Thin-provisioned disks with QEMU and KVM

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QEMU vs. KVM

- QEMU is where the cool stuff happens
  - Fast paravirtualized hardware (virtio)
  - Virtual machine lifecycle (including migration)
  - Storage stack
- kvm.ko lets you use QEMU for virtualization
  - Narrow-scoped, mature code
  - Also cool :)
- This talk will be about QEMU

Outline

- Thin provisioning concepts
- What was there
- Requirements
- Designing a thin-provisioning API
- Future work

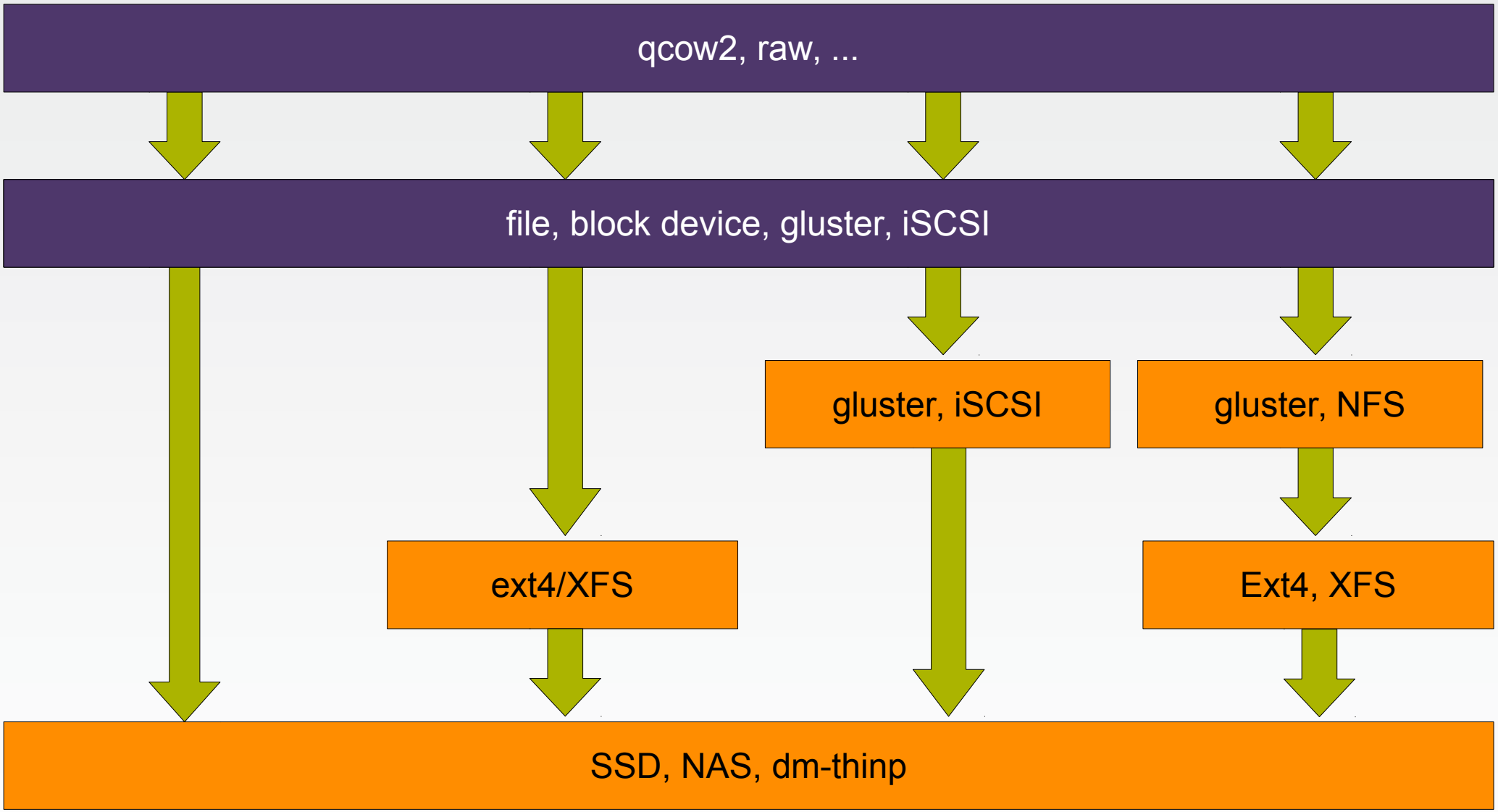
Thin provisioning concepts

- A disk is made of many blocks
- The user tells the disks how it's using them
- The disk can be used more efficiently
  - Speed and durability gains for SSDs
  - Oversubscription of networked storage
  - Efficient maintenance operations
- Better name (from SCSI standard): “Logical block provisioning”

Thin provisioning and virtualization

- The advantages extend to virtualization
  - Can be applied to any storage backend
  - “Software-defined storage” before it became cool
- The user is the guest administrator
  - Only pay for actually used space
  - Guest disks can be overprovisioned
- Host admin saves disk space

Multiple storage layers



What was there

- Lazy allocation of blocks
- Differential disks (copy-on-write)
- High-level watermark: management can query the highest sector in use
- QEMU-specific formats: qcow, qcow2
- Foreign formats: cow, vdi, vmdk, vpc, vhdx, ...

What was missing

- Could not reclaim space at the host level
  - Blocks will never be discarded once written
- No support for “raw” block devices or files
  - Mandatory performance cost from additional layers
  - Cannot unify management for physical and virtual machines

Objectives (host)

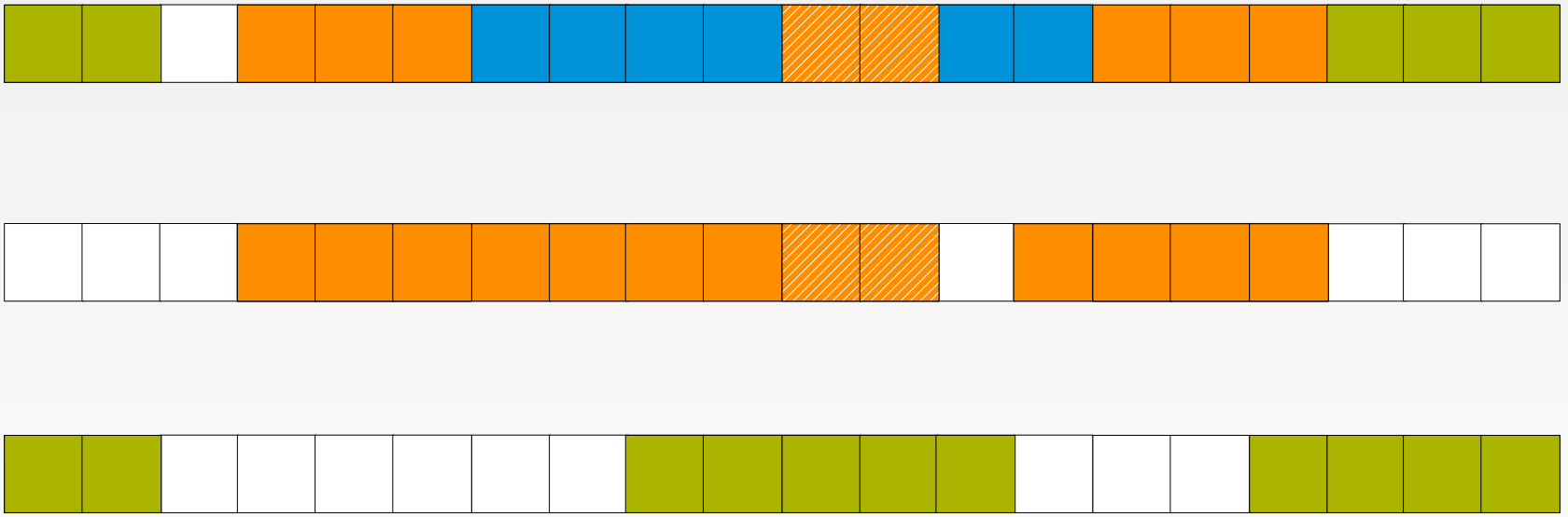
- Support a wide range of backends
- Maintenance operations should be faster thanks to hints from the guest
- Maintenance operations should have access to all the capabilities of the backend

Example: maintenance operations (1)

- Raw block devices may be nonzero when they are assigned to a VM
- Expensive scrubbing required when a virtual disk is created
  - BLKZEROOUT can offload this to the storage
  - The disk can optimize the operation (e.g. won't scrub all the way down to the platters)

Example: maintenance operations (2)

- Data copied from backing file for faster access



Objectives (guest)

- virtio-blk support not required
  - Use SCSI commands with virtio-scsi
  - Accurate implementation of SCSI commands
- Changing the host backend should not modify the guest hardware
- Guests should have access to most capabilities of the backend

SCSI logical block provisioning

- Three types of disks
  - ~~Fully-provisioned~~
  - Thin-provisioned
  - Resource-provisioned

  } Logical block management enabled

- Three types of blocks
  - Deallocated
  - Anchored
  - Mapped

  } On disk space allocated

  } Block not in use

SCSI logical block provisioning

VPD page 0xb2

- LBPU: UNMAP command supported
- LBPWS/LBPWS10: unmap with WRITE SAME
- LBPRZ: “unmapped” blocks read zero
- ANC_SUP: ANCHOR supported

UNMAP

Bit / Byte	7	6	5	4	3	2	1	0
1								ANCHOR

WRITE SAME

Bit / Byte	7	6	5	4	3	2	1	0
1				ANCHOR	UNMAP			

GET LBA STATUS

SCSI logical block provisioning commands

- UNMAP: unmap aligned group of sectors
  - Granularity also available in VPD
- WRITE SAME: write the same block to a consecutive group of sectors
  - No alignment considerations
  - Without UNMAP: just write them
  - With UNMAP: can also unmap, as long as sectors read back to the given payload

SCSI logical block provisioning and Linux

- Can use either UNMAP, or WRITE SAME with UNMAP bit set
  - UNMAP preferred if both available
  - Can be tweaked from sysfs
- GET LBA STATUS: not directly accessible
  - lseek(fd, ..., SEEK_HOLE/DATA) could do it
- ANCHOR: not supported
- WRITE SAME without UNMAP: only supported with zero payload (BLKZEROOUT ioctl)

Guest interface limitations

- Host will notnecessarily zero discarded sectors
  - LBPRZ must not change when changing storage backend
  - Choice 1: if host cannot discard-and-zero, never discard sectors and just write out zeroes
  - Choice 2: guest must default to LBPRZ=0
- Choice 1 not plausible, kills thin provisioning
- Can still detect WRITE SAME + UNMAP + zero payload and optimize it

Guest interface limitations

- Discard not always desirable
  - May want to keep files preallocated (for performance)
  - Avoid too much fragmentation
- Disable it by default
  - Enable it with QEMU “-drive ...,discard=on” or equivalent libvirt XML
  - SCSI commands will remain available but do nothing
  - Permitted by SCSI spec with LBPRZ=0

Layers & APIs

Guest	ATA: Trim SCSI: Unmap, Write Same, Get Block Status
QEMU	discard, get_block_status, write_zeroes, get_info
Network	Gluster: discard, zerofill iSCSI: Unmap, Write Same, Get Block Status, LBPRZ
Linux	File system: fallocate, FIEMAP, xfsctl Block device: BLKDISCARD, BLKZEROOUT, BLKDISCARDZEROES
Storage	ATA: Trim SCSI: Unmap, Write Same, Get Block Status, LBPRZ

QEMU APIs: discard

- Discards a range of sectors (or an aligned subset of it)
- No-op unless the “discard=on” option was passed
- Users: ATA and SCSI emulation

QEMU APIs: get_block_status

- Return metadata for a group of sectors
  - Are the sectors read from an older snapshot?
  - Are the sectors allocated in the backend?
  - Are the sectors known to be zero?
  - Where is the data stored in the backend?
- More powerful than SCSI Get Block Status
- Users: “qemu-img convert”, “qemu-img map”, image streaming/mirroring, SCSI emulation (not yet)

QEMU APIs: write_zeroes

- Resembles SCSI Write Same with zero payload
- BDRV_O_MAY_UNMAP flag available
  - Same as SCSI “UNMAP” bit
  - Only matters if discard=on
- Users: “qemu-img convert”, SCSI emulation

QEMU APIs: get_info

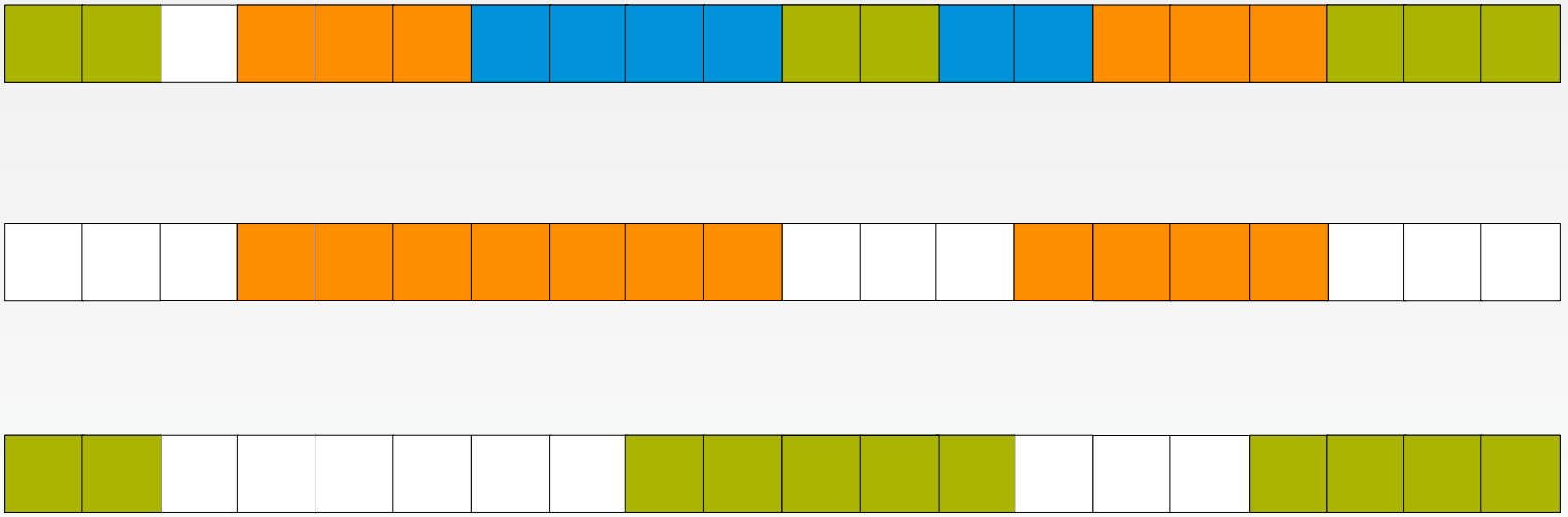
- unallocated_blocks_are_zero
  - “This block is unallocated, do I know it's zero?”
  - Same as LBPRZ
  - Used by generic get_block_status code
- can_write_zeroes_with_unmap
  - “Will write_zeroes+BDRV_O_MAY_UNMAP try to unmap some blocks?”
  - Same as LPBRZ && LPBWS

Future work

- Improved tuning of file formats
- More homogeneous functionality for backends
- Better support for preallocation

Tuning of file formats

- qcow2 currently lets backing file data through after discard



Homogeneous functionality for backends

	ext4	**XFS**	Blockdev	**iSCSI**	Gluster
Discard	Yes	**Yes**	Yes	**Yes**	Yes
Write zero	No	**Yes**	Yes	**Yes**	Yes
Discard+zero	Yes	**Yes**	Yes	**Yes**	No
Get status	Yes	**Yes**	No	**Yes**	No
Fast convert	Yes	**Yes**	Yes	**Yes**	No

Better support for preallocation

- Preallocation avoids performance problem of thin provisioning
- Three types of blocks
  - Deallocated
  - Anchored
  - Mapped

  Anchored, Mapped: On disk space allocated

  Deallocated: Block not in use
- Problem: limited support in Linux

Questions