How To Turn a Penguin Into a Dog

...or...
Things To Do That Will Avoid Linux on z Success

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Goals

Examine Linux on z historical roadmap

Learn from others’ hard-won experiences

Understand some things not to do—and why
1999: Linux released for (then) System/390
- IBM “skunkworks” effort
- Works, but not a “real” IBM product

2000: “41,000 Linux guests on a VM system”
- Proof-of-concept, no relation to reality
- Garnered tremendous press attention
- Vendors jump in: Linuxcare, Aduva, BMC…
2001–2006: z/Linux growth slow

- IBM pushes Linux on z hard (IFL loaners, etc.)
- Many failed pilots, ROI not realized in many cases
- zSeries CPUs not fast enough to compete with Intel
- Levanta (Linuxcare), BMC, Aduva(?) quit market
- Rocket enters with Linux Provisioning Expert
- IBM adds Director for z

The Dirty Little Secret:

An **untuned** penguin can be a **dog**!

- But they can be trained, with some tools and effort
2006–present: z/Linux starts to grow up

- New, faster processors (z9) make z competitive
- Nationwide, Wells Fargo, Citi, other “poster children” validate ROI

“Now it gets real…”

- ...and now performance must be tamed!
Mainframes have been around for a while...

- z/OS (OS/390, MVS/ESA, MVS/XA, MVS, MVT, MFT): 43 years (OS/360, 1964)
- z/VM (VM/ESA, VM/XA, VM/SP, VM/370, CP/67): 43 years (CP/40, 1964)
- z/TPF (TPF, ACP): 43 years (PARS, 1964)
- z/VSE (VSE/ESA, VSE/SP, DOS/VSE, DOS/VS): the youngster, 42 years (DOS/360, 1965)

We’re spoiled by decades of experience

- We expect that someone, somewhere has done it all
Linux is just sixteen years old

- Elderly in penguin years…
- …still immature as an OS

Only seven years of mainframe Linux

- Adult in dog or penguin years…
- Progress made, but many apps still *not* well-behaved!

*z/Linux* tuning and capacity planning still largely unknown territory to many

- Each new kernel level offers new opportunities (and old opportunities return with kernel changes!)
Still a Brave New World

Nobody really knows all the answers yet

- This is like tuning MVS circa 1980
- …or maybe more like tuning VM/370 circa 1975

Not a reason to avoid Linux!

- Just something to keep awareness of
- You **cannot** believe everything you hear, good or bad
Linux Success Requirements

Management buy-in and distributed support group support

- Without both of these, either:
  - Management won’t care about success
  - Distributed folks will protect their turf and torpedo you
- Management can force distributed folks’ support

Appropriate application choices

- No fractal reductions, SETI@home
- Java OK in moderation (many apps are evil, though)
- VMware has similar constraints (plus no memory overcommitment)
More Success Requirements

A willingness to say “I was wrong”
- Some applications may turn out to be poor choices
- Some tuning choices will have the opposite effect
  - Requires a political climate that lets you say so

Monitoring, tuning, and capacity planning
- IYDMIWGS*
- Many Linux apps are not well-behaved, mature!
- Must make correct tuning choices

* If You Don’t Measure It You Will Get Screwed
Reasons Linux POCs Fail

Lack of management buy-in leading to distributed group non-support
- “They just didn’t show up for the meetings”

Inappropriate application choices
- “The application we chose just didn’t perform”
- “Management lost patience”

Disappointed by performance
- Without tools, no way to understand
- “There is no think, only do” — Master Yoda
Inappropriate expectations

- Running thousands of Linuxen on one system
- “Just port it and it will run”
- “Mainframes are large and fast”

The reality

- Plan dozens or hundreds of Linuxen per system, *tops*
- Porting requires understanding, (maybe) rearchitecting
- Mainframes are *fairly* large and *fairly* fast—now (z9)
Unmeasured Equals Unsuccessful

Make unjustified assumptions

- “Tune it like MVS” (aka “Linux apps are well-behaved”)
- “The app needs 4GB on Intel, so we’ll give it 4 on z”
- “More CPUs are good”
- “Swapping is bad”
- “z/VM is 64-bit, so we should run 64-bit Linux”

Critical requirement: You **must** measure it!

- I’ve believed this since long before joining Velocity
Performance Tuning “Back in the day”

VM in days of old
- Hundreds (or thousands!) of CMS users
- Relatively small, well-behaved applications
- Performance degradation was typically gradual

Performance tuning was easier and harder
- **Easier**: smaller problems, smaller changes
- **Harder**: smaller changes, smaller effects
Why Linux is Different

z/VM today

- Tens (or hundreds) of z/Linux guests
- Very large, often poorly behaved Linux applications
- Performance degradation can be precipitous

Performance tuning is harder *and* easier

- **Harder**: bigger problems, bigger changes
- **Easier**: bigger changes, bigger effects
Herding Penguins

The single most important lesson in this presentation

(but easier than herding cats)
Your idle Linux guests must go truly idle

- This is a memory (storage) management issue, not a CPU usage issue.

What does “idle” mean?

- Means “transaction” complete, guest drops from queue.
- CP defines 300ms of idle time = end of transaction.
- Theoretically represents interactive user “think time”.
- Less meaningful for servers, but what better metric?

* Thanks to Rob van der Heij for this line!
What’s a “Transaction”? 

Anatomy of the average transaction

- Periods of activity with short idle time between them
- Starts with a timer interrupt (or perhaps I/O interrupt)
- Longer idle period at end is followed by queue drop

Example:

```
<table>
<thead>
<tr>
<th>Time (s)</th>
<th>run</th>
<th>idle</th>
<th>run</th>
<th>idle</th>
<th>run</th>
<th>test idle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queue time</td>
<td>180</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trans time</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Queue drop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dormant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

Queue time = 180

Trans time = 9

Queue drop

Dormant

87%  1.4
Scheduler and Dispatcher 101

Some critical concepts

- Guests must be *runnable* to do work
- CP must be willing to schedule the guest
- CP must be willing to dispatch the guest

A guest is always in one of three lists:

- **Dormant** list: guest has no work to do
- **Dispatch** list: guest is active, CP is allowing it to run
- **Eligible** list: guest is active, CP is not allowing it to run
- (Can also be *running*...special case of Dispatch list!)
CP scheduler analyzes resources, decides whether enough to give guest service

- Entirely storage-related (memory)
- If not enough available, guests get put on the E-list

CP dispatcher gives guests access to CPUs

- If multiple guests are active, they take turns
- VM is very good at this — supports tens of thousands of active users with excellent response time
 Dispatch Classes – Class 1

When first dispatched, guest is Class 1 (“Q1”)

- CP waits one Class 1 Elapsed Timeslice (C1ETS) to see if it goes idle voluntarily.
- Guests that do not go idle within that timeslice are preemptively stopped from execution—sent back to the scheduler.
- C1ETS is dynamically calculated to keep a fixed % of guests in class 1.
- C1ETS should be enough for short, interactive transactions (minor CMS commands).
Dispatch Classes – Class 2

If guest does not go idle in one C1ETS, it enters Class 2 (“Q2”)

- Next time CP runs it, given 8x C1ETS
- Guests that do not go idle within that amount of time are rescheduled
- Such guests are presumed to be running a command, but not necessarily doing something “major”
If guest does not go idle within class 2 C1ETS multiple, it enters Class 3 ("Q3")

- Next time CP runs it, given $6 \times \text{Class 2} = 48 \times \text{C1ETS}$
- Guests that do not go idle within that amount of time are rescheduled
- Such users are presumed to be running a long-running command
**Dispatch Classes – Class 0**

**QUICKDSP ON** bypasses some rules
- Still get rescheduled, but never held in eligible list

Interactive guests (on terminals, hitting keys) also get Q0 stays (“hotshot” stays)
- Still get rescheduled, but “go to head of line” briefly
- Return to their previous queue level after Q0 stay
- Virtual machines holding certain short-term system locks are also considered to be in Q0
Leaving the Dispatch List

Guests leave dispatch list because they:

- Use up their current CnETS multiple
- Go idle voluntarily (load a wait PSW)—see below

300ms **test idle timer** set when guest loads wait PSW

- Guest resuming activity within that period are reinserted into previous place in queue
- Guests that don’t go idle never get queue dropped!
How This Plays Out...

CP scheduling is based on storage analysis

- If not enough, guests are held in **Eligible list (E-list)**
- Assumption: other guests will go idle, storage will become available soon
- If not, E-listed guests never get scheduled
- There are actually a host of other bad side-effects of too-large Linux guest virtual storage sizes
Why This Goes Wrong

Linux real storage requirements higher than CMS guests because Linux guests:

- Are quite large (virtual storage size)
- Use all storage (working set = virtual storage size)
- Don’t interact with CP to release unused storage
- Stay active (rarely/never go idle)

If enough Linux guests are logged on, CP notices it will overcommit real storage

- One or more such guests “lose”, are E-listed — and stay there!
System is running along fine
- One guest too many is started
- Things “just stop”!

Dispatched guests “should” go idle
- Linux guests typically don’t, stay runnable all the time

Historically, guests doing I/O were “active”
- Recent releases have mostly eliminated this

Remember the test idle timer
- Guests never go idle (as far as CP can tell)
- Never get scheduled properly, so E-listing permanent!
**CP INDICATE QUEUES EXPANDED** shows:

<table>
<thead>
<tr>
<th></th>
<th>Q</th>
<th>PS</th>
<th>00013577/00013567</th>
<th>....</th>
<th>-232.0</th>
<th>A00</th>
</tr>
</thead>
<tbody>
<tr>
<td>LINUX902</td>
<td>Q3</td>
<td>PS</td>
<td>00030109/00030099</td>
<td>....</td>
<td>-231.7</td>
<td>A00</td>
</tr>
<tr>
<td>LINUX901</td>
<td>Q3</td>
<td>PS</td>
<td>00000128/00000106</td>
<td>.I..</td>
<td>-208.7</td>
<td>A00</td>
</tr>
<tr>
<td>VSCS</td>
<td>Q1</td>
<td>R</td>
<td>00052962/00051162</td>
<td>....</td>
<td>-.9398</td>
<td>A00</td>
</tr>
<tr>
<td>VMLINUX3</td>
<td>Q3</td>
<td>IO</td>
<td>00000000/00000000</td>
<td>....</td>
<td>.0612</td>
<td>A00</td>
</tr>
<tr>
<td>VMLINUX3 MP01</td>
<td>Q3</td>
<td>PS</td>
<td>00177823/00196608</td>
<td>....</td>
<td>5255</td>
<td>A00</td>
</tr>
</tbody>
</table>

- HELP INDICATE QUEUES shows meaning of output
- CP privilege class E required
- **Note:** “deadline time” (sixth column) indicates when CP thinks the guest will run
- Guest LINUX123 is not running any time soon…
Remediation

Buy lots more storage ($<6K/GB — cheap!)

Tune applications so guests do queue drop
  - Obviously only meaningful if guests are nominally idle
  - Remember cron et al. may wake them anyway

Log off some guests
  - You didn’t need that WAS application, did you?

➢ Tune guest storage sizes
  - Linux uses “extra” storage for file buffers
  - Smaller guests may actually perform better
Why Idle Guests are Important

CP analyzes storage use when guests go idle
- Avoids taking pages from active guests

Three-pass process
- First pass analyzes users on dormant list—never happens if Linux guests never go idle!
- Result: CP must steal pages, makes wrong guesses
- Causes thrashing—pages go out, come right back in

Linux and z/VM paging algorithms collide
- When Linux wants a page, where does it look? (LRU)
- Where is that page most likely to be?
Care and Feeding of Aptenodytes

Keeping your penguins from becoming dogs
“Jiffies”: Frequent Linux timer pops
  - Controlled via setting in `/proc`

“Correct” setting is perhaps unintuitive
  - 0 is what you want:
    `echo 0 > /proc/sys/kernel/hz_timer`

Why do “jiffies” hurt?
  - 10ms is a lot less than the CP idle timer of 300ms
  - Guests with the timer ON never go idle

Make sure “jiffies” are off!
Don’t use virtual MPs without *good* reason

- Most Linux applications don’t exploit MP
- Exception: apps that use more than one CPU of MIPS

Bogus advice, frequently heard:
“Define as many vCPUs as real CPUs”
- Valid *only* in lab, single-Linux-guest environment

Note: Linux doesn’t report MP usage
- Harder to prove MP need (or lack thereof)
Virtual Multiprocessors

Why does this hurt?

- Guest isn’t idle until all vCPUs are idle
- Virtual MP spreads timer events over vCPUs
- Thus MP = more transactions = more in-queue time

Bigger problem: significant CPU wastage

- Inter-vCPU management isn’t free
- Linux spin locks can use an *entire CPU*

Use virtual MP only if proven need
Extra Services

Be careful about `cron` and friends

- Services such as `cron` wake guests up from idle
- Obviously necessary in some cases, but examine, understand, and experiment!

Understand requirement for every service
Watch for the “thundering herd” phenomenon

- Things like Red Hat Network tend to wake guests up
- All your guests waking up at once is not a good thing!
- Examine, understand, and stagger the wakeups

Avoid/aggregate services such as updates

- Why check for updates on every guest?
- Use a single update server!
z/VM no longer runs on 31-bit hardware
  - 31-bit guests still supported, but…

Natural assumption: 64-bit guests “better”
  - 64-bit guests require significantly more resources
  - Page tables alone are twice as large (16MB per GB)
  - Other control structures can also be significant

Use 64-bit guests only when > 2G virtual memory or specific application requirement
Intel boxes have fast CPU, RAM; slow disk
  - Conventional wisdom: “Swapping is bad”

Swapping to DASD is slow
  - But z/VM has VDISK (virtual disk in storage)
  - “Minidisks” that exist in z/VM paging subsystem

z/VM paging subsystem is pretty darned fast
  - Conventional wisdom thus mostly wrong under z/VM

Swapping to VDISK is way fast
  - Linux still does I/O, but CP intercepts and handles
  - CP can manage VDISK better (LRU problem again)
Swapping and VDISK

Most applications can stand to swap some

- Exception: Oracle Shared Global Area (SGA) **must** stay in-memory for reasonable performance
- Other exceptions surely exist

Use small virtual storage + Swap to DASD to slow down guest that’s too fast ;-)
VDISK Myths and Realities

Fear: “VDISK will use too much real storage”
- Reality: VDISK lives in VM paging subsystem
- Linux virtual storage lives in VM paging subsystem
- Real storage use not really affected

Reality: VM does better managing both
- Use smaller Linux virtual storage + VDISK for swap
- VM controls both, rather than Linux caching data, causing VM paging through LRU mismatch

Myth: “VDISK pages never migrate to DASD”
- Fact: CP Monitor records prove otherwise

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VDISK Notes and Recommendation

VDISK notes:
- Max size: 2G-1 page (4194296 512-byte blocks)
- Control via CP SET VDISK command (privileged)

Use two VDISKs, prioritized
- Linux “moving cursor” algorithm wanders across disk
- With one, large VDISK, entire disk winds up “dirty”
- With two, Linux will use higher priority first
- Avoids old, “dirty” pages lingering in VM paging space
- Note: “higher priority” is numeric — 10 is higher than 1 (unlike your tasks at work!)
Large Virtual Storage (Memory)

Example: 256MB virtual storage vs. 1024MB

- 8MB more real storage required just for page tables
- 16MB if 64-bit guest!
- Significant even if not actually using the storage!

Recommendation: Tune virtual storage size

- “Squeeze until it hurts”
- Then give it a bit more
  (or not — let it Swap, to VDISK)
Virtual Storage and Linux Caching

Linux caches data (read **and** write)

- Data may be replicated five times:
  1. Linux file buffers
  2. z/VM minidisk cache/paging subsystem
  3. Controller cache
  4. Device cache
  5. “Brown, round, & spinning”

Multiply cached data probably not helpful!

- Tuning virtual storage size controls this
Minidisk cache (MDC) is a powerful tool

- But only for data that actually gets reread
- And not if the data is cached by Linux too…

Default: MDC uses both main and XSTORE

- CP “Arbiter” that controls XSTORE use seems broken
- MDC can use huge amounts of XSTORE for no gain
- Even decent MDC hit ratio may not justify increased paging load due to reduced main/XSTORE available

```
CP SET MDCACHE XSTORE 0M 0M
```
CP SET QUICKDSP ON sounds good

- “This guest is important, we want it to run fast!”

Reality: makes guest avoid scheduler, not “run faster”

- Circumvents scheduler “smarts”
- Result: when storage overcommitted, CP thrashes
- Result: worse performance for everyone

Use QUICKDSP only by prescription*

* And for MAINT, when you’re doing performance tuning…!
ABSOLUTE SHAREs *sound* good

- “We can ensure that this machine gets xx% of a CPU!”

Reality: Difficult to manage with many guests

- With one or two, quite feasible—but at that point, RELATIVE SHAREs work just as well
- Use ABSOLUTE for TCPIP et al (machines others depend on) to ensure service even when system busy
- Note ABSOLUTE SHAREs are % of *entire system*

Leave SHARE at **RELATIVE 100** unless addressing *specific* performance problem
CP SRM settings provide some system performance management “knobs”

- Be careful: These are \textit{big} knobs
- \textit{Misapplied, they will hurt!}

Default SRM settings based on CMS users

- Most are still OK for z/Linux
- Be careful of “lore” suggesting changes unsupported by measured results
Some “lore” suggests raising **SRM LDUBUF** is a good idea

- Actual measured results suggest otherwise
- Controls the number of “loading” users (users with significant paging activity) allowed in-queue

**Never never increase this with z/Linux!**

- In large shops, may actually want to *lower* it
- E.g., 50 page packs on 8 CHPIDs—CP probably can’t really support that many loading users
**SRM STORBUF and XSTOR**

**STORBUF** controls CP’s storage usage calculations by queue
- Linux guests are always Q3, so default incorrect
- Best to essentially disable its function
- Default: `SET SRM STORBUF 125 95 75`
- Suggest: `SET SRM STORBUF 300 300 300`

Also: `SET SRM XSTORE 50%`
- Includes 50% of expanded storage in calculations

*Measure* results on your system!
IBM has done *tons* of work to make z/VM a better host for Linux

- Example: fixes allow queue drop when I/O outstanding

**z/VM 5.2/5.3 continue the tradition**

- Many small enhancements that make Linux run better
- z/VM upgrades aren’t a big deal any more

**If you aren’t on 5.2 or 5.3, get there ASAP!**

- 5.3 is better, but is also brand-new
- You decide whether “bleeding edge” is appropriate for your shop
CMM: Collaborative Memory Management*

- Allows dynamic Linux storage tuning

Driver from IBM Böblingen

- Accepts commands via CP SMSG, allocates storage within Linux, tells CP “fuhgeddaboudit”
- CP no longer has to manage those pages

Lets you “inflate a balloon” within Linux

- Linux continues operation, working set greatly reduced
- If swapping becomes a problem, release some pages!

* Or possibly “Cooperative Memory Management” — nobody seems to be sure!
Linux without CMM

4GB virtual storage

Linux still *thinks* it has 4GB

“Rest” of storage *not managed by VM*

Multiply savings by *n* guests…

Linux with CMM

4GB virtual storage minus *nn* pages
CMM avoids most of the complaints about storage tuning

- “We don’t want to reboot”
- “This isn’t peak load, and we can’t reboot when it is!”

Critical for Linux success in some shops

- Real example: Oracle said “App needs 4GB”; Linuxen have 4GB, but only 1GB really available!
- Apps folks still think they have 4GB
- Without CMM, $n \times 4GB = $$$ for more real storage (or unacceptable performance)
z9 adds hardware support for “CMM2”
- Cooperative z/VM–z/Linux page management
- Intended to reduce double paging, LRU thrashing

Adds CP SET and QUERY MEMASSIST
- Requires z/VM 5.2 with PTFs UM31784, UM31868
- SLES 10 SP1 supports via `cmma=on` IPL option
- No support in RHEL4 or RHEL5 (yet?)

No proven success in the field
- Stick with CMM(1) for now
XIP = eXecute-In-Place

- DCSSs under Linux, containing stored, shared data
- Manifest as special filesystem type

Use XIP when possible to share static data

- Common applications can save significant real storage
- Requires some management and care
- Evolving area, stay tuned!

Explore for common apps (SNMP, etc.)
Summary

Linux on System z is reaching adolescence
  - Much progress made, lots more to do

Tuning Linux on z is an emerging science
  - We’re still learning, and it’s a moving target

As always, use the community
  z/Linux mailing list: LINUX-390@marist.edu
  z/VM mailing list: IBM-VM@listserv.uark.edu

➤ Measure, test, **prove** — don’t rely on rumor, innuendo, and lore!
Questions?

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