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Raft in etcd

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Introduction

- Who am I
  - github.com/jingyih
  - A maintainer of etcd (https://github.com/etcd-io/etcd)
- Hopefully would be helpful for
  - Developers who are new to etcd Raft package. This talk provides a starting point for reading the source code.
  - Developers who want to understand the relationship between etcd and Raft. This talk provides a brief description on how etcd uses the Raft package.
  - Developers who want to import and use Raft package in their own project.

Agenda

- Raft Recap
- Raft as part of etcd
- Raft Implementation Details
- Roadmap

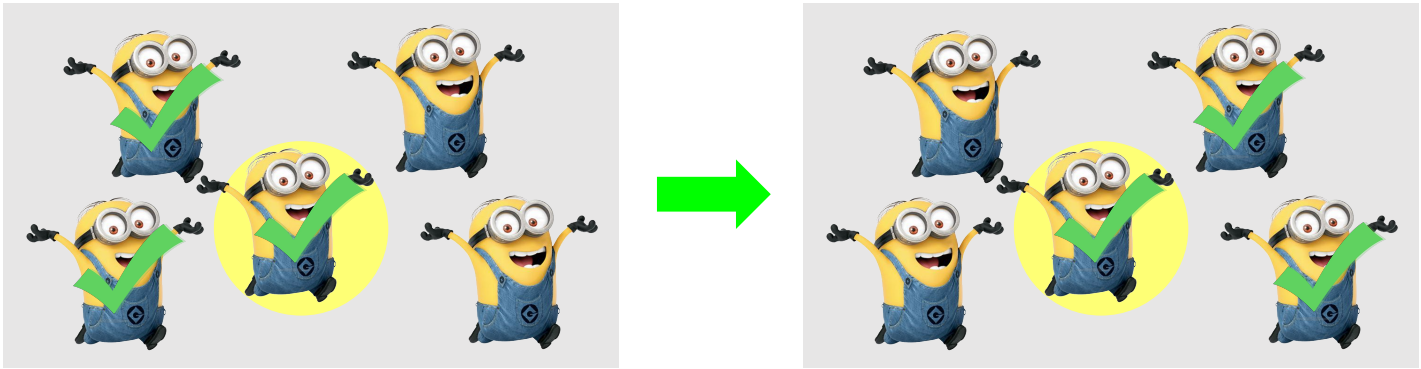
Raft Recap

- Consensus and Quorum
- Replicated state machine
- Leader election
- Log replication

Raft Recap

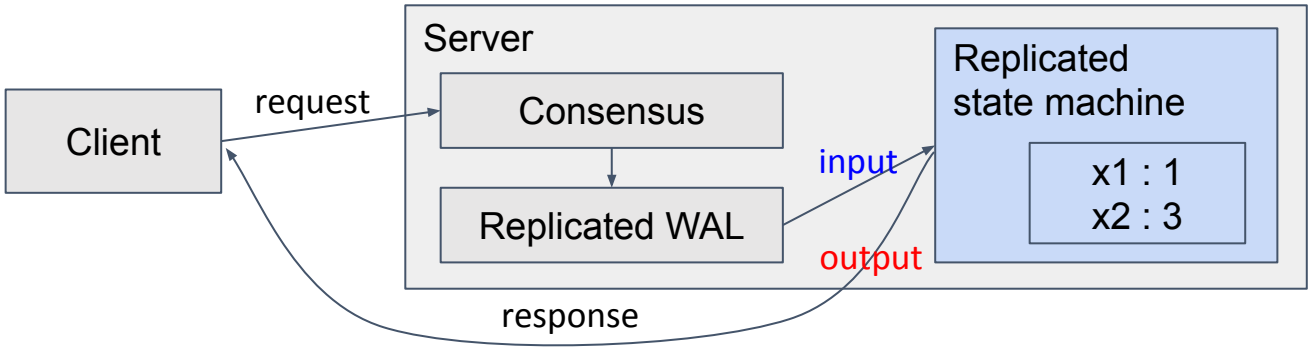
- Consensus and Quorum
  - If Q1 and Q2 are quorum, their intersection is not empty.
  - Cluster can make progress as long as consensus among quorum - high availability / fault tolerance.

(Image source: http://pngimg.com/imgs/heroes/minions/)



Raft Recap

- Replicated state machine
  - Same initial state
  - Same input sequence - replicated write ahead log (WAL)
  - Results in same output and (internal) state transition.



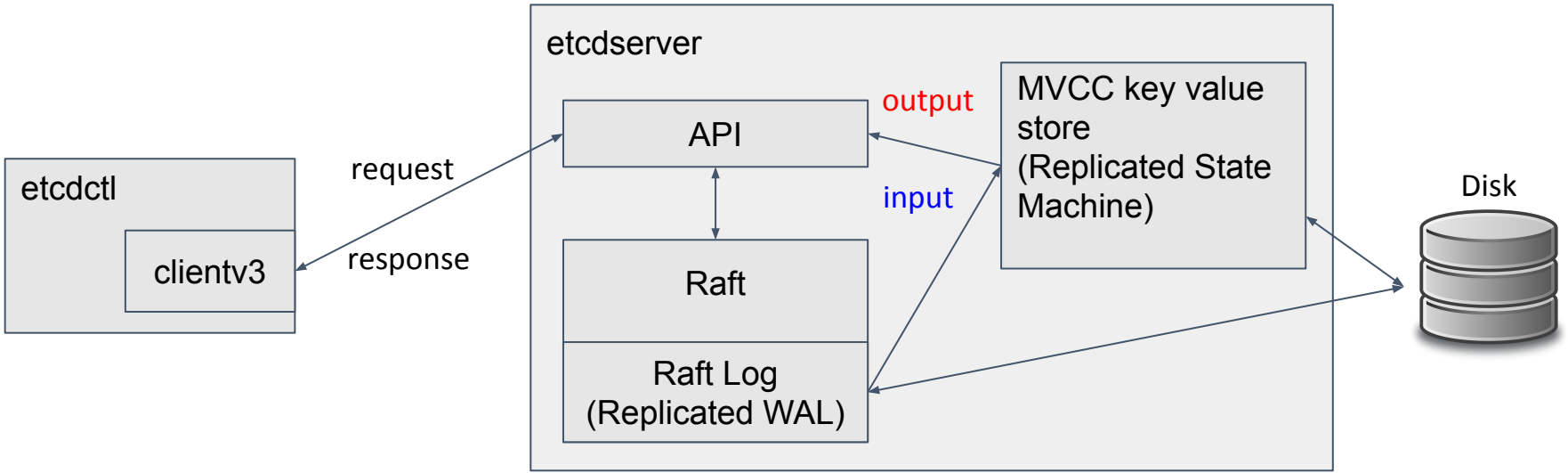
Raft Recap

- Leader election
  - Candidate, Follower, Leader
  - Term
  - Election
  - Heartbeat

Raft Recap

- Log Replication
  - Only leader manages the replicated logs.
  - Leader only append to log.
  - Leader keeps trying to replicate its logs to followers.
  - Committed index
  - Applied index (always smaller than committed index)

Raft in etcd



We will revisit this graph (with more details) after we talked about the Raft implementation.

Raft Implementation

- Minimalistic design for flexibility, deterministic and performance
  - Raft package does not implement network transport between peers
  - Raft package does not implement storage to persist log and state

Raft Implementation

- Raft is modeled as a state machine
  - State
  - Input, output
  - Transition between states

Raft Implementation

- State

```
type raft struct {
   id   uint64
   Term uint64
   Vote uint64
   ...
   raftLog *raftLog // replicated WAL
   ...
   state StateType // Leader, Candidate, Follower
   ...
   step stepFunc
   ...
}


type stepFunc func(r *raft, m pb.Message) error

func stepLeader(r *raft, m pb.Message) error

func stepFollower(r *raft, m pb.Message) error

func stepCandidate(r *raft, m pb.Message) error
```

- Input

```
type Message struct {
   Type              MessageType
                     // e.g. MsgVote, MsgApp
   To                uint64
   From              uint64
   Term              uint64
   LogTerm           uint64
   Index             uint64
   Entries           []Entry // raft log entries
   ...
}
```

Raft Implementation

- Output

```
type Ready struct {
   pb.HardState
   // {Term, Vote, Committed Index}, to be saved to
staroge
   ...
   Entries []pb.Entry
   // Raft entries to be saved to storage
   ...
   CommittedEntries []pb.Entry
   // Raft entries ready to be applied to
   // replicated state machine
   ...
   Messages []pb.Message
   // messages to be sent to peers
   ...
}
```

- State Transition

```
// Step advances the Raft state machine using the given
message.
Step(ctx context.Context, msg pb.Message) error


func (r *raft) Step(m pb.Message) error {
   ...
   // Common logic for leader, candidate, follower:
   // 1. Handle m.Term, which may result in leader stepping
down to a follower
   // 2. Handle campaign and voting

   r.step(m)
   // stepLeader
   // stepCandidate
   // stepFollower
}
```

Raft Implementation

- Example: Propose a change to replicated state machine (KV store)

A

```
Message {
    Type:    pb.MsgProp,
    Entries: []pb.Entry{{Data: data},
}
```

Follower

```
func (n *node) Propose(ctx context.Context, data []byte)
error {
    return n.stepWait(ctx,
        pb.Message{
            Type:    pb.MsgProp,
            Entries: []pb.Entry{{Data: data}},
        })
}
```

Raft Implementation

- Example: Propose a change to replicated state machine (KV store)

A

```
Message {
    Type:    pb.MsgProp,
    Entries: []pb.Entry{{Data: data},
}
```

Follower

B

```
Message {
    Type:    pb.MsgProp,
    To:      r.lead,
    From:    r.id,
    Entries: []pb.Entry{{Data: data},
}
```

```
func stepFollower(r *raft, m pb.Message) error {
    switch m.Type {
    ...
    case pb.MsgProp:
        if r.lead == None {
            return ErrProposalDropped
        }
        m.To = r.lead
        r.send(m)
    }
}


func (r *raft) send(m pb.Message) {
    m.From = r.id
    r.msgs = append(r.msgs, m)
}


func newReady(r *raft, ...) Ready {
    rd := Ready{
        Messages: r.msgs,
    }
    return rd
}
```

Raft Implementation

- Example: Propose a change to replicated state machine (KV store)

B

```
Message {
    Type:    pb.MsgProp,
    To:      r.lead,
    From:    r.id,
    Entries: []pb.Entry{{Data: data},
}
```

Leader

C

```
Message {
    Type:    pb.MsgApp,
    To:      peer 1 id,
    From:    r.id,
    Entries: ents,
    Commit:
r.raftLog.committed,
    ...
}
```

D

```
Message {
    Type:    pb.MsgApp,
    To:      peer 2 id,
    From:    r.id,
    Entries: ents,
    Commit:
r.raftLog.committed,
    ...
}
```

```
func stepLeader(r *raft, m pb.Message) error {
    switch m.Type {
    ...
    case pb.MsgProp:
        if !r.appendEntry(m.Entries...) {
            return ErrProposalDropped
        }
        r.bcastAppend()
    }
}


For each peer:
func (r *raft) maybeSendAppend(to uint64, ...) bool {
    m := pb.Message {
        Type:    pb.MsgApp,
        To:      to, // peer id
        Entries: ents, // from last matched entry to latest
        Commit:  r.raftLog.committed,
        ...
    }

    r.send(m)
}
```

Raft Implementation

- Example: Propose a change to replicated state machine (KV store)

C

```
Message {
    Type:    pb.MsgApp,
    To:      peer 1 id,
    From:    r.id,
    Entries: ents,
    Commit:  r.raftLog.committed,
    ...
}
```

Follower

E

```
Message {
    Type:    pb.MsgAppResp,
    To:      lead id,
    From:    r.id,
    Index:   mlastIndex,
}
```

```
func stepFollwer(r *raft, m pb.Message) error {
    switch m.Type {
    ...
    case pb.MsgApp:
        ...
        r.lead = m.From
        r.handleAppendEntries(m)
    }
}

func (r *raft) handleAppendEntries(m pb.Message) {
    ... // do not need to append if already has more updated
log entries, and report my progress to leader
    if mlastIndex, ok := r.raftLog.maybeAppend(m.Index,
m.LogTerm, m.Commit, m.Entries...); ok {
        r.send(pb.Message{
            To:    m.From, // this is lead id
            Type:  pb.MsgAppResp,
            Index: mlastIndex,
        })
    } else {...} // reject the log entries from leader
}
```

Raft Implementation

- Example: Propose a change to replicated state machine (KV store)

E

```
Message {
    Type:    pb.MsgAppResp,
    To:      lead id,
    From:    r.id,
    Index:   mlastIndex,
}
```

Leader

F, G

```
Message {
    Type:    pb.MsgApp,
    To:      peer 1 id,
    From:    r.id,
    Entries: ents,
    Commit:  r.raftLog.committed,
    // Commit is updated
    ...
}
```

```
func stepLeader(r *raft, m pb.Message) error {
    switch m.Type {
    ...
    case pb.MsgAppResp:
        if m.Reject {...} else {
            ...
            if pr.maybeUpdate(m.Index) {
                r.bcastAppend()
            }
            ...
        }
    }
}

func (r *raft) handleAppendEntries(m pb.Message) {
    ...
    // maybeAppend may advance the committed index in
follower's raft log
    if mlastIndex, ok := r.raftLog.maybeAppend(m.Index,
m.LogTerm, m.Commit, m.Entries...); ok {...}
    ...
}
```

Raft Implementation

- Example: Propose a change to replicated state machine (KV store)

F

```
Message {
    Type:    pb.MsgApp,
    To:      peer 1 id,
    From:    r.id,
    Entries: ents,
    Commit:  r.raftLog.committed,
    // Commit is updated
    ...
}
```

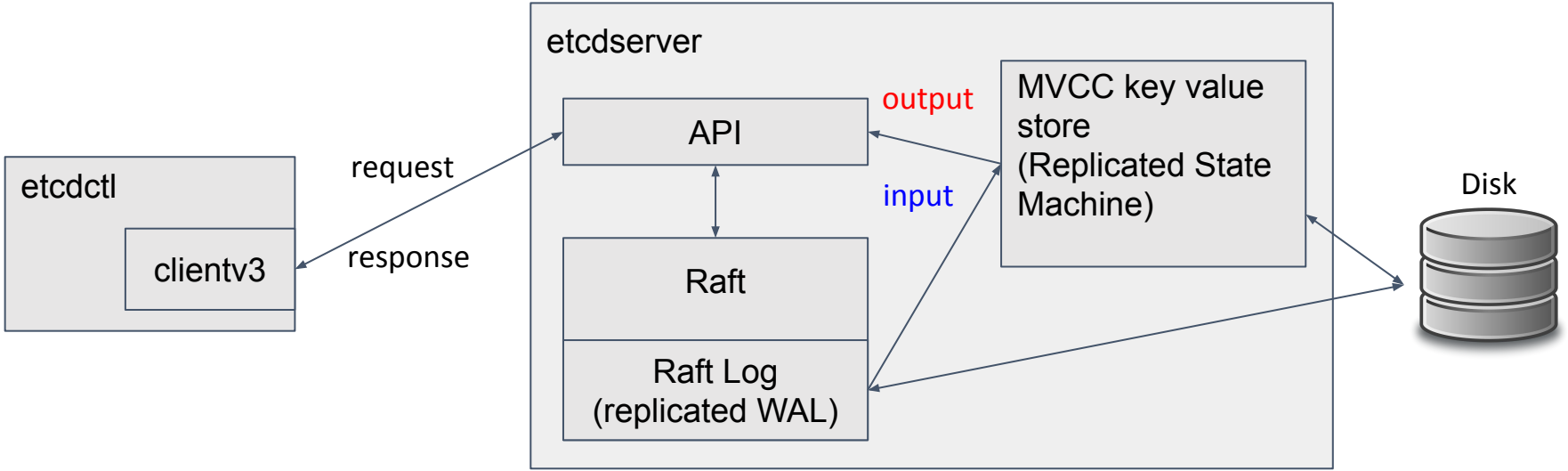
Follower

```
Ready {
    Messages: // Messages includes a message
of type pb.MsgAppResp to leader
    CommittedEntries: // new committed
entries as the result of maybeAppend()
    ...
}
```

```
// Recap: the output of Raft state machine

type Ready struct {
    pb.HardState
    // Term, Vote, Committed Index
    ...
    Entries []pb.Entry
    // Raft entries to be saved to storage
    ...
    CommittedEntries []pb.Entry
    // Raft entries ready to be applied to
    // replicated state machine
    ...
    Messages []pb.Message
    // messages to be sent to peers
    ...
}
```

Raft in etcd



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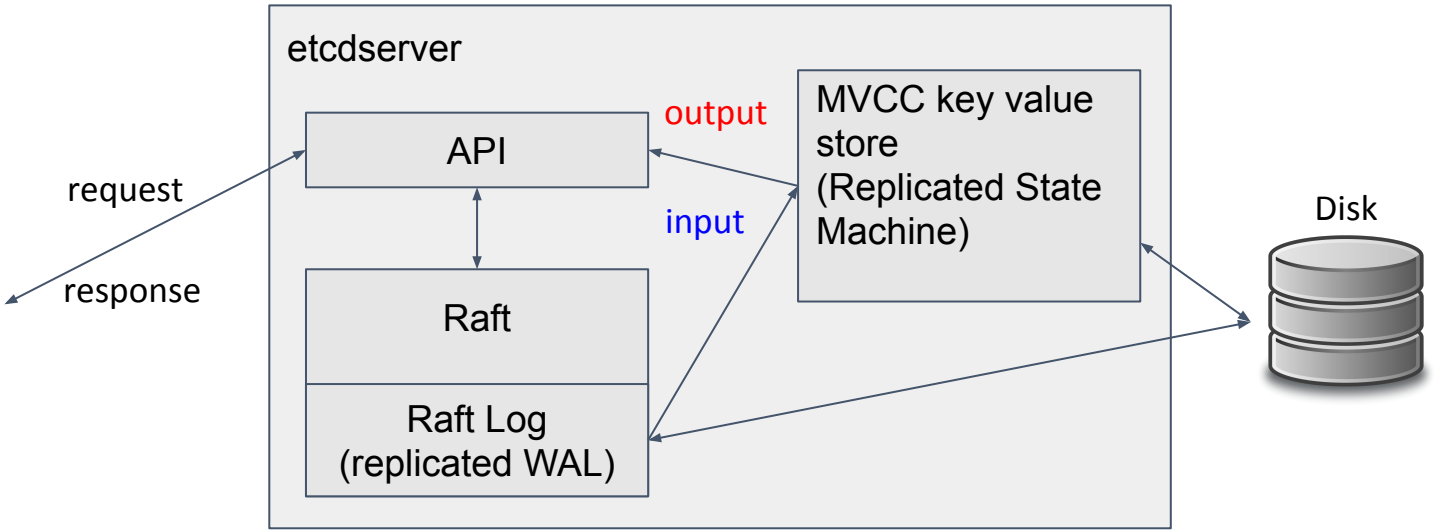
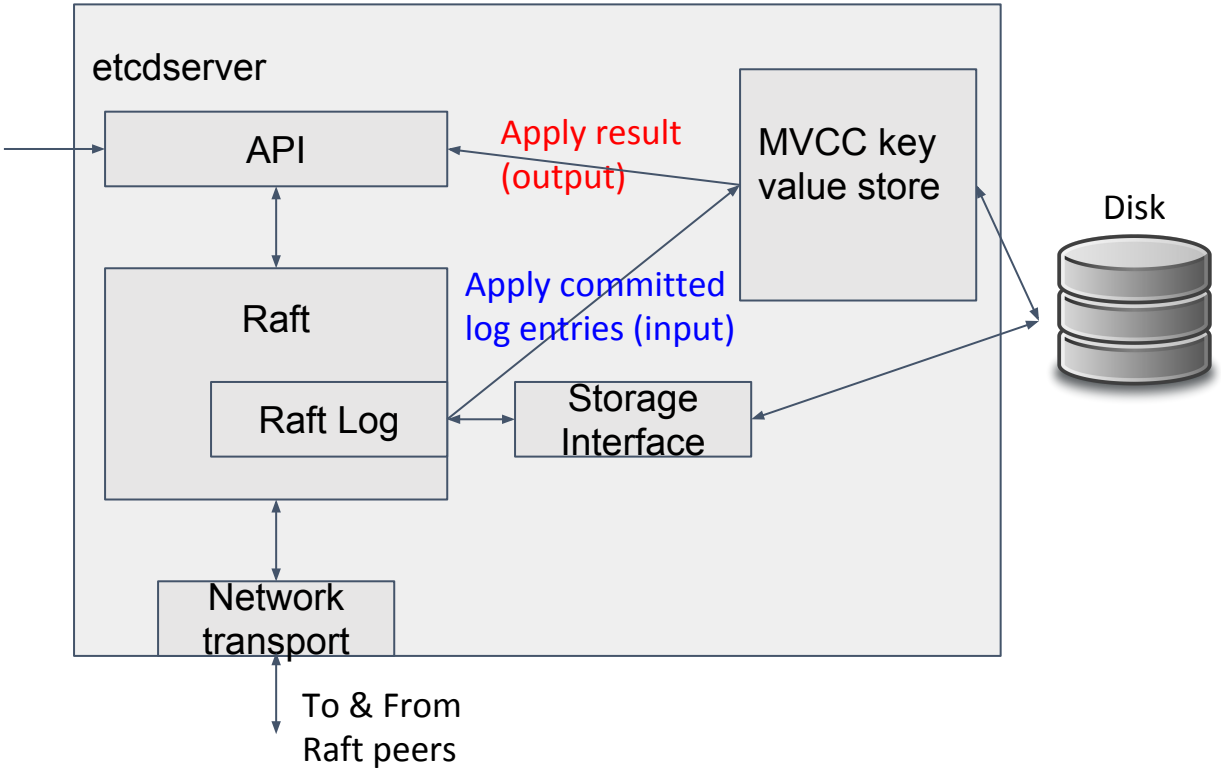
Raft in etcd


etcdserver
API
output
input
MVCC key value store (Replicated State Machine)
request
response
Raft
Raft Log (replicated WAL)
Disk

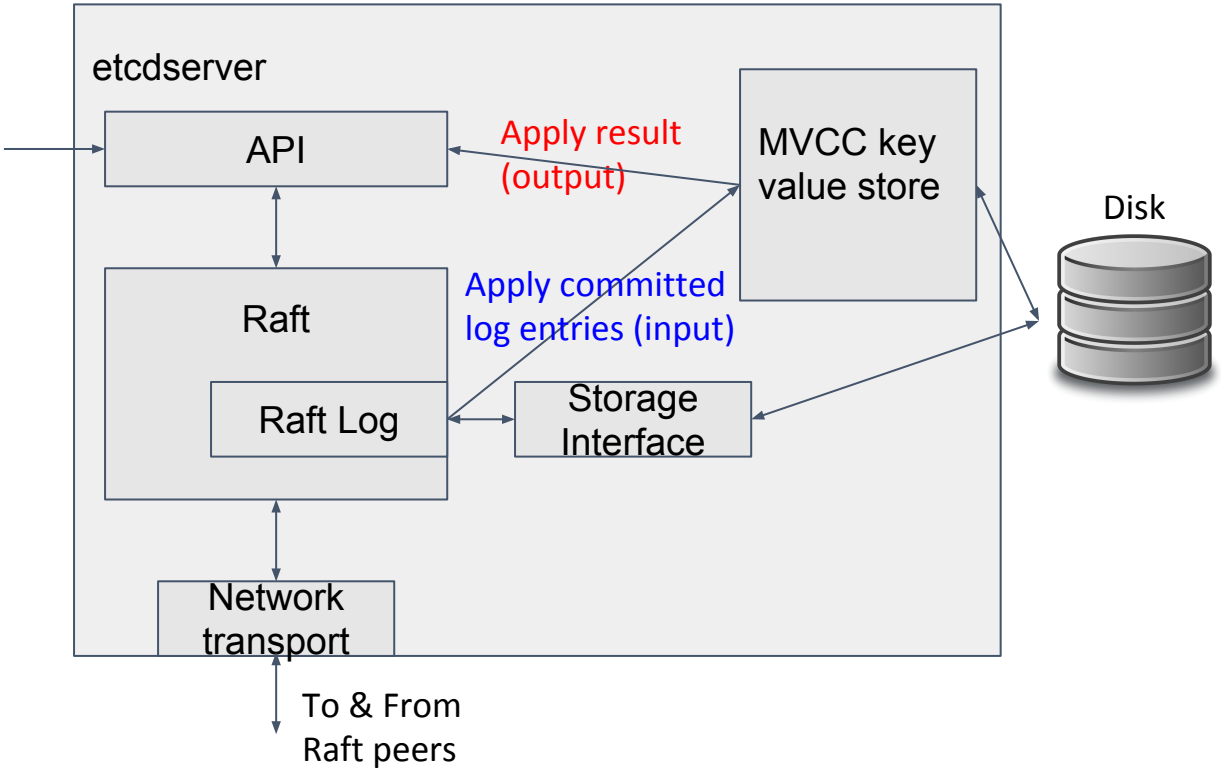
Revisit: Raft in etcd



Revisit: Raft in etcd


```
// Server's handling loop

for {
    select {
    ...
    case rd := <-r.Ready():
        r.storage.Save(rd.HardState,
rd.Entries, rd.Snapshot)
        r.transport.Send(rd.Messages)
        s.Apply(rd.CommittedEntries)
        ...
    }
}
```



Revisit: Raft in etcd


```
// Server's handling loop

for {
    select {
    ...
    case rd := <-r.Ready():
        r.storage.Save(rd.HardState,
rd.Entries, rd.Snapshot)
        r.transport.Send(rd.Messages)
        s.Apply(rd.CommittedEntries)
        ...
    }
}
```

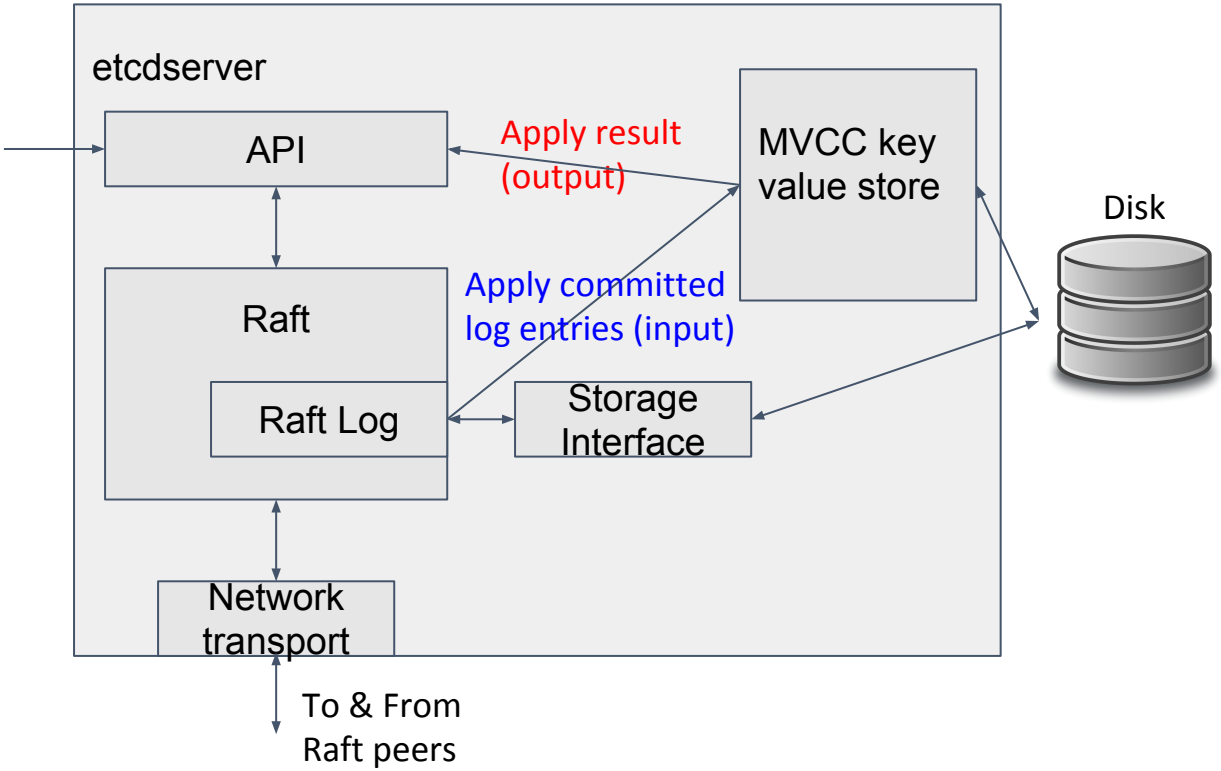
```
// Request lifecycle

1. Send proposal to Raft
r.Propose(ctx, data)

2. If successfully committed, data
will appear in rd.CommittedEntries

3. Apply committed entries to MVCC

4. Return apply result to client
```



Roadmap

- Raft learner / non-voting member feature in etcd v3.4.
  - Design Doc:

    https://github.com/etcd-io/etcd/blob/master/docs/server-learner.rst
  - Implementation: PR #10725, #10727, #10730
- Joint consensus for Raft membership reconfiguration?
  - https://github.com/etcd-io/etcd/issues/7625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Thanks!
Q&A