Linux on System z Performance Update
Part 1: z10 CPU, Compiler, Java, Linux Kernel

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Performance is in Internal Throughput Rate (ITR) ratio based on measurements and projections using standard IBM benchmarks in a controlled environment. The actual throughput that any user will experience will vary depending upon considerations such as the amount of multiprogramming in the user's job stream, the I/O configuration, the storage configuration, and the workload processed. Therefore, no assurance can be given that an individual user will achieve throughput improvements equivalent to the performance ratios stated here.

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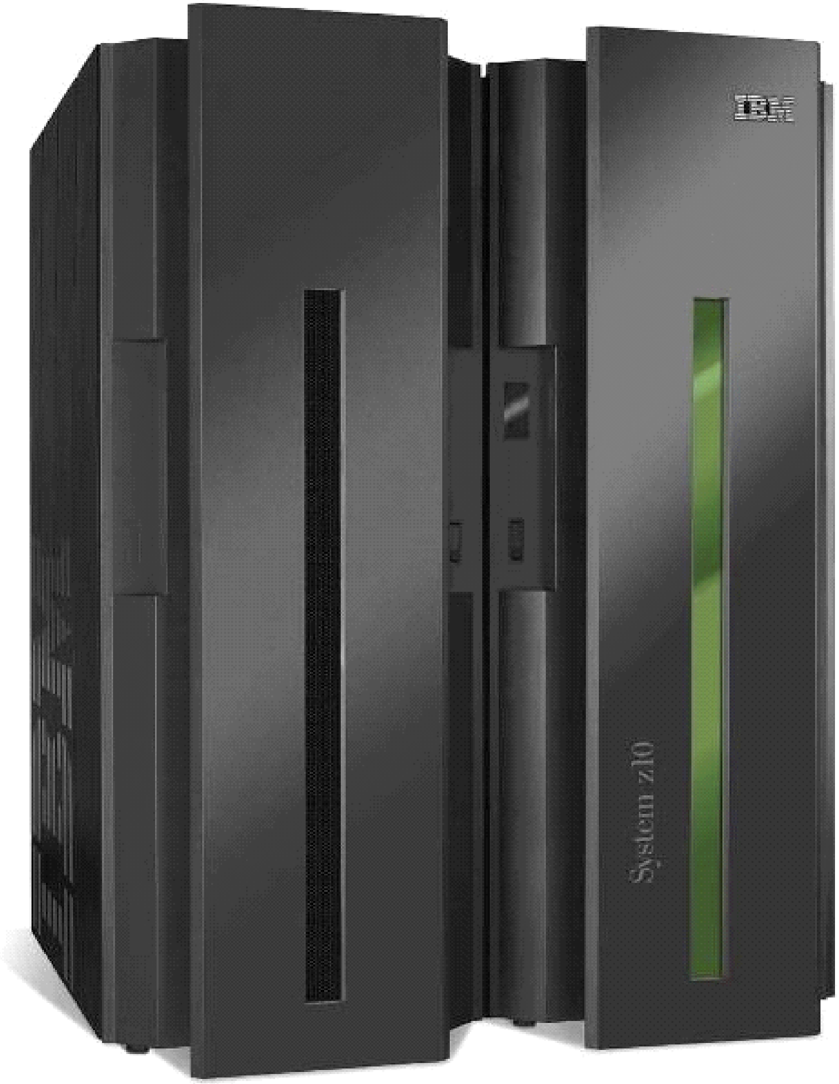
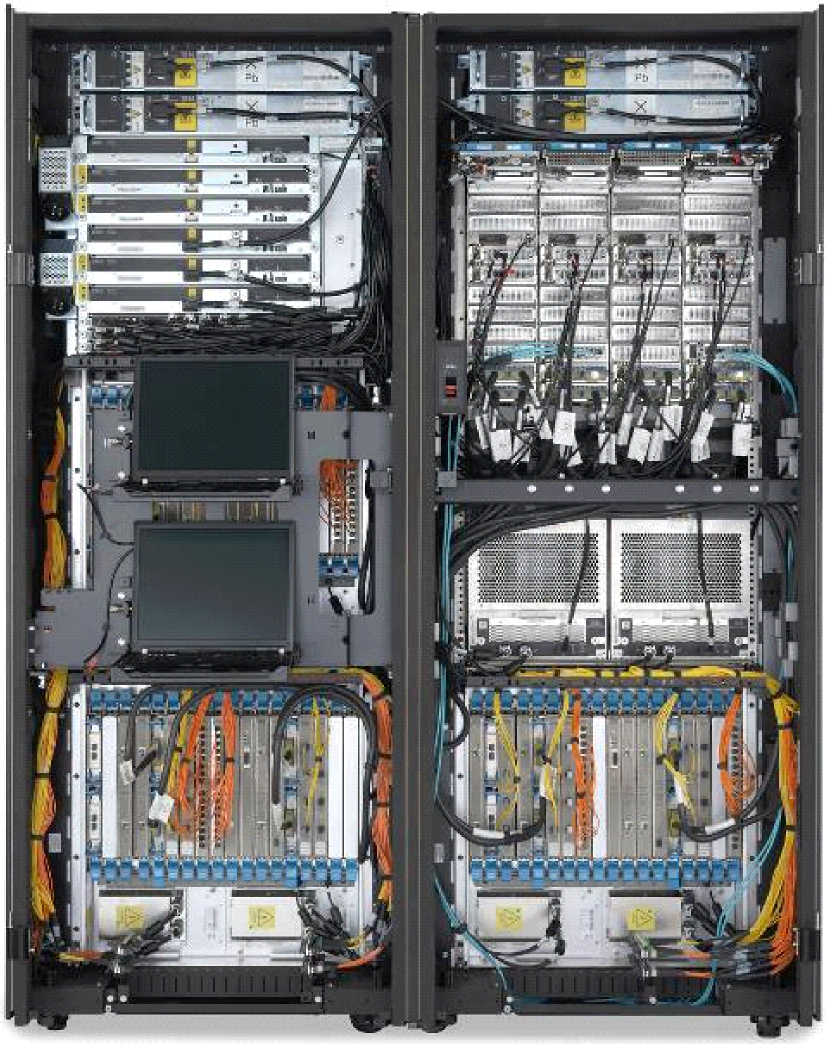
Agenda

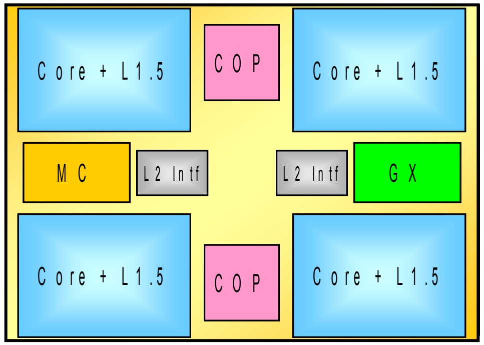
- z10 CPU, Compiler, Java, Linux Kernel
  - short System z HW overview
  - z10 Performance
  - GCC compiler
  - Java server performance
  - CPU hotplug function


IBM
System z10

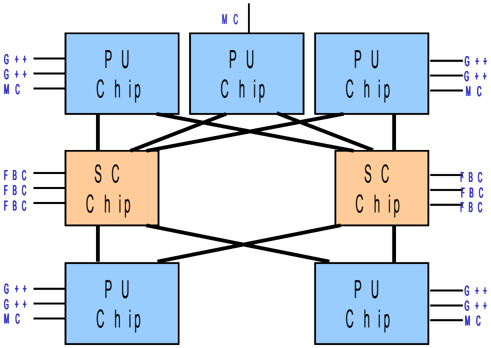


z10 Technology

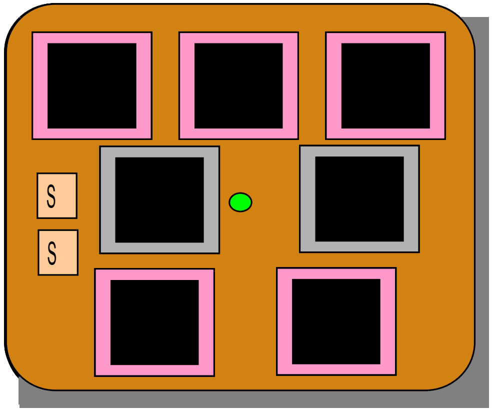
CP Chip



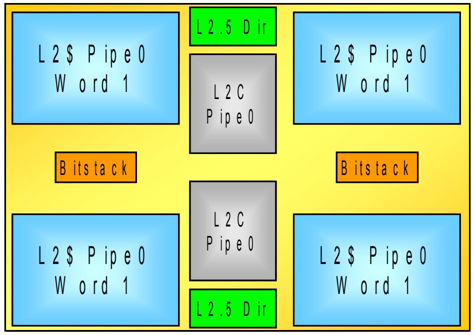
20w Node



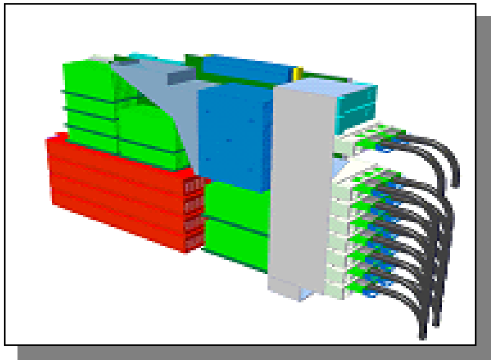
MCM



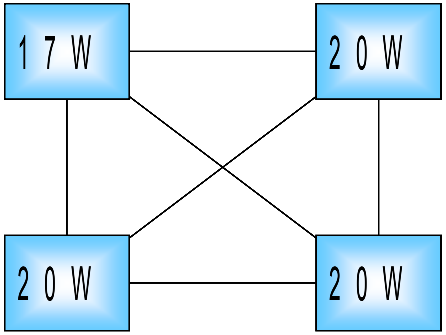
SC Chip



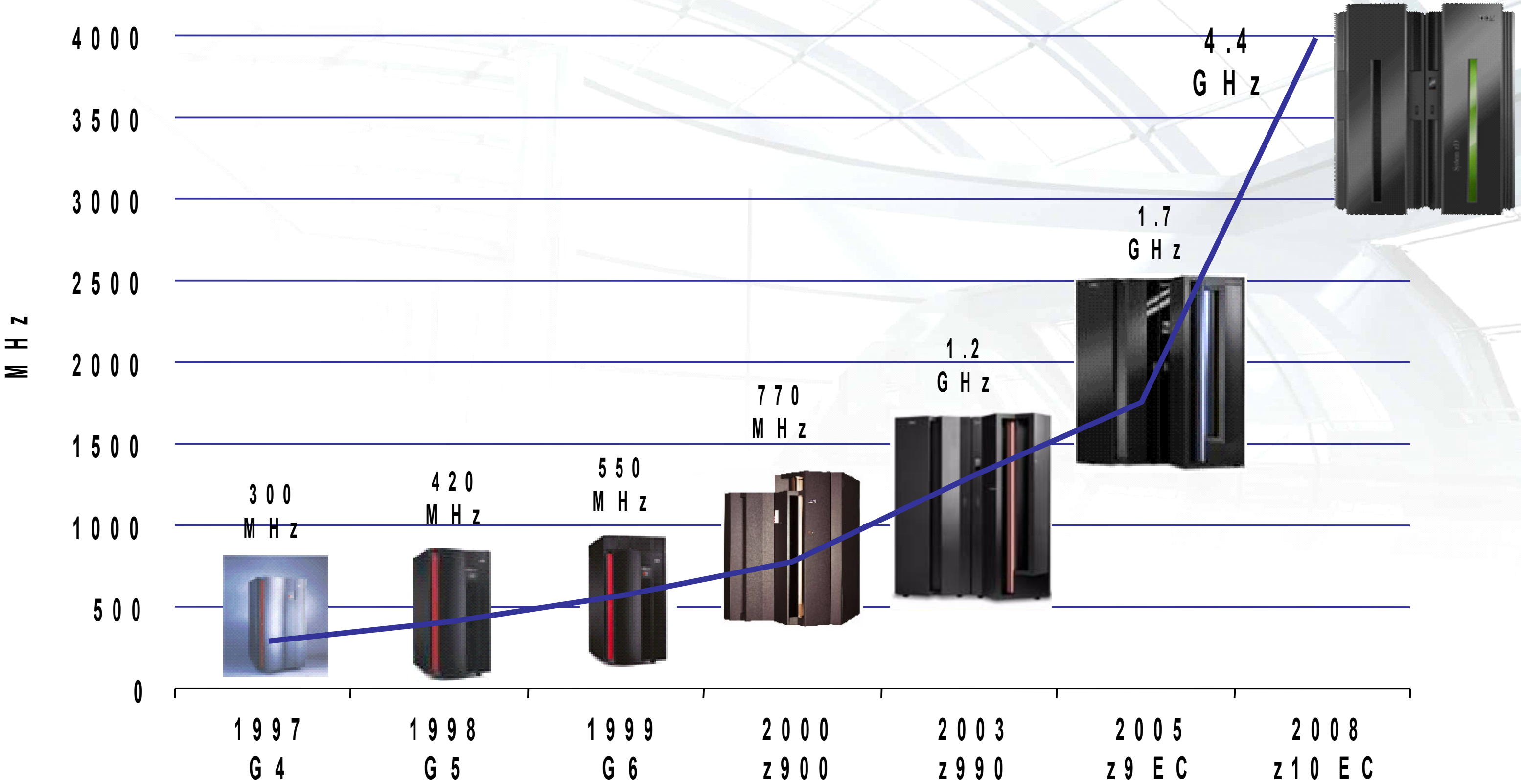
Node package



77w CEC



IBM z10 EC Continues the CMOS Mainframe Heritage

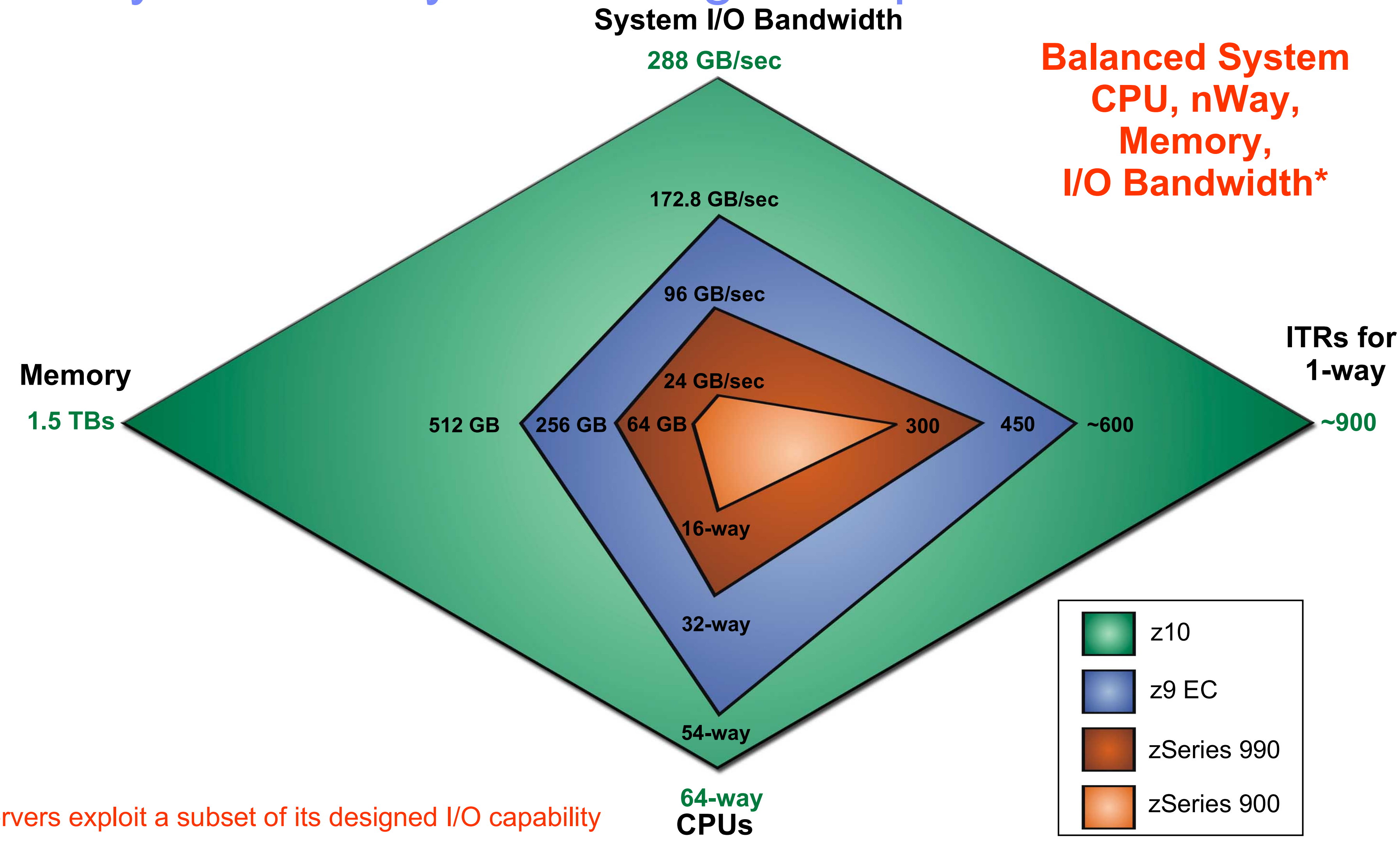


- G4 - 1st full-custom CMOS S/390®
- G5 - IEEE-standard BFP; branch target prediction
- G6 - Cu BEOL

- IBM eServer zSeries 900 (z900) - Full 64-bit z/Architecture®
- IBM eServer zSeries 990 (z990) - Superscalar CISC pipeline
- z9 EC - System level scaling

- z10 EC - Architectural extensions

IBM System z – system design comparison



Balanced System CPU, nWay, Memory, I/O Bandwidth*

*Servers exploit a subset of its designed I/O capability

LSPR Mixed Workload for System z10 EC

	z10 EC to z9 EC Ratios
LSPR Mixed workload average, multi-image for z/OS 1.8 with HiperDispatch active on z10 EC!	
Uni-processor	1.62
16-way z10 EC to 16-way z9 EC	1.49
32-way z10 EC to 32-way z9 EC	1.49
56-way z10 EC to 54-way z9 EC	1.54
64-way z10 EC to 54-way z9 EC	1.70

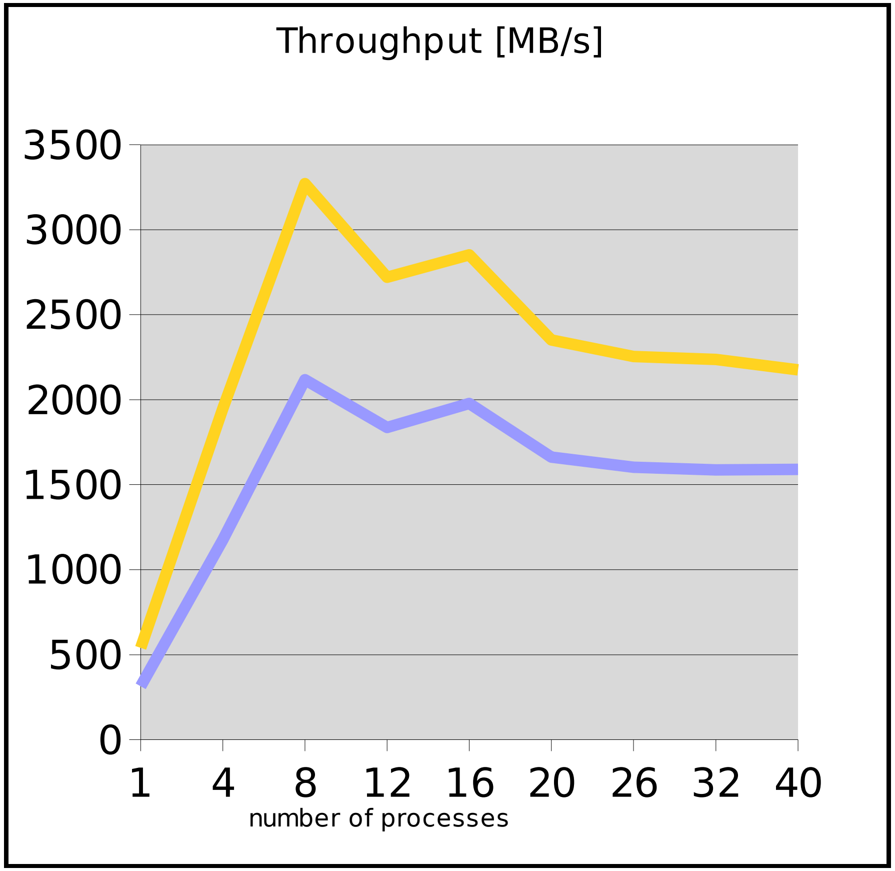
IBM Large System Performance Reference (LSPR)
http://www.ibm.com/systems/z/advantages/management/lspr/lsprwork.html

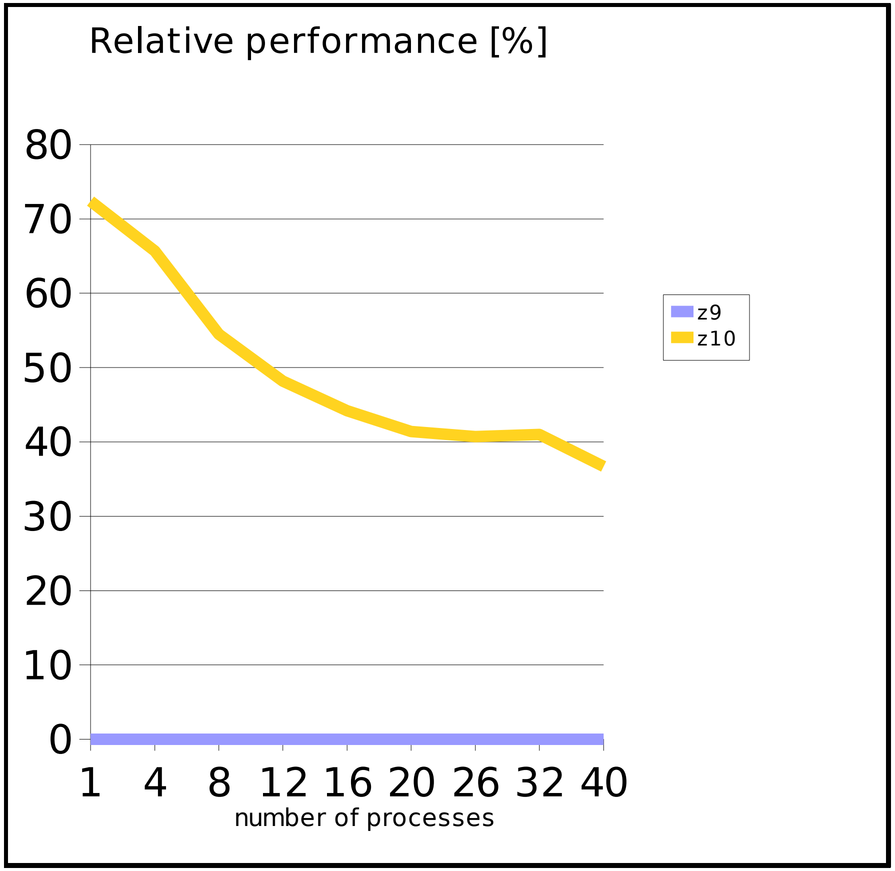
File server benchmark description

- dbench 3
  - Emulation of Netbench benchmark, rates windows file servers
  - Mainly memory operations (large page cache)
  - Mixed file operations workload for each process: create, write, read, append, delete
  - 8 CPUs and 1, 4, 8, 12, 16, 20, 26, 32, 40 processes
  - 2 GB memory

z10 Performance: dbench 3

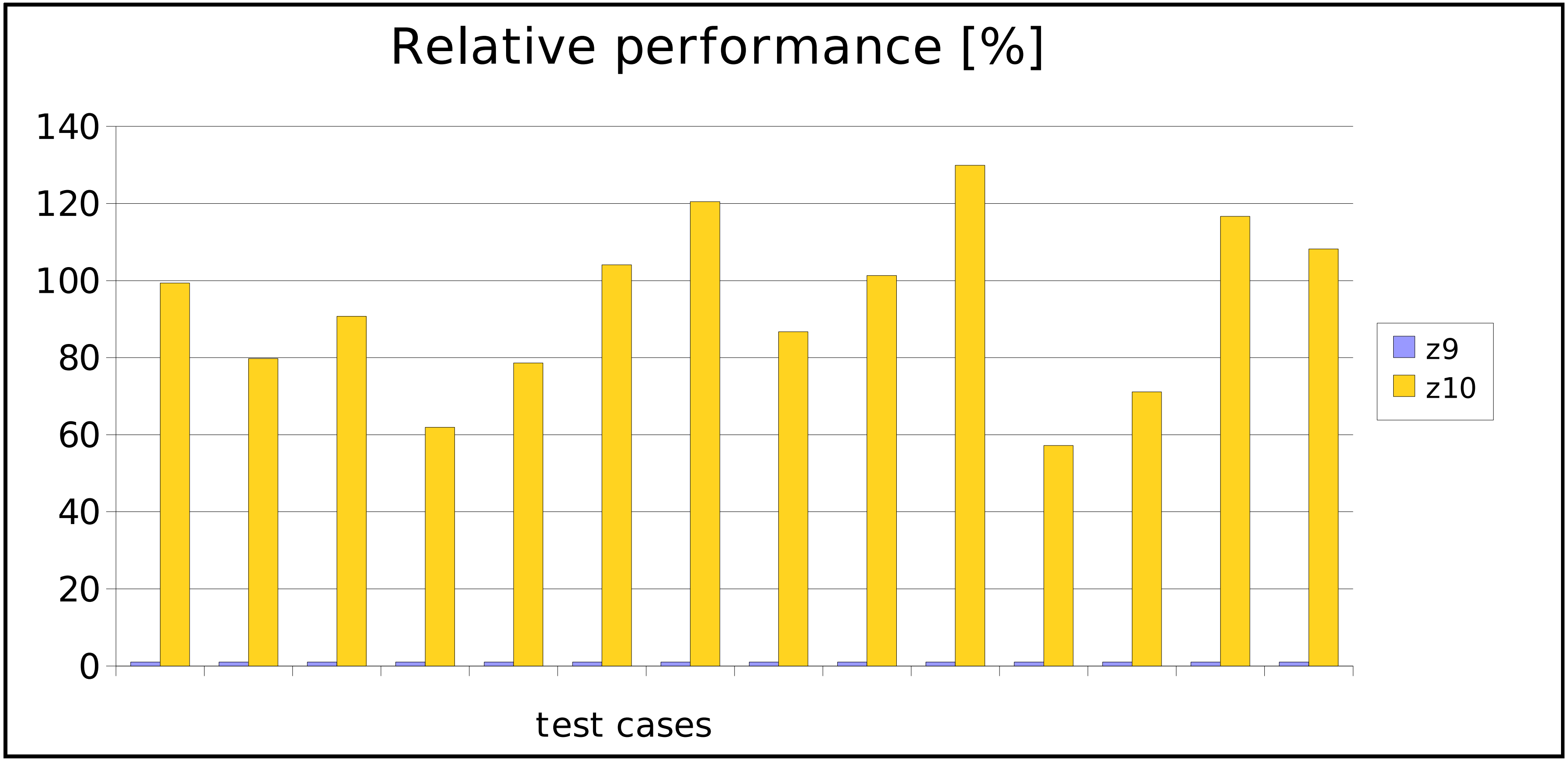
- Improvement z10 versus z9:
  - Measured with 8 CPUs: average improvement is 50%





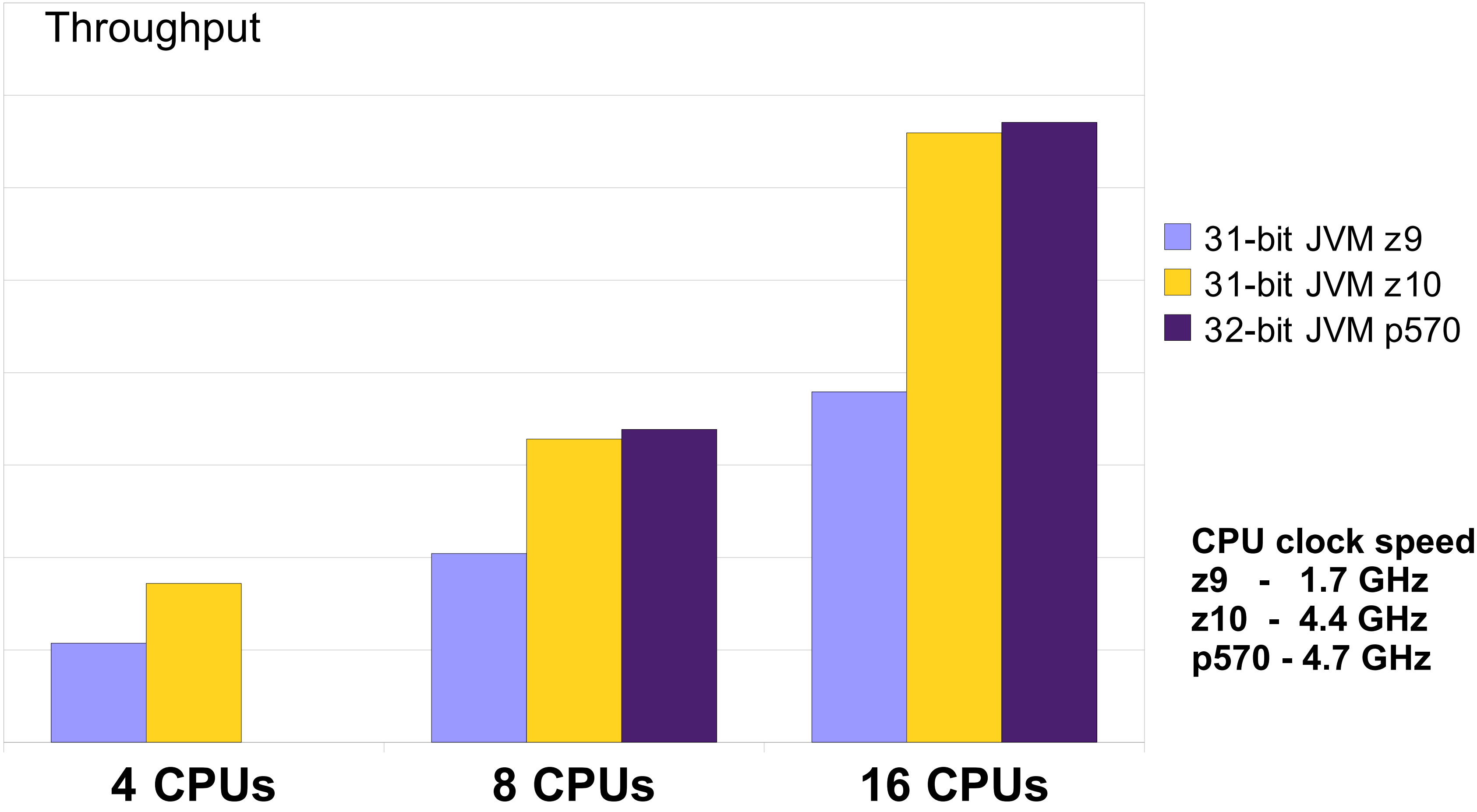
z10 Performance: CPU intensive workloads

- Overall improvement with z10 versus z9: 1.9x
- GCC-4.3 compiler can use -march=z10 option



z10 Performance: Java workload

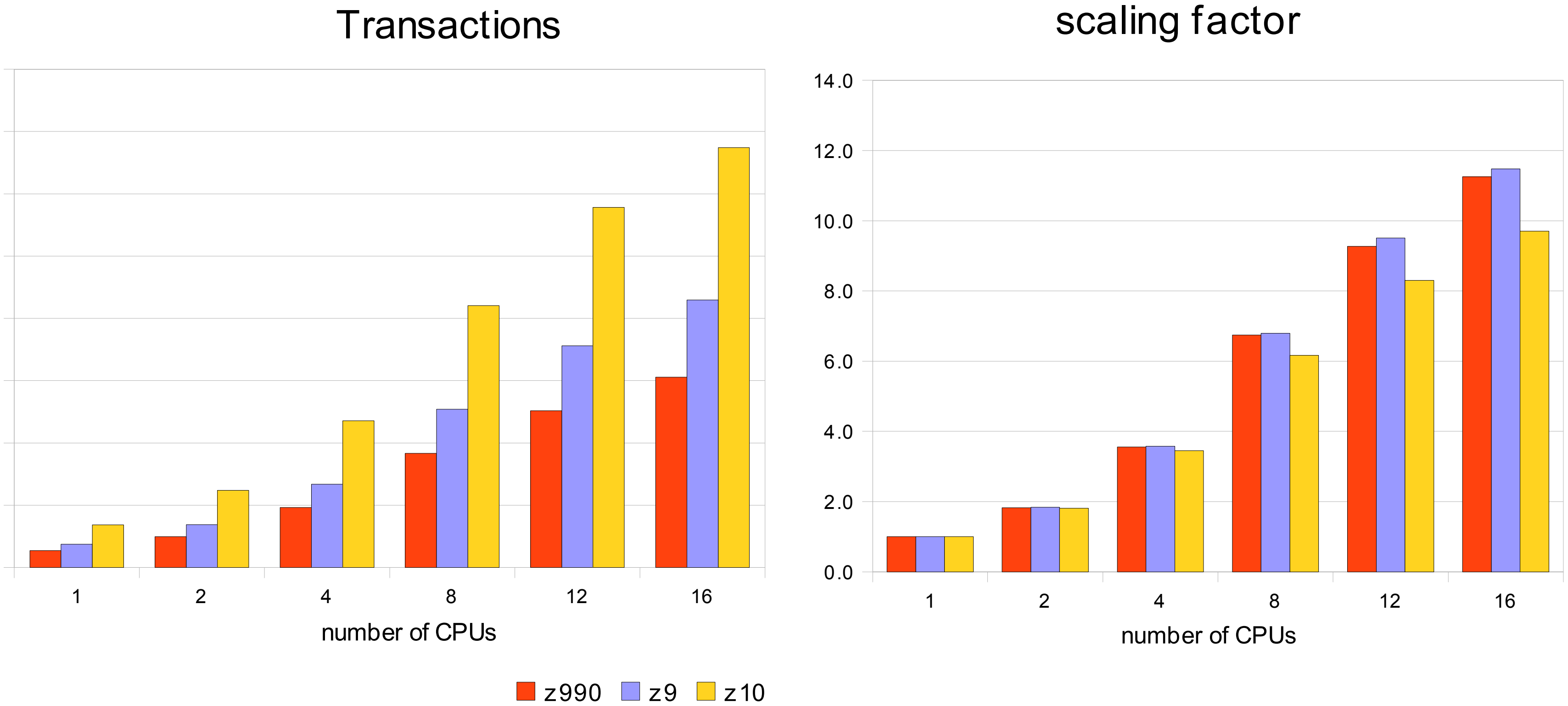
- System z versus System p



CPU clock speeds
z9 - 1.7 GHz
z10 - 4.4 GHz
p570 - 4.7 GHz

z10 with Informix IDS 11 OLTP workload

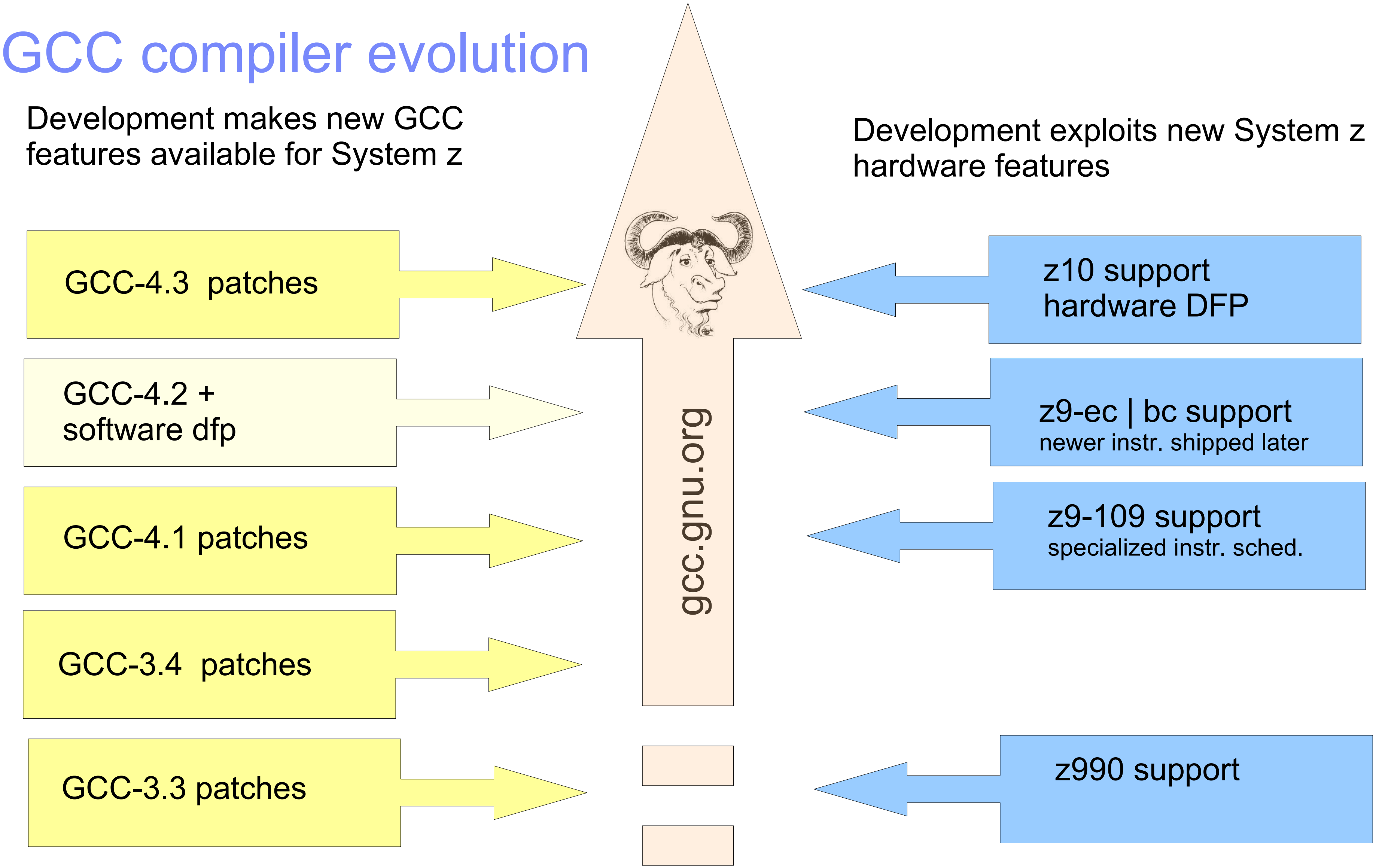
- Throughput improvements
  - z9 to z10: 65% - 82%
  - x numbers of z10 CPUs can do the same work as 2x z9 CPUs



z10 Performance summary

- System z evolution continues
- Performance boost from z9 to z10
- Balanced System
- LSPR expectations met
- Excellent on compute intensive and Java workloads
- GCC 4.3 available with SLES11

GCC compiler evolution



Development makes new GCC features available for System z

Development exploits new System z hardware features

GCC-4.3 patches

GCC-4.2 + software dfp

GCC-4.1 patches

GCC-3.4 patches

GCC-3.3 patches

z10 support
hardware DFP

z9-ec | bc support
newer instr. shipped later

z9-109 support
specialized instr. sched.

z990 support

GCC versions supported on System z

GCC version	Used in SUSE distribution	Used in Red Hat distribution
GCC-3.3	SLES9	
GCC-3.4		RHEL4
GCC-4.0		
GCC-4.1	SLES10	RHEL5
GCC-4.2		
GCC-4.3	SLES11	
GCC-4.4		

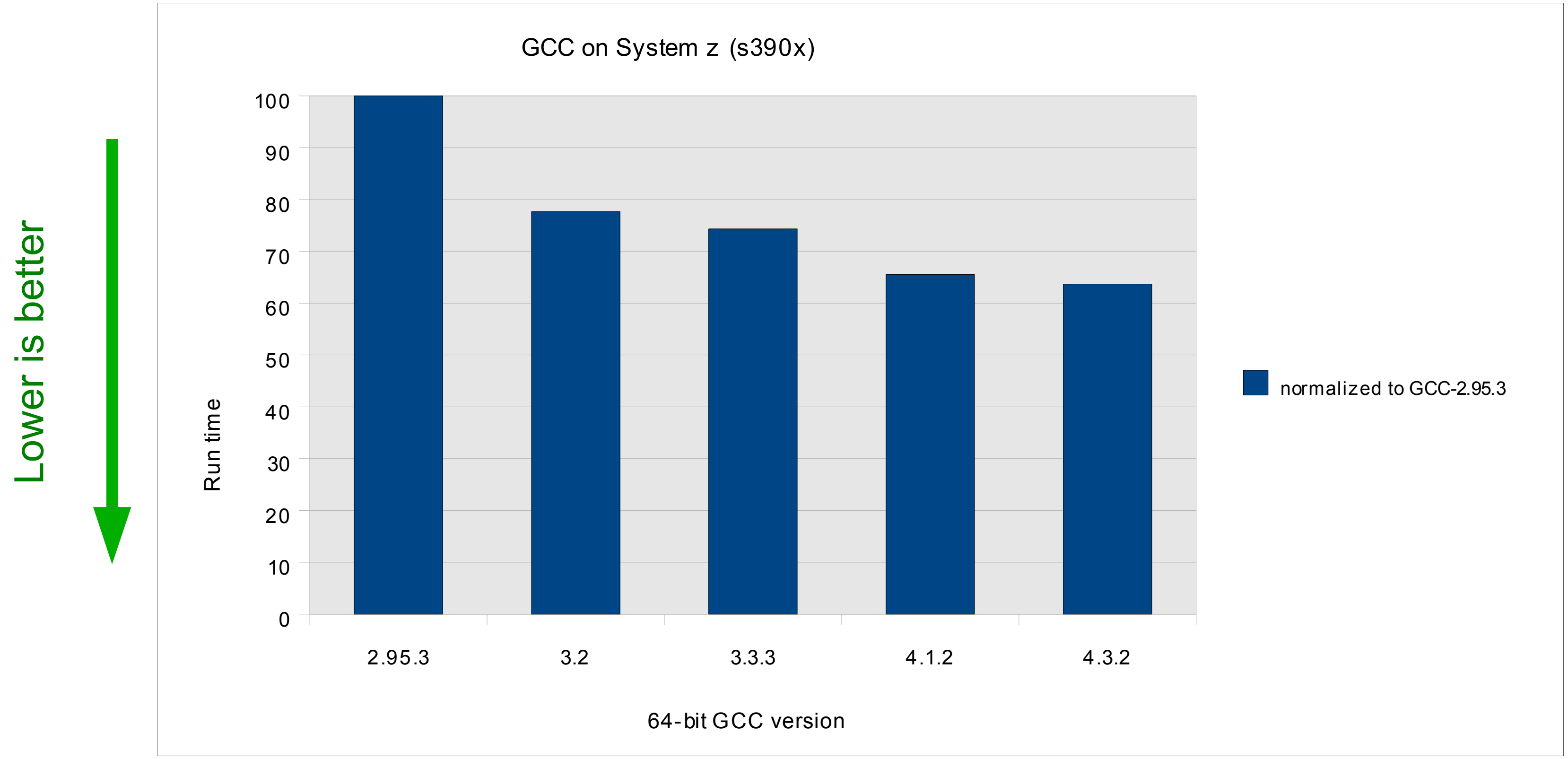
Optimizing C/C++ code

- Produce optimized code
  - Options -O3 or -O2 (often found in delivered Makefiles) are a good starting points
  - Optimize GCC instruction scheduling with the performance critical target machine in mind
    - -mtune=values <z900,z990>, <z9-109 with GCC-4.1>,
      <z9-ec | bc with GCC-4.2 and GCC-4.3>, <z10 with SLES11 GCC-4.3>
  - If you know the target machine exploit improved machine instruction set
    - -march=values <z900,z990>, <z9-109 with GCC-4.1>,
      <z9-ec | bc with GCC-4.2 and GCC-4.3>, <z10 with SLES11 GCC-4.3>
    - -march build binaries are only upward compatible!

- Fine Tuning: additional general options on a file by file basis
  - Use inline assembler for performance critical functions may have advantages
  - Avoid -fPIC for executables (gen. position independent code)
  - -funroll-loops often has advantages
  - -ffast-math speeds up calculations (if not exact implementation of IEEE or ISO rules/specifications for math functions is needed)
  - Don't use debugging options in the final executable

GCC performance evolution on System z

- Run time of industry standard benchmark applications with newer GCC versions is much shorter



DFP – Decimal Floating Point
Limitations of binary numbers in economy

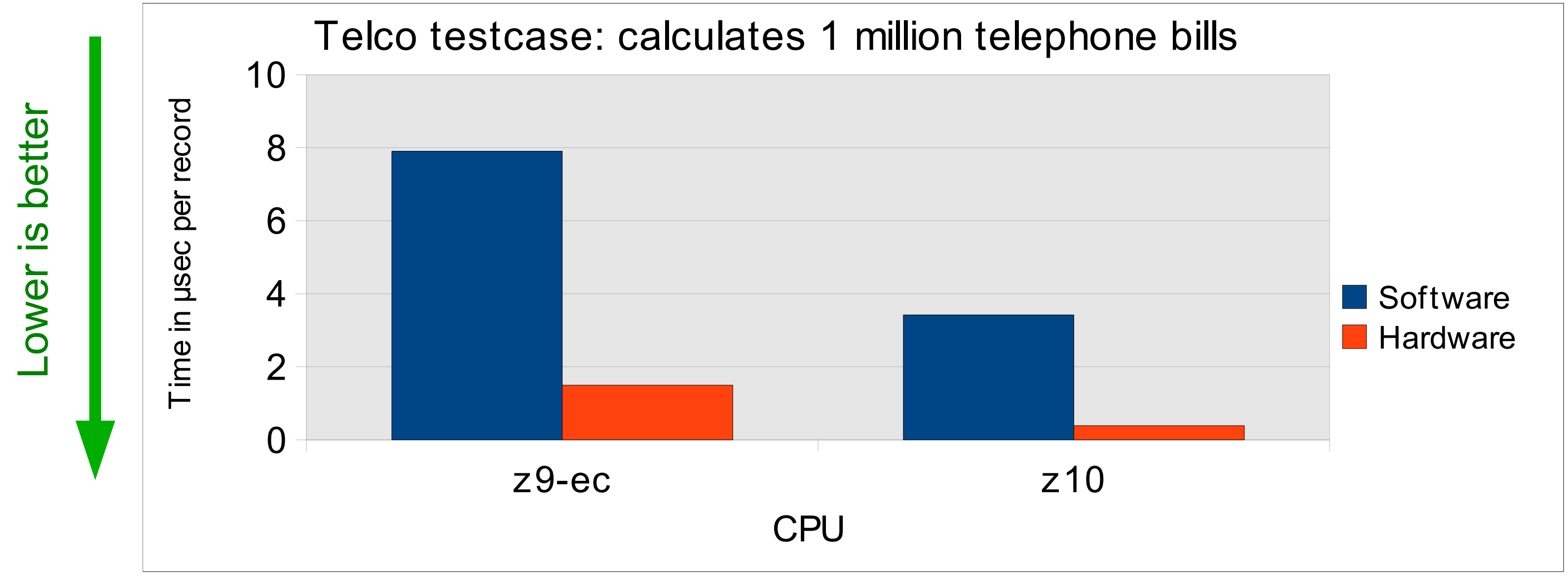
- Trading goods and amounts of money cannot be calculated or represented exactly by <u>binary floating point</u> numbers
  - Many numbers cannot be represented properly (1/5, 1/10)
  - People who are used to decimal numbers expect results and calculations to be available with full precision
  - The traditional binary representation is not suitable for usual calculations
    - $ 0.70 x 1.05 = $ 0.73499999999999998667732370449812151491641998291015625
    - Rounding to two digital places gives $ 0.73
    - Expected is $ 0.70 x 1.05 = $ 0.735 => rounded to $ 0.74
- If you rely on correctly calculated results without DFP you have to add many lines of code to your program
  - Example: troublesome binary floating point rounding mechanisms
    - Sometimes more than 50 times the number of lines than in an DFP implementation
  - Additional code is error-prone
  - Depending on the amount of calculations a performance degradation is to expect
  - TCO is higher due to service, maintenance, run time

DFP - support added in GCC

- Front end support (C, C++, Fortran, Java):
  - Support for the 3 new data types: _Decimal{32|64|128}
  - Support for DFP constants written with DF suffix
- Middle end support:
  - Complete DFP arithmetic layer for constant folding
  - Support for integer or IEEE floating point conversion routines
- GCC - versions
  - Software DFP support in GCC-4.2 added
  - Hardware DFP support in GCC-4.3 added (usable with z9-EC, z10)
- GCC-4.3.2 is available in SLES11
  - offers DFP in a supported environment on Linux on System z
  - The usage of DFP arithmetics in applications requires the explicit use of DFP data types
  - If GCC is used with -march=z9-ec and -march=z10 the HW DFP support is used by default (-mhard-dfp/-mno-hard-dfp options)

DFP - decimal floating point performance

- Telco benchmark models a telephone company's billing system
  - Billing of one million telephone calls including tax using DFP arithmetics
- Big advantage if DFP hardware support is exploited
  - z9-EC DFP hardware support in millicode
  - z10 DFP hardware support by real hardware -> much faster



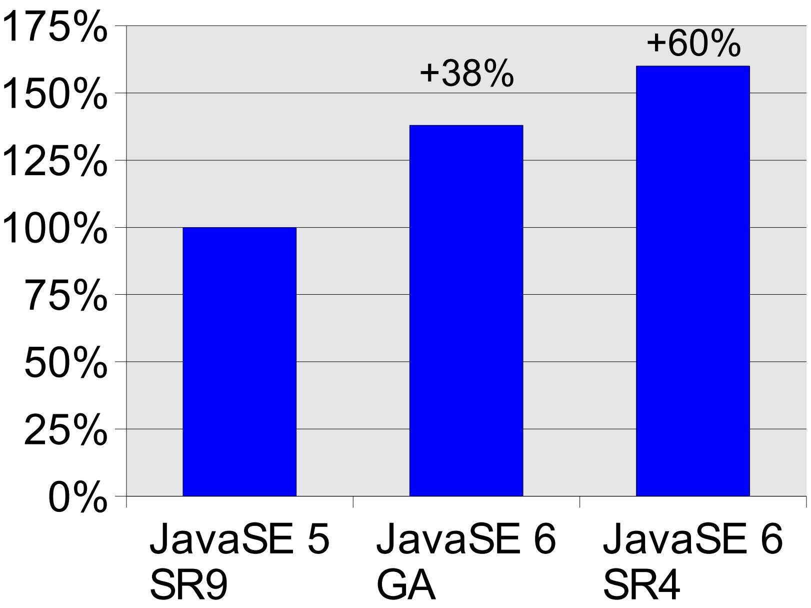
Java on servers: Workload

- evaluates server side Java
  - emulates 3-tier system
    - random input from user
    - middle tier business logic implemented in Java
    - no explicit database --> emulated by Java objects
- stressed components
  - Java
    - Virtual Machine (VM)
    - Just-In-Time compiler (JIT)
    - Garbage Collection (GC)
  - Linux operating system
    - Threads
    - CPUs
    - Caches and Memory

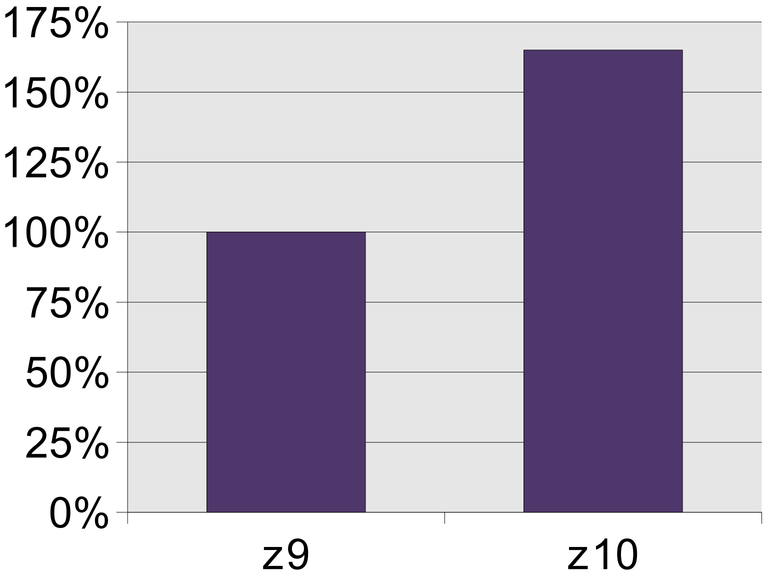
Java on servers: Performance Improvements

- better virtual machines (VMs) and just-in-time (JIT) compilers
- better garbage collection (GC) technologies
- improvements through new hardware

History of Java versions



System z with Java SE 6 GA

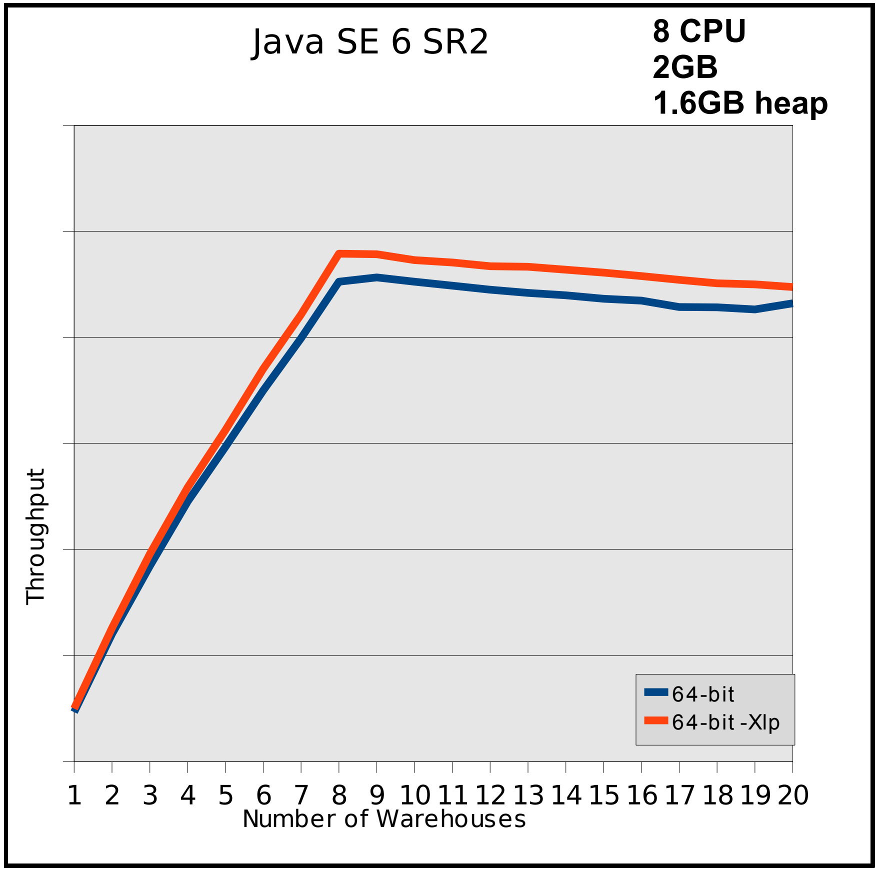


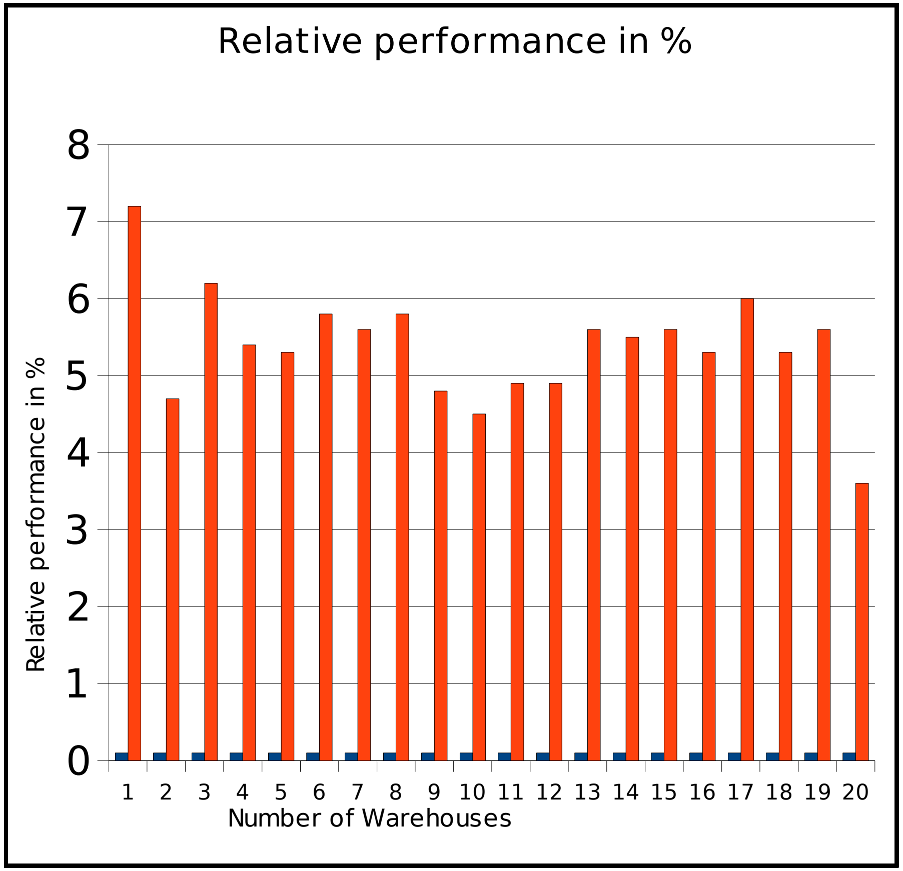
Java on servers: Heap size

- Heap size needs to be sized adequately
  - maximum heap size <= available memory
    - avoids paging in Linux and z/VM
  - Heap too small: frequent garbage collection and OutOfMemoryErrors
  - Heap too big: infrequent garbage collection; Linux starts swapping
  - 31-bit Java kits: larger heap sizes up to 1.6 GB (modify memory layout)
    - also true for 31-bit Java kits in a 64-bit Linux environment
- useful Java interpreter parameters for fine tuning – workload dependent
  - setting a fixed heap size: **-Xms** (initial), **-Xmx** (maximum), when initial==maximum
  - monitor garbage collection (GC): **-verbose:gc**
  - **-Xlp** tries to allocate large pages for the heap
    - prereq: Linux kernel needs to be setup for large pages (vm.nr_hugepages)
  - control GC behavior: **-Xgcpolicy:[optthruput, optavgpause, gencon]**
  - 64-bit: smaller size of heap objects: **-Xcompressedrefs**

Java on servers: Large page support (z10 feature)

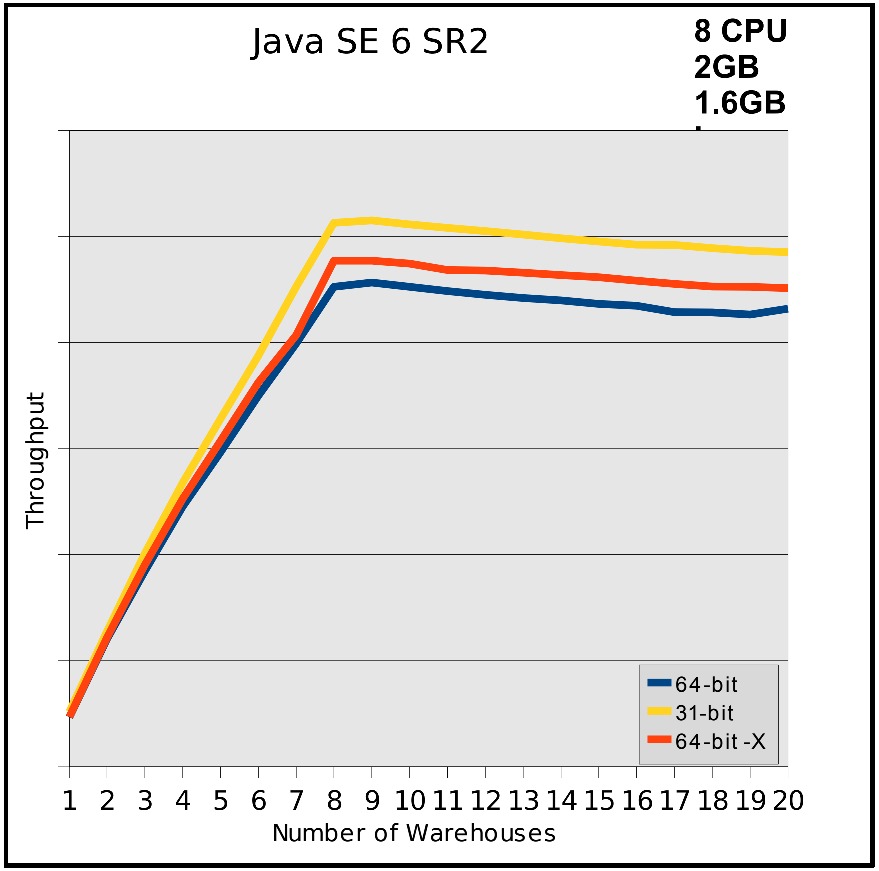
- use of **-Xlp** improves throughput
- large page size was 2 MB (default for SLES10 and RHEL5)

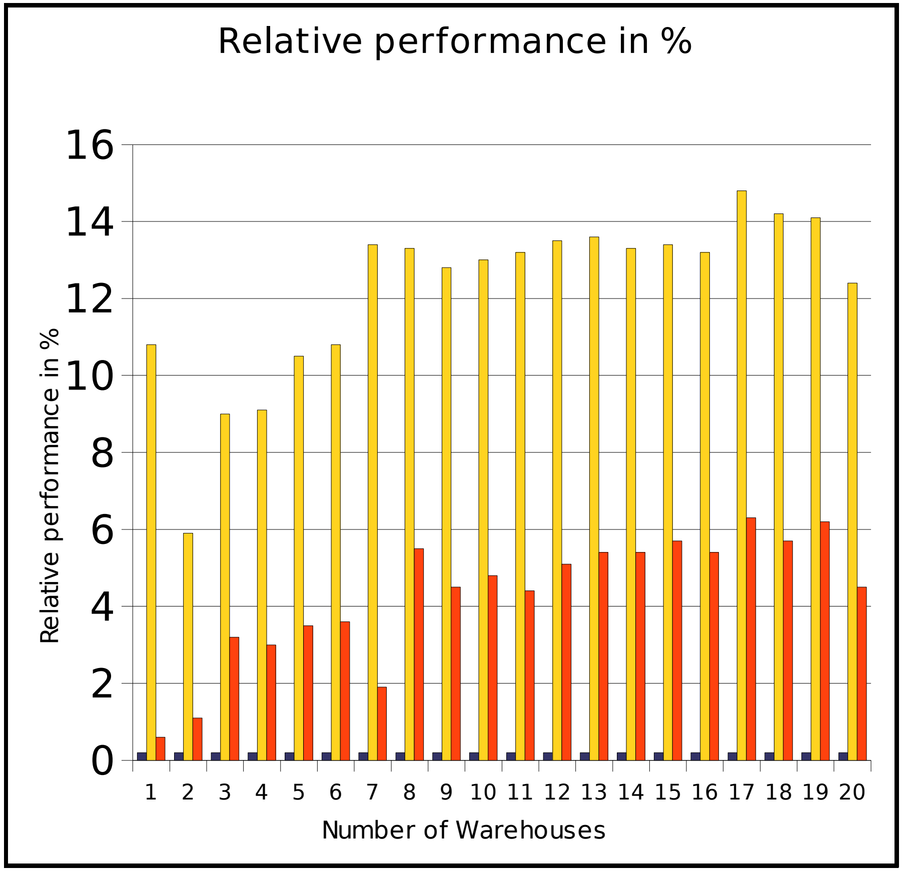




Java on servers: 31-bit vs. 64-bit

- use of **-Xcompressedrefs** provides relief for 64-bit (new in Java SE 6 SR2)
- smaller size of 64-bit heap objects





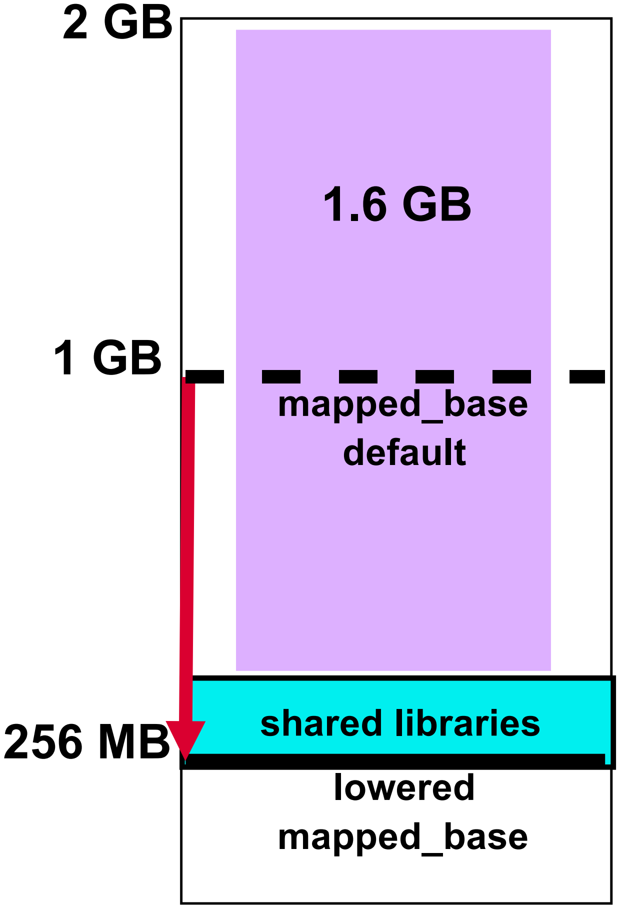
Java on servers: larger heaps for 31-bit Java kits (1)

- modify Linux memory layout
  - reorder mapped base for shared libraries
- 31-bit emulation mode for Novell SLES 9,10

HOWTO:

- PID is the process ID of the process you want to change the layout (usually the bash shell)
  - $$ gives the current shell **PID**, /proc/self/... works as well
- display memory map of any PID by
  - **cat /proc/<PID>/maps**
- check the mapped base value by
  - **cat /proc/<PID>/mapped_base**
- lower the value to e.g. 256 MB by
  - **echo 268435456 >/proc/<PID>/mapped_base**

==> retry to allocate a larger heap size



Java on servers: larger heaps for 31-bit Java kits (2)

- modify Linux memory layout
  - RHEL includes flex-mmap patch; turn off Linux prelinking
- applies RHEL 4,5 distributions (31-bit emulation mode)

HOWTO:

- show state of flex-mmap patch
  - **cat /proc/sys/vm/legacy_va_layout**
  - 0 means flex-mmap is enabled; 1 means old memory layout
- enable flex-mmap if disabled
  - **echo 0 > /proc/sys/vm/legacy_va_layout**
- disable Linux prelinking
  - in **/etc/sysconfig/prelink** set PRELINKING=no
- apply setting by running the daily cron prelink job immediately
  - **# /etc/cron.daily/prelink** <ENTER>

==> retry to allocate a larger heap size

Java on servers: Summary & Hints

- try to use the latest **Java version**
  - up to 60% release to release improvements
  - up to 15% with newer service releases (SR) for a release
  - middleware applications often bring their own Java Kit
- make sure that you've got **JIT enabled**
  - command 'java -version' says “JIT enabled/disabled”
- lots of java interpreter **-X...** parameters for fine tuning
  - to get an idea type 'java -X'
- provide an optimal **heap size** to your application
- don't use the java interpreter in batch mode – call x-times 'java Myprog'
  - try to put the loop logic into your Java application

CPU hotplug function

- Changes the number of used processors on the fly, depending on the current overall utilization and load
- available with SLES10 SP2
- Expectation:
  - **Increases the performance of single threaded applications within a z/VM or LPAR environment with multiple CPUs**
- Enables or disables CPUs based on a set of rules
- Is enabled in the kernel configuration by setting

```
Base setup --->
--- Processor type and features ---
...
Symmetric multi-processing support (CONFIG_SMP)
 └─Support for hot-pluggable CPUs (CONFIG_HOTPLUG_CPU)
```

CPU hotplug parameters

- The configuration information is stored at `/etc/sysconfig/cpuplugd`
- Minimum number of CPUs is set with `cpu_min="<number>"`
- Maximum number of CPUs is set with `cpu_max="<number>"`
  - `0 means number of detected CPUs`
- The update interval is set with `update="<value in seconds>"`
  - `Default is 10 seconds`
- Consider the effect of kernel "cpu" parameters:
  - `maxcpus=<n>` sets the number of processors which will be active after system boot
  - `possible_cpus=<n>` is the upper limit for hotpluggable CPUs
  - If `possible_cpus` is not specified but `maxcpus` is, then `maxcpus` is the upper limit for hotpluggable CPUs

CPU hotplug rules

- The default rule for increasing the number of CPUs is

  ```
  HOTPLUG="(loadavg > onumcpus + 0.75) & (idle < 10.0)”
  ```

  - An additional CPU is enabled, if the loadaverage is greater than the number of active (online) CPUs plus 0.75 and the current idle percentage is less than 10 percent.
- The default rule for decreasing the number of CPUs is

  ```
  HOTUNPLUG="(loadavg < onumcpus - 0.25) | (idle > 50)”
  ```

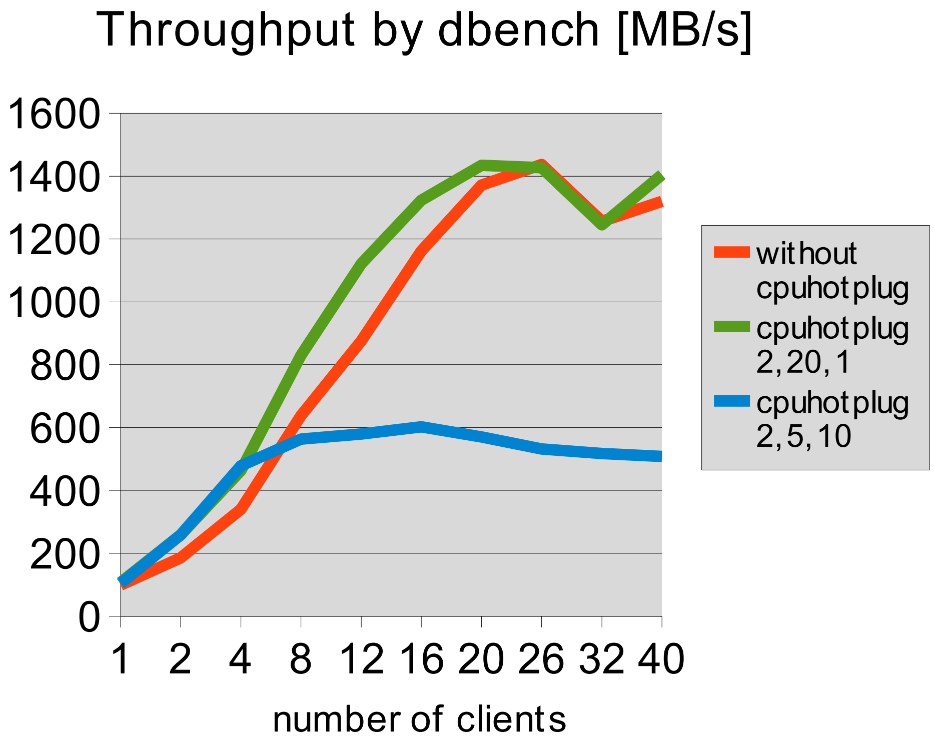
  - A CPU is disabled, either if the current load is below the number of active CPUs minus 0.25 or if the idle percentage is greater than 50%.
- The formulas for these rules can be modified. See “Device Drivers, Features and Commands” for valid expressions.
- Note:
  - `loadavg` is a value that changes slowly
  - `idle` changes fast
  - Increments and decrements of active CPUs are done in steps of 1 every time when the rules are checked.

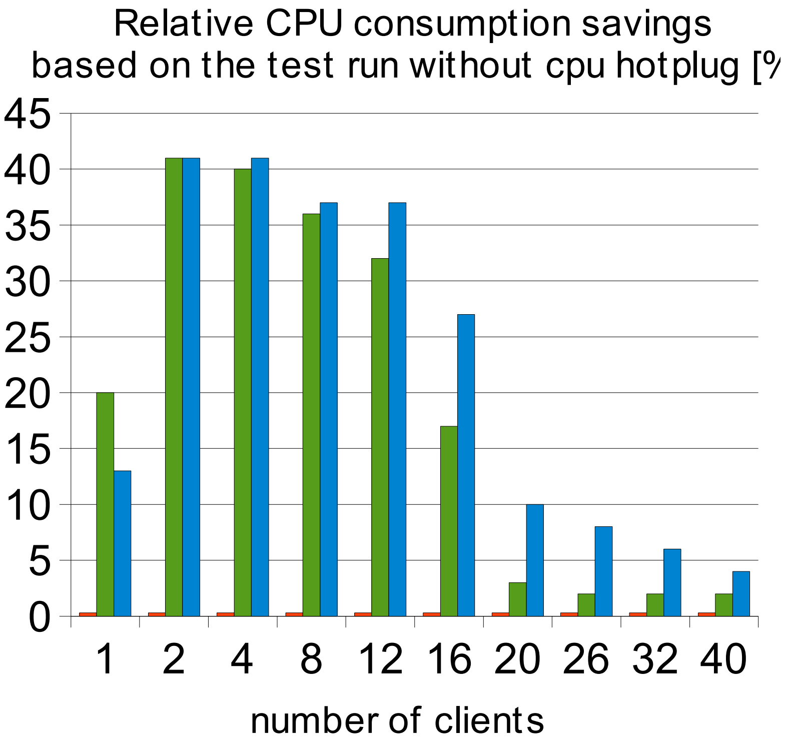
CPU hotplug test workload

- dbench 3
  - Emulation of Netbench benchmark, rates windows file servers
  - Mainly memory operations (large page cache)
  - Mixed file operations workload for each process: create, write, read, append, delete
  - Scaling with 1,2,4,8,16 CPUs and 1,4,8,12,16,20,26,32 and 40 clients
  - 20 CPUs available, 2 GB memory
- Modification to the standard code:
  - Purpose:
    - Need more interaction between clients
  - Create two processes per client and communicate with POSIX message queues
  - First process:
    - Read the I/O commands from the control file
    - Pass this information to the second process
  - Second process:
    - Performs the execution of this command
    - Reports the end of the operation back to the first process

CPU hotplug performance results

- Improvements in case where the default (high) number of CPUs is not needed
- Up to 40% more throughput, up to 40% CPU cost savings



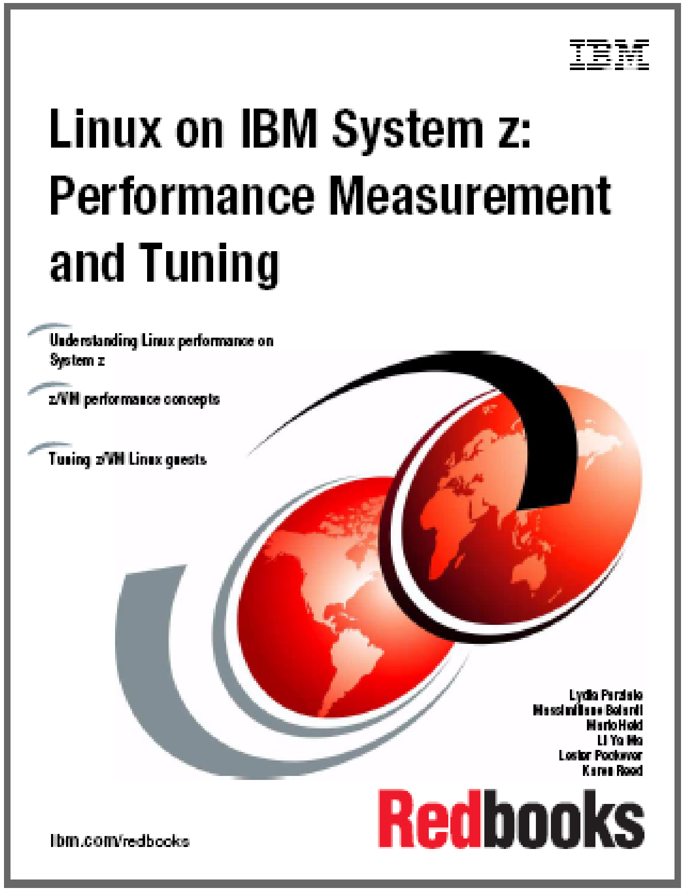


CPU hotplug summary

- This feature improves the performance by
  - sizing the correct amount of processors for a Linux system depending on its current load
  - avoiding the Linux scheduler queue balancing in partial load situations
- Set the minimum and maximum number of CPUs to values which apply to the real workload:
  - Setting `cpu_min` to 2 may be too high
  - `cpu_max` should be set so that it really covers the peaks
- Linux guests under z/VM: use z/VM 5.4
  - Guarantees that stopped processors are no longer included in virtual processor prioritization calculations
  - Ensures share redistribution

Visit us !

- Linux on System z: Tuning Hints & Tips
  - http://www.ibm.com/developerworks/linux/linux390/perf/
- Linux-VM Performance Website:
  - http://www.vm.ibm.com/perf/tips/linuxper.html
- IBM Redbooks
  - http://www.redbooks.ibm.com/



IBM

Linux on IBM System z: Performance Measurement and Tuning

Understanding Linux performance on System z

z/VM performance concepts

Tuning z/VM Linux guests

Lydia Parziale
Massimiliano Belardi
Mario Held
Li Ya Mo
Lester Peckover
Karen Reed

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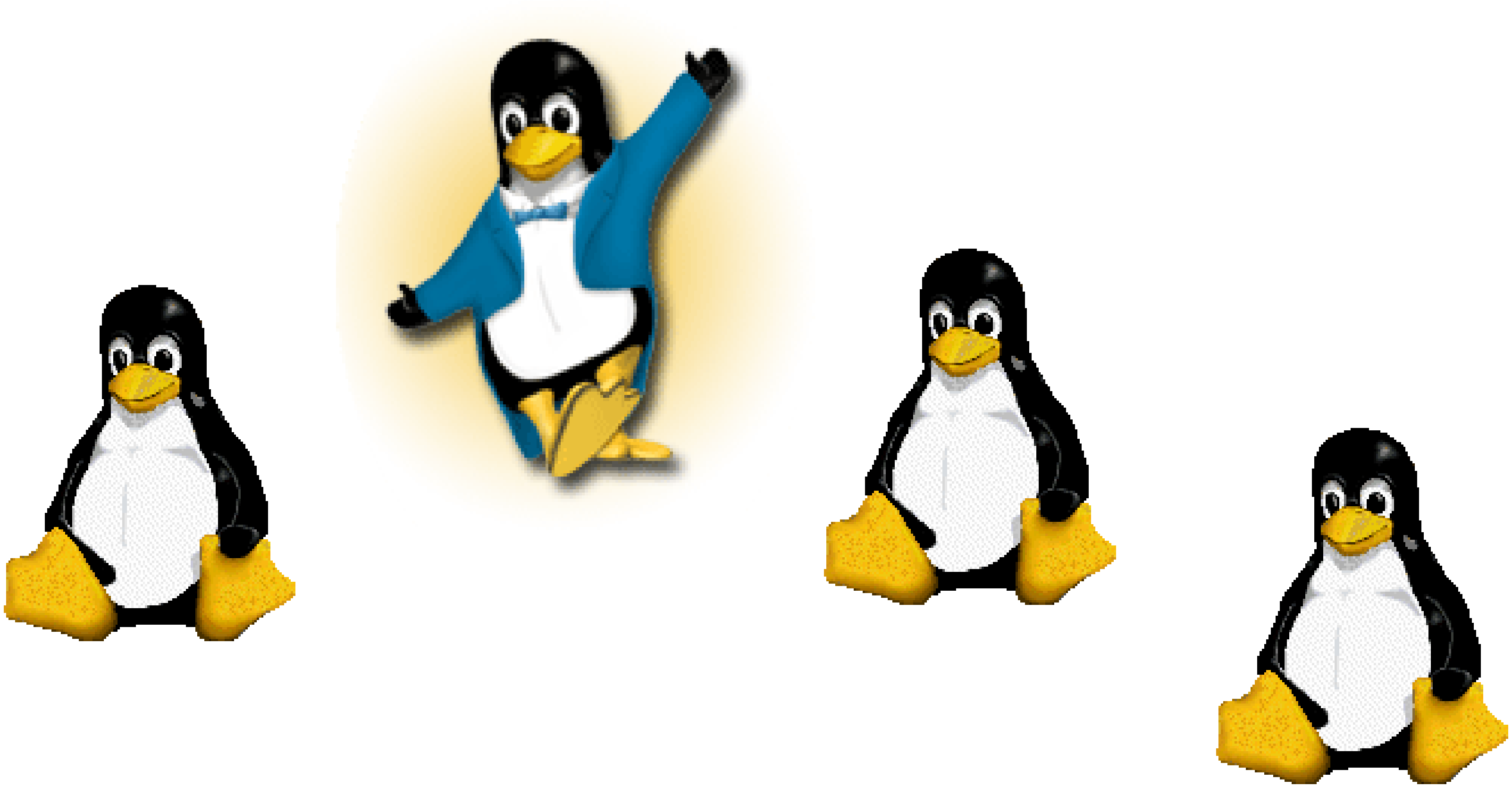
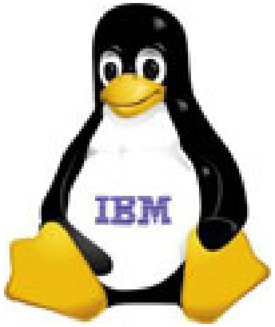
Questions



BACKUP



oprofile – the Open Source sampling tool

- oprofile offers profiling of all running code on Linux systems, providing a variety of statistics
  - By default, kernel mode and user mode information is gathered for configurable events
- System z hardware currently does not have support for hardware performance counters, instead timer interrupt is used
  - Enable the hz_timer(!)
- The timer is set to whatever the jiffy rate is and is not user-settable
- Novell / SUSE: OProfile is on the SDK CDs
- More info at:
  - http://oprofile.sourceforge.net/docs/
  - http://www.redhat.com/docs/manuals/enterprise/RHEL-4-Manual/sysadmin-guid

oprofile – short HowTo

```
sysctl -w kernel.hz_timer=1
gunzip /boot/vmlinux-2.6.16.46-0.4-default.gz
```

– specify the kernel level of `uname -r`

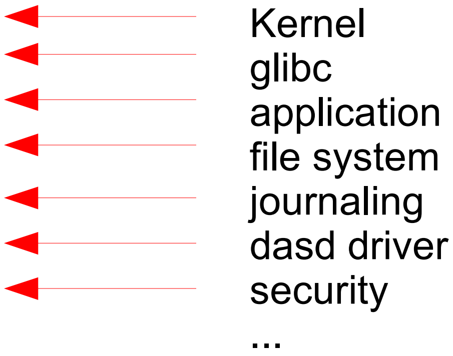
```
opcontrol --vmlinux=/boot/vmlinux-2.6.16.46-0.4-default
opcontrol --start

<DO TEST>

opcontrol --shutdown
opreport
```

any next test to run? If yes

```
opcontrol --reset
```

opreport

```
>opreport
CPU: CPU with timer interrupt, speed 0 MHz (estimated)
Profiling through timer interrupt
          TIMER:0|
  samples|      %|
------------------
   140642 94.0617 vmlinux-2.6.16.46-0.4-default
     3071  2.0539 libc-2.4.so
     1925  1.2874 dbench
     1922  1.2854 ext3
     1442  0.9644 jbd
      349  0.2334 dasd_mod
      152  0.1017 apparmor
        6  0.0040 oprofiled
        5  0.0033 bash
        5  0.0033 ld-2.4.so
        1 6.7e-04 dasd_eckd_mod
        1 6.7e-04 oprofile
```



Kernel
glibc
application
file system
journaling
dasd driver
security
...

opreport -l

```
>opreport -l
warning: /apparmor could not be found.
warning: /dasd_eckd_mod could not be found.
warning: /dasd_mod could not be found.
warning: /ext3 could not be found.
warning: /jbd could not be found.
warning: /oprofile could not be found.
CPU: CPU with timer interrupt, speed 0 MHz (estimated)
Profiling through timer interrupt
samples  %        app name                 symbol name
130852   87.5141  vmlinux-2.6.16.46-0.4-default cpu_idle
1922      1.2854  ext3                     (no symbols)
1442      0.9644  jbd                      (no symbols)
734       0.4909  vmlinux-2.6.16.46-0.4-default memcpy
662       0.4427  libc-2.4.so              strchr
619       0.4140  dbench                   next_token
567       0.3792  vmlinux-2.6.16.46-0.4-default do_gettimeofday
536       0.3585  vmlinux-2.6.16.46-0.4-default __link_path_walk
525       0.3511  vmlinux-2.6.16.46-0.4-default copy_to_user_std
435       0.2909  libc-2.4.so              strstr
413       0.2762  dbench                   child_run
349       0.2334  dasd_mod                 (no symbols)
347       0.2321  vmlinux-2.6.16.46-0.4-default _spin_lock
328       0.2194  vmlinux-2.6.16.46-0.4-default sysc_do_svc
285       0.1906  dbench                   all_string_sub
283       0.1893  vmlinux-2.6.16.46-0.4-default __d_lookup
251       0.1679  vmlinux-2.6.16.46-0.4-default __find_get_block
231       0.1545  libc-2.4.so              ____strtol_l_internal
216       0.1445  dbench                   vsnprintf
209       0.1398  vmlinux-2.6.16.46-0.4-default filldir64
205       0.1371  vmlinux-2.6.16.46-0.4-default memset
196       0.1311  vmlinux-2.6.16.46-0.4-default _atomic_dec_and_lock
166       0.1110  vmlinux-2.6.16.46-0.4-default strchr
155       0.1037  libc-2.4.so              memmove
152       0.1017  apparmor                 (no symbols)
148       0.0990  libc-2.4.so              readdir
147       0.0983  vmlinux-2.6.16.46-0.4-default __brelse
146       0.0976  vmlinux-2.6.16.46-0.4-default generic_file_buffered_write
144       0.0963  vmlinux-2.6.16.46-0.4-default generic_permission
140       0.0936  vmlinux-2.6.16.46-0.4-default __getblk
140       0.0936  vmlinux-2.6.16.46-0.4-default kmem_cache_free
```

almost idle

unresolved symbols

opreport -l --image-path=...

```
>opreport -l --image-path=/lib/modules/2.6.16.46-0.4-default/kernel/fs/ext3/,/lib/modules/2.6.16.46-0.4-
default/kernel/fs/jbd/,/lib/modules/2.6.16.46-0.4-default/kernel/drivers/s390/block/,/lib/modules/2.6.16.46-
0.4-default/kernel/security/apparmor/,/lib/modules/2.6.16.46-0.4-default/kernel/arch/s390/oprofile
CPU: CPU with timer interrupt, speed 0 MHz (estimated)
Profiling through timer interrupt
samples  %        image name               app name                 symbol name
130852   87.5141  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default cpu_idle
734        0.4909  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default memcpy
662        0.4427  libc-2.4.so              libc-2.4.so              strchr
619        0.4140  dbench                   dbench                   next_token
567        0.3792  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default do_gettimeofday
536        0.3585  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default __link_path_walk
525        0.3511  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default copy_to_user_std
435        0.2909  libc-2.4.so              libc-2.4.so              strstr
413        0.2762  dbench                   dbench                   child_run
361        0.2414  ext3.ko                  ext3                     ext3_get_block_handle
347        0.2321  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default _spin_lock
328        0.2194  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default sysc_do_svc
285        0.1906  dbench                   dbench                   all_string_sub
283        0.1893  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default __d_lookup
251        0.1679  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default __find_get_block
231        0.1545  libc-2.4.so              libc-2.4.so              ____strtol_l_internal
226        0.1511  ext3.ko                  ext3                     ext3_try_to_allocate
223        0.1491  dasd_mod.ko              dasd_mod                 dasd_smalloc_request
216        0.1445  dbench                   dbench                   vsnprintf
209        0.1398  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default filldir64
205        0.1371  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default memset
196        0.1311  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default _atomic_dec_and_lock
188        0.1257  ext3.ko                  ext3                     ext3_new_inode
166        0.1110  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default strchr
157        0.1050  jbd.ko                   jbd                      journal_init_dev
155        0.1037  libc-2.4.so              libc-2.4.so              memmove
148        0.0990  libc-2.4.so              libc-2.4.so              readdir
147        0.0983  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default __brelse
146        0.0976  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default generic_file_buffered_write
144        0.0963  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default generic_permission
140        0.0936  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default __getblk
140        0.0936  vmlinux-2.6.16.46-0.4-default vmlinux-2.6.16.46-0.4-default kmem_cache_free
```