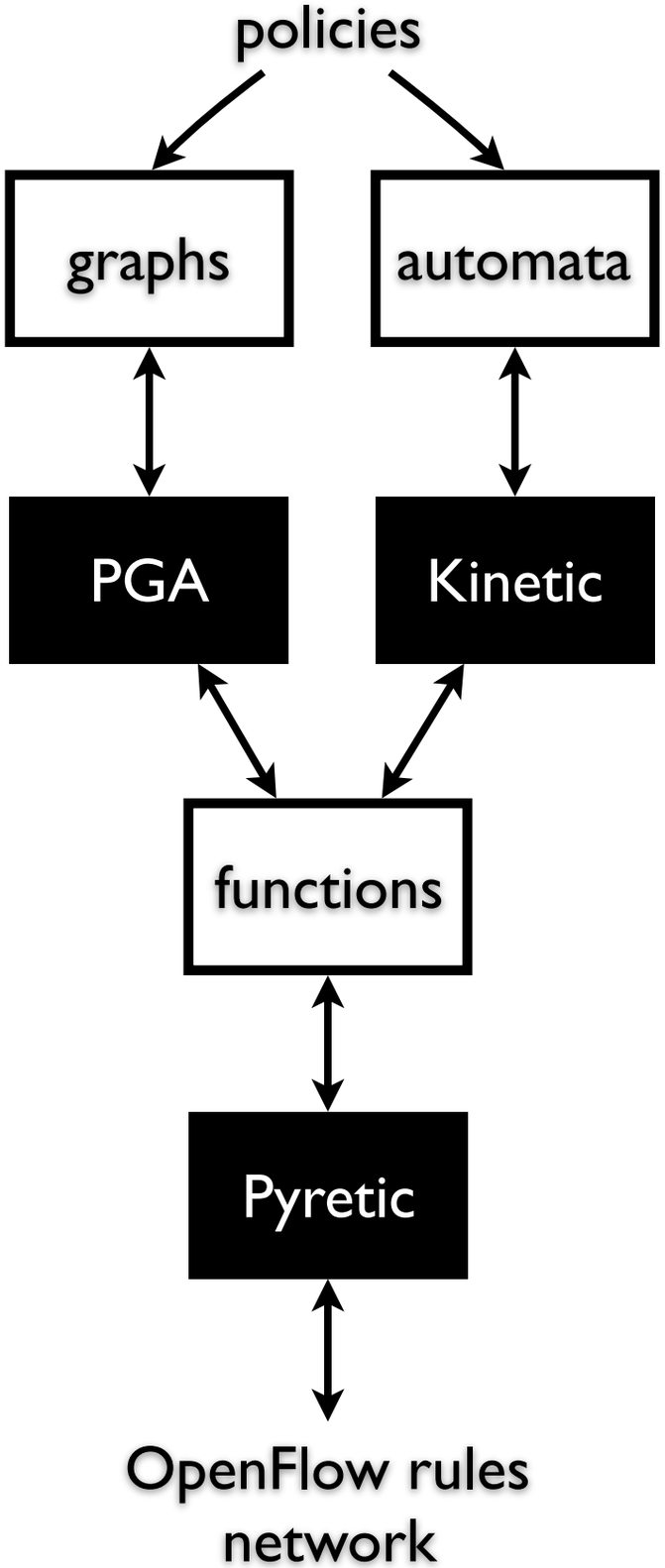
but network keeps evolving



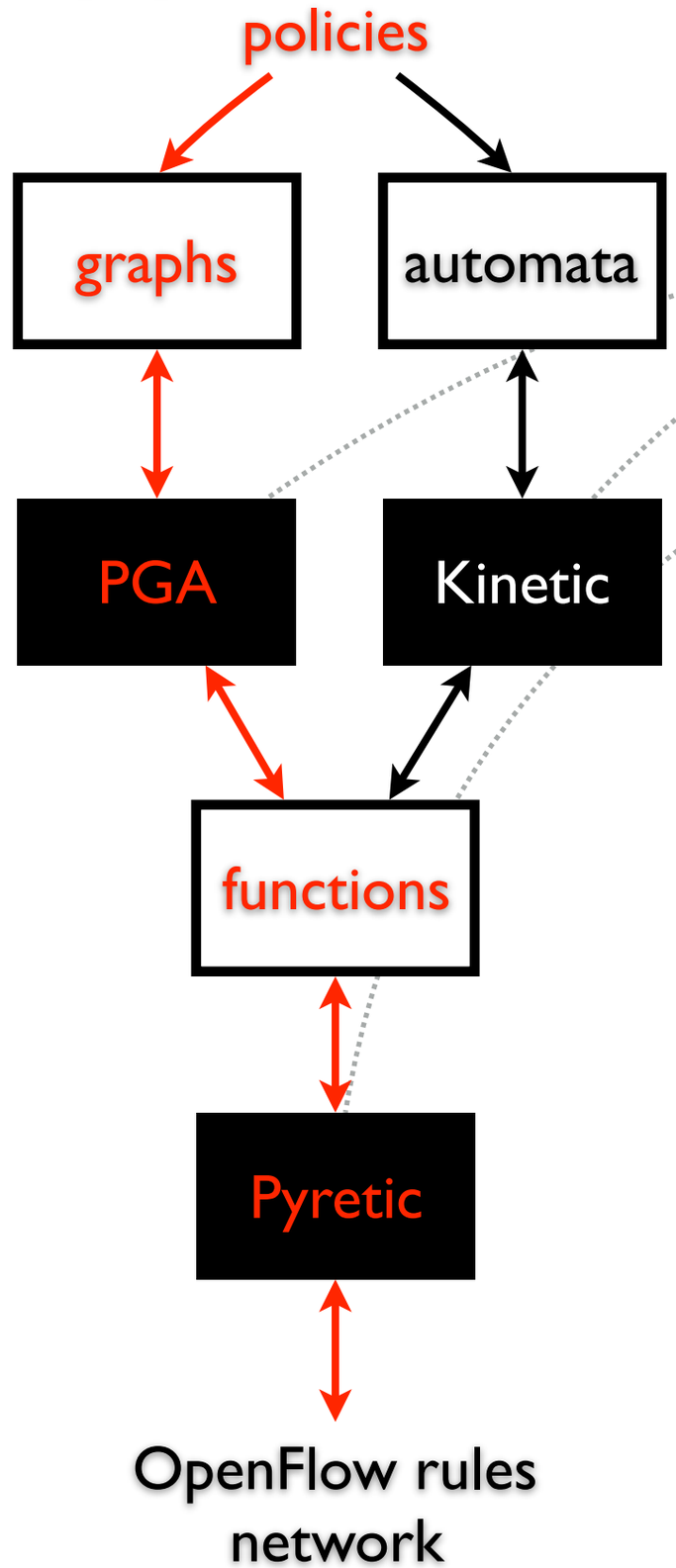
but network keeps evolving



and applications (components) interact



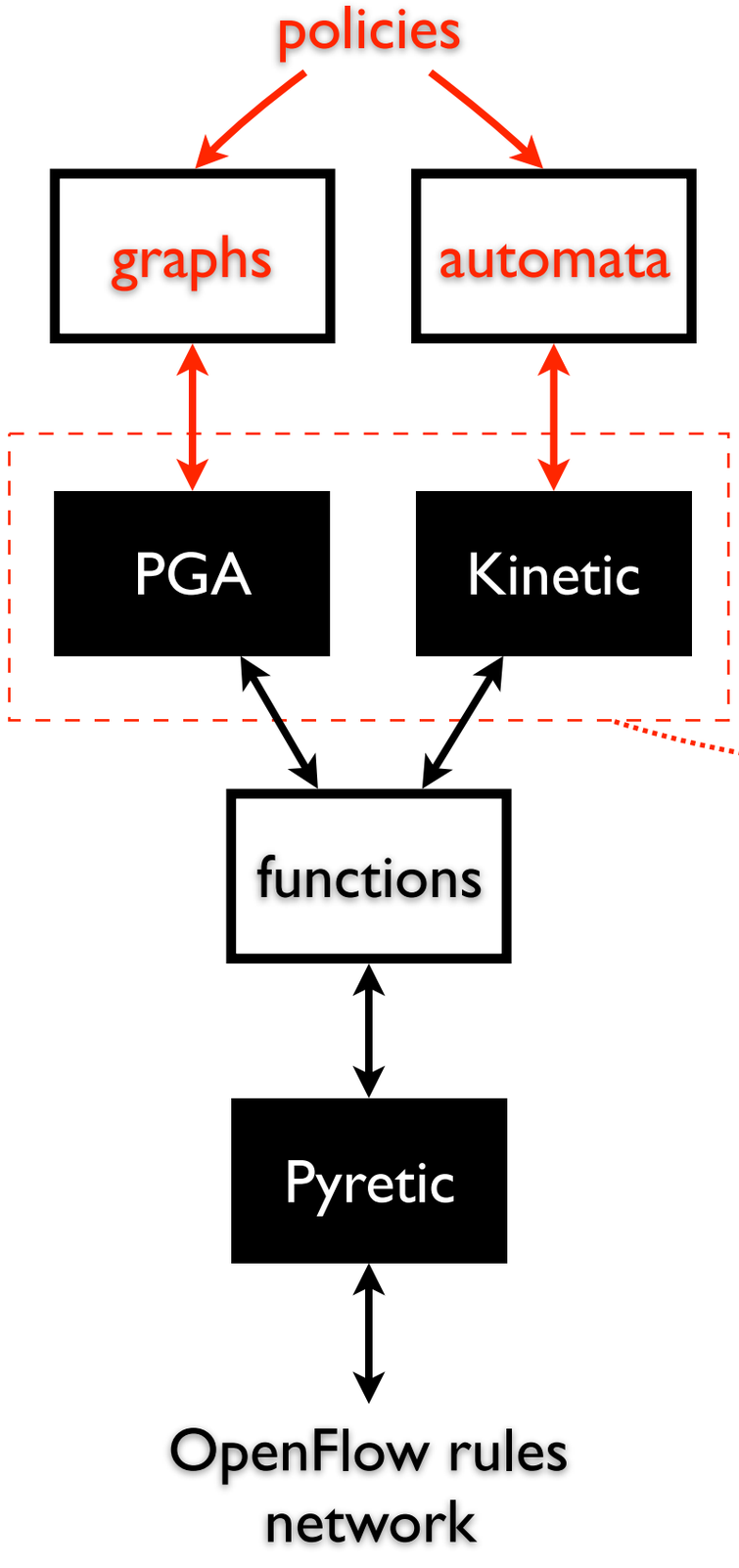
and applications (components) interact



language-level orchestration restricted to each abstraction

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

and applications (components) interact

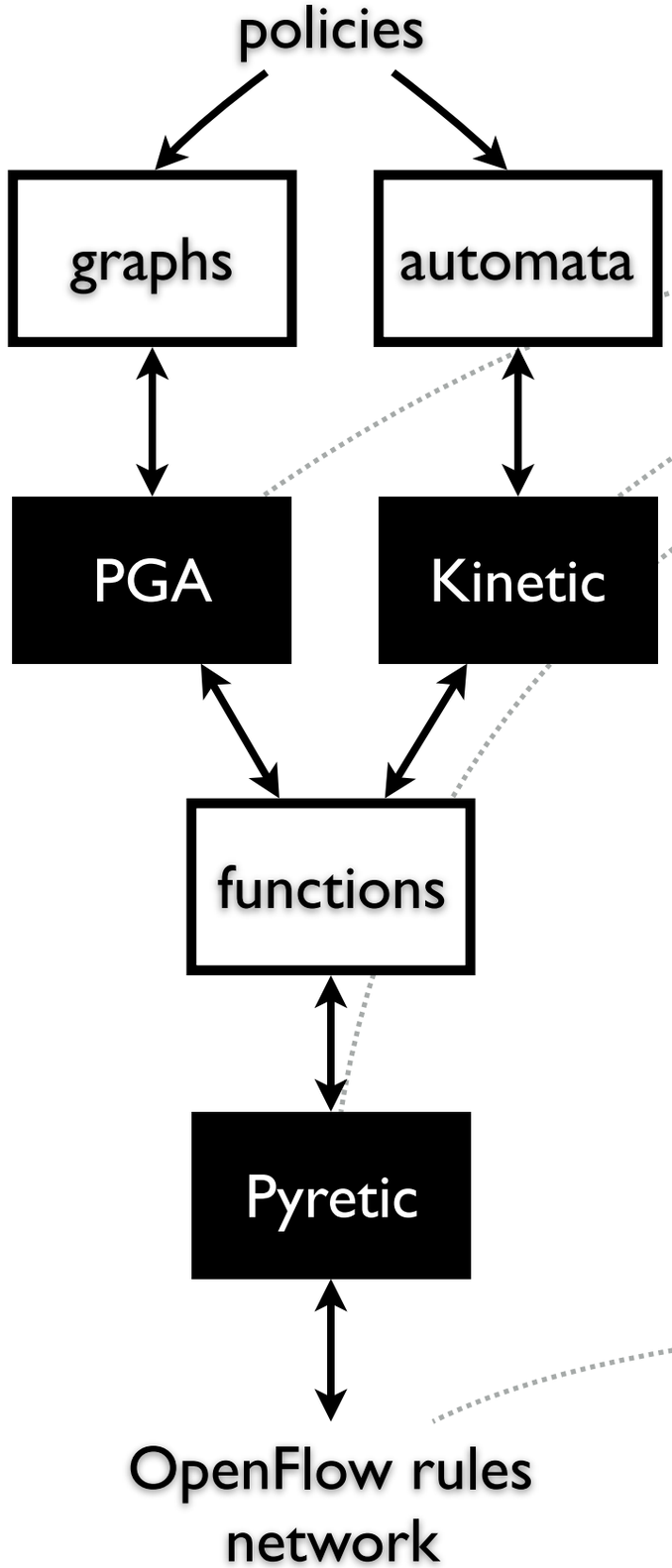


language-level orchestration restricted to each abstraction

composing (+) policy
→ graph +? automata

integrate the runtime, hard-wiring internals?

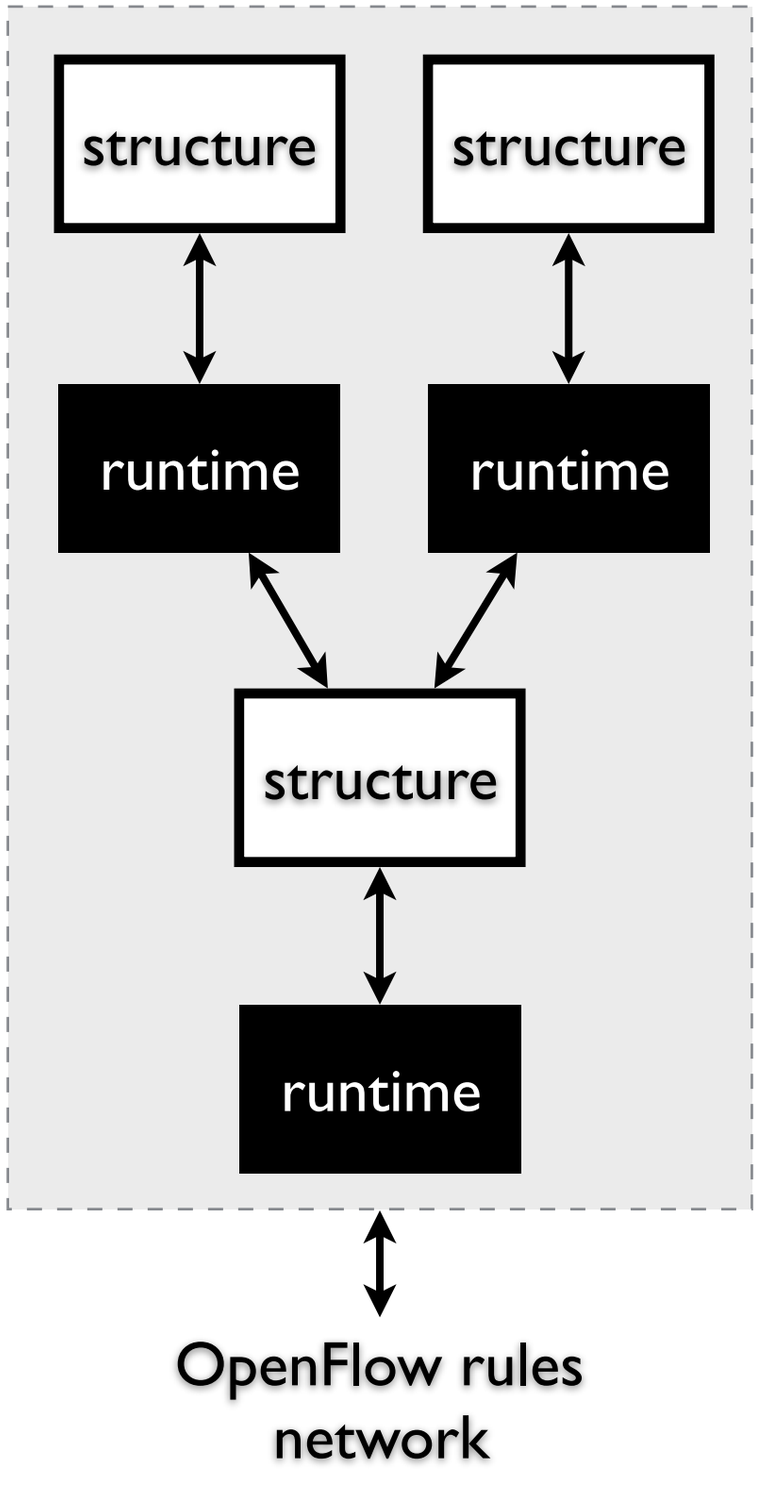
and applications (components) interact



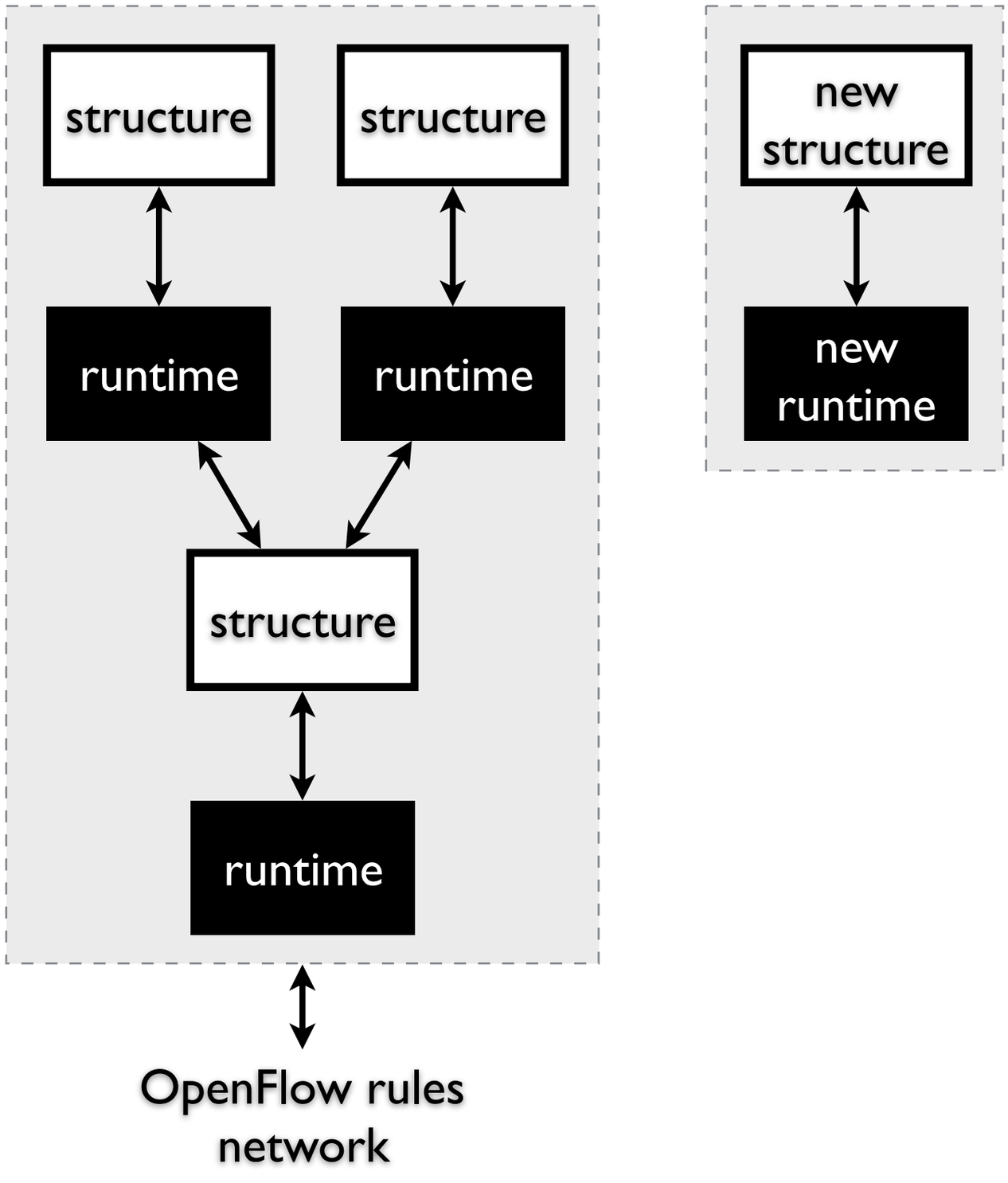
language-level orchestration restricted to each abstraction

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

current states of abstraction

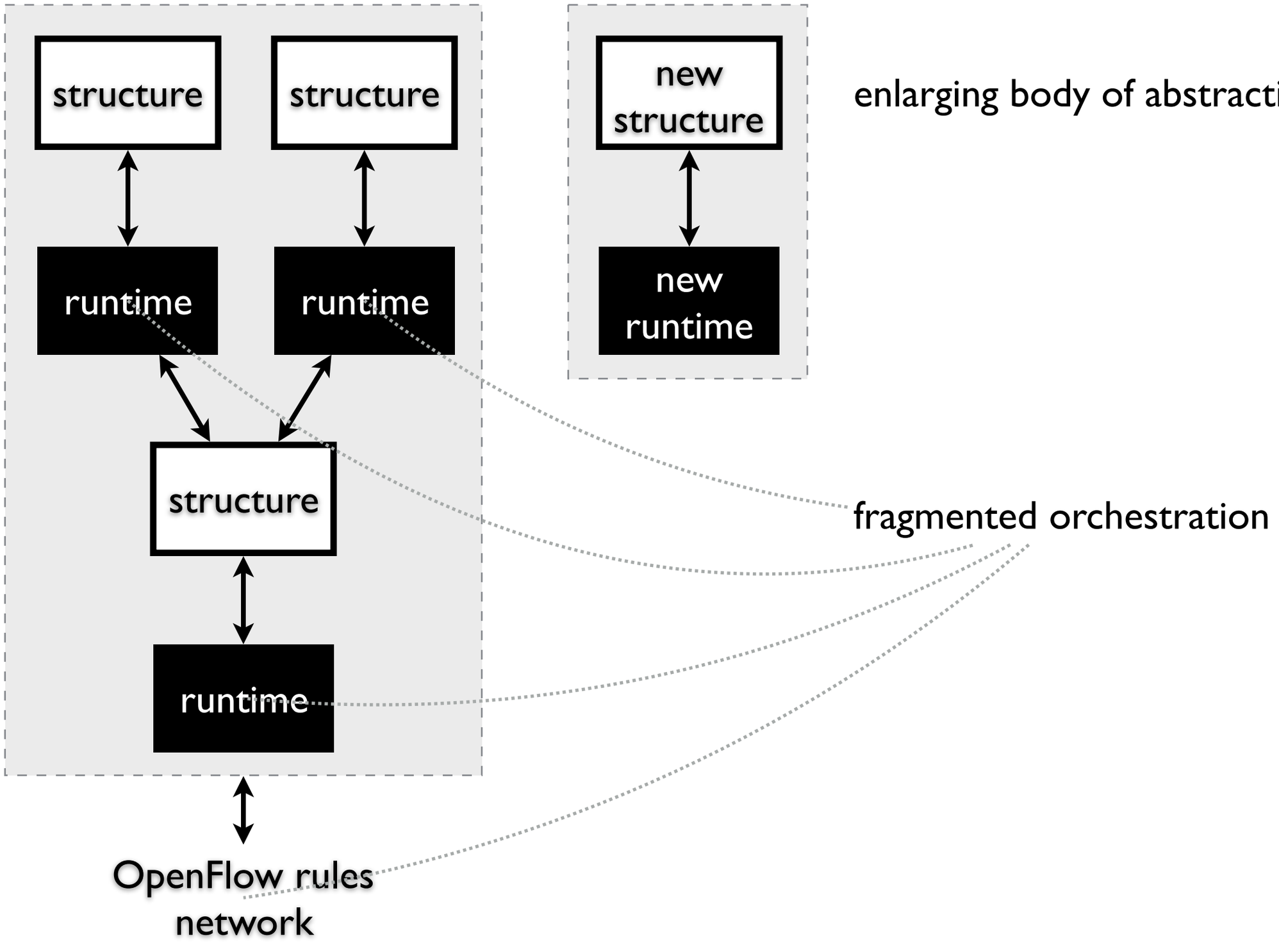


current states of abstraction

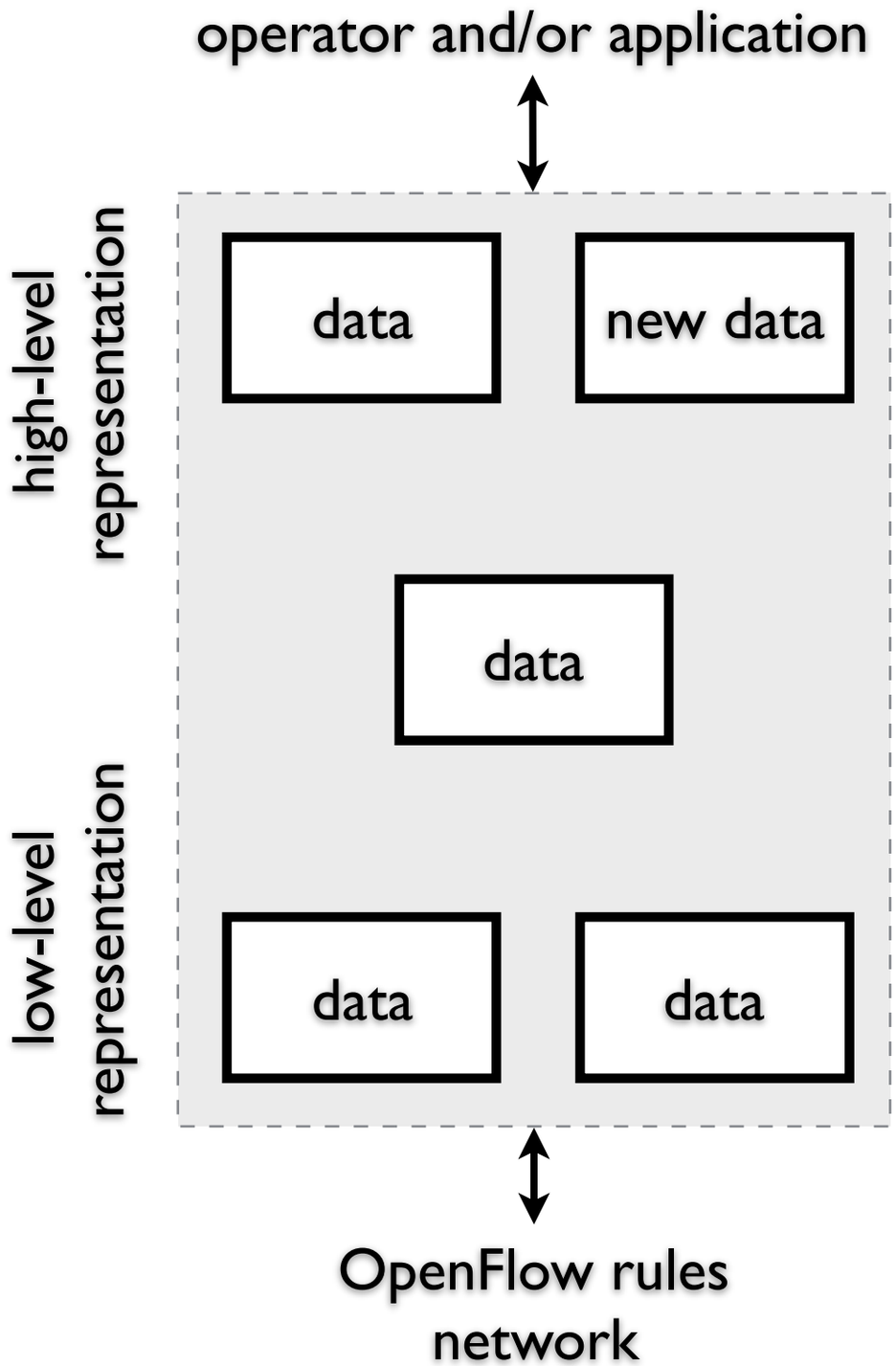


enlarging body of abstractions

current states of abstraction



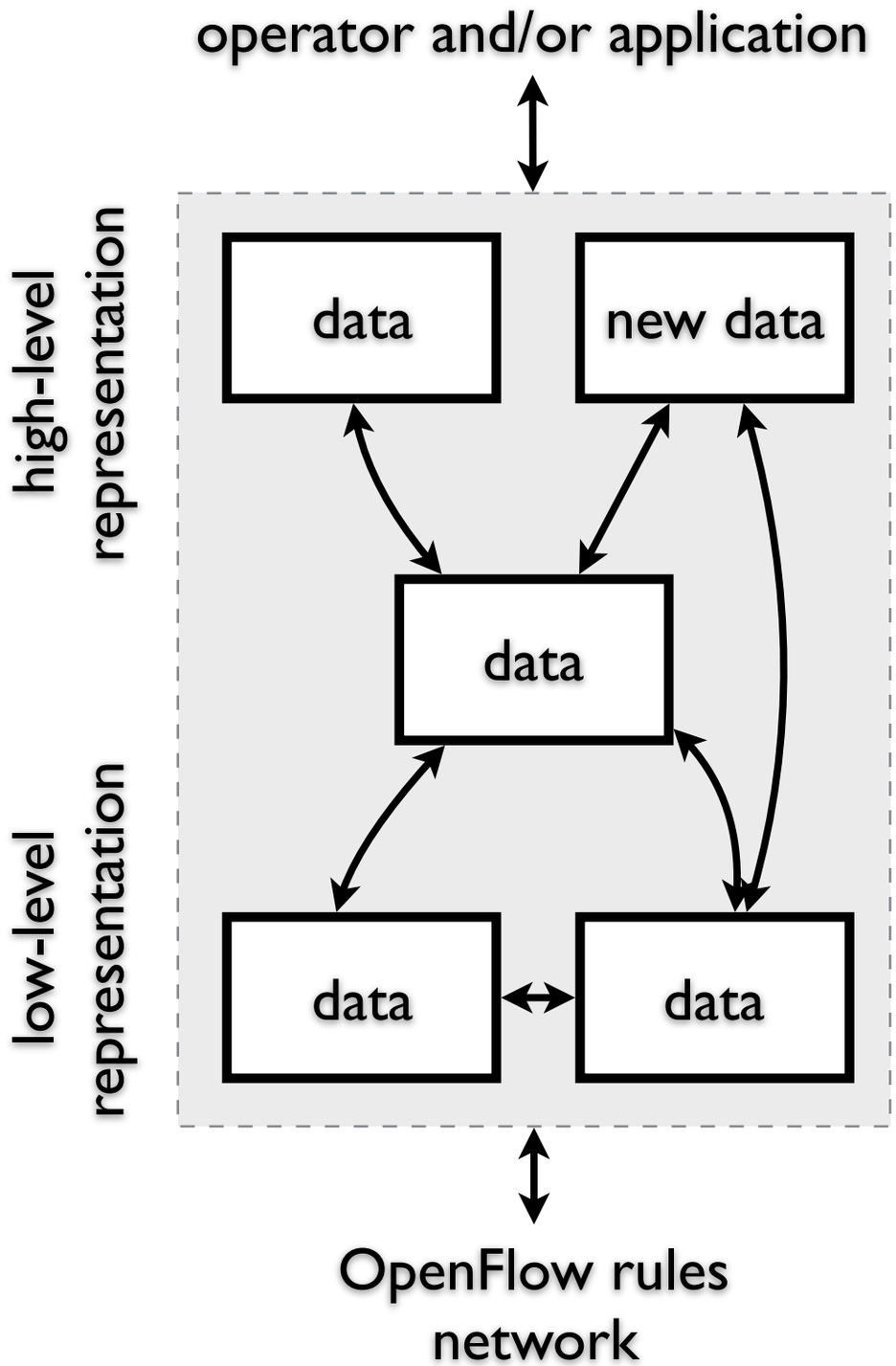
our perspective



SDN control revolves around data representation

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

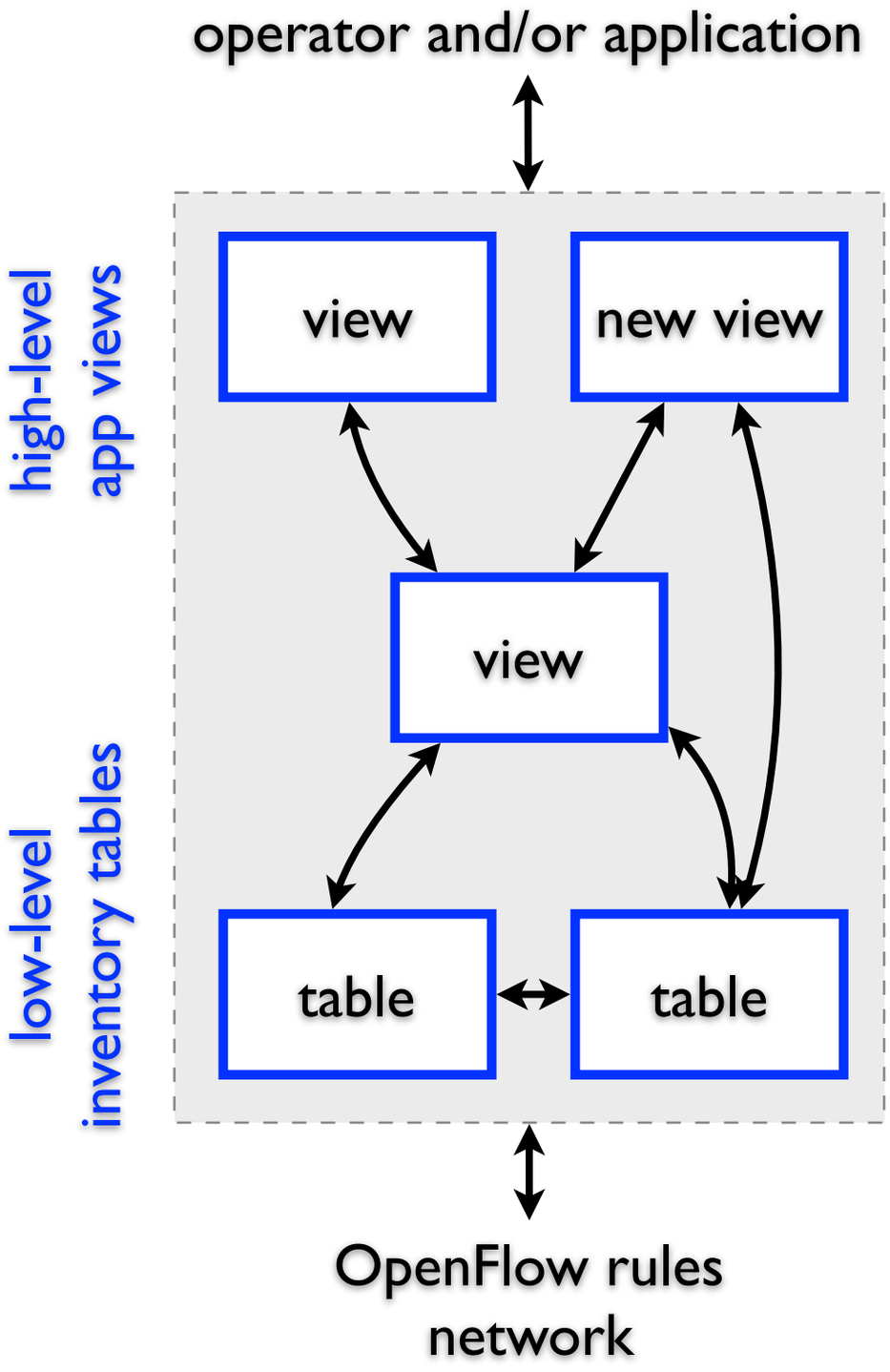
our perspective



SDN control revolves around data representation

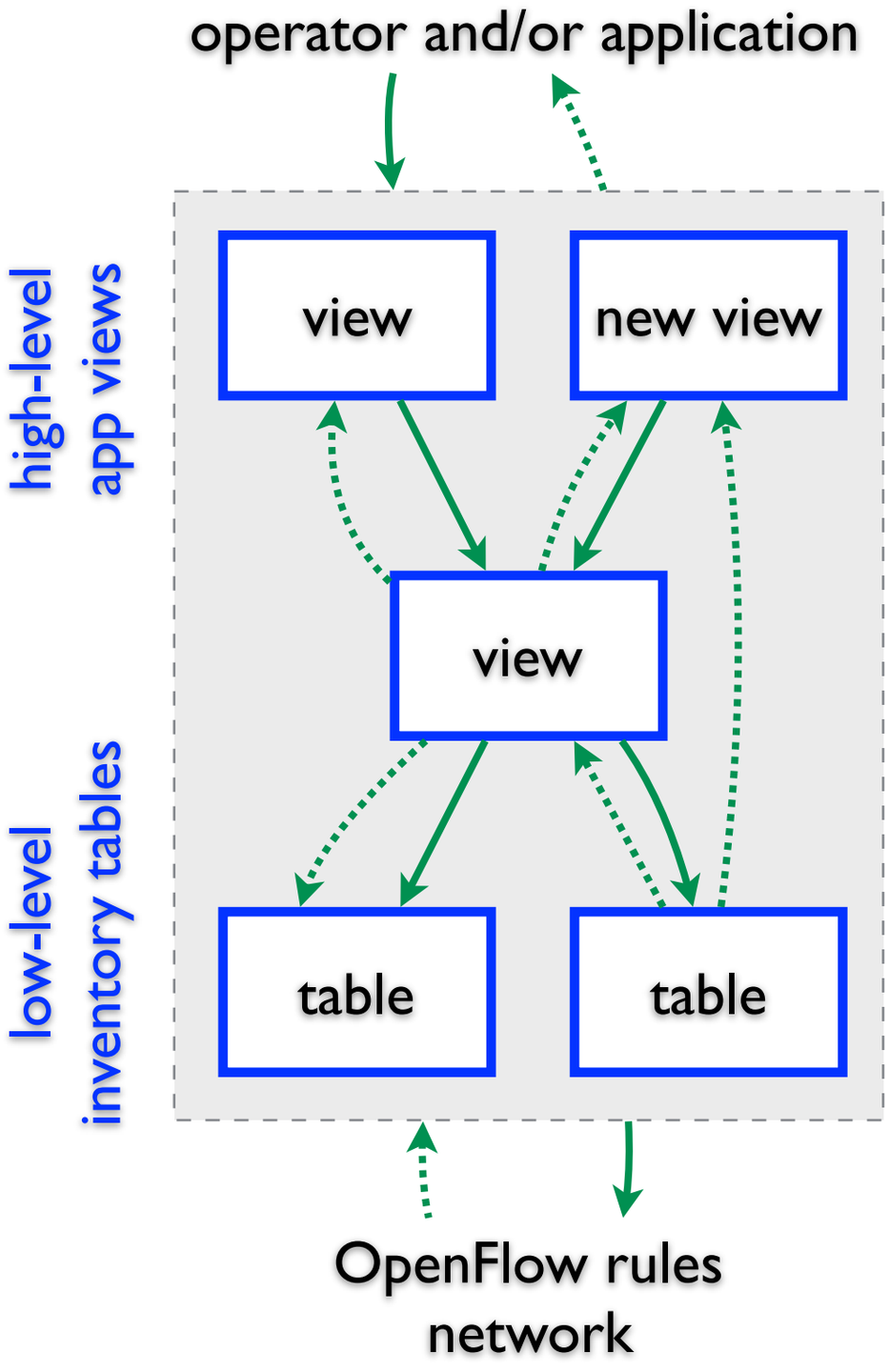
- discard specialized, pre-compiled, fixed structures
- adopt a *plain data representation*
- use a *universal data language*

a database-defined network



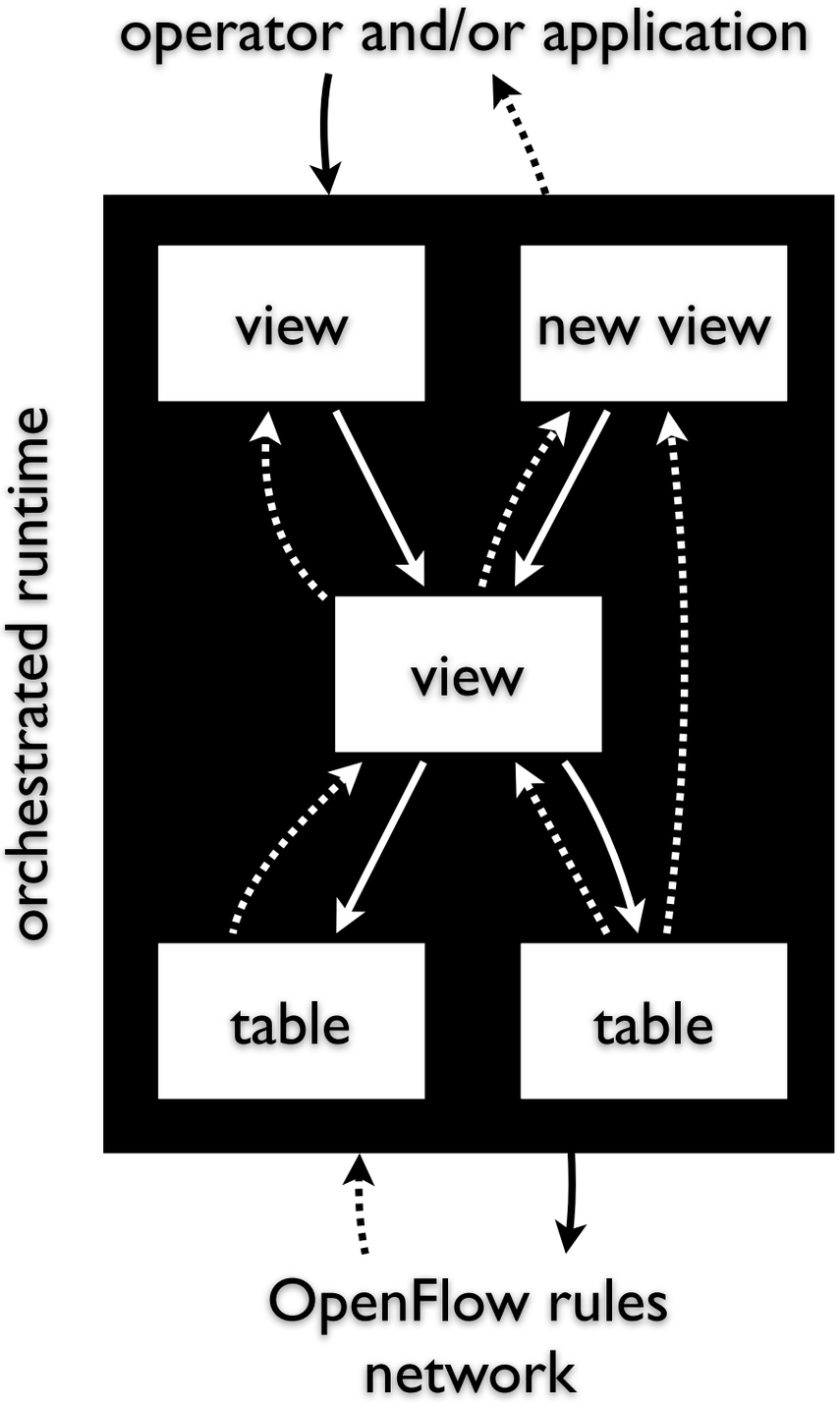
- relation — the plain data representation
  - table — stored relation
  - view — virtual relation

a database-defined network



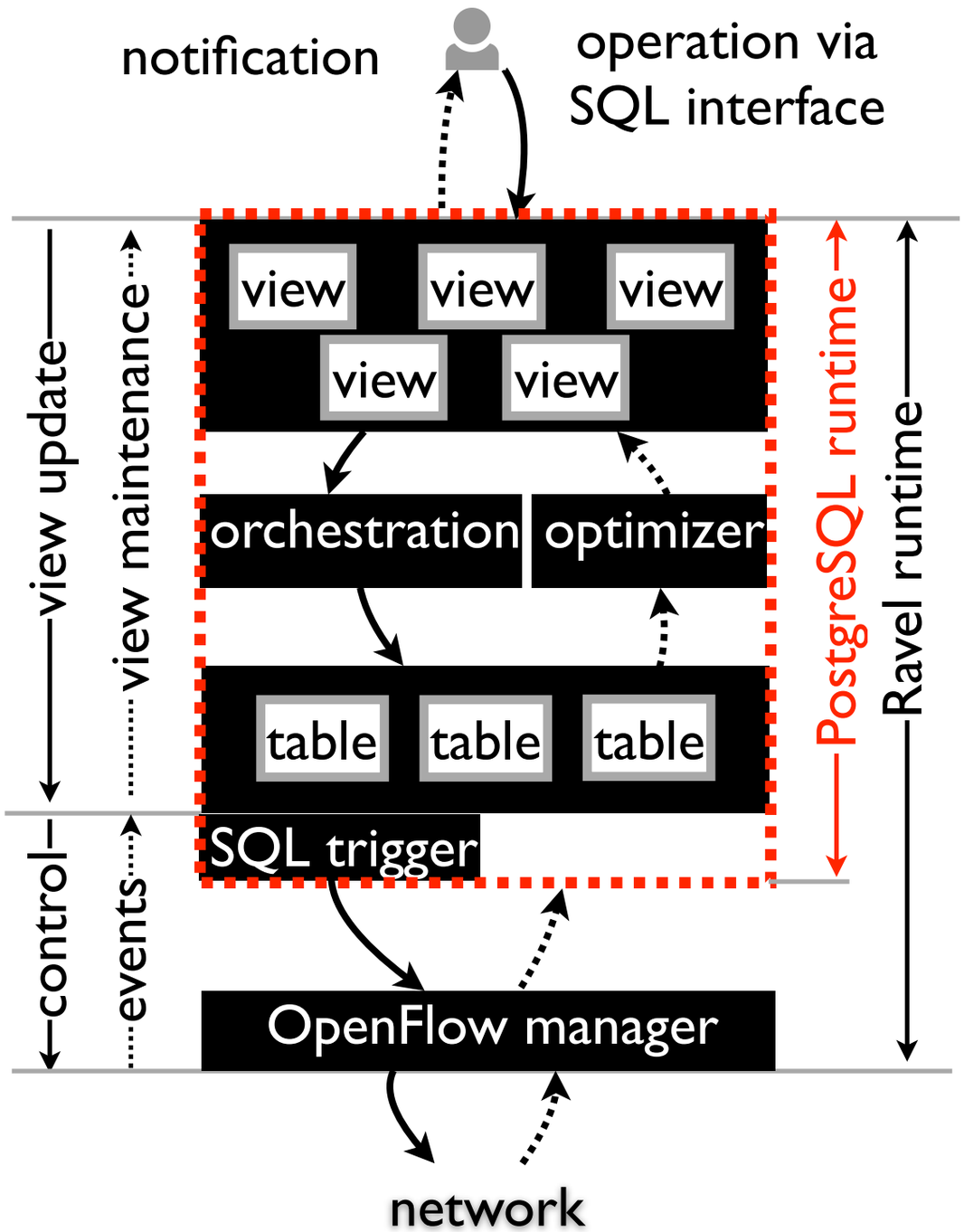
- relation — the plain data representation
  - table — stored relation
  - view — virtual relation
- SQL — the universal data language
  - query, update, trigger, rule

a database-defined network



- relation — the plain data representation
  - table — stored relation
  - view — virtual relation
- SQL — the universal data language
  - query, update, trigger, rule
- SQL database — the high-performance runtime
  - orchestration challenge: refine runtime behavior by data mediation

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

abstraction: network tables

base tables

rm

rechability matrix

fid	src	dst	vol	…
1	A	D	5	
2	C	F	9	

tp

topology

sid	nid
1	2
1	3
1	A

…

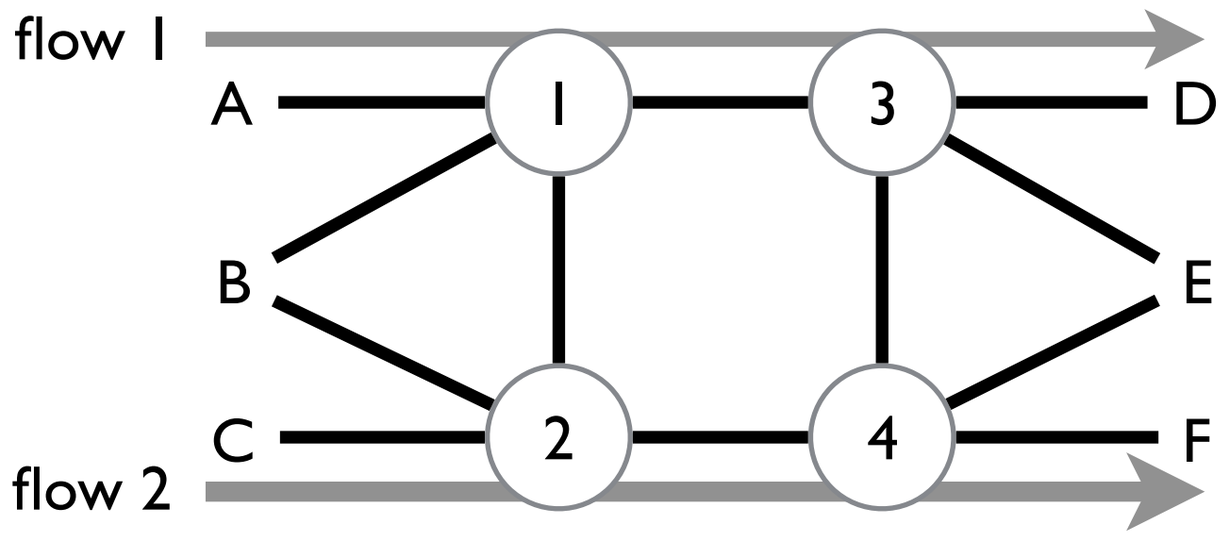
cf

configuration

fid	sid	nid
1	1	3
1	3	D

network event

control command



abstraction: application view

firewall view

```
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
);
```

abstraction: application view

firewall view

```
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
);
```

control loop: monitoring firewall view and 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

```
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
);
```

control loop: monitoring firewall view and 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 …

abstraction: application view

firewall view

```
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)
);
```

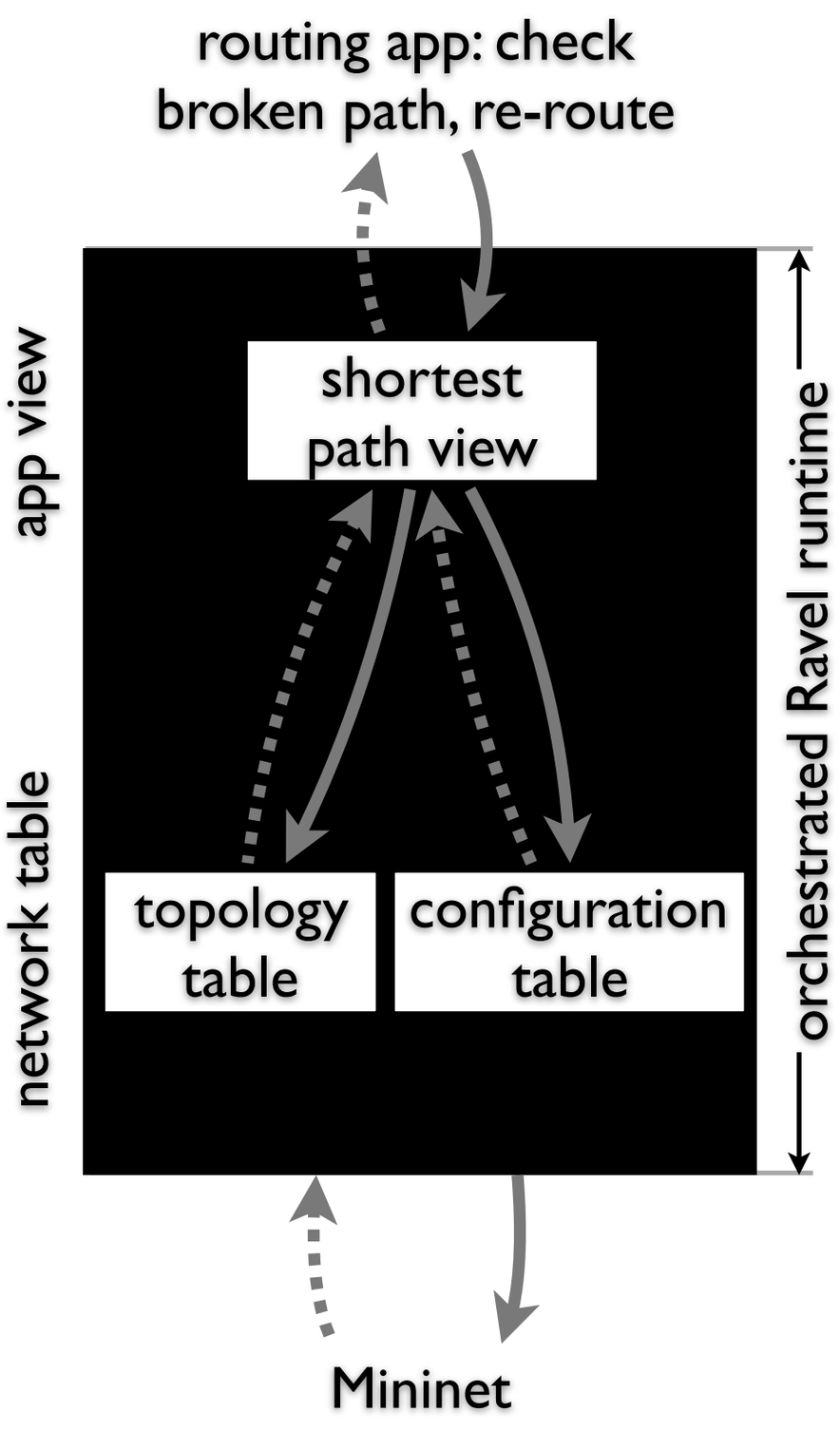
```
CREATE TABLE acl (
  end1 integer, end2 integer, allow integer
);
```

control loop: monitoring firewall view and 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 …
- optimizing application by materializing views
  - (one order of magnitude) faster access with small maintenance overhead (.01~10ms)

orchestration across representations



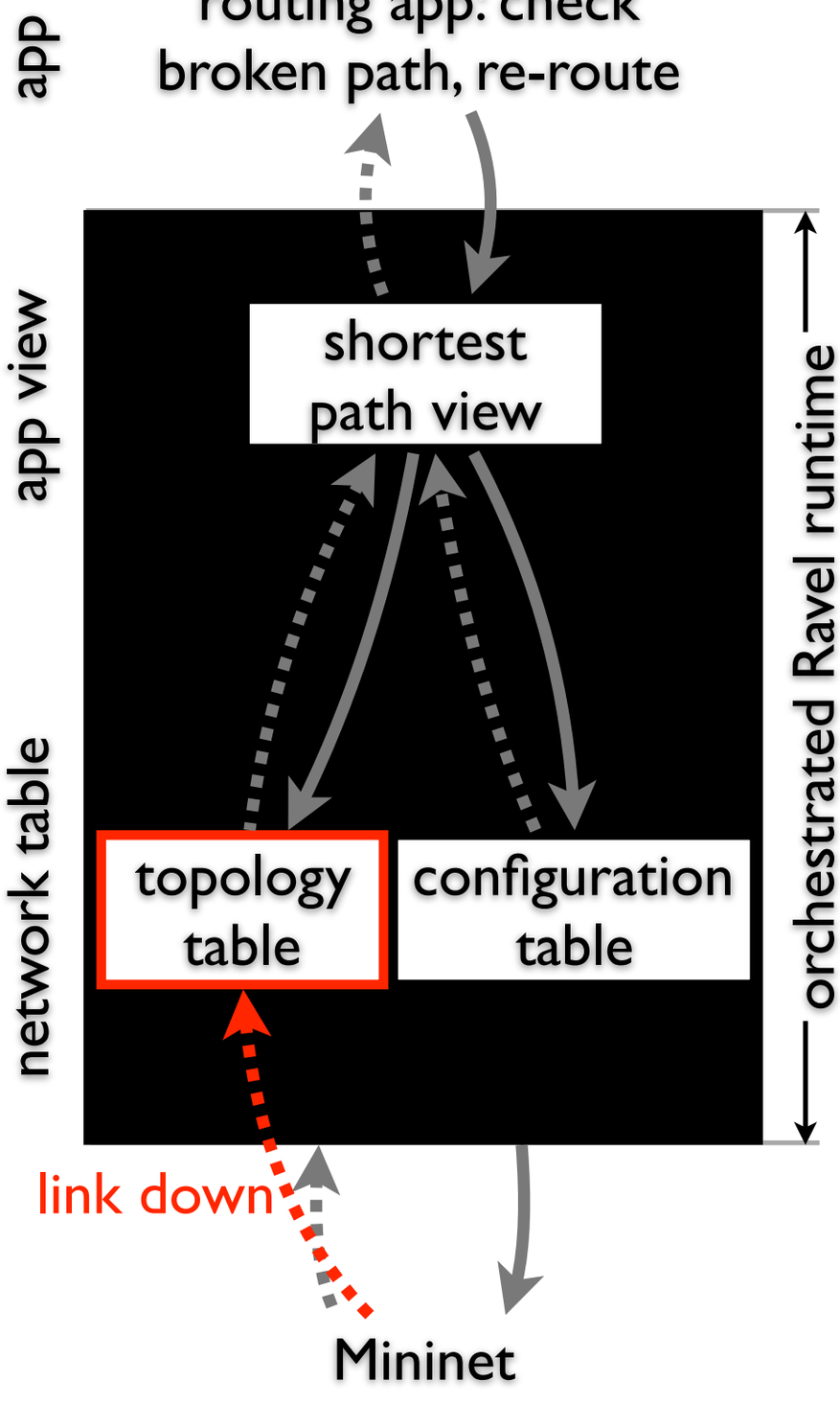
SQL rule:
upon broken path, re-route

shortest path	

topology		

configuration		

orchestration across representations



SQL rule:
upon broken path, re-route

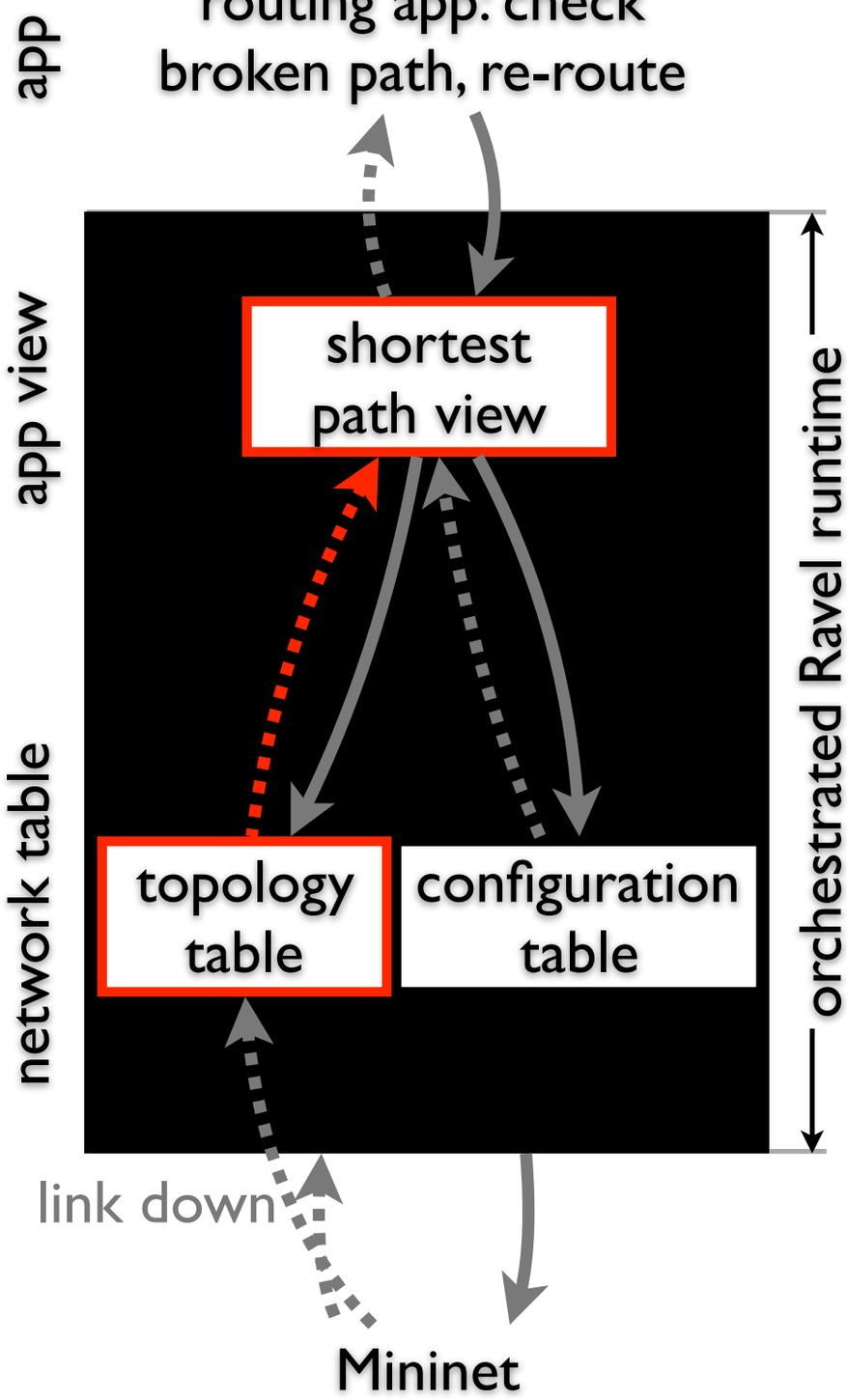
shortest path	

	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

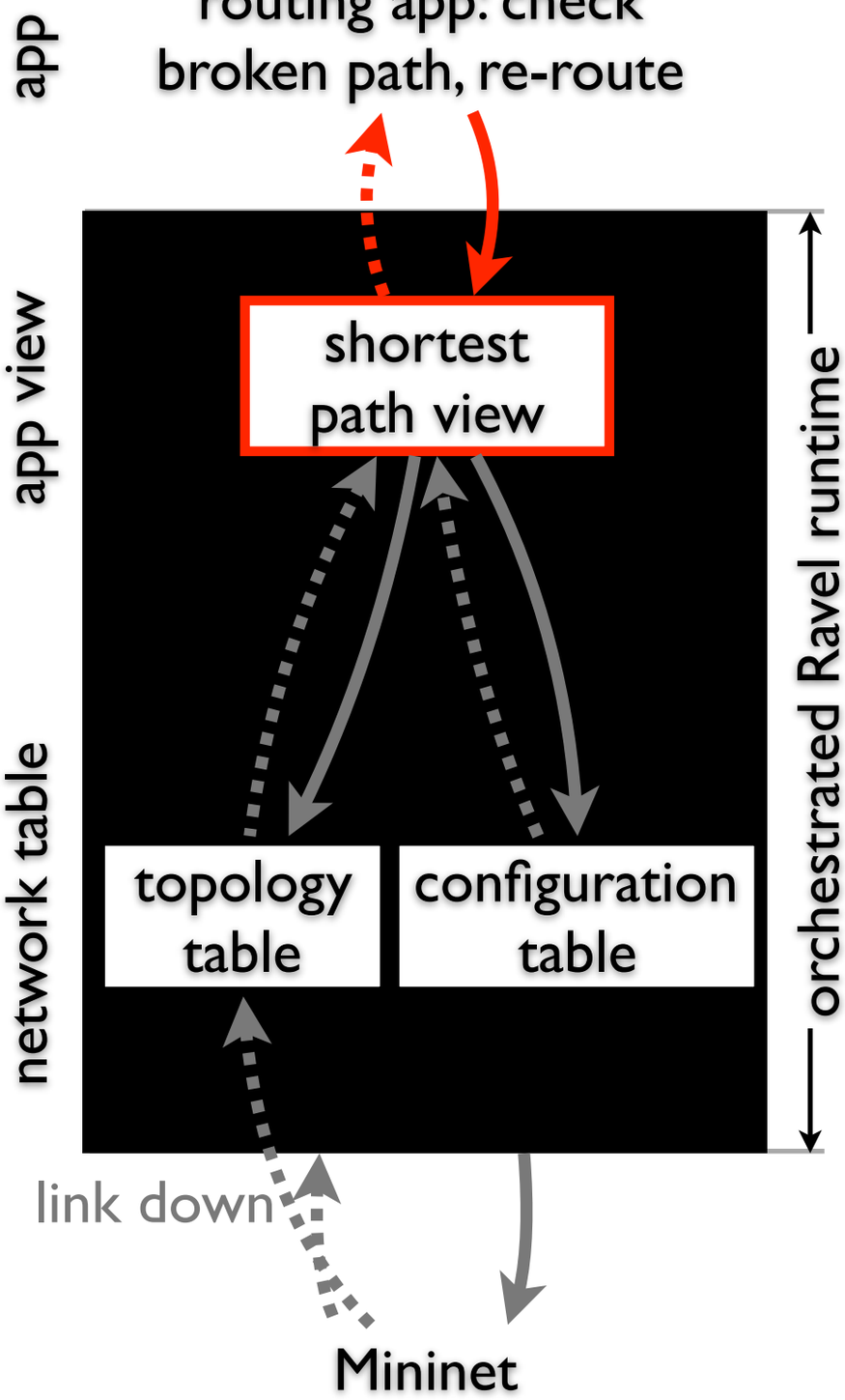
	shortest path	
	…	path
-		{…,172,39,156,…}

	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

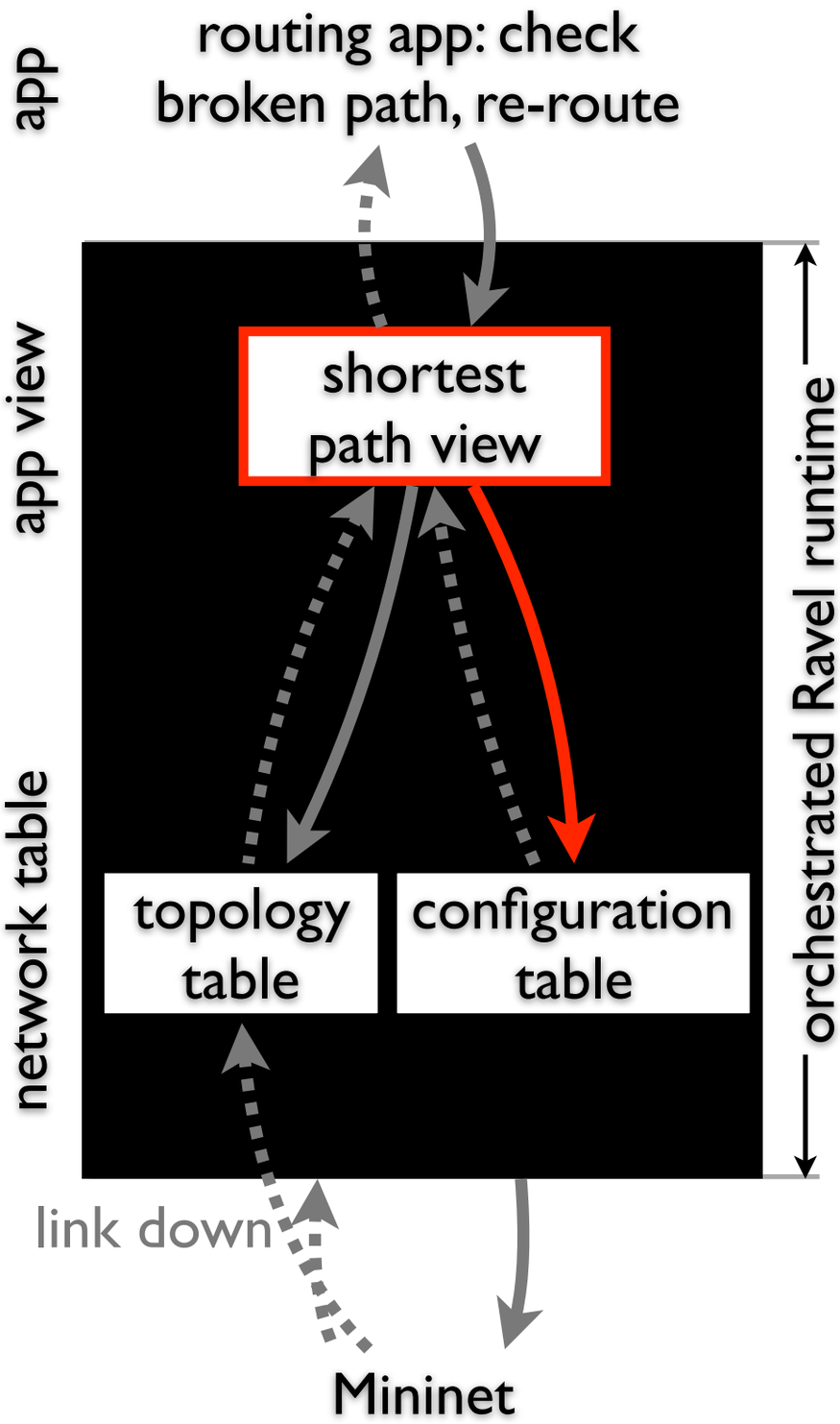
	shortest path	
	…	path
-		{…,172,39,156,…}
+		{…,172,38,148,…}

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

configuration		

Mininet link (172,39) down

orchestration across representations



SQL rule:
upon broken path, re-route

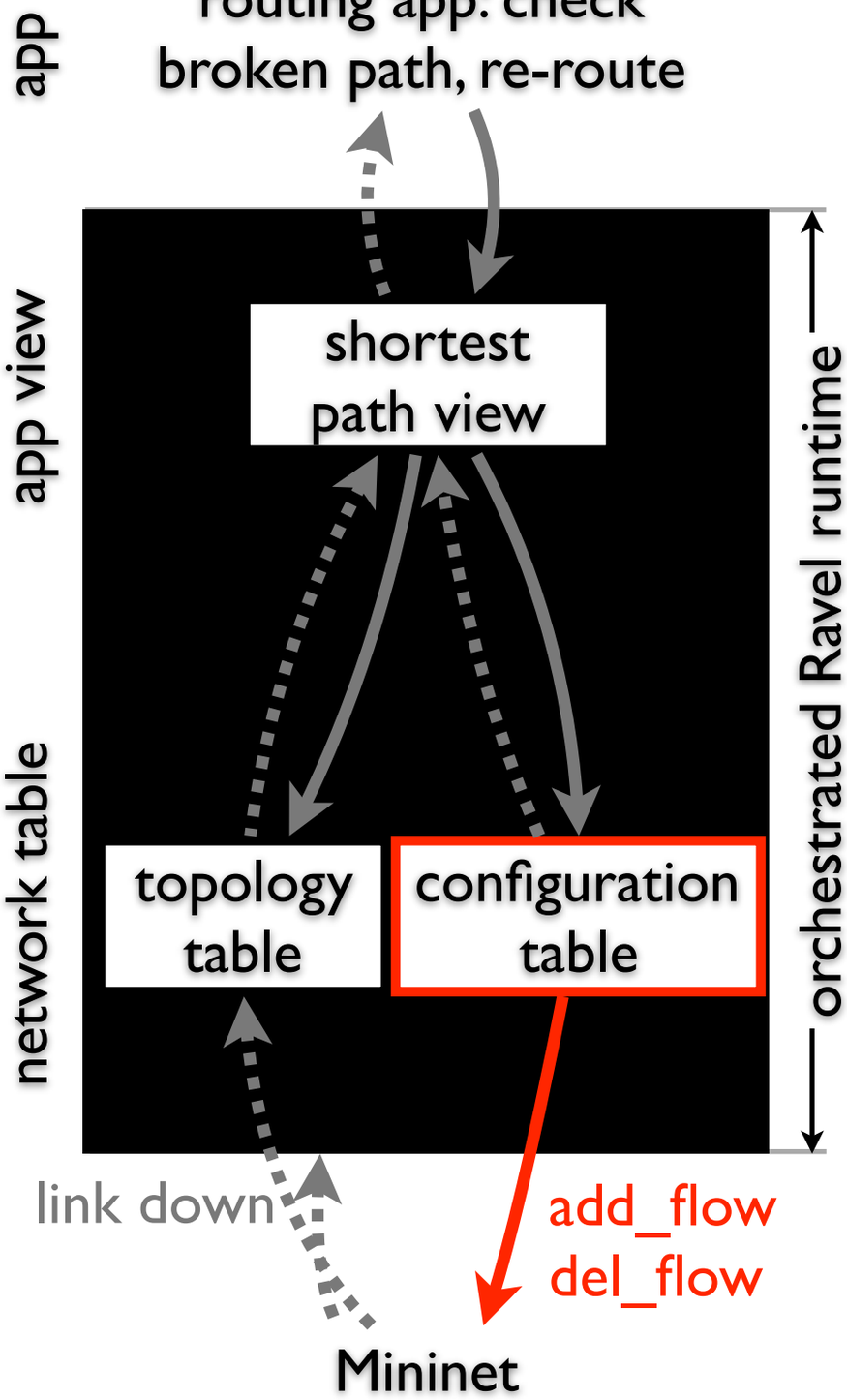
	shortest path	
	…	path
-		{…,172,39,156,…}
+		{…,172,38,148,…}

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

	configuration		
	fid	sid	nid
-	…	172	39
-	…	39	156
+	…	172	38
+	…	38	148

Mininet link (172,39) down

orchestration across representations



SQL rule:
upon broken path, re-route

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

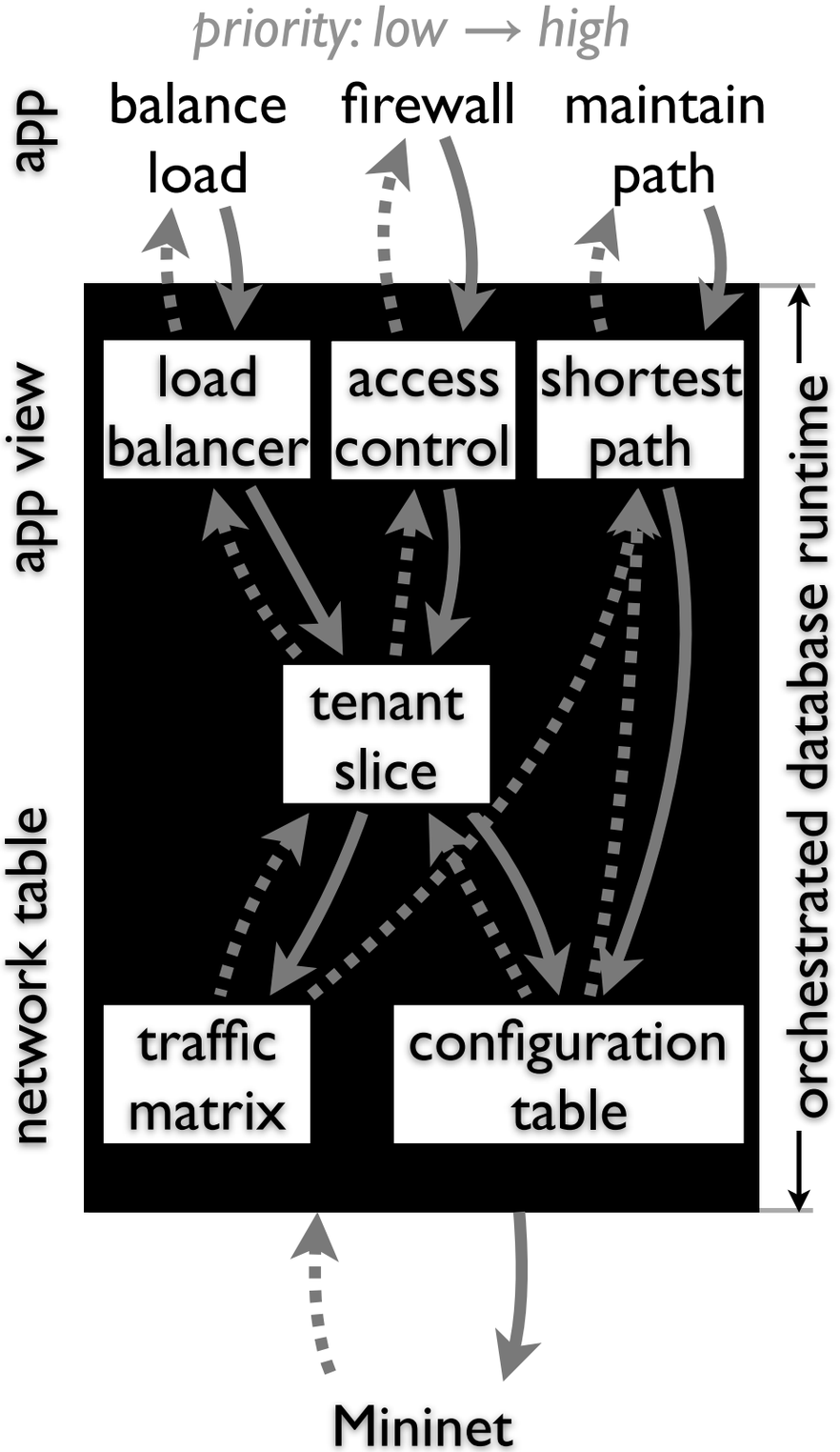
	topology		
	sid	nid	active
-	172	39	1
+	172	39	0

	configuration		
	fid	sid	nid
-	…	172	39
-	…	39	156
+	…	172	38
+	…	38	148

Mininet link (172,39) down

orchestrated updates:
re-route via (172, 38)

orchestration across applications



load balancer

access control

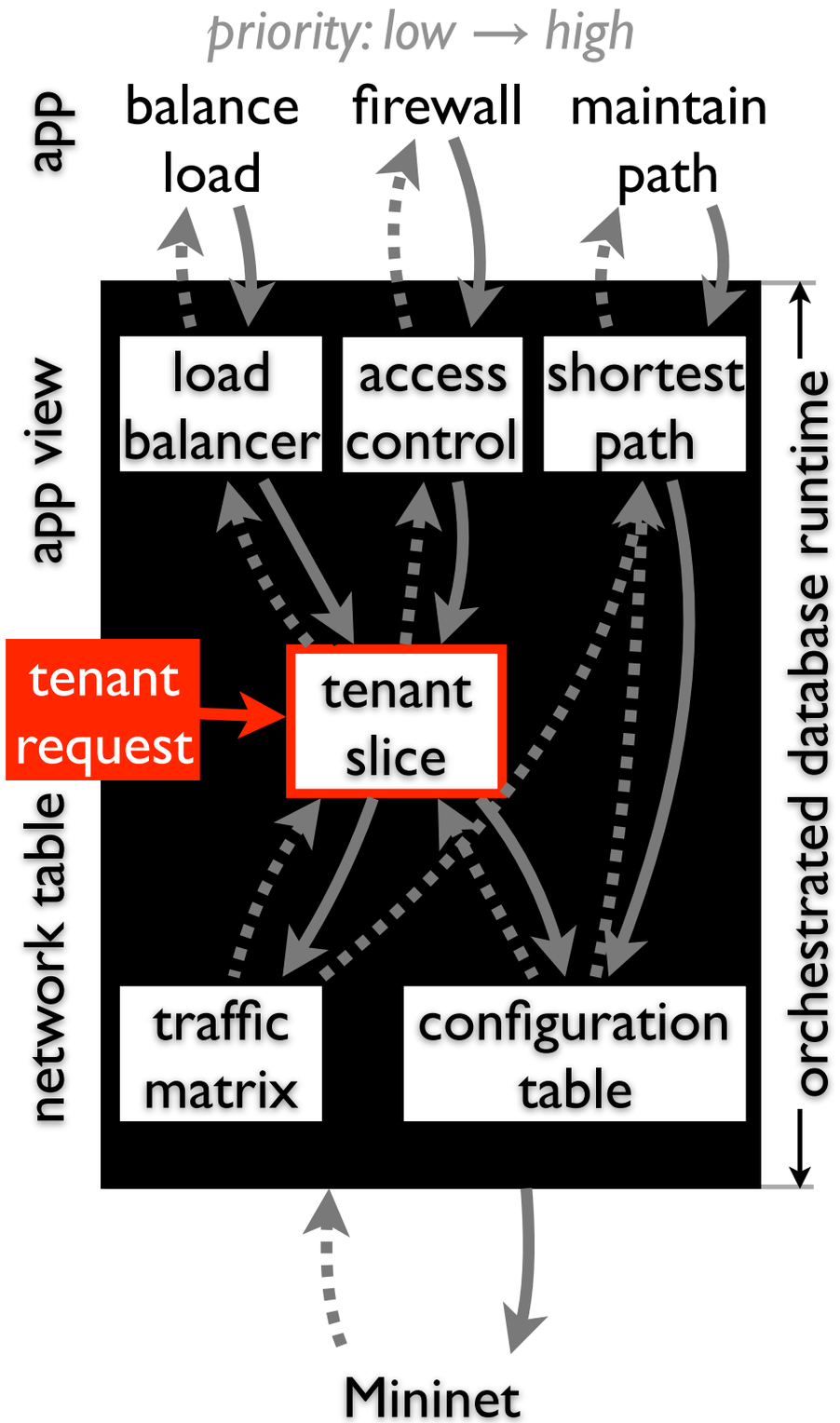
shortest path

tenant policy

traffic matrix

configuration

orchestration across applications



load balancer		

access control			

shortest path		

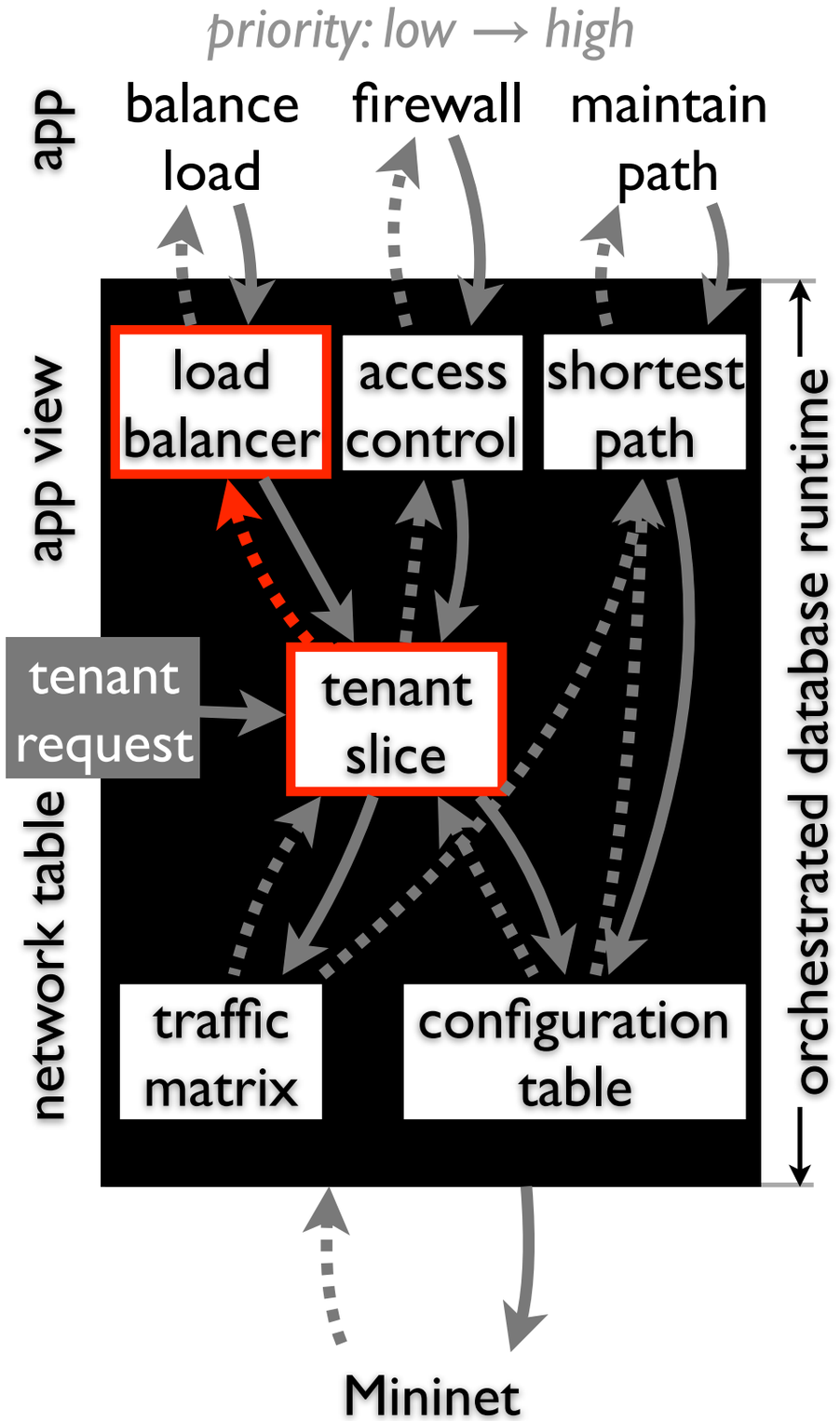
tenant request host 1238 to server 1003

	tenant policy		
	…	host	server
+	…	1238	1003

traffic matrix			

configuration			

orchestration across applications



	load	
	sid	load
+	1003	4
-	1003	3

access control		

shortest path	

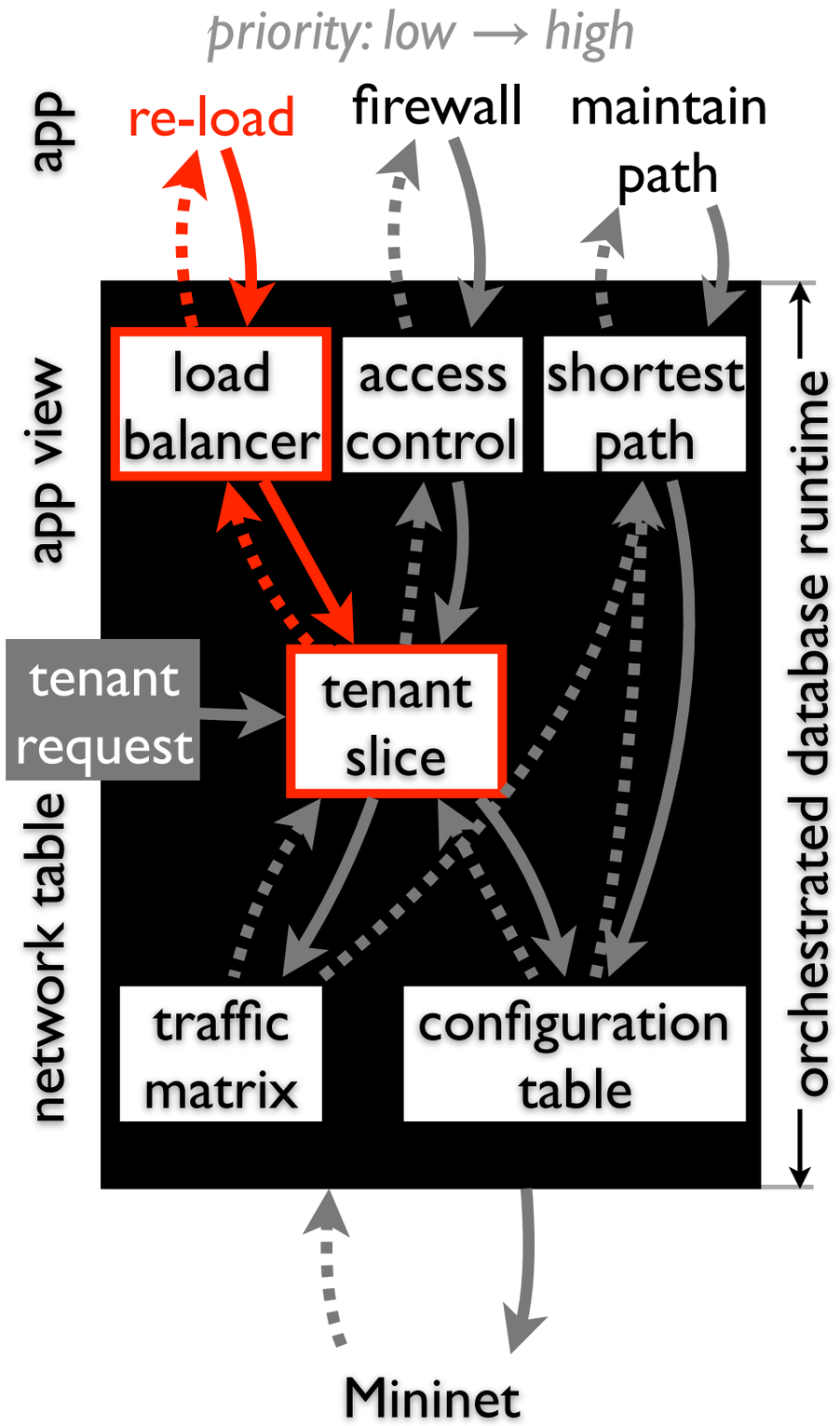
tenant request host 1238 to server 1003

	tenant policy		
	…	host	server
+	…	1238	1003

traffic matrix		

configuration		

orchestration across applications



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

access control		

shortest path	

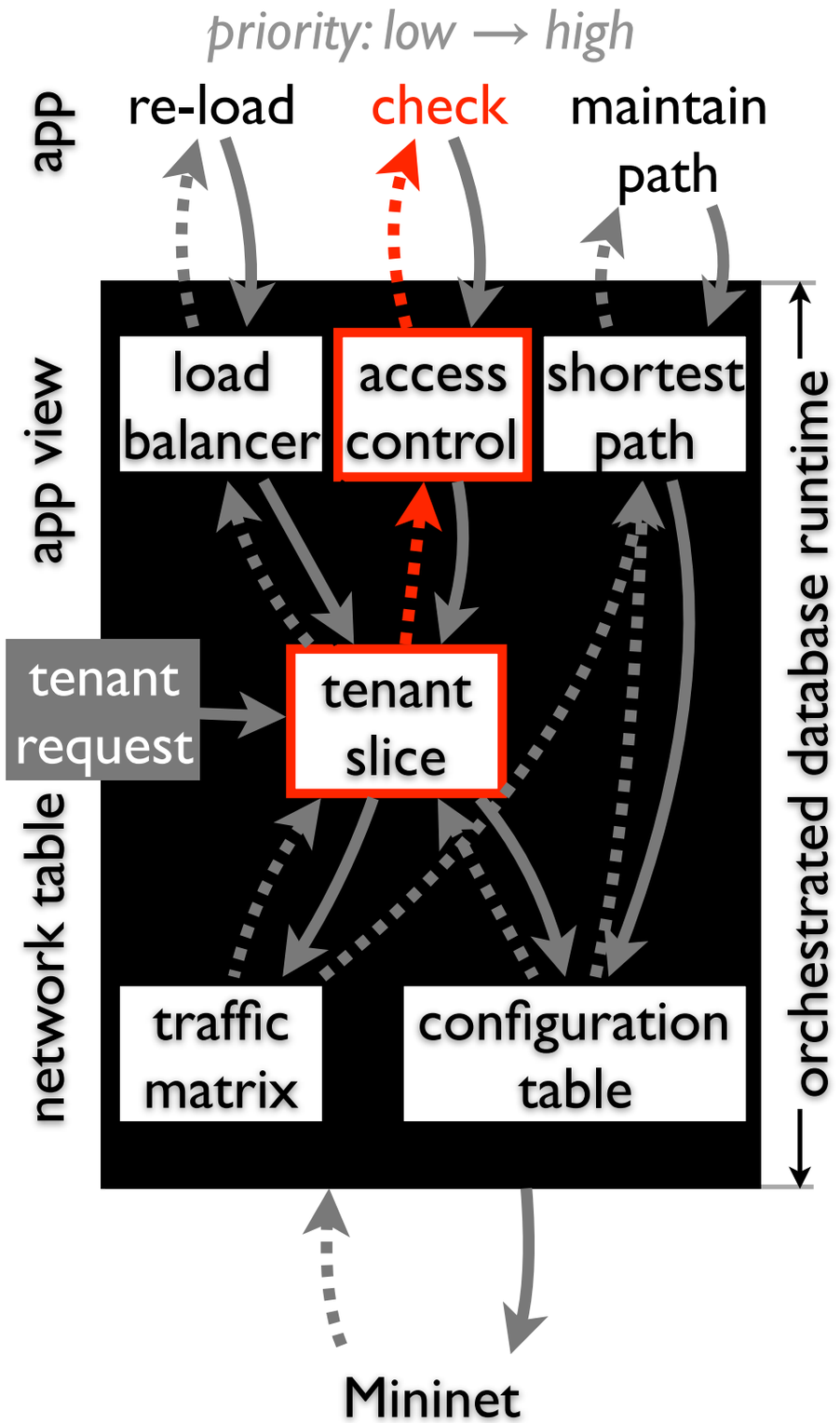
tenant request host 1238 to server 1003

	tenant policy		
	…	host	server
±	~~…~~	~~1238~~	~~1003~~
+		1238	1034

traffic 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	

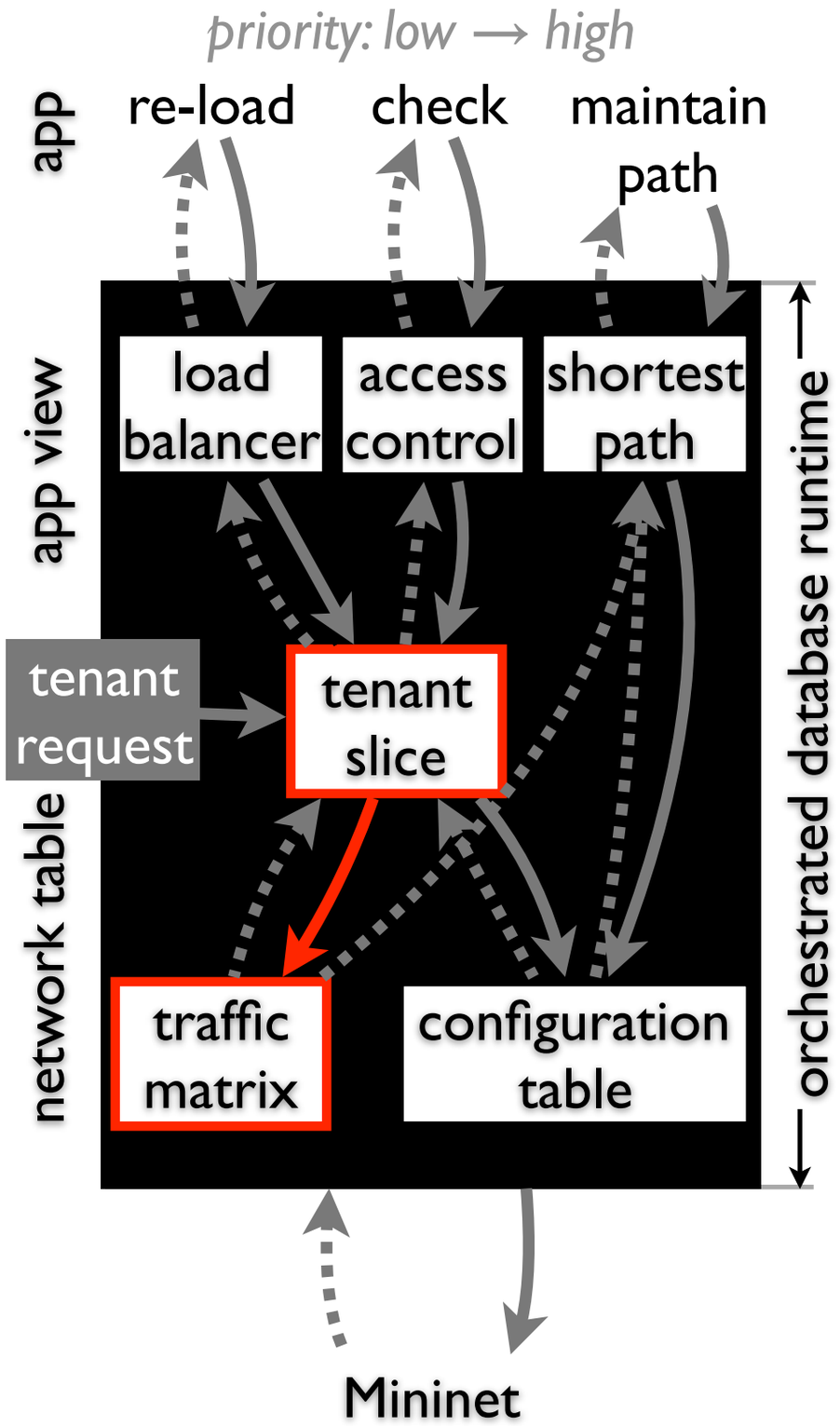
tenant request host 1238 to server 1003

	tenant policy		
	…	host	server
±	…	~~1238~~	~~1003~~
+		1238	1034

traffic 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	

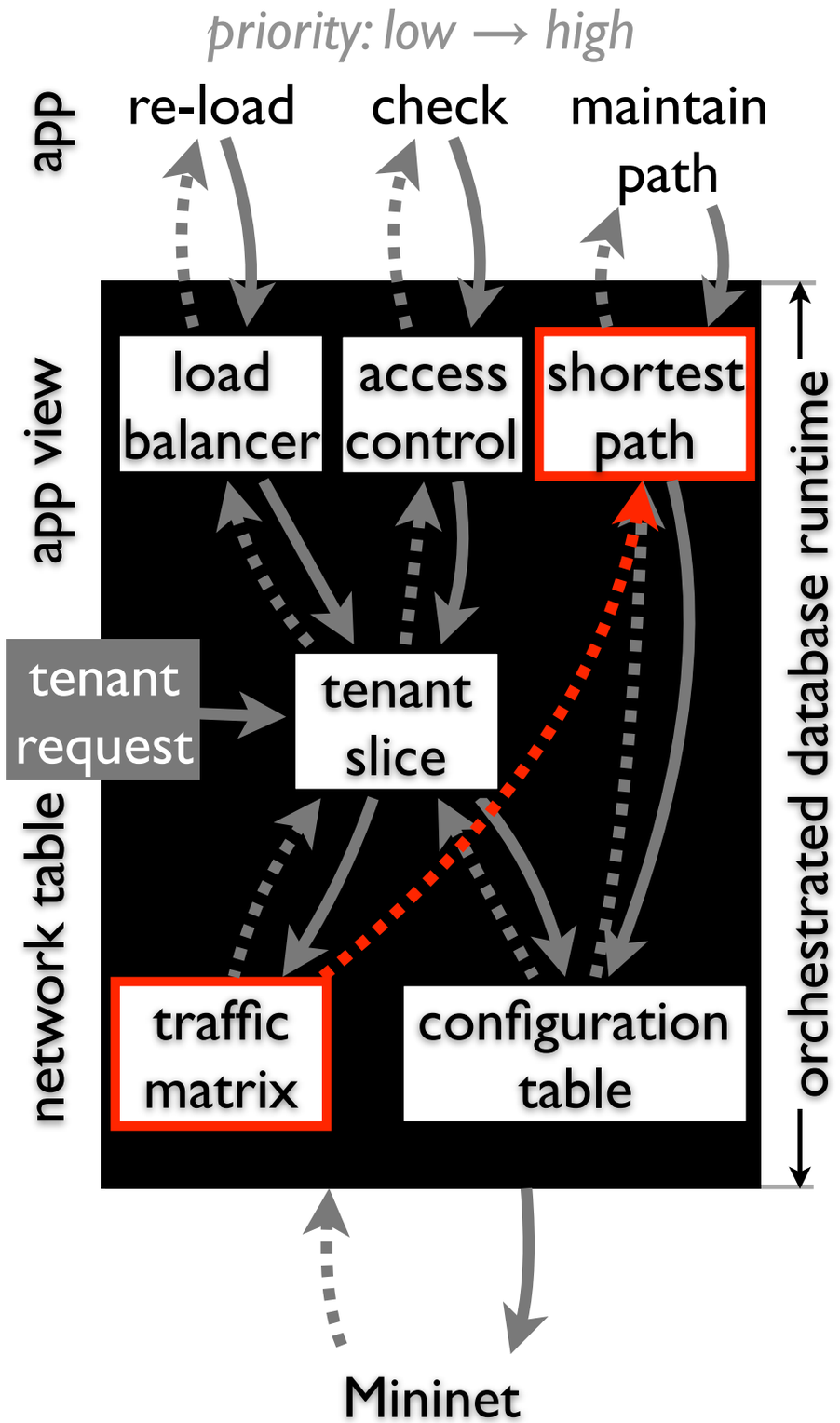
tenant request host 1238 to server 1003

	tenant policy		
	…	host	server
±	…	~~1238~~	~~1003~~
+		1238	1034

	traffic 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}

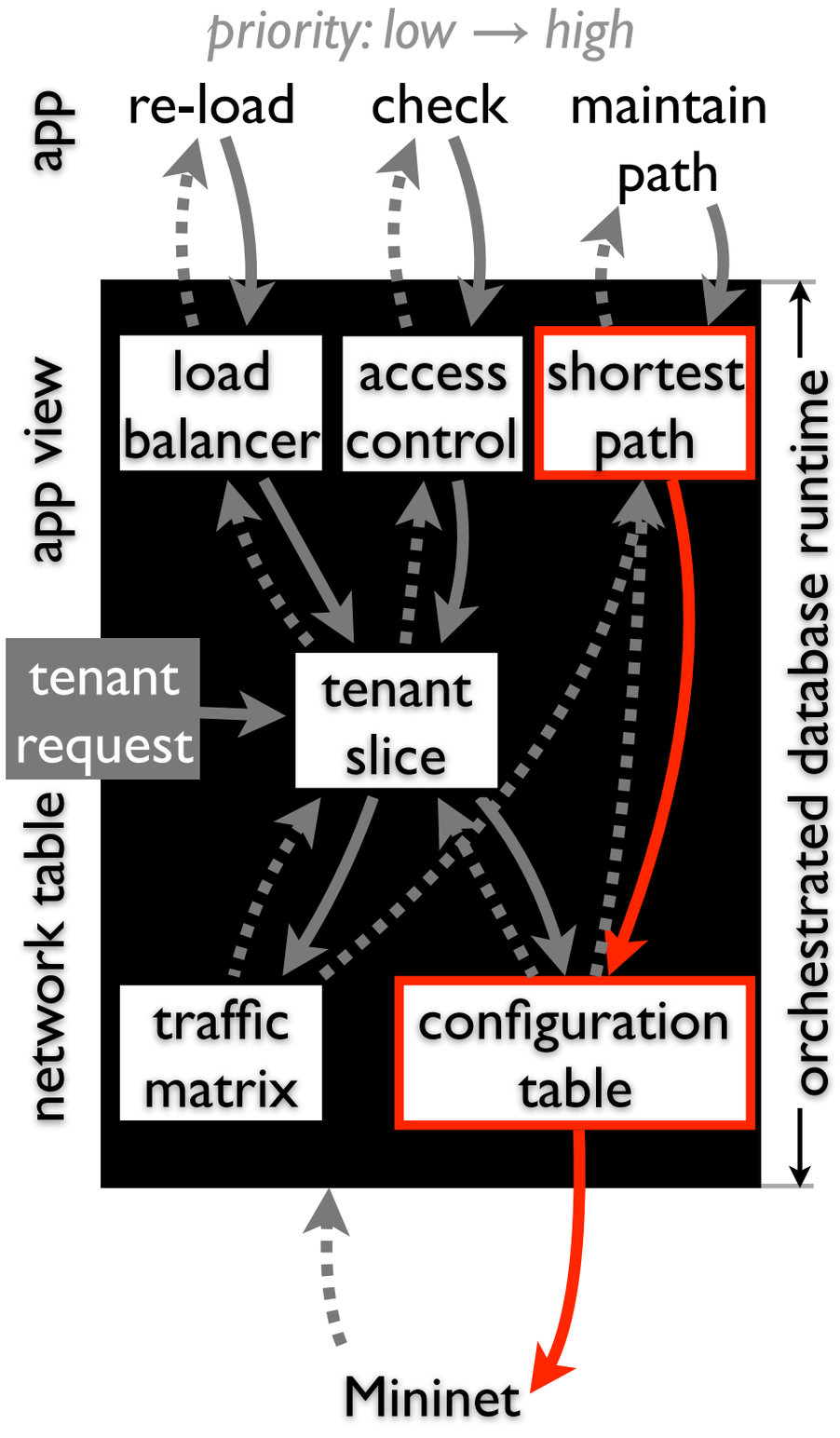
tenant request
host 1238 to
server 1003

	tenant policy		
	…	host	server
±	~~…~~	~~1238~~	~~1003~~
+		1238	1034

	traffic 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 policy		
	…	host	server
±	…	~~1238~~	~~1003~~
+		1238	1034

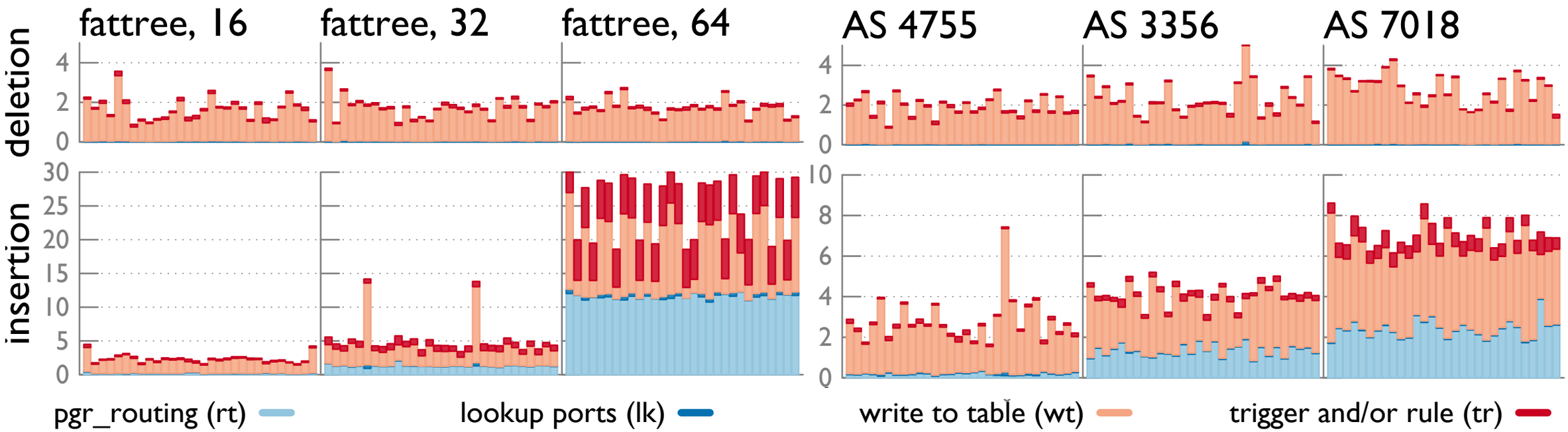
	traffic matrix		
	fid	sid	nid
+	…	1238	1034

	configuration		
	fid	sid	nid
+	…	…	1034

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

evaluation

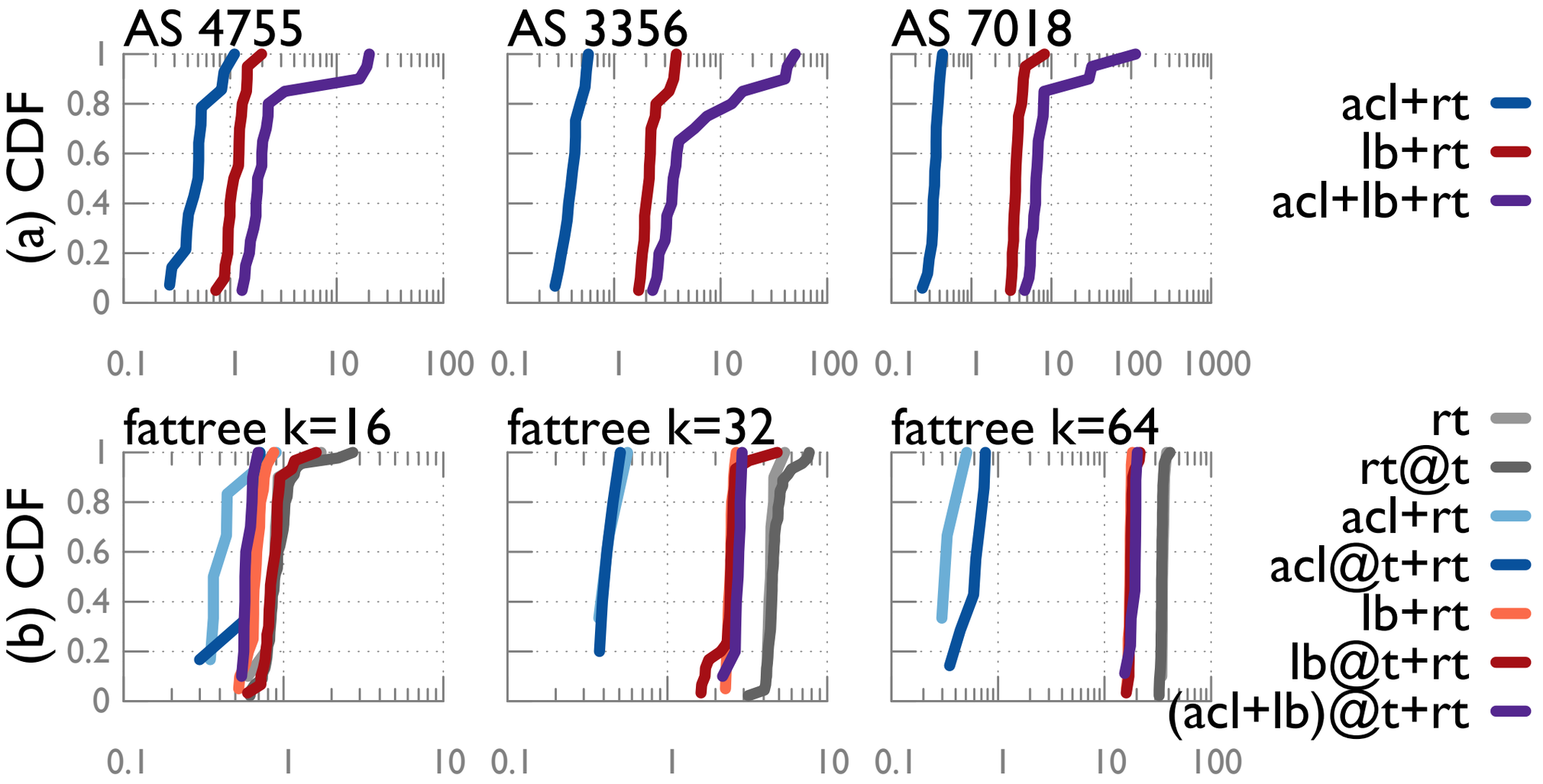
profiling database delay — route insertion/deletion



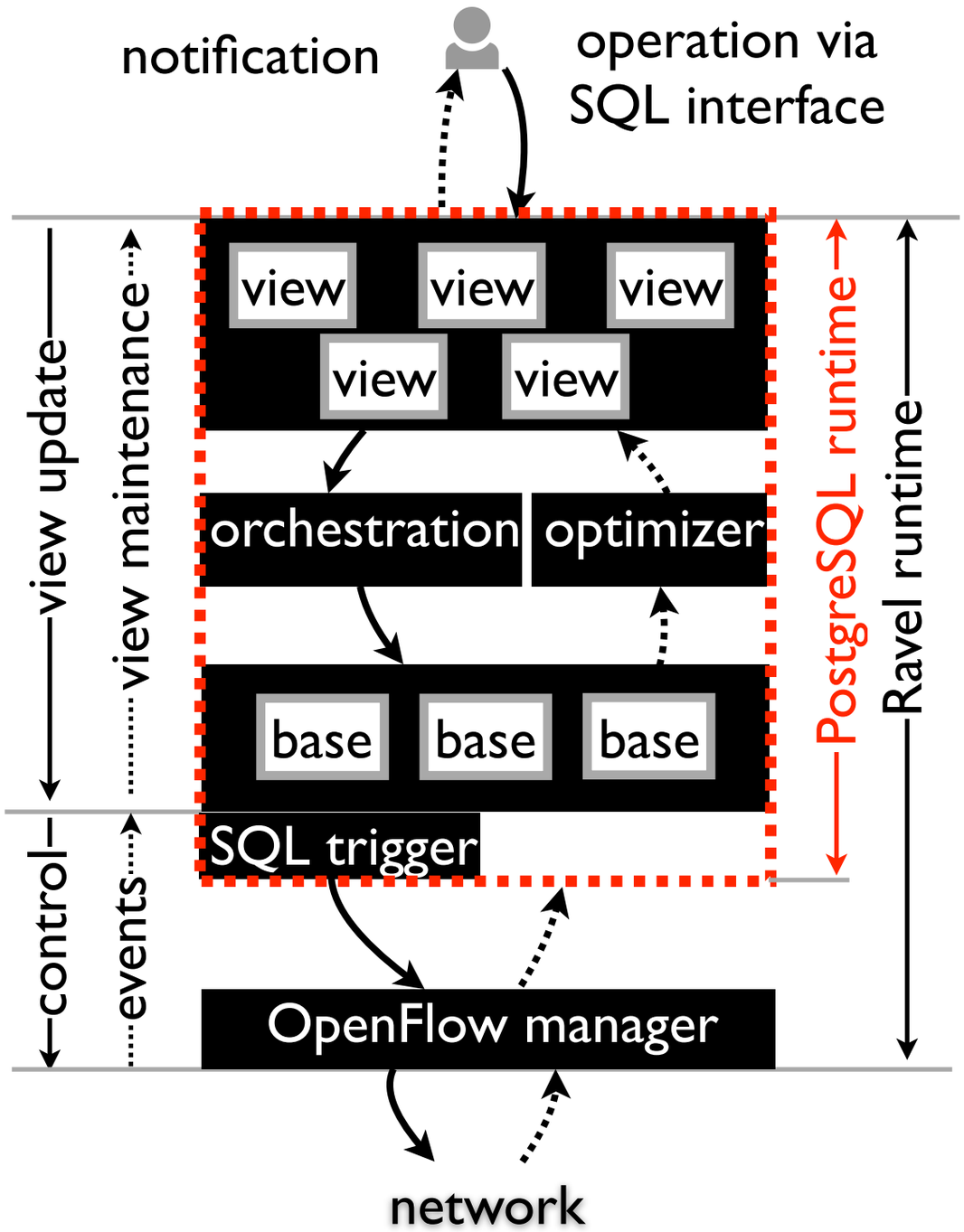
fat-tree			ISP		
k	switches	links	AS#	nodes	links
16	320	3072	4755	142	258
32	1280	24576	3356	1772	13640
64	5120	196608	7018	25382	11292
			2914	5939	16520

evaluation

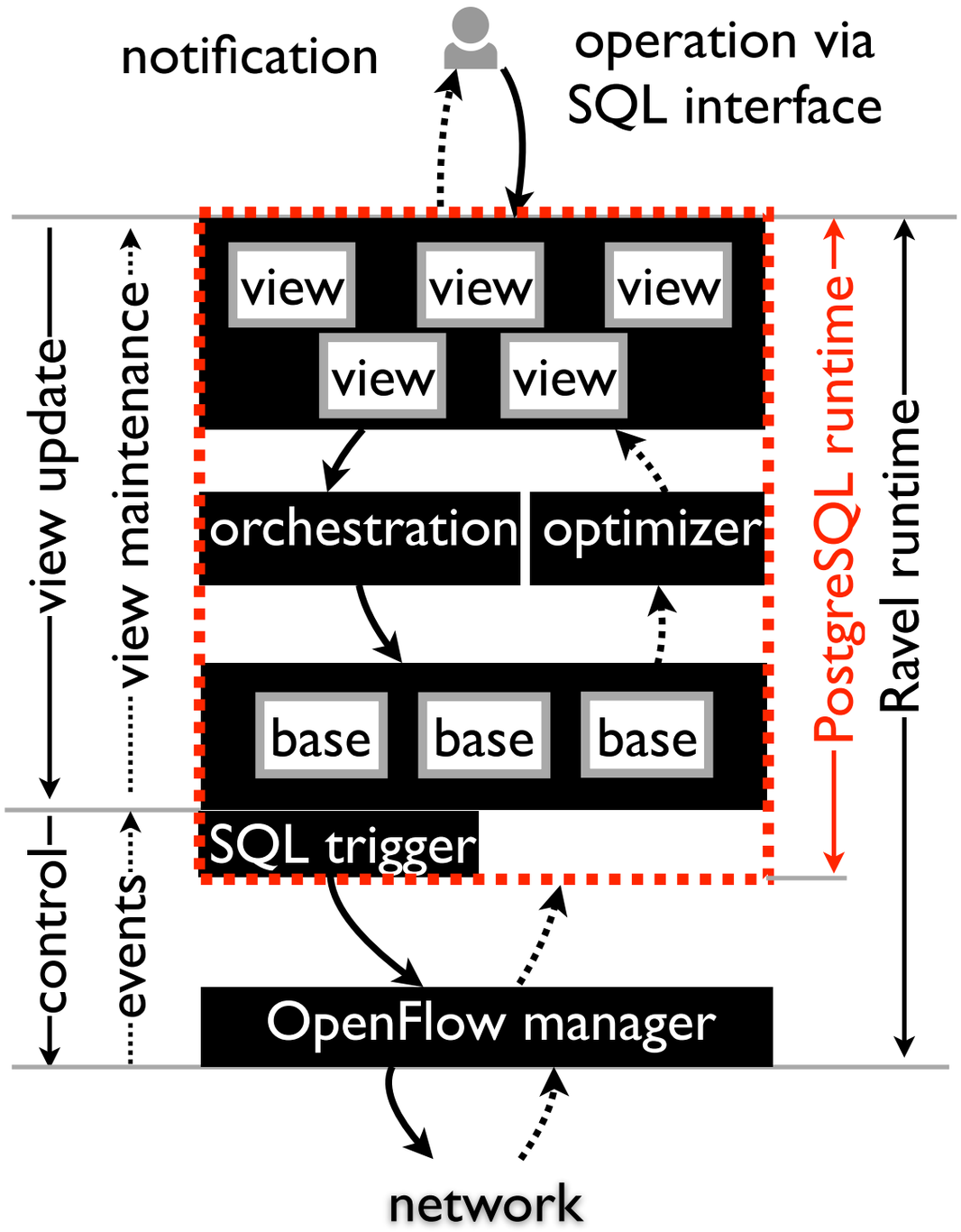
orchestrating access control(acl), load balancer(lb), and routing(rt): normalized per-rule delay (ms)



conclusion


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

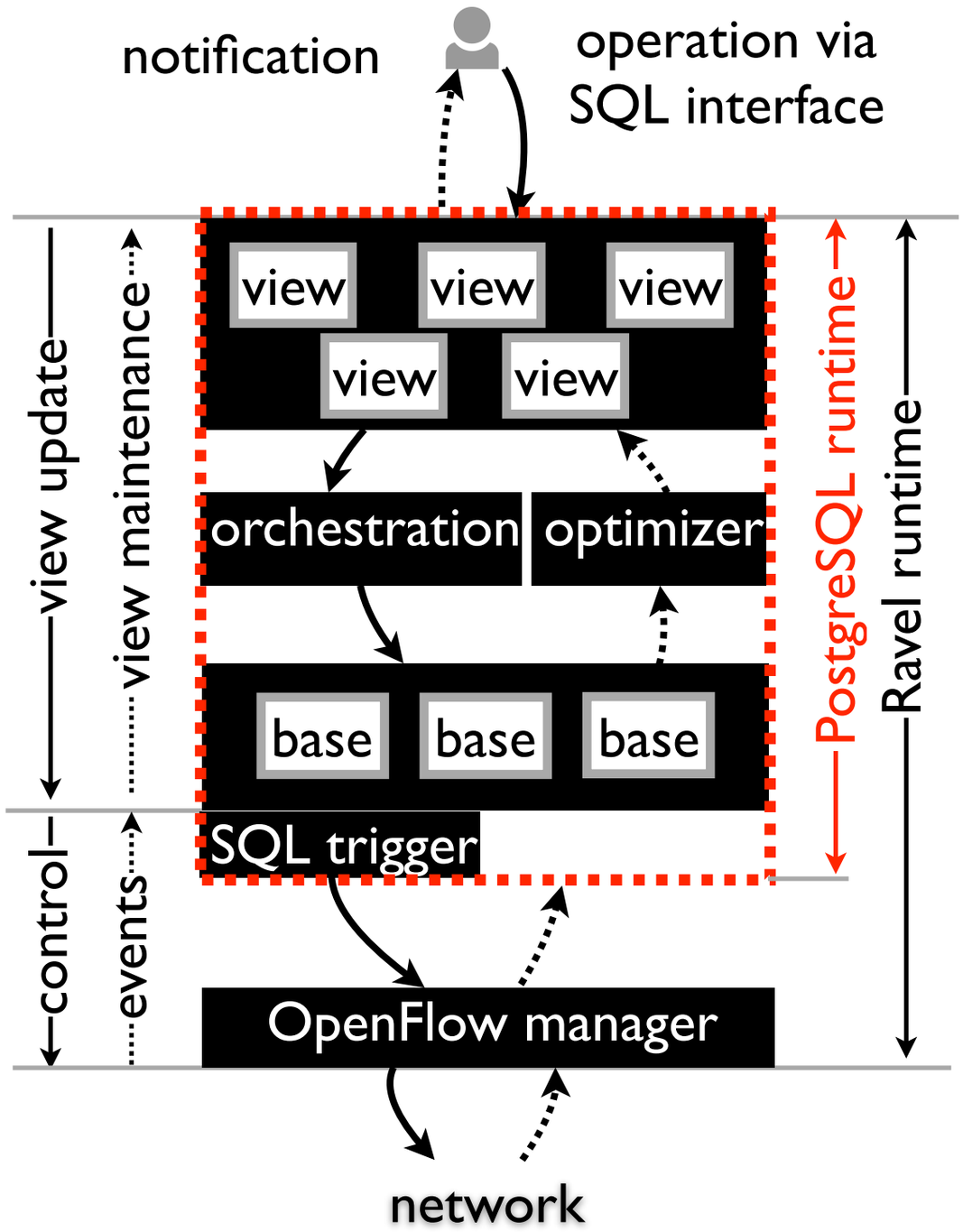
conclusion



flexible abstraction via SQL

- ad-hoc extensible, orchestratable
- promising performance

conclusion



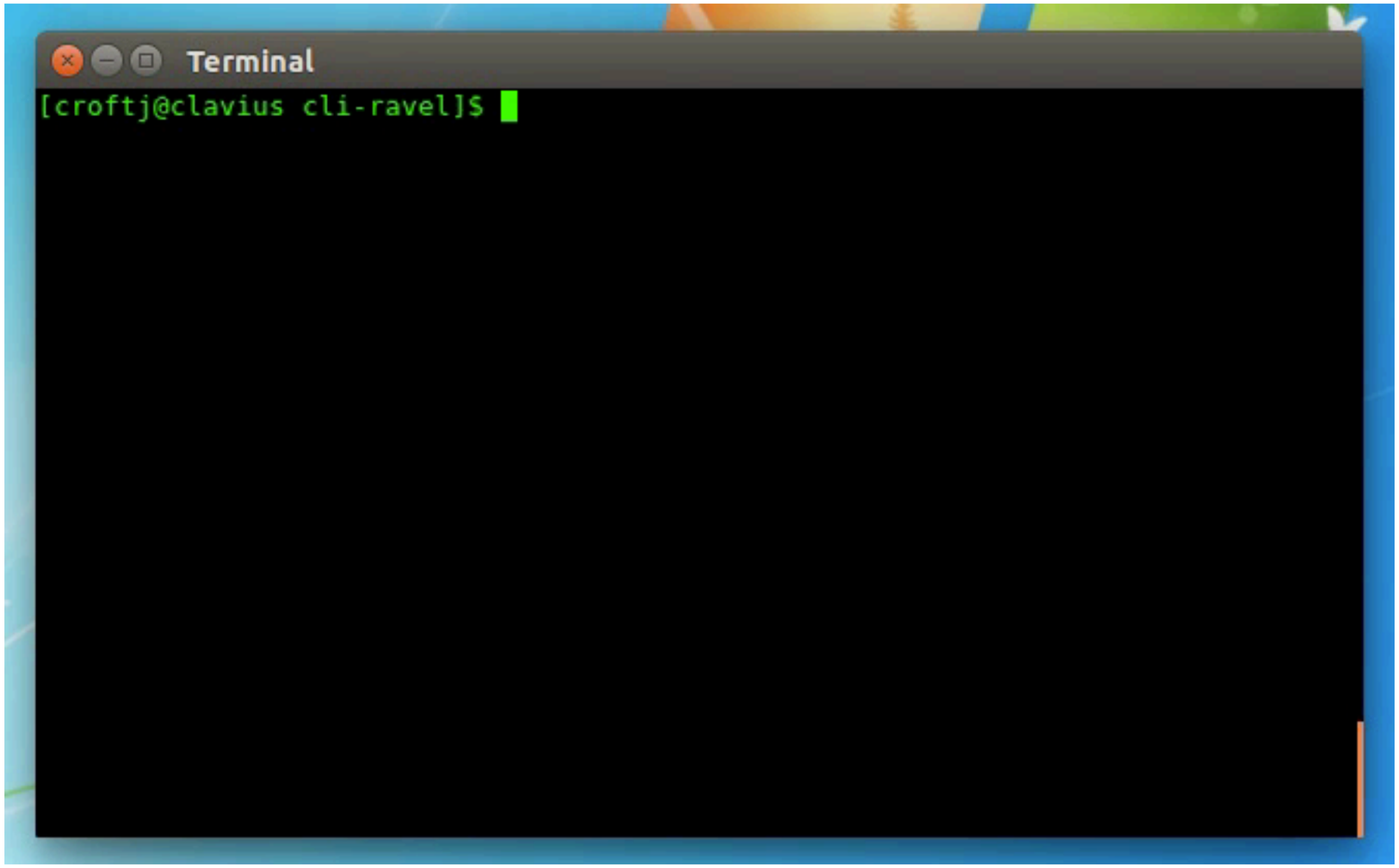
flexible abstraction via SQL

- ad-hoc extensible, orchestratable
- promising performance

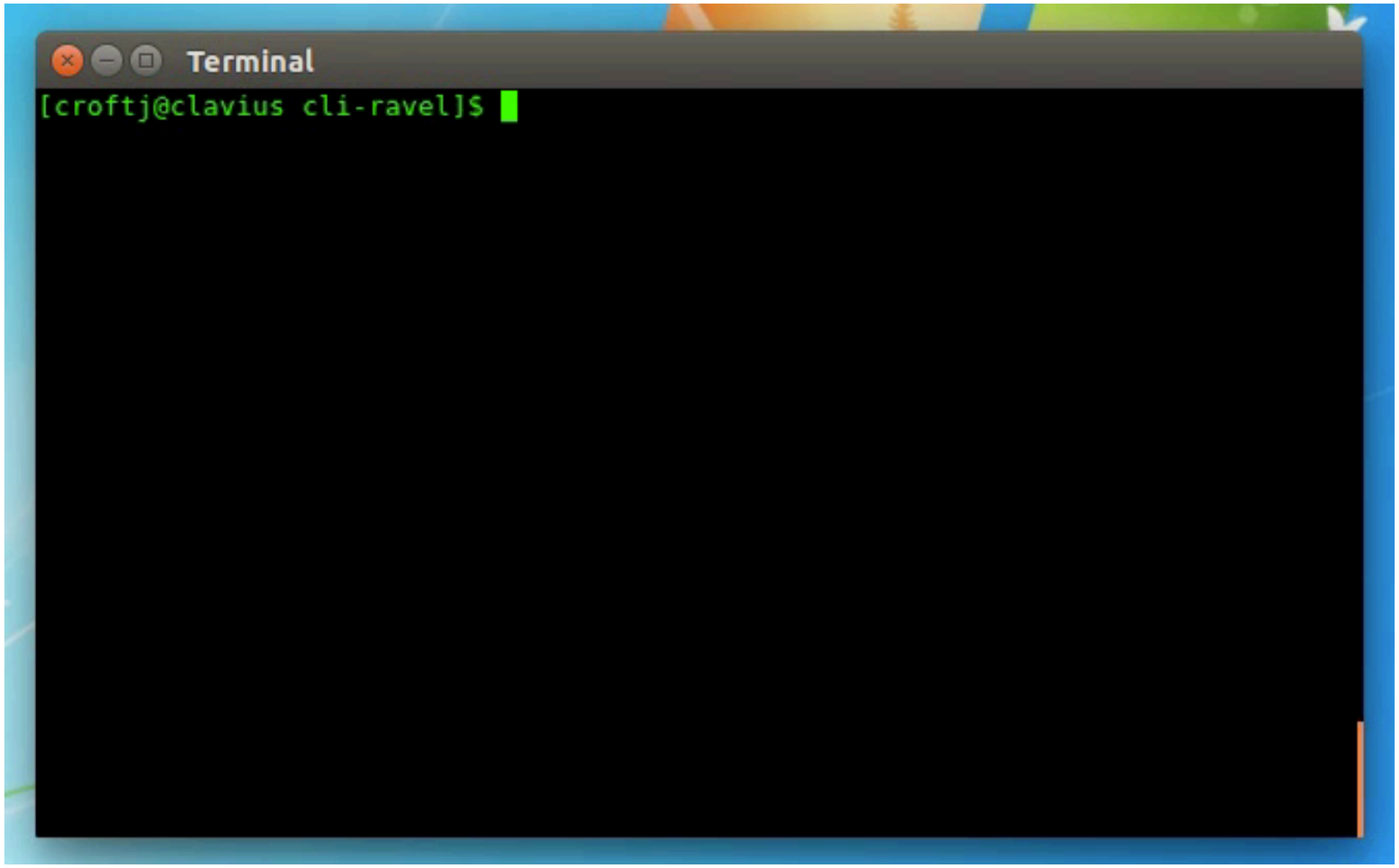
looking forward

- 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

download *Ravel* and install

ravel-net.org/download

start playing: tutorials, add your own app

ravel-net.org

more to explore

github.com/ravel-net