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
Linux on z: Ancient History

- 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) made 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
The New Kid on the Block

- 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 be aware 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)
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
The Real Cause

- 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 (z10)
How To Guarantee Failure

www.dvdrewinder.com

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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:
  - Queue time = 180
  - Trans time = 9
  - Queue drop
  - Dormant
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
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)
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 6x Class 2 = 48x 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!
How Does This Manifest?

- 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:

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LINUX902</td>
<td>Q3</td>
<td>PS</td>
<td>00013577/00013567</td>
<td>....</td>
<td>-232.0 A00</td>
</tr>
<tr>
<td>LINUX901</td>
<td>Q3</td>
<td>PS</td>
<td>00030109/00030099</td>
<td>....</td>
<td>-231.7 A00</td>
</tr>
<tr>
<td>VSCS</td>
<td>Q1</td>
<td>R</td>
<td>000000128/000000106</td>
<td>...</td>
<td>-208.7 A00</td>
</tr>
<tr>
<td>VMLINUX3</td>
<td>Q3</td>
<td>IO</td>
<td>00052962/00051162</td>
<td>....</td>
<td>-.9398 A00</td>
</tr>
<tr>
<td>VMLINUX3 MP01</td>
<td>Q3</td>
<td>PS</td>
<td>00000000/00000000</td>
<td>....</td>
<td>.0612 A00</td>
</tr>
<tr>
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<td>E3</td>
<td>R</td>
<td>00177823/00196608</td>
<td>....</td>
<td>5255. 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”

- “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!
Virtual Multiprocessors

- 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
Swapping and VDISK

- 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 ;-)
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
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!)
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)
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

- 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**
QUICKDSP ON

- **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 *big* knobs
- Misapplied, they *will hurt!*

Default SRM settings based on CMS users
- Most are still OK for z/Linux
- Be careful of “lore” suggestion 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 CHPIDṣ—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 best choice
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 Benefits

- 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 added hardware support for “CMM2”
  - Cooperative z/VM–z/Linux page management
  - Intended to reduce double paging, LRU thrashing

Addrs 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

- 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: IBMVM@listserv.uark.edu
- Measure, test, **prove** — don’t rely on rumor, innuendo, and lore!
Questions?

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