Ravel: a database-defined network

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

*Temple University    †University of Illinois Urbana-Champaign

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software-defined network

control applications of disparate nature

forwarding  service chain  stateful middlebox ...

controller

OpenFlow network

switch  switch  switch  switch
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

what is the right abstraction?

forwarding  service chain  stateful middlebox ...

abstraction runtime

OpenFlow rules
abstractions

what is the right abstraction?

functions

service chain

stateful middlebox

...

Frenetic / Pyretic

[NSDI'13] [PLDI'13]

OpenFlow rules
What is the right abstraction?

functions

graphs

stateful middlebox

PGA
[SIGCOMM'15]

OpenFlow rules
abstractions

what is the right abstraction?

functions  graphs  automata ...

Kinetic [NSDI’15]

OpenFlow rules
but network keeps evolving

functions  graphs  automata

new/changing requirements

abstraction runtime

OpenFlow rules
but network keeps evolving

- functions
- graphs
- automata

new structure

add / re-engineer runtime

OpenFlow rules
and applications (components) interact

graphs

functions

Policies

automata

PGA

Kinetic

Pyretic

OpenFlow rules

network
and applications (components) interact

language-level orchestration restricted to each abstraction

composing (+) policy
→ graph +PGA graph
→ function +Pyretic function

graphs

automata

PGA

Kinetic

functions

Pyretic

OpenFlow rules
network
and applications (components) interact

- **graphs**
- **automata**

Policies

- PGA
- Kinetic

Functions

- Pyretic

OpenFlow rules network

language-level orchestration restricted to each abstraction

composing (+) policy

→ graph +? automata

how to integrate the runtime?

hard-wire internals?
and applications (components) interact

graphs
automata

PGA
Kinetic

functions

Pyretic

OpenFlow rules
network

policies

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

Structure

- Runtime

OpenFlow rules

Network
current state of abstraction research

- **structure**
  - runtime
  - structure
- **new structure**
  - new runtime
  - fragmented orchestration

- enlarging body of abstractions

- OpenFlow rules
  - network
our perspective

SDN control revolves around data representation

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

![Diagram showing high-level and low-level representations with data and new data boxes connected by OpenFlow rules for network operation and/or application.](image)
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

operator and/or application

view
new view

view

table

OpenFlow rules
network

high-level
app views

low-level
inventory tables
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

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**Ravel: a realization with SQL database**

**attractive features**

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Ravel: a realization with SQL database

attractive features

- abstraction
- orchestration
- SQL

operator and/or application

(view
new view)

view

table

table

OpenFlow rules

network

database runtime
abstraction: network tables

reachability matrix

<table>
<thead>
<tr>
<th>fid</th>
<th>src</th>
<th>dst</th>
<th>vol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>h₁</td>
<td>h₄</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>h₂</td>
<td>h₃</td>
<td>9</td>
</tr>
</tbody>
</table>

flow 1

h₁ → S₁ → S₄ → h₄

flow 2

h₂ → S₂ → S₃ → h₃

topology

<table>
<thead>
<tr>
<th>sid</th>
<th>nid</th>
</tr>
</thead>
<tbody>
<tr>
<td>S₁</td>
<td>S₂</td>
</tr>
<tr>
<td>S₁</td>
<td>S₃</td>
</tr>
<tr>
<td>S₁</td>
<td>h₁</td>
</tr>
</tbody>
</table>

configuration

<table>
<thead>
<tr>
<th>fid</th>
<th>sid</th>
<th>nid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S₁</td>
<td>S₄</td>
</tr>
<tr>
<td>1</td>
<td>S₄</td>
<td>h₄</td>
</tr>
</tbody>
</table>

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

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)  
);

firewall view: monitoring unsafe flows violating acl policy
abstraction: application view

firewall view: monitoring unsafe flows violating acl policy

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

```
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)
);
```

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

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

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)
);
```

firewall control: repairing violation

```sql
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

routing app: check broken path, re-route

SQL rule: upon broken path, re-route

Mininet

network table

app view

shortest path view

orchestrated Ravel runtime

topology table

configuration table

shortest path

topology

configuration
orchestration across representations

Routing app: check broken path, re-route

SQL rule: upon broken path, re-route

Mininet link (172,39) down

Network table

Topology table

Configuration table

App view

Shortest path view

Orchestrated Ravel runtime

Mininet

App

Shortest path

Configuration

Topology

Link down
**orchestration across representations**

Routing app: check broken path, re-route

- **app**
  - **app view**
    - shortest path view

- **network table**
  - **configuration table**

- **topology table**

- **Mininet link down**

- **Mininet link (172,39) down**

- **SQL rule:** upon broken path, re-route

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

- **configuration**

<table>
<thead>
<tr>
<th>sid</th>
<th>nid</th>
<th>active</th>
</tr>
</thead>
<tbody>
<tr>
<td>172</td>
<td>39</td>
<td>1</td>
</tr>
<tr>
<td>172</td>
<td>39</td>
<td>0</td>
</tr>
</tbody>
</table>
orchestration across representations

SQL rule: upon broken path, re-route

<table>
<thead>
<tr>
<th>shortest path</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
</tr>
<tr>
<td>path</td>
</tr>
<tr>
<td>- {...,172,39,156,...}</td>
</tr>
<tr>
<td>+ {...,172,38,148,...}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>topology</th>
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<tbody>
<tr>
<td>sid</td>
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<tr>
<td>-----</td>
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<tr>
<td>-</td>
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<td>+</td>
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Mininet link (172,39) down
orchestration across representations

Routing app: check broken path, re-route

SQL rule: upon broken path, re-route

Mininet link (172,39) down
**orchestration across representations**

- **Routing app:** check broken path, re-route
- **SQL rule:** upon broken path, re-route
  - **Topological table:**
    - Mininet link (172,39) down
    - **Configuration table:** orchestrating updates: re-route via (172, 38)
orchestration across applications

priority: low → high

balance firewall maintain
load path

load balancer access control shortest path

tenant virtual net

reachability matrix configuration table

Mininet
orchestration across applications

Priority: low → high

Apps:
- Balance
- Firewall
- Maintain path

App view:
- Tenant request

Tenant request:
- Virtual net

Tenant virtual net:

<table>
<thead>
<tr>
<th>...</th>
<th>Host</th>
<th>Server</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
<td>1238</td>
<td>1003</td>
</tr>
</tbody>
</table>

Network table:
- Reachability matrix
- Configuration table

Mininet

Load balancer

Access control

Shortest path

Reachability matrix

Configuration
orchestration across applications

priority: low → high

load balancer access control shortest path

load balancer

access control

shortest path

load balancer

access control

shortest path

load balancer

access control

shortest path

tenant virtual net

tenant request

host 1238 to server 1003

reachability matrix

configuration table

Mininet

network table

app view

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network table
orchestration across applications

priority: low → high

load balancer
access control
shortest path

access control

shortest path

load balancer

access control

shortest path

tenant virtual net

reachability matrix
configuration table

reachability matrix
configuration table
orchestration across applications

priority: low → high

load balancer

access control

reachability matrix

configuration table

tenant virtual net

tenant request

network table

orchestrated database runtime

app view

Mininet
orchestration across applications

priority: low → high

load balancer

<table>
<thead>
<tr>
<th>sid</th>
<th>load</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1003</td>
<td>4</td>
</tr>
<tr>
<td>-1003</td>
<td>3</td>
</tr>
<tr>
<td>-1034</td>
<td>1</td>
</tr>
<tr>
<td>+1034</td>
<td>2</td>
</tr>
</tbody>
</table>

access control

<table>
<thead>
<tr>
<th>src</th>
<th>dst</th>
<th>allow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1238 1034</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1238 1003</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

shortest path

load balancer

<table>
<thead>
<tr>
<th>tenant virtual net</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
</tr>
<tr>
<td>+</td>
</tr>
<tr>
<td>+</td>
</tr>
</tbody>
</table>

reachability matrix

<table>
<thead>
<tr>
<th>fid</th>
<th>sid</th>
<th>nid</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>...</td>
<td>1238</td>
</tr>
</tbody>
</table>
orchestration across applications

priority: low → high

load balancer
- load: 1003
  - load: 1003
  + load: 1034
+ load: 1034

access control
- src: 1238
  - dst: 1003
  + dst: 1034
+ dst: 1034

shortest path
- path: ...
+ path: {1238,...,1034}

tenant virtual net
- host: 1238
  - server: 1003
+ host: 1238
- server: 1034
+ server: 1034

reachability matrix
- fid: ...
  - sid: 1238
  + sid: 1034
+ sid: 1034

configuration
orchestration across applications

priority: low → high

re-load check maintain path

load balancer access control shortest path

load balancer
<table>
<thead>
<tr>
<th>sid</th>
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<tbody>
<tr>
<td>1003</td>
<td>4</td>
</tr>
<tr>
<td>1003</td>
<td>3</td>
</tr>
<tr>
<td>1034</td>
<td>1</td>
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<tr>
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<td>2</td>
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access control
<table>
<thead>
<tr>
<th>src</th>
<th>dst</th>
<th>allow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1238</td>
<td>1034</td>
<td>1</td>
</tr>
<tr>
<td>1238</td>
<td>1003</td>
<td>0</td>
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</table>

shortest path
<table>
<thead>
<tr>
<th>path</th>
</tr>
</thead>
<tbody>
<tr>
<td>... 1238, ..., 1034</td>
</tr>
</tbody>
</table>

tenant request host 1238 to server 1003

reachability matrix
<table>
<thead>
<tr>
<th>fid</th>
<th>sid</th>
<th>nid</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1238</td>
<td>1034</td>
</tr>
</tbody>
</table>

configuration
<table>
<thead>
<tr>
<th>fid</th>
<th>sid</th>
<th>nid</th>
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</thead>
<tbody>
<tr>
<td>+</td>
<td>...</td>
<td>1034</td>
</tr>
</tbody>
</table>
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
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
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
SDN control via SQL

- challenge: database lacks connection to network data plane
- solution: SQL trigger + OF manager
a high-performance runtime
- PostgreSQL
- orchestration
- optimizer
- SQL trigger and OF manager
We present a novel SDN design, Ravel, based on a standard SQL database. Like overlay [18] and active networks [11], Ravel differs in every implementation and deployment of new distributed protocols, making extensible and efficient routing infrastructure. This allows rapid implementation — uses a distributed recursive query engine as an intensive datalog) and distributed system (distributed query optimization) research — uses a distributed recursive query engine as an intensive datalog) and distributed system (distributed query optimization). Declarative networking.

7. RELATED WORK

Optimizing application views of equivalent. (b,c) CDF of maintenance delay (ms). Figure 4: CDF of orchestration delay: normalized per-rule orche-
evaluation

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<tr>
<th>AS#</th>
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<td>4755</td>
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<td>258</td>
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Rocketfuel ISP topology

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

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

Rocketfuel ISP topology

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compute path
lookup ports
write to table
trigger/rule
evaluation

profile end to end delay (normalized per-rule, 30 rounds) for route insertion and deletion
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compute path
lookup ports
write to table
trigger/rule
evaluation

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

![CDF graphs for AS 4755, AS 3356, AS 7018]

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

Figure 3: Sources of Ravel delay (ms) for route insertion and deletion.

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
Conclusion

Notification operation via SQL interface

OpenFlow manager network

SQL trigger PostgreSQL Ravel runtime

View maintenance view update

Optimizer orchestration table

Table table table

Control events view
conclusion

this talk
- orchestratable abstraction via SQL

notification operation via SQL interface

view view view

view view

view maintenance

view orchestration optimizer

table table table

SQL trigger

OpenFlow manager

network

view

PostgreSQL

Ravel runtime
conclusion

this talk

- orchestratable abstraction via SQL

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
[ravel@ravelvm ravel]$
[ravel@ravelvm ravel]$
playtime

download *Ravel*

ravel-net.org/download

start playing: tutorials, add your own app

ravel-net.org

explore more

github.com/ravel-net