redhat.

Incremental Backups

(*Good things come in small packages!*)

John Snow (*yes, I know*)
Software Engineer, Red Hat
2017-02-05

Acknowledgments

(Because computers are awful and I need help sometimes)

No feature is an island, so I'd like to acknowledge:

- Jagane Sundar
  - Initial feature proposal and prior work (2011)
- Fam Zheng
  - Initial drafts for current version (2014-2015)
- Stefan Hajnoczi & Max Reitz
  - Reviews and patience

Acknowledgments

(Because computers are awful and I need help sometimes)

No feature is an island, so I'd like to acknowledge:

- Vladimir Sementsov-Ogievskiy, Virtuozzo
  - Advanced features (Persistence, Migration)
  - Performance enhancements
  - Reviews, Patience, and general excellence
- Denis Lunev, Virtuozzo
  - Dedicated and persistent involvement

Overview

(Things I hope not to stammer through)

Prologue

- Problem Statement
- Approach
- Design Goals

Act I: Building Blocks

- Block Dirty Bitmaps
- QMP interface and usage
- QMP transactions

Overview

(Things I hope not to stammer through)

Act II: Life-cycle

- Incremental backup life-cycle
- Examples

Aside: Transactions

- BlockJobs
- Transactions
- Multi-drive Coherency
- Errors

Overview

(Things I hope not to stammer through)

Act III: Advanced Features

- Migration
- Persistence
- Push vs Pull model backups
- TODOs

Dénouement

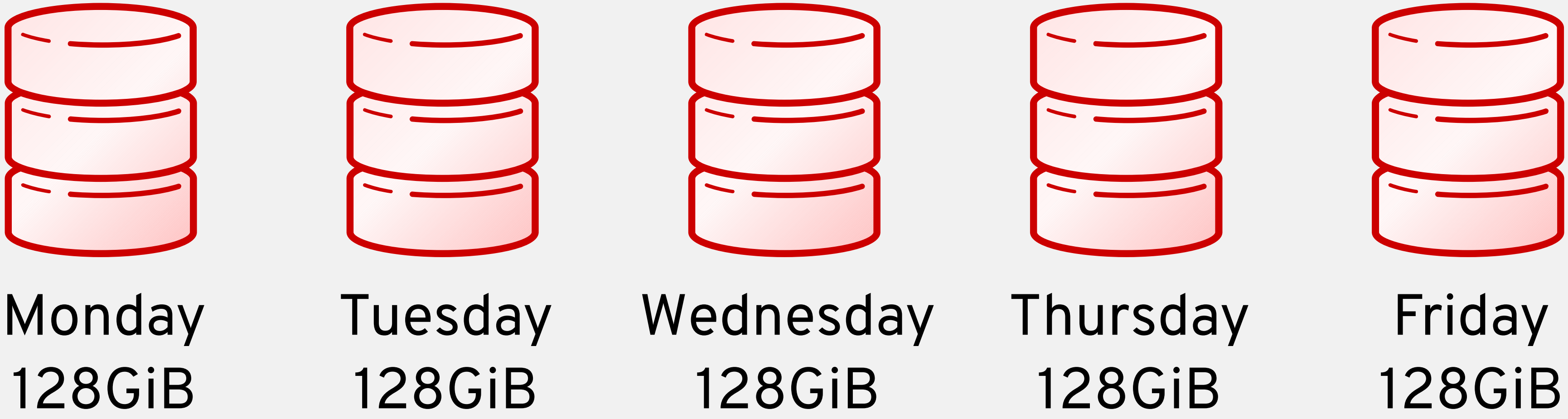
- Project Status, Questions and Answers

PROLOGUE

(In which our heroes come to know the enemy)

The Problem

(I just wandered into this talk, what's it about?)



Monday
128GiB

Tuesday
128GiB

Wednesday
128GiB

Thursday
128GiB

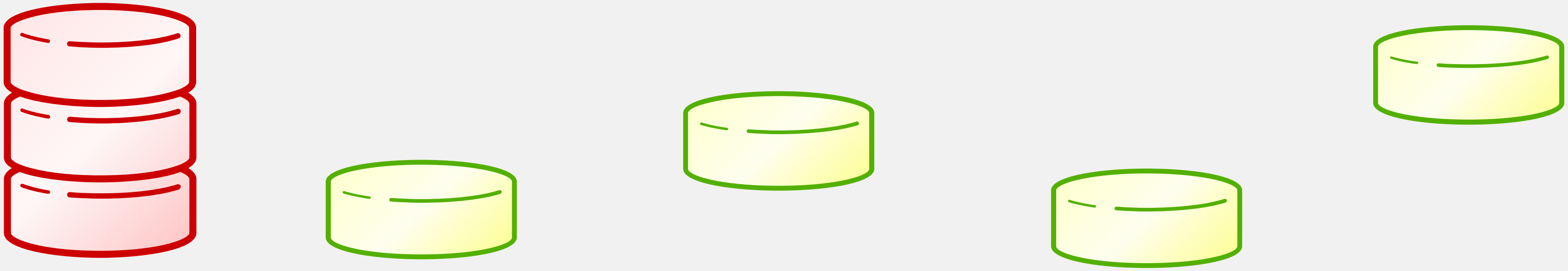
Friday
128GiB

Gross.

- Abysmal storage efficiency
- Clunky, slow
- But admittedly simple and convenient

The Problem

(I just wandered into this talk, what's it about?)



Monday 128GiB

Tuesday 2GiB

Wednesday 2.5GiB

Thursday 2.21GiB

Friday 1GiB

Much Better!

- Efficient: only copies modified data
- Fast!
- More complicated...?

Welcome!

(You’re in my world now)

QEMU added preliminary support for incremental backups in QEMU 2.4, 2015-08-11.

- (I can’t commit to either US or EU dates, so enjoy this ISO one instead)
- Development is ongoing as of 2.8
- Not included as “supported” in a Red Hat product yet
  - So, it’s mostly for the brave.
  - But we’re nearing feature completion.

Approach

(Where did we come from; where did we go)

Incremental Live Backups have a storied lineage.

- Jagane Sundar's LiveBackup (2011)
  - Separate CLI tools
  - Entirely new network protocol
  - Ran as an independent thread
  - Utilized temporary snapshots for atomicity
  - Implemented with in-memory dirty block bitmaps
  - Was ultimately not merged

Approach

(Where did we come from; where did we go)

Fam Zheng's Incremental Backup (2014)

- Also dirty sector bitmap based
  - Uses existing HBitmap/BdrvDirtyBitmap primitives
- No new external tooling or protocols
- Managed via QMP
- Implemented simply as a new backup mode
- Can be used with any image format
- Maximizes compatibility with existing backup tools

Design Goals

(What do we want?)

- Reuse existing primitives as much as possible
  - Key structure: 'block driver dirty bitmap'
    - Already tracks dirty sectors
    - Used for drive mirroring, block migration
    - Configurable granularity
    - Many bitmaps can be used per-drive

Design Goals

(What do we want? Efficient Backups!)

- Reuse existing primitives
  - Key interface: drive-backup
    - Implemented via well-known QMP protocol
    - Used to create e.g. full backups
    - Already capable of point-in-time live backups
    - Can already export data via NBD
    - We merely add a new sync=incremental mode
      - ...And a bitmap=<name> argument.

Design Goals

(When do we want it?)

- Coherency
  - Multi-drive point-in-time backup accuracy
  - Utilize existing QMP transaction feature
- Persistence
  - Bitmaps must survive shutdowns and reboots
  - Must not depend on drive data format
  - Nor on the backup target format

Design Goals

(When do we want it? By 2.9 hopefully!)

- Migration-safe
  - Migrating must not reset or lose bitmap data
- Error Handling
  - Bitmap data must not be lost on backup failure
  - Starting a new full backup is not sufficiently robust
- Integrity
  - We *must* be able to detect desync between persistence data and block data

Why not use snapshots?

(Saving you time during the Q&A)

“Both offer point-in-time views of data, why not use the existing mechanism?”

- No need to parse format-specific snapshots on disk
- We can use *any format*
- Incremental backups are *inert* and do not grow
  - No IO required to delete incrementals
- We can utilize existing backup frameworks
- Access to QEMU's NBD server

ACT I: BUILDING BLOCKS

(In which our heroes prepare for battle)

Block Dirty Bitmaps

(Nothing to do with your image search settings)

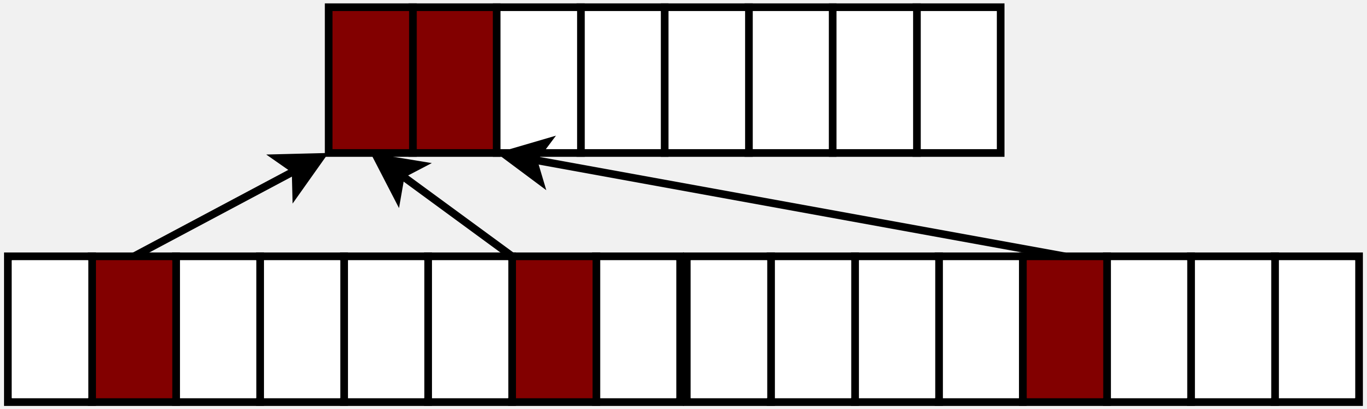
Before showcasing incrementals, some background:

- BdrvDirtyBitmap is the existing block layer structure used to track writes
  - Already used for drive-mirror, live block migration
  - Implemented using hierarchical bitmap
  - Any number can be attached to a drive
    - Allows for multiple independent backup regimes

Block Dirty Bitmaps

(Nothing to do with your image search settings)

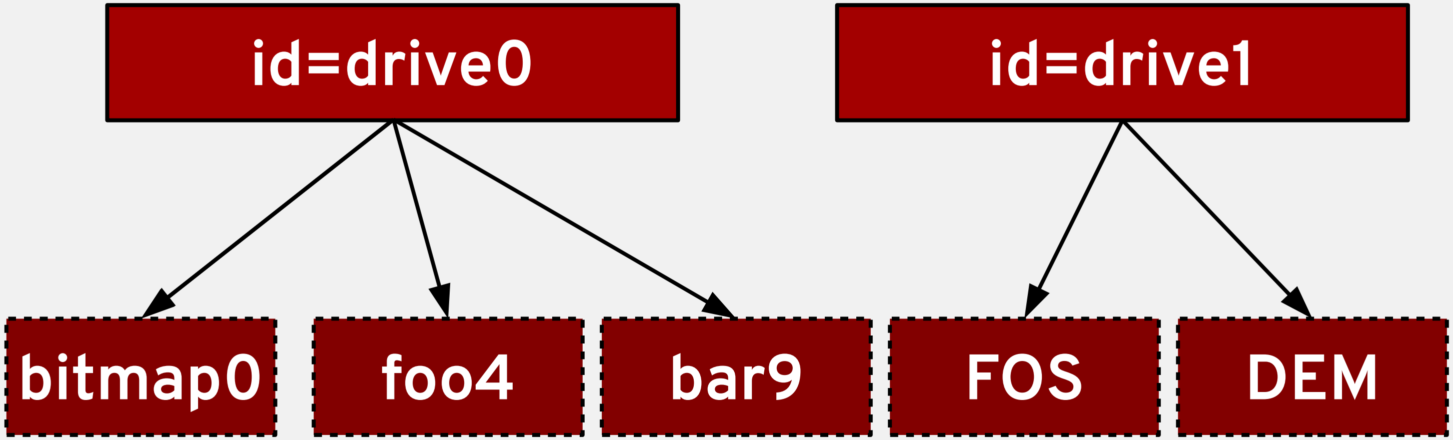
Hbitmap hierarchy:



Block Dirty Bitmaps

(Nothing to do with your image search settings)

Bitmap plurality:



Block Dirty Bitmaps - Naming

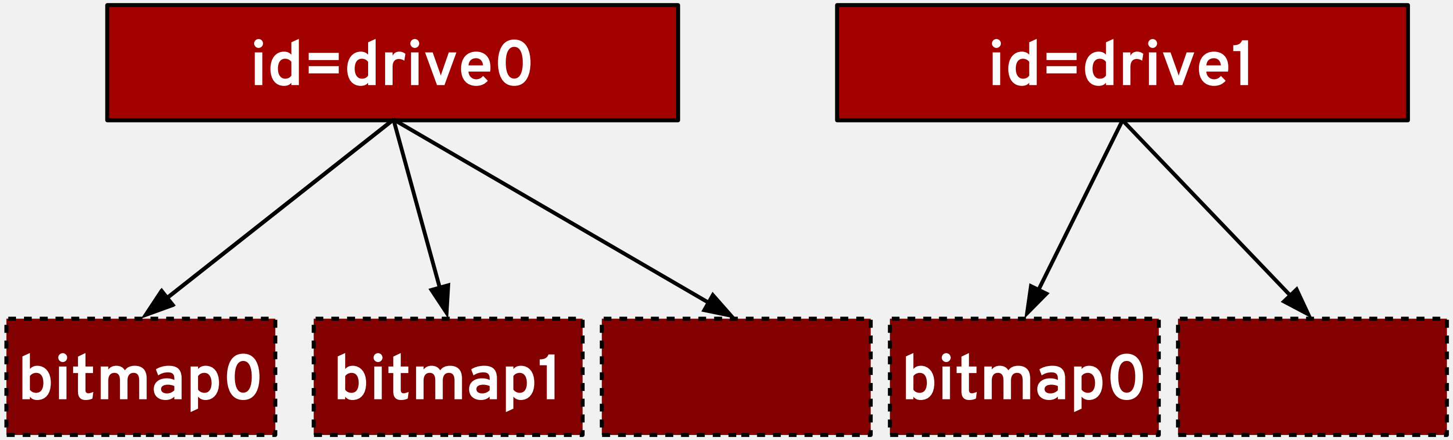
(A bitmap by any other name would smell as sweet...?)

- Block dirty bitmaps may have names:
  - Existing internal usages are anonymous
  - The name is unique to the drive
  - Bitmaps on different drives can have the same name
  - The (node, name) pair is the bitmap ID
    - Used to issue bitmap management commands

Block Dirty Bitmaps - Naming

(A bitmap by any other name would smell as sweet…?)

Bitmap naming:



Block Dirty Bitmaps - Granularity

(Backups from *French Press* to *Turkish*)

- Block dirty bitmaps have granularities:
  - Small granularity – smaller backups*
    - Uses more memory
      - 1 TiB w/ g=32KiB → 4MiB
      - 1 TiB w/ g=128KiB → 1MiB
- Default: 64KiB**
  - Attempts to match cluster size
  - 64KiB clusters (default) for qcow2

Granularities – In Detail

(Tuned like the finest $4 ukulele)

- Bitmaps track writes ***per-sector***
  - Configure granularity in ***bytes***
  - 64K → 128 sectors (512 bytes/sector)
- The backup engine itself copies out per-cluster
  - Currently: non-configurable, 64K clusters
- The file format also has a cluster size
  - qcow2 defaults to 64K.
- Conclusion: 64K is probably best (for now)

Block Dirty Bitmaps - Management

(Bitmap wrangling 101)

We need to manage these bitmaps to make backups.

- Managed via QMP
  - Good news if you're a computer!
- Four commands:
  - `block-dirty-bitmap-add`
  - `block-dirty-bitmap-remove`
  - `block-dirty-bitmap-clear`
  - `query-block`

Block Dirty Bitmaps - Creation

(Let there be... bits!)

- Bitmaps can be created at any time, on any node
- Bitmaps begin recording writes immediately
- Granularity is optional

```
{ "execute": "block-dirty-bitmap-add",
  "arguments": {
    "node": "drive0",
    "name": "bitmap0",
    "granularity": 131072
  }
}
```

Block Dirty Bitmaps - Deletion

(For days when *less* is *more*)

- Can only be deleted when not in use
- Bitmaps are addressed by their (node, name) pair
- Has no effect on backups already made
- Has no effect on other bitmaps or nodes

```
{ "execute": "block-dirty-bitmap-remove",
  "arguments": {
    "node": "drive0",
    "name": "bitmap0"
  }
}
```

Block Dirty Bitmaps - Resetting

(Sometimes we just want a second chance)

- Bitmaps can be cleared of all data
- Primarily for convenience
- Begins recording new writes immediately, like add

```
{ "execute": "block-dirty-bitmap-clear",
  "arguments": {
    "node": "drive0",
    "name": "bitmap0"
  }
}
```

Block Dirty Bitmaps - Querying

(Who are you? Who who, who who?)

Bitmap data can be retrieved via block-query.

```
{"execute": "query-block", "arguments": {}}

{"return": [{ …
  “device”: “drive0”,
  "dirty-bitmaps": [{
     "status": "active",
     "count": 296704,
     "name": "bitmap0",
     "granularity": 65536 }]
… }]}
```

Block Dirty Bitmaps - Querying

(Who are you? Who who, who who?)

Bitmap data can be retrieved via block-query.

```
{"execute": "query-block", "arguments": {}}

{"return": [{ …
  “device”: “drive0”,
  "dirty-bitmaps": [{
     "status": "active",       (or “frozen”!)
     "count": 296704,
     "name": "bitmap0",
     "granularity": 65536 }]
… }]}
```

Block Dirty Bitmaps - Querying

(Who are you? Who who, who who?)

Bitmap data can be retrieved via block-query.

```
{"execute": "query-block", "arguments": {}}

{"return": [{ …
  “device”: “drive0”,
  "dirty-bitmaps": [{
     "status": "active",
     "count": 296704,          (sectors!)
     "name": "bitmap0",
     "granularity": 65536 }]  (2318 clusters)
… }]}
```

Building Cognitive Dissonance

(Problem Statement 2: Electric Boogaloo)

- QMP commands are not particularly useful alone
  - They are not atomic
  - Only “safe” when VM is offline
  - No cross-drive coherence guarantee

Incremental Transactions

(Dissonance abated!)

- Bitmap management transactions allow us to—
  - Create full backups alongside a bitmap reset
  - Create a full backup alongside a new bitmap
  - Reset bitmaps across multiple drives
  - Issue a number of incremental backups across multiple drives

Incremental Transactions

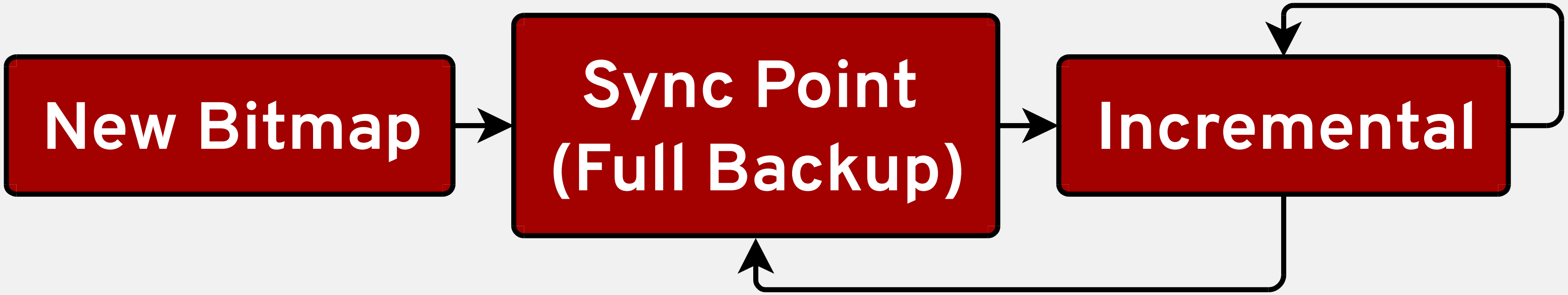
(Dissonance abated!)

- Supported transaction actions:
  - `type:block-dirty-bitmap-add`
  - `type:block-dirty-bitmap-clear`
- No transaction needed for remove
- Works in conjunction with `type:drive-backup`
  - For incrementals (multi-drive coherency)
  - For full backups
    - new incremental chains / sync points

ACT II: LIFE CYCLE

(In which our heroes save time and money)

Incrementals – Life Cycle



1) Create a new backup chain, or

2) Synchronize an existing backup chain

3) Create the first incremental backup

4) Create subsequent incremental backups

Life Cycle – New Chain

(There and backup again)

Example 1: Start a new backup chain atomically

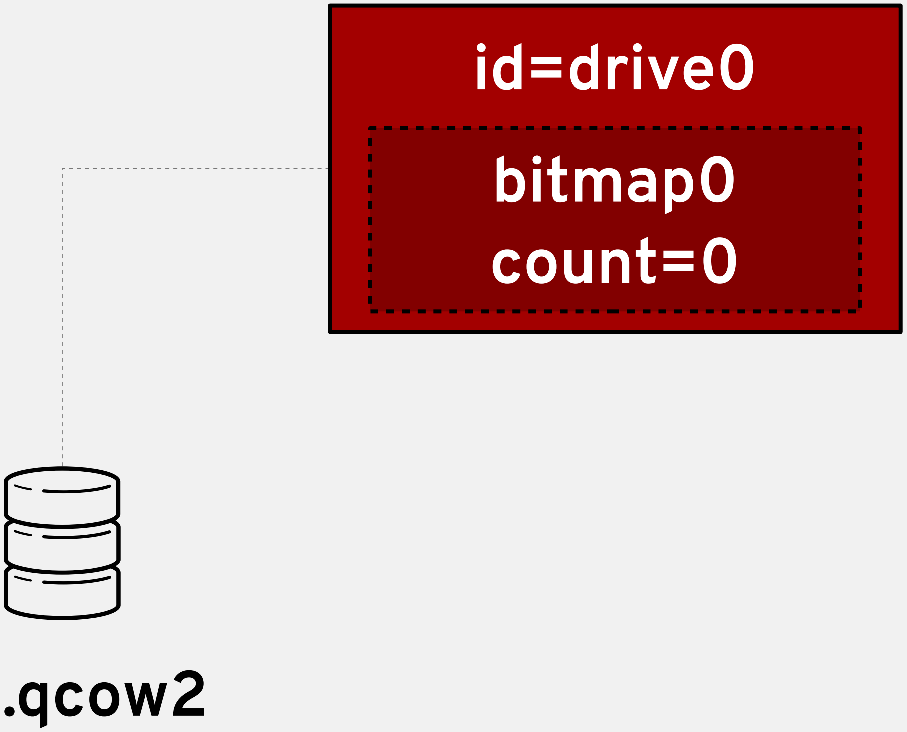
```
{ "execute": "transaction",
  "arguments": {
    "actions": [
      {"type": "block-dirty-bitmap-add",
       "data": {"node": "drive0", "name": "bitmap0"} },
      {"type": "drive-backup",
       "data": {"device": "drive0",
                "target": "/path/to/full.qcow2",
                "sync": "full", "format": "qcow2"} }
    ]
  }
}
```

Life Cycle – New Chain

(There and backup again)

Life Cycle – New Chain

(There and backup again)



Life Cycle – New Sync Point

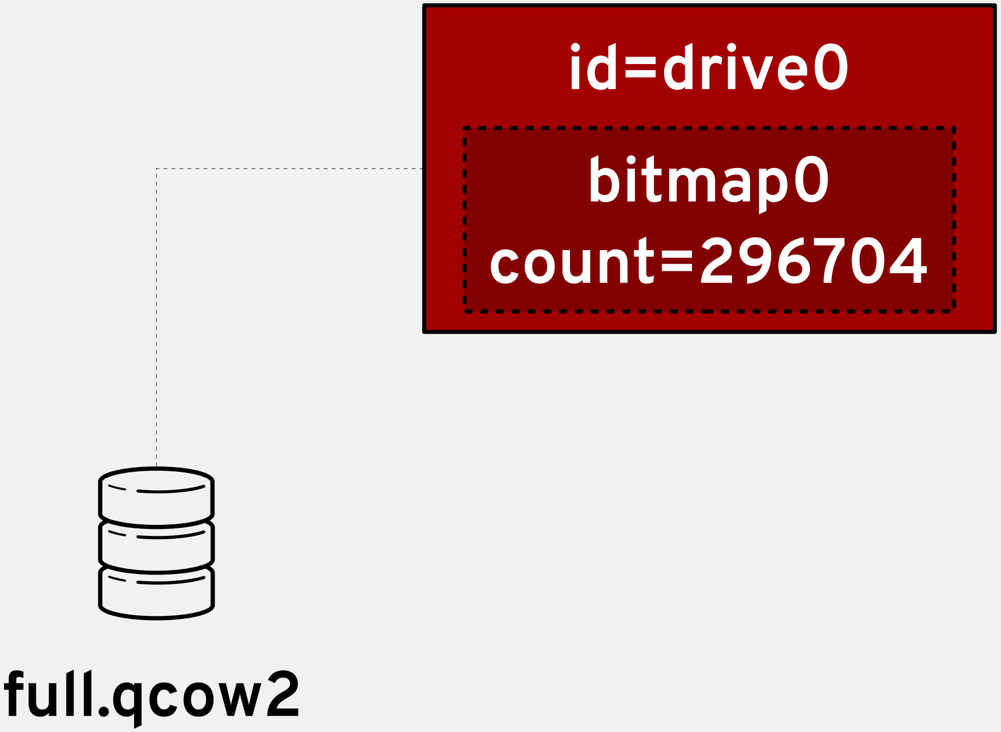
(Sunday night maintenance blues)

Example 2: Take an existing bitmap and create a new full backup as a synchronization point.

```
{ "execute": "transaction",
  "arguments": {
    "actions": [
      {"type": "block-dirty-bitmap-clear",
       "data": {"node": "drive0", "name": "bitmap0"} },
      {"type": "drive-backup",
       "data": {"device": "drive0",
                "target": "/path/to/new_full_backup.qcow2",
                "sync": "full", "format": "qcow2"} }
    ]
  }
}
```

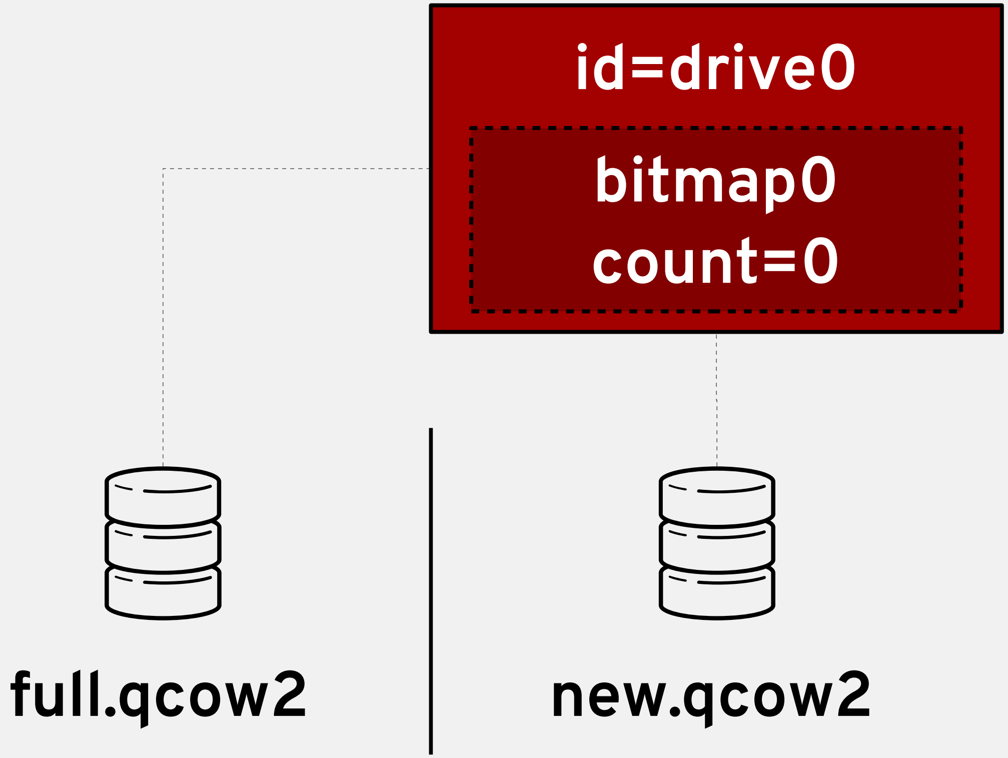
Life Cycle – New Sync Point

(Sunday night maintenance blues)



Life Cycle – New Sync Point

(Sunday night maintenance blues)



id=drive0

bitmap0

count=0

full.qcow2

new.qcow2

Life Cycle – First Incremental

(The first step of our journey)

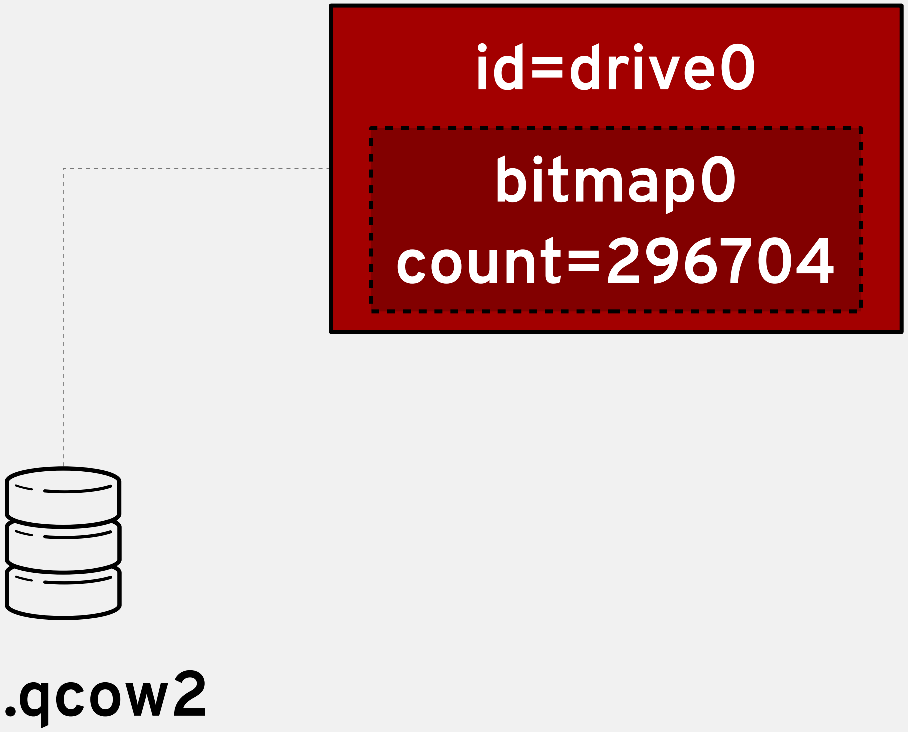
Example 3: Create an incremental backup. Can be done via transaction or single QMP command.

```
# qemu-img create -f qcow2 inc.0.qcow2 -b full.qcow2 -F qcow2
```

```
{ "execute": "drive-backup",
  "arguments": {
    "device": "drive0",
    "bitmap": "bitmap0",
    "target": "inc.0.qcow2",
    "format": "qcow2",
    "sync": "incremental",
    "mode": "existing"
  }
}
```

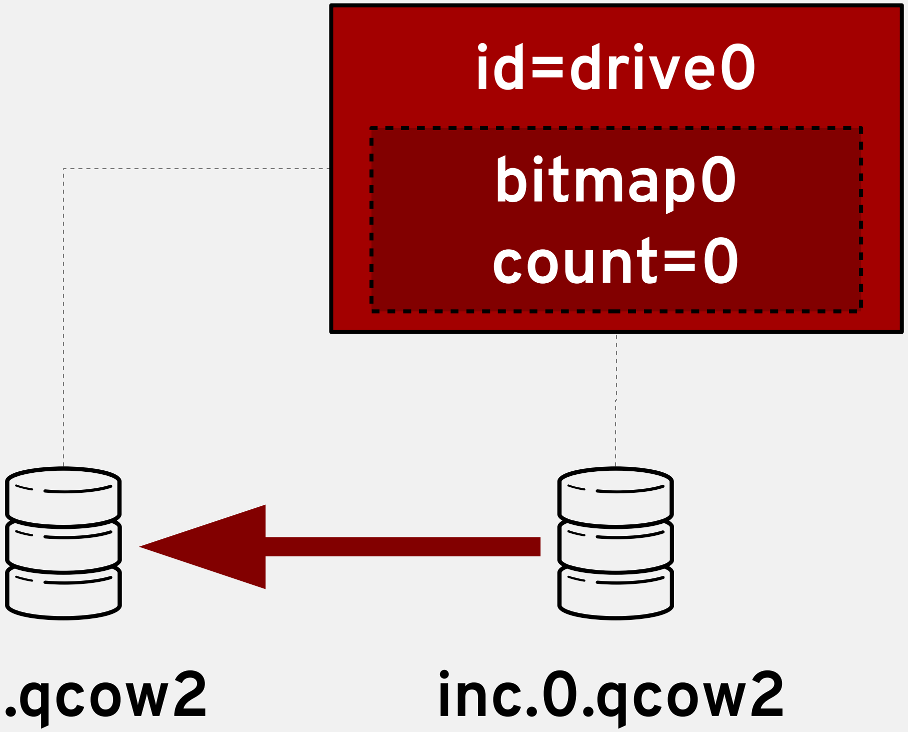
Life Cycle – First Incremental

(The first step of our journey)



Life Cycle – First Incremental

(The first step of our journey)



Life Cycle – Subsequent Backups

(To infinity, and beyond!)

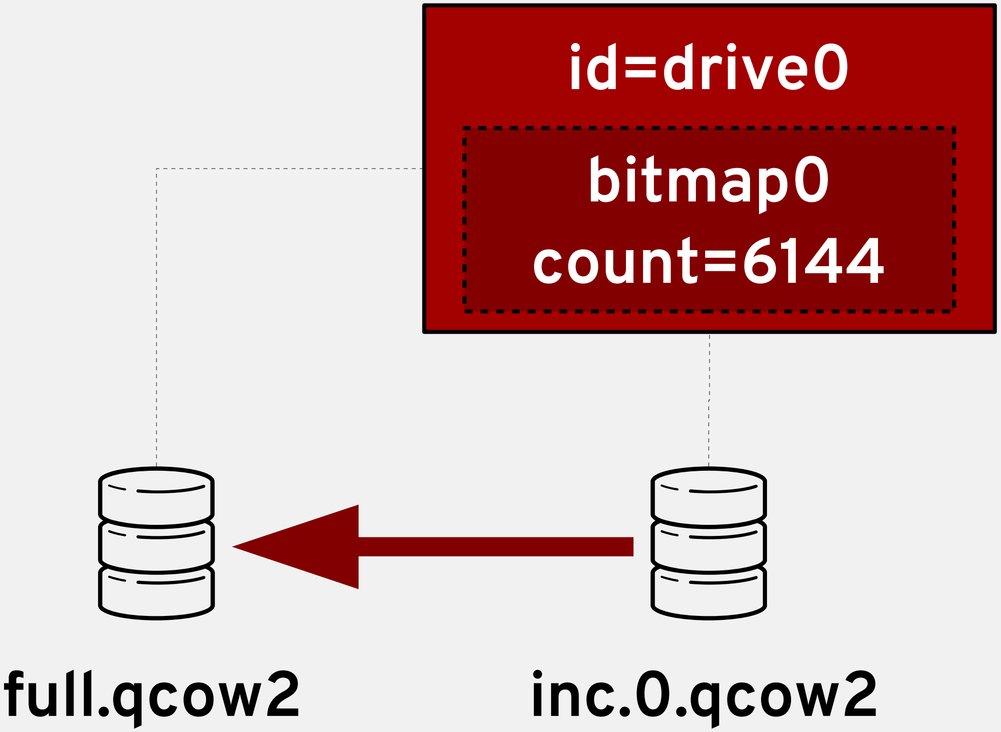
Examples [4,∞): Create subsequent incrementals.

```
# qemu-img create -f qcow2 inc.<n>.qcow2 -b inc.<n-1>.qcow2 -F qcow2
```

```
{ "execute": "drive-backup",
  "arguments": {
    "device": "drive0",
    "bitmap": "bitmap0",
    "target": "inc.<n>.qcow2",
    "format": "qcow2",
    "sync": "incremental",
    "mode": "existing"
  }
}
```

Life Cycle – Subsequent Backups

(To infinity, and beyond!)



id=drive0

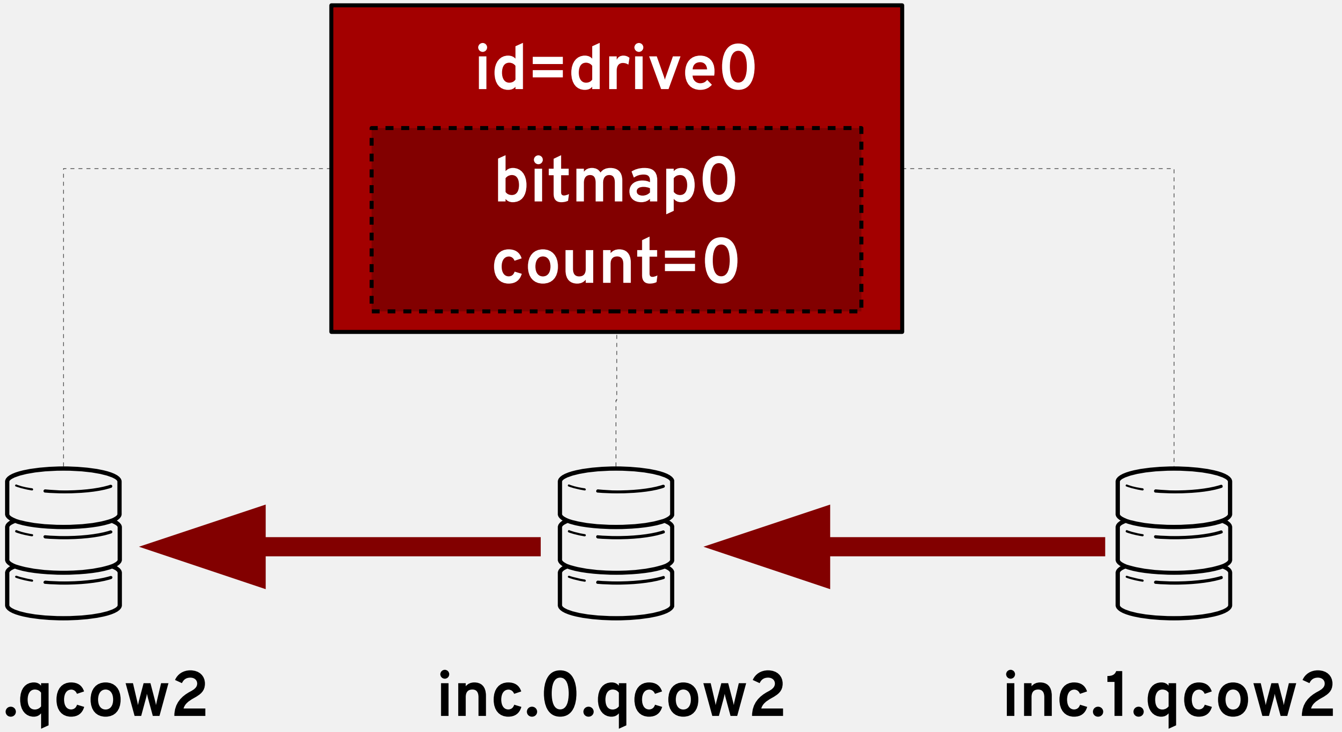
bitmap0
count=6144

full.qcow2

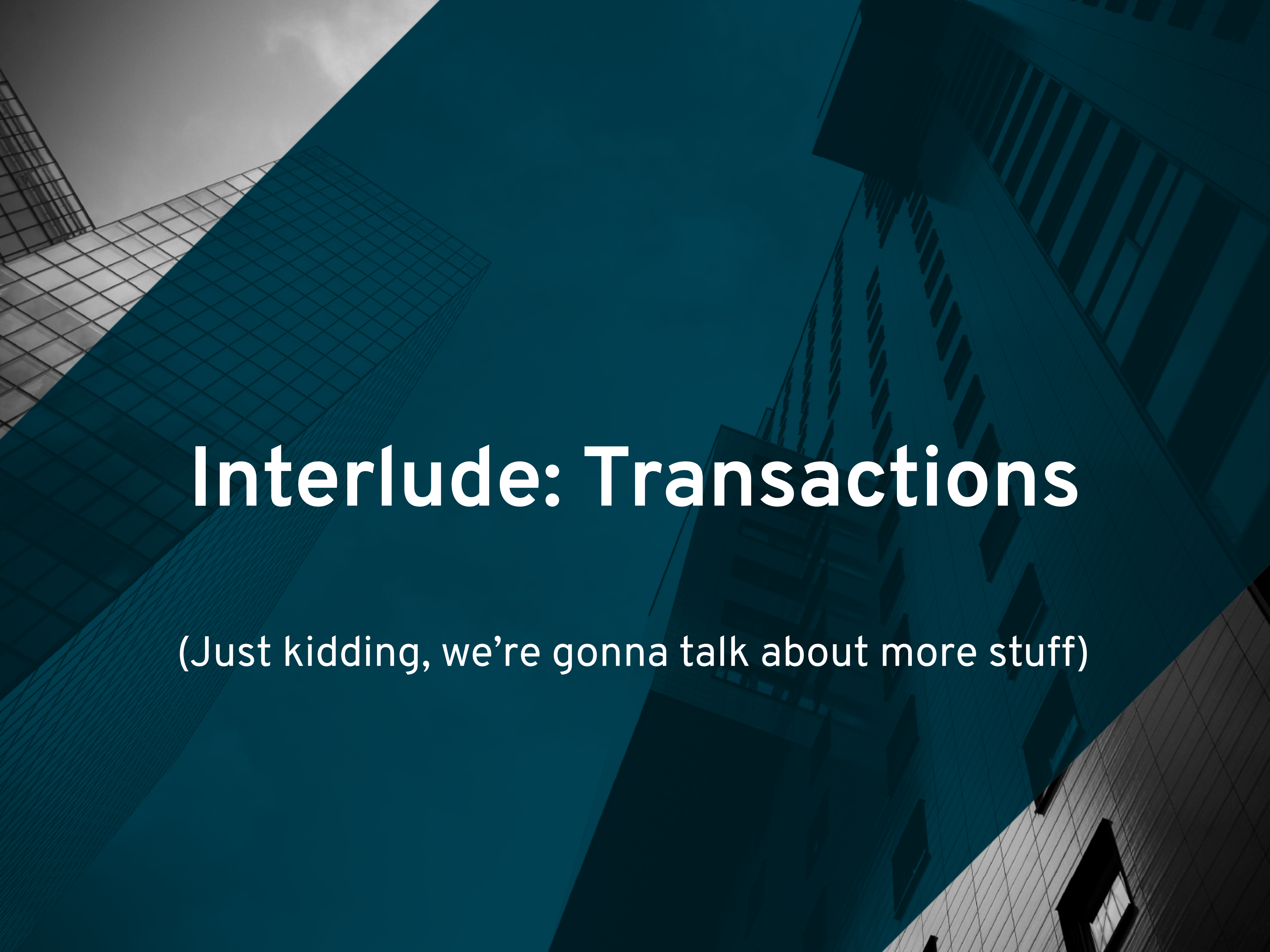
inc.0.qcow2

Life Cycle – Subsequent Backups

(To infinity, and beyond!)



Interlude



Interlude: Transactions

(Just kidding, we’re gonna talk about more stuff)

Explainer: Block Jobs

(Jobs & The Economy: Redux)

- What are jobs? (ha ha ha)
  - QMP commands are synchronous
  - QMP socket blocks on each command
  - So what about long-running commands?
- BlockJobs: Asynchronous task API
  - Allows management via further QMP commands
  - For more info: See literally* any talk from KVM Forum 2016

*figuratively

Transactions - detail

(In case you forgot? Sorry, there’s a lot of stuff.)

Transactions:

- Allow batching of certain QMP commands
- Each individual item is an “action”
- Transaction succeeds only if all actions do
- Some actions/commands launch jobs
- Some do not.
- Wow, I hope that doesn’t cause any problems.

(Of course it did.)

Transactions X Jobs

(Transaction Interaction Intersection)

How do job-actions work?

- Before 2.5:
  - Action succeeds if job is *started*
  - Jobs failing later have no effect on other jobs
  - Some backups succeed, some fail
  - `completion_mode=individual`

Transactions X Jobs

(Transaction Interaction Intersection)

How do job-actions work?

- After 2.5, with `completion_mode=grouped` …
  - Action succeeds if job is started
    - No change from ‘individual’ mode
  - Jobs cannot complete until **all** jobs ready to
  - One job will cause all others to fail
- Clients can avoid keeping state on partial failures

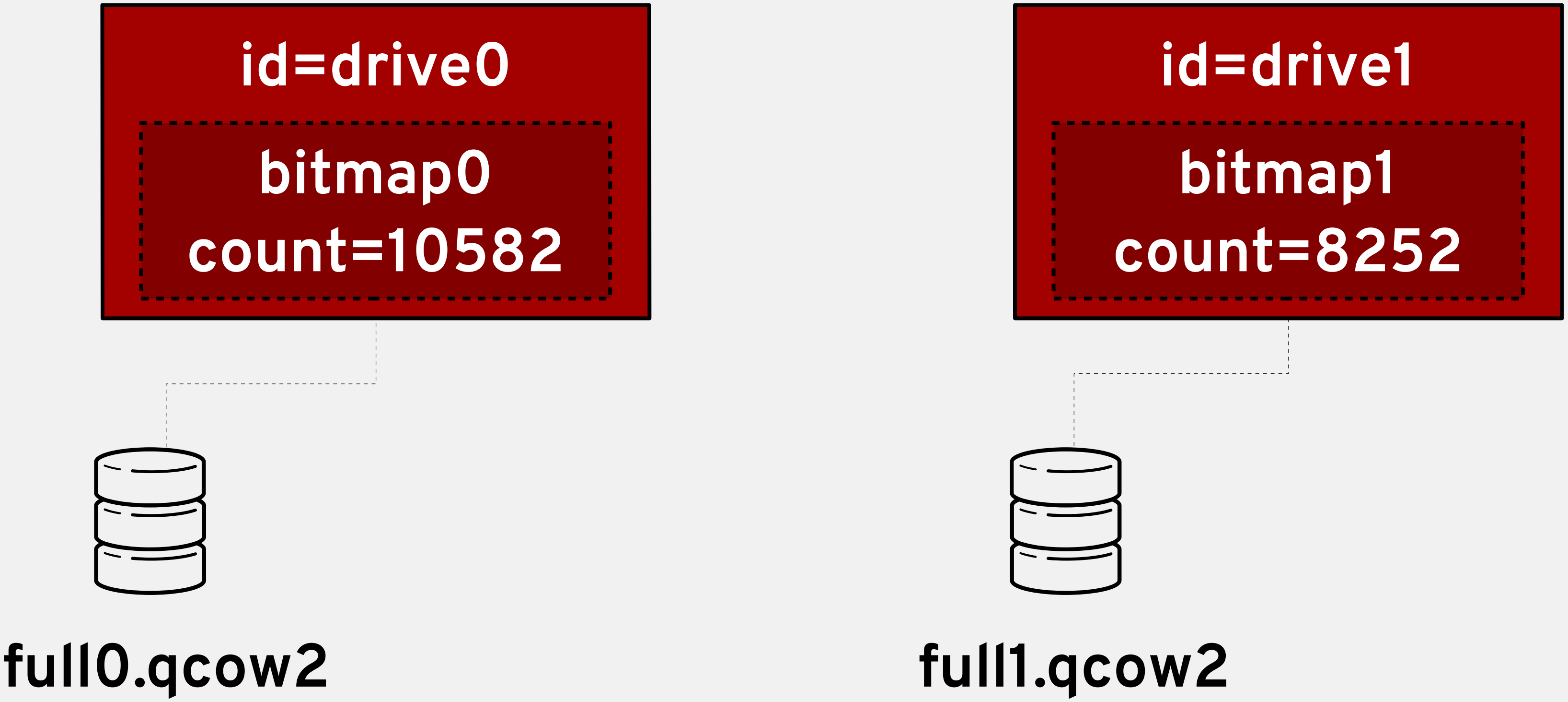
Multidrive Coherency

(Transaction actions in action (not to be confused with inaction))

```
{ "execute": "transaction",
  "arguments": {
    "actions": [
      { "type": "drive-backup",
        "data": { "device": "drive0", "bitmap": "bitmap0",
                  "format": "qcow2", "mode": "existing",
                  "sync": "incremental",
                  "target": "inc0.a.qcow2" } },
      { "type": "drive-backup",
        "data": { "device": "drive1", "bitmap": "bitmap1",
                  "format": "qcow2", "mode": "existing",
                  "sync": "incremental",
                  "target": "inc1.a.qcow2" } },
    ]
  }
}
```

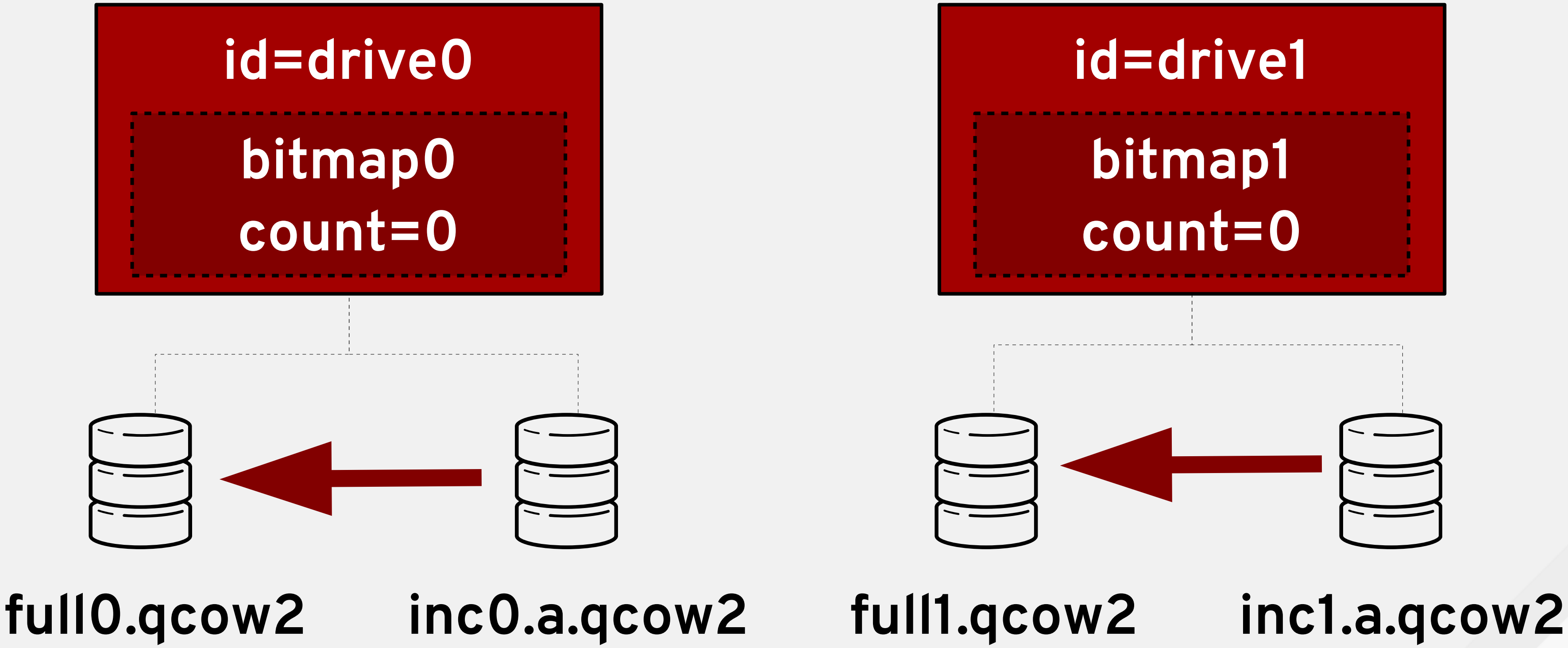
Multidrive Coherency

(Twice as nice!)



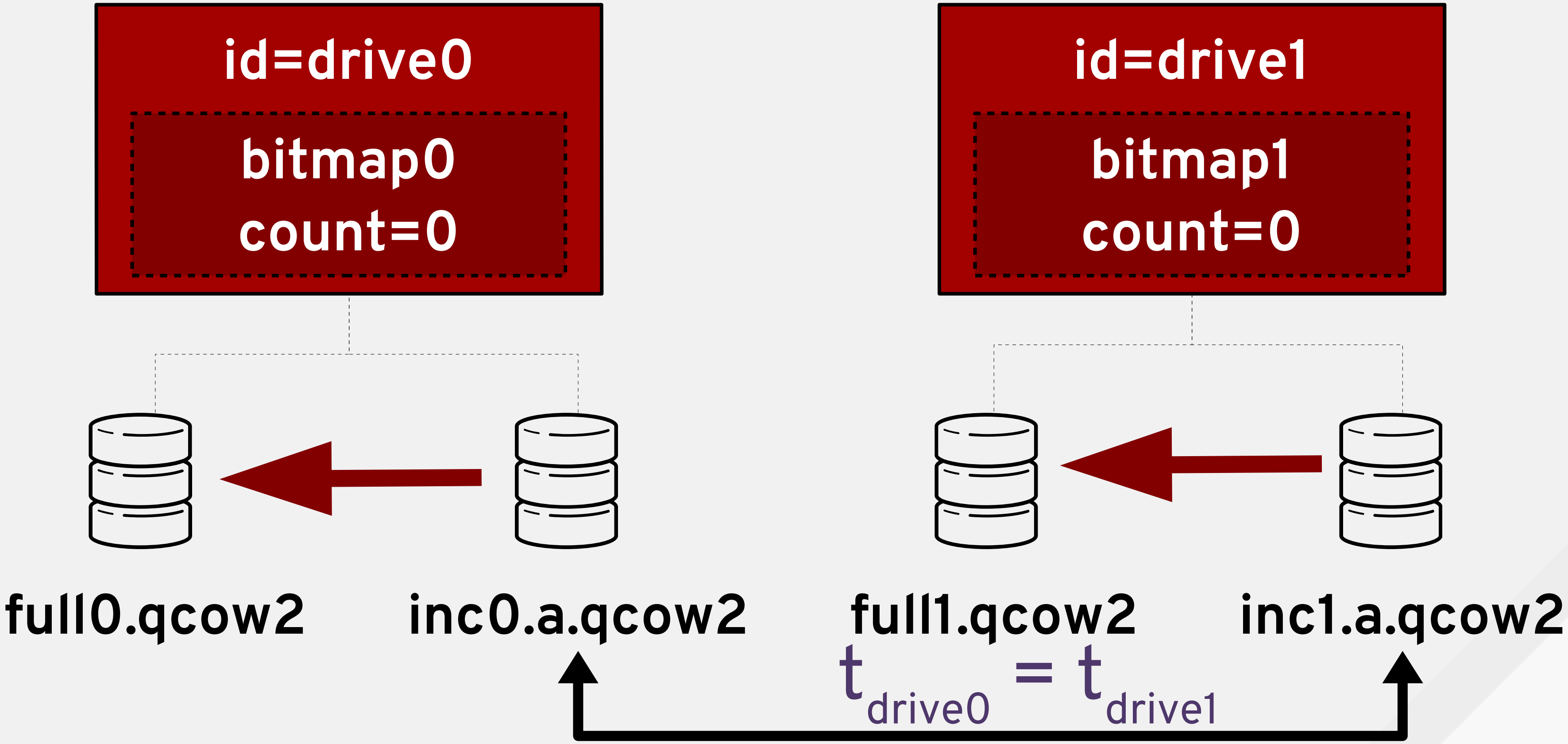
Multidrive Coherency

(Thrice as nice?)



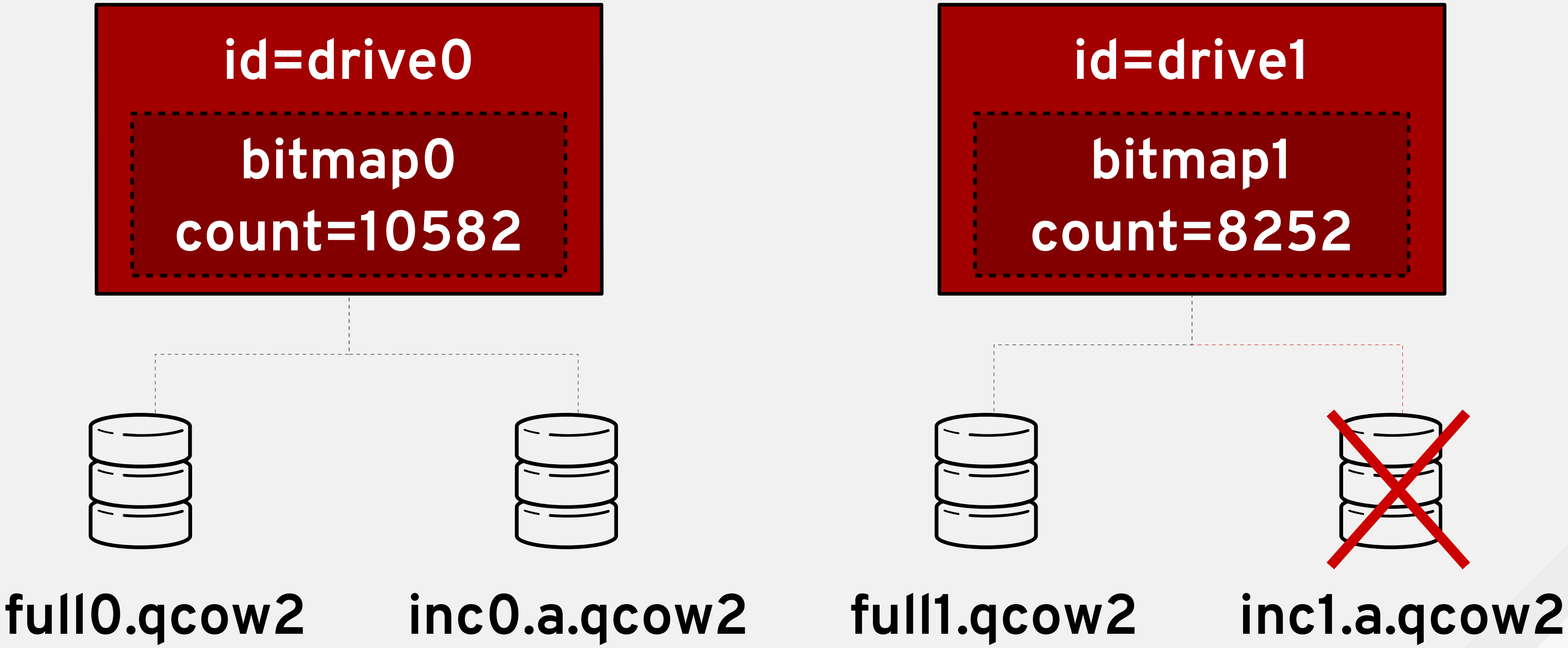
Multidrive Coherency

(...frice?)



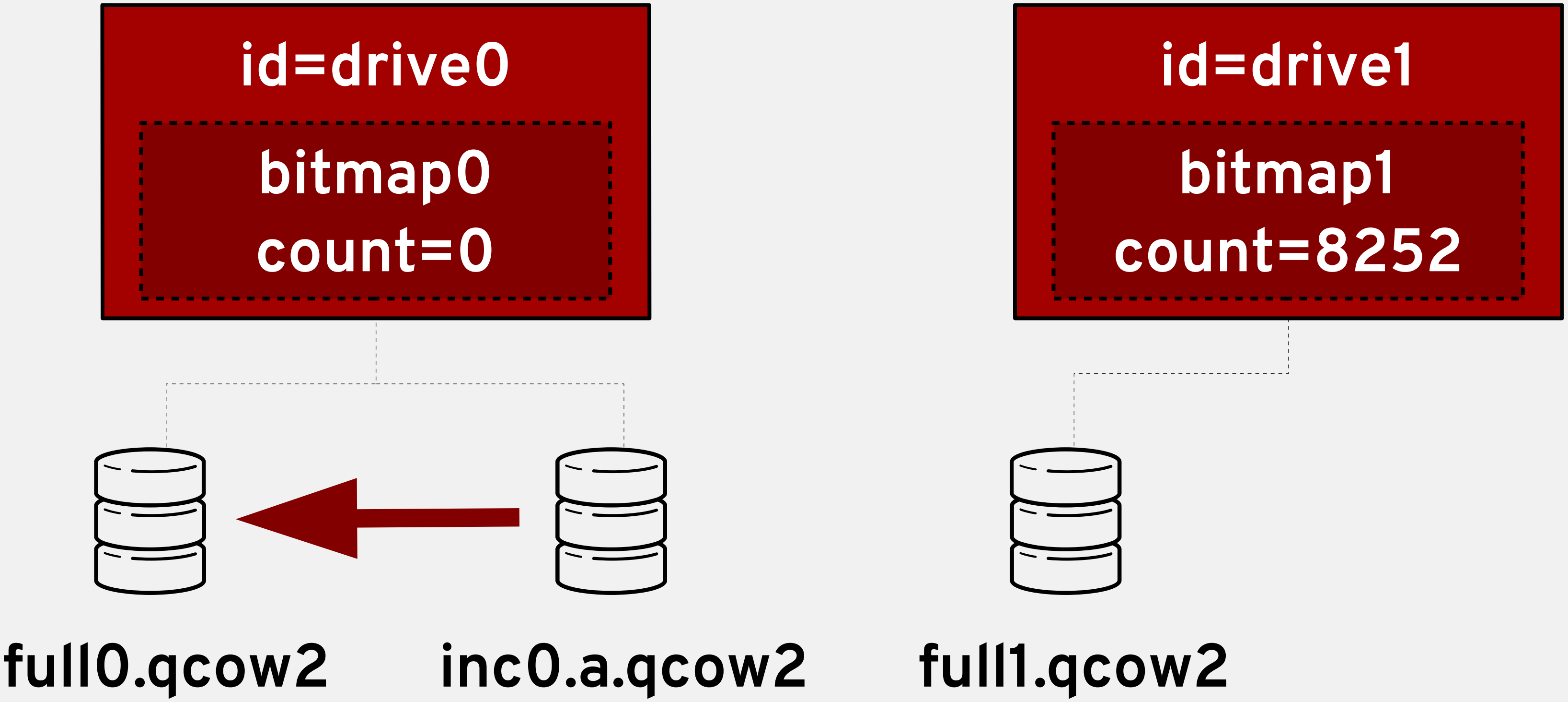
Partial Failures, Individual

(Not *my* problem)



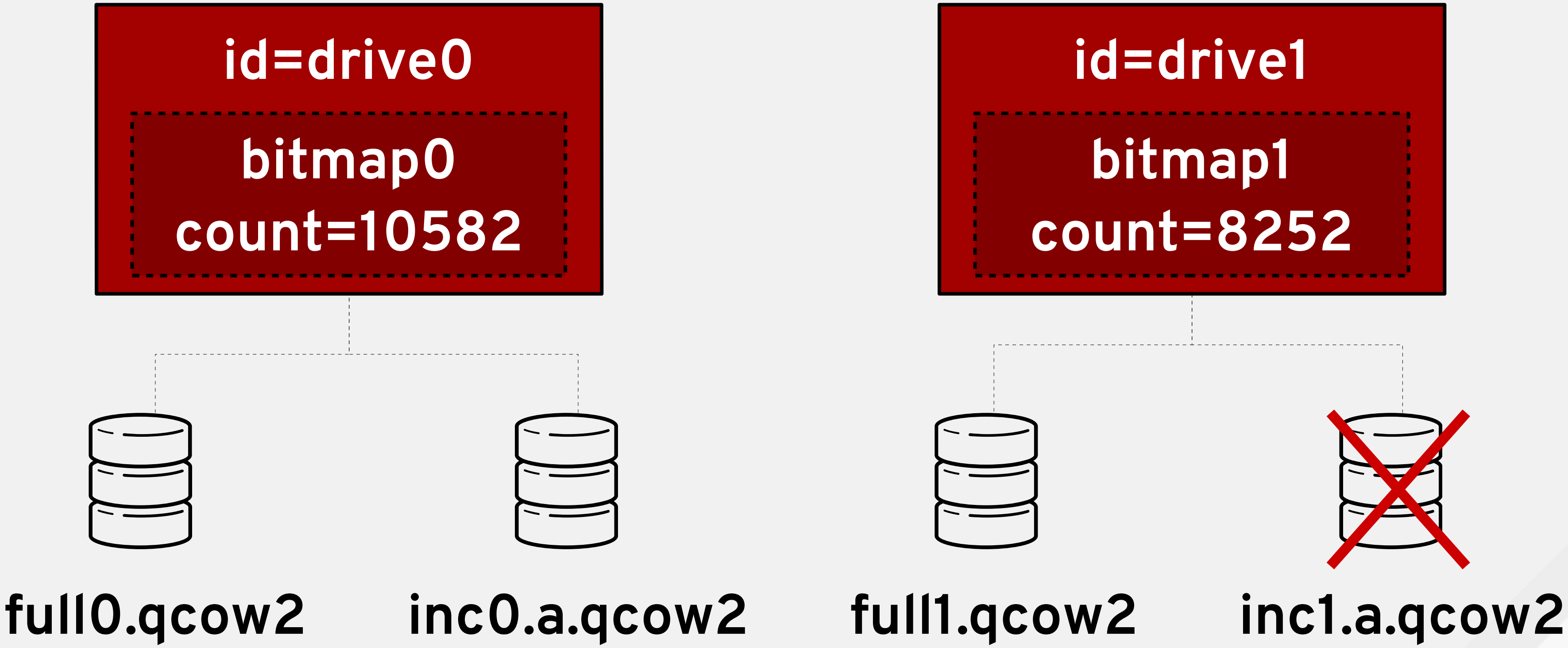
Partial Failures, Individual

(Not *my* problem)



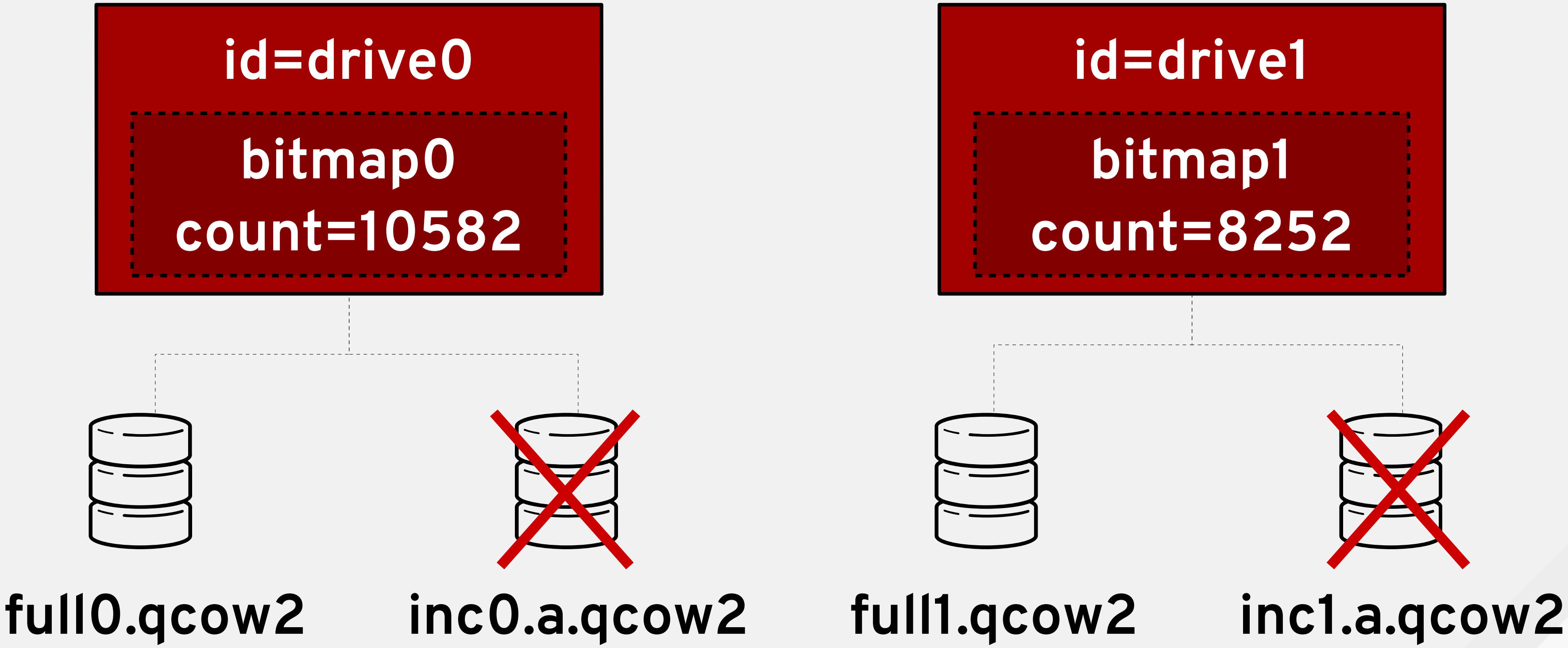
Partial Failures, Grouped

(Stronger together?)



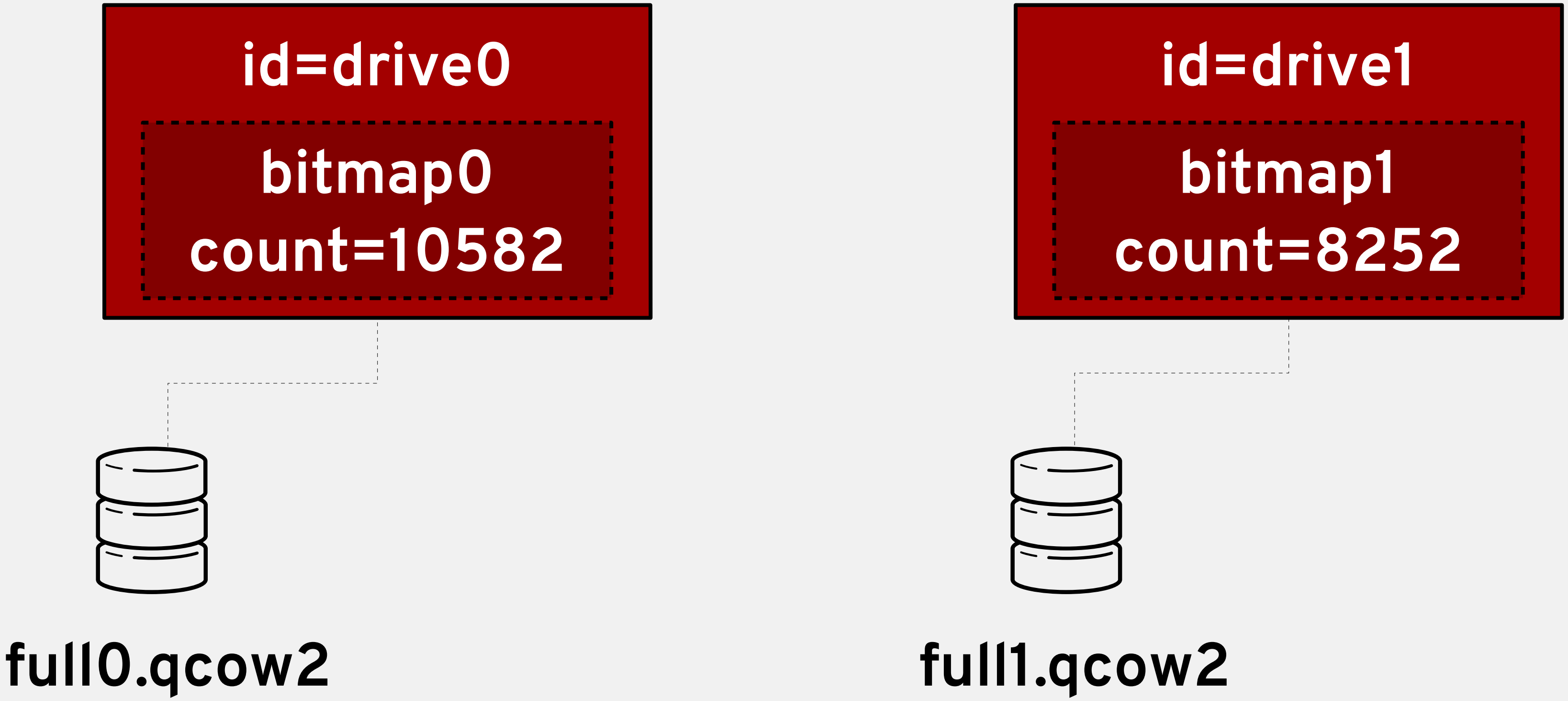
Partial Failures, Grouped

(Stronger together?)



Partial Failures, Grouped

(Stronger together?)



ACT III: ADVANCED FEATURES

(In which our heroes *rise above*)

Bitmap Migration - 1st attempt

(Pack your data, we're moving to <target>)

- Mechanism similar to disk migration
- Data split into chunks (1KiB)
  - Bitmaps serialized piece-by-piece
- For sets of bitmaps below 1MiB...
  - Skip the live phase and copy the data wholesale.
  - 64GiB disk bitmap is only 128KiB
    - (+node and bitmap names, and stream metadata)

Bitmap Migration - 1st attempt

(Pack your data, we're moving to <target>)

- Bitmaps not transferred alongside data
  - Transferred separately for flexibility
- “meta bitmaps” (*dirty “dirty bitmap” bitmaps!?*)
  - Captures changes during live migration
  - Pieces can be resent if needed.
  - Uses *very little* memory: 64GiB → 16 bytes

Bitmap Migration - 2^{nd} attempt

(We’re on the road again…)

- 1^{st} approach worsens convergence problem
  - May not scale well
- New approach uses a post-copy technique
  - Simply send the whole bitmap post-pivot
  - Record new writes on target
    - Prohibit backups until data arrives
    - Re-merge bitmaps on target

Bitmap Migration - Failures

(Mission Failed! We’ll get ‘em next time.)

What happens if the source dies post-pivot?

- Considered non-critical loss
- Bitmap chains can be re-started
- Future:
  - Reconstruct bitmap from two images?
- Other Options:
  - Use shared-storage migration
    - With persistence <stay tuned>

Bitmap Persistence – Change of Plans

(I have altered the code. Pray I do not alter it further.)

- Plans *were* for a format-agnostic format
  - Using qcow2 to store bitmaps for arbitrary files
  - Plans scrapped…
- Now, we're targeting qcow2
  - More on other formats in a bit…!

Bitmap Persistence

(Object permanence: not just for toddlers)

- Persistence targets the qcow2 format.
  - Multiple bitmaps can be stored per-file
  - Bitmaps have ‘types,’ we use a ‘dirty’ bitmap
  - Bitmaps can ‘autoload’ in QEMU
  - Spec amendment is merged!
  - Patches ready on-list from Virtuozzo

Bitmap Persistence – Non qcow2

(AKA, “Can I please use this with raw?”)

- We have some options for other formats.
- Some formats may add primary support
  - Virtuozzo has expressed interest for parallels
- Qcow2 with write-forwarding backing files?
  - Instead of read-only
  - Offer to forward writes
  - Allow for any format
  - Other benefits

“Push Model” backups

(Let’s take all our problems… and push them somewhere else!)

Backups described so far are “Push” model:

- QEMU “pushes” the data to a target
- It knows what sectors need to be pushed
- This works out pretty OK, but…
  - Some vendors wanted a different model

“Pull Model” backups

(sometimes it’s nice when doors work both ways)

The “Pull model” is different:

- QEMU offers a temporary, lightweight snapshot
  - “Image Fleecing”
  - Exported via NBD
- Via NBD extensions, client queries for status
- Client controls data flow
- Snapshot is deleted on close

“Pull Model” backups

(sometimes it’s nice when doors work both ways)

- Snapshot view is point-in-time
  - (like push model)
- Requires on-disk cache
- Offers full control on what is copied
  - How the data is stored is decided by the client
  - Most “QEMU-agnostic” method
- Only way to query dirty blocks

TODOs

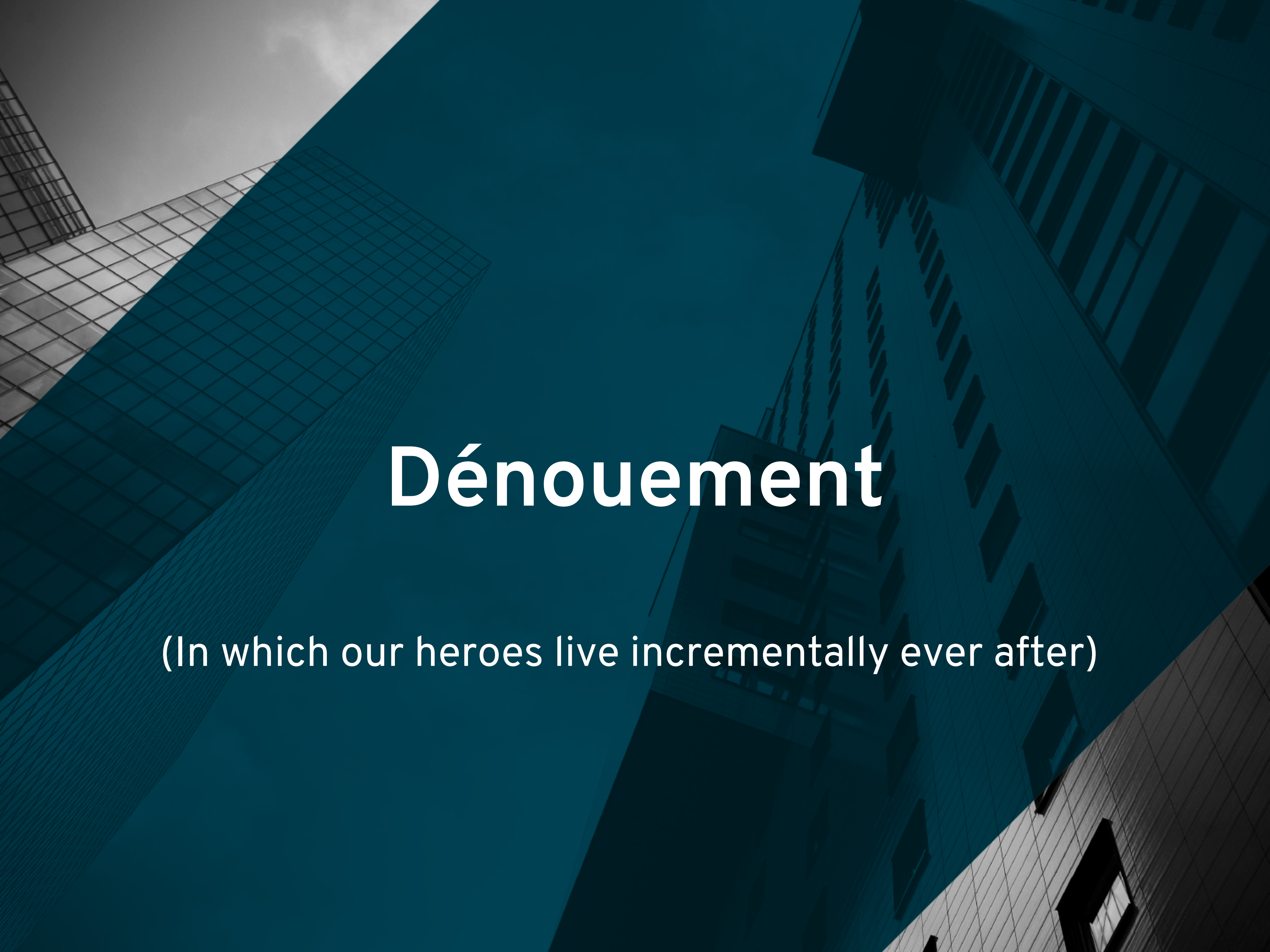
(<TODO: insert cheeky joke>)

- QMP interface for “pull” model
- QMP interface for modifying persistence attributes
- CLI tools for verification, analysis
  - Deletion/cleaning tools
  - “Offline” incremental backup support?
- “fsck support”
  - qemu-img check -r (?)

TODOs

(<TODO: insert cheeky joke>)

- Data integrity
  - Periodic/opportunistic flushing
- **GSOC / Outreachy 2017:**
  - Reference implementation
  - CLI backup tool
  - Python?
  - Keep your eyes peeled:
  - http://wiki.qemu.org/Google_Summer_of_Code_2017



Dénouement

(In which our heroes live incrementally ever after)

Project Status

(When do we get to use it!?)

• block-dirty-bitmap QMP interface	• Merged! (2.4)
• sync=incremental mode (*push)*	• Merged! (2.4)
• Transactions	• Merged! (2.5)
• Qcow2 Persistence (Spec)	• Merged! (2.6)
• Grouped Transactions	• Merged! (2.8)
• Migration	• Review, (2.9)
• Persistence	• Review, (2.9)
• Pull model	• Specs, (2.10+)

Questions?

Further Reading:

QEMU project wiki:
    http://qemu-project.org/Main_Page
Bitmaps Documentation:
    .../qemu/docs/bitmaps.md
QEMU iotests:
    .../qemu/tests/qemu-iotests/124
Project status whitepaper (PDF):
    http://goo.gl/tT6n8S
KVM Forum 2016 ‘jobs’ talk:
http://events.linuxfoundation.org/sites/events/files/slides/kvm2016_v16.pdf

THANK YOU!

More questions?
jsnow@redhat.com
cc: qemu-devel@nongnu.org