



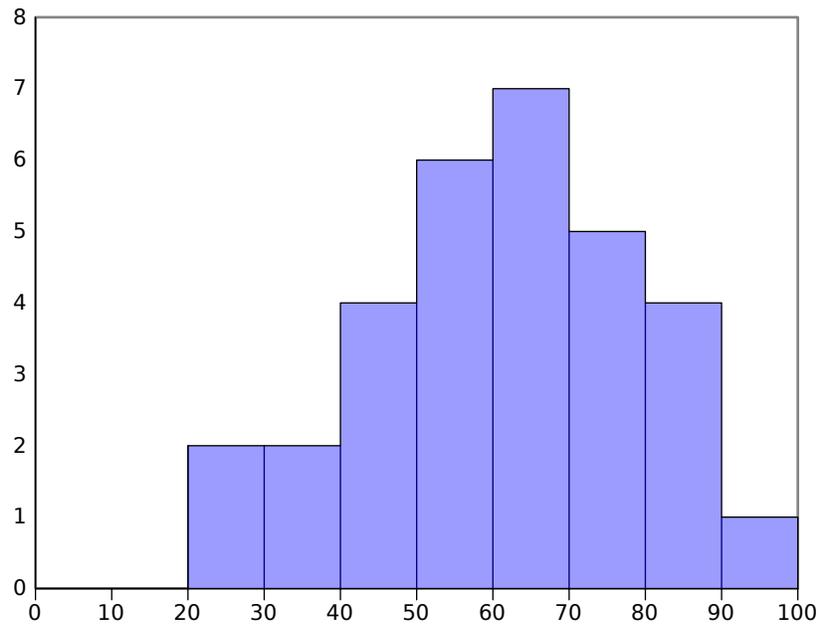
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Quiz II Solutions

Mean 61.3 Median 64 Std. dev. 17.2



I Paper questions

1. [6 points]: Many disks have a cache of disk blocks inside the disk and reorder writes to get better performance. Such reordering could cause problems for the version of ext3 as described by Tweedie in “Journaling the Linux ext2fs Filesystem;” give a scenario that results in inconsistent file system metadata structures.

Answer: A journal flush writes out a sequence of metadata blocks and then updates a header block to point to the new head of the journal. If the header block is flushed to disk before the others and then the power fails, upon recovery the file system will try to replay stale records from the journal.

2. [6 points]: How could you extend ext3 to fix this problem without disabling the disk’s cache?

Answer: We could extend the header block to include a hash of the metadata blocks added to the journal. Upon replay, we recompute the hash of the metadata blocks found in the journal and disregard the header block if the hash doesn’t match.

3. [6 points]: KeyKOS’s use of capabilities is motivated by the “confused deputy” problem. Give an example of the confused deputy problem in Unix. Give an example how a KeyKOS application developer uses capabilities to avoid your example of the confused deputy problem in Unix.

Answer: The paper gives an example of a compiler service that also tracks billing information. If the compiler is passed the path to the billing information as the output file, it can overwrite the billing information because the system can’t distinguish between the compiler operating as its own principle and it operating on behalf of the user’s principle. In KeyKOS, the compiler must provide a key for each file access, forcing the compiler-writer to specify the capability with the right permissions.

4. [6 points]: To track dependencies introduced by Unix system calls, BackTracker (as described in “Backtracking Intrusions” by King and Chen) maintains objects for processes, files, and filenames. Ben thinks it’s redundant to maintain both file objects, which identify files by inode numbers, and file-name objects, which identify files by absolute path. He proposes modifying BackTracker to collapse the two into just filename objects, identifying files solely by their absolute path. Alyssa argues that this change will make BackTracker inaccurate (i.e., BackTracker could fail to identify an attack that influences a suspicious file or process). Give an example showing that Alyssa is correct.

Answer: Consider a file with two hard-linked path names. The attacker could write to one of these path names and if a legitimate application then reads from the other path name, Ben’s BackTracker will miss this dependency.

5. [6 points]: Louis Reasoner proposes to extend BackTracker to recover from attacks by undoing all the attacker’s actions, but not regular user actions. Using BackTracker, he can identify the starting event of an attack. He proposes to first use ReVirt to roll the system back to just before that starting event. For example, for the attack in Figure 1 of the paper, he would roll the system back to just before the “[sh,bash]” process was created. He would then *selectively* roll the system forward using ReVirt, skipping all the events that could have been influenced by the attacker, according to the dependencies that BackTracker has computed. For example, Louis’ extension would not replay any operation that depended on the “[sh,bash]” node. Ben points out that this approach may fail to re-execute regular user actions. Give an example showing that Ben is right.

Answer: Just because an event depends on one of the events involved in the attack doesn’t mean that the attack depends on that event. Suppose the attacker creates a file in `/tmp` and then a legitimate user runs `ls -l /tmp`. This will create a dependency from the legitimate user’s actions to the file involved in the attack. `ls` only observed the attack; it did not partake in it.

6. [6 points]: Figure 8 in the Klee paper (“Unassisted and automatic generation of high-coverage tests for complex systems programs”) shows an example of a bug found by Klee in the `pr` utility. Specially, executing `pr -e t2.txt` will result in a buffer overflow if `t2.txt` has the content:

```
\b\b\b\b\b\b\b\b\t
```

Explain how Klee is able to construct this input.

Answer: Somewhere in `pr`, there must be a conditional in a loop that checks if the next character is `\b`. When KLEE encounters this conditional, it will fork the program and one fork will force the value of the character to be `\b`. Eventually, KLEE will construct a sequence of `\b` characters, encounter the conditional for the `\t`, and discover the buffer overflow in this symbolic execution path.

II Lock-free data structures

Joe Buck is increasing the performance of the the Linux physical page allocator using a lock-free LIFO data structure to track free pages. He reasons that recently freed pages will still be in on-chip hardware caches, so allocating those pages first will improve performance. Joe Buck's code for the lock-free LIFO is below.

```
// Compare the value at addr with oldval. If equal, store newval
// at addr and return 1, otherwise return 0. Executes atomically.
int cmpxchg(void *addr, uint32_t oldval, uint32_t newval);

struct page {
    struct page *next;
    /* Other page metadata ... */
};
struct page *head;

void push(struct page *page) {
    while (1) {
        page->next = head;
        if (cmpxchg(&head, (uint32_t)page->next, (uint32_t)page))
            break;
    }
}

struct page * pop(void) {
    while (1) {
        struct page *page = head;
        if (page == NULL)
            return NULL;
        struct page *next = page->next;
        if (cmpxchg(&head, (uint32_t)page, (uint32_t)next))
            return page;
    }
}
```

7. [10 points]: Unfortunately Joe Buck's code has a race condition. Describe a sequence of events for two CPUs that could cause the LIFO to be in an inconsistent state (that is, an allocated page appears in the LIFO or an unallocated page does not appear in the LIFO). For your convenience, we provided the first two events of a sequence; your job is to add the others.

1. Initially, $head \rightarrow \text{page A} \rightarrow \text{page B} \rightarrow \text{page C} \rightarrow \text{NULL}$.
2. CPU 1 starts to pop; it sets $page = A$ and $next = B$.

Answer:

3. CPU 2 pops A, now $head \rightarrow \text{page B} \rightarrow \text{page C} \rightarrow \text{NULL}$
4. CPU 2 pops B, now $head \rightarrow \text{page C} \rightarrow \text{NULL}$
5. CPU 2 pushes A, now $head \rightarrow \text{page A} \rightarrow \text{page C} \rightarrow \text{NULL}$
6. CPU 1 sees that $head == A$ and sets $head = B$, now page B, which is allocated, appears in the LIFO.

8. [10 points]: Some CPUs provide atomic instructions that make it easier to write lock-free code. For example, PowerPC CPUs provide the Load-Linked and Store-Conditional instructions. LL must be paired with a SC. LL loads a value from memory and the CPU remembers that the address is load-linked. SC stores a value to an address if the address has not been written to by any other CPU since the corresponding LL. Write a correct lock-free LIFO implementation that uses LL and SC.

```
// Return the 32-bit value at addr and remember addr is load-linked.
uint32_t ll(void *addr);
// Store val at addr if *addr has not been written to since the last ll from addr.
// Return 0 on failure, 1 on success.
int sc(uint32_t val, void *addr);

void push(struct page *page) {
```

Answer:

```
while (1) {
    page->next = (struct page*)ll(&head);
    if (sc((uint32_t)page, &head))
        break;
}
```

```
}
```

```
struct page * pop(void) {
```

Answer:

```
while (1) {
    struct page *page = (struct page*)ll(&head);
    if (p == NULL)
        return NULL;
    if (sc((uint32_t)page->next, &head))
        return page;
}
```

```
}
```

III VMM

Many x86 CPUs now have support in hardware for CPU, MMU, and IO port virtualization. The CPU virtualization features provide each guest VM with its own segment/interrupt descriptor tables, control registers, and segment registers. A virtual machine monitor (VMM) can use CPU virtualization to trap a VM when it executes an instruction or causes an event that could affect the VMM or other VMs. IO port virtualization allows VMMs to control VM access to IO ports, trapping into the VMM when the VM accesses certain IO ports.

9. [6 points]: AMD virtualization hardware allows the VMM to intercept certain CPU instructions and events by setting bits in a bitmask. As discussed in Section 4.4 of “A Comparison of Software and Hardware for x86 Virtualization” the performance of a VMM depends on the frequency of exits from the VM. To help avoid frequent exits, AMD hardware copies (or shadows) CPU state into a Virtual Machine Control Block (VMCB). Guest instructions that manipulate CPU state (e.g. `lcr0`) operate on the shadow state instead of the real CPU state. Circle the instructions that the VMM *must* intercept, because it is not possible to shadow the state they manipulate.

- Instructions that read or write control registers (e.g. `cr3`)
- Instructions that cause the computer to shutdown
- Instructions that load descriptor tables (e.g. `lgdt`)
- Instructions that clears cache contents without writing back to memory
- `pushf` and `popf`
- `iret`

10. [6 points]: You are unhappy with the performance of networking in JOS. On x86 hardware, port-based IO is not optimized and JOS’s e100 driver is executing many `in` and `out` instructions, which hurt performance. The e100 exposes all of the same control registers using memory-mapped IO, which is much faster than port-based IO. Suppose we’re running JOS in a virtual machine, but giving it direct access to our host’s e100 card. Describe how you might use dynamic binary translation in the VMM to transparently convert JOS’s e100 driver from using `in` and `out` port-based IO to using memory-mapped IO.

Answer: When the binary translator encounters an `in` or `out` instruction, it should replace the instruction with the appropriate memory load or store from the corresponding memory-mapped register.

11. [10 points]: Modern MMU virtualization hardware works as described in Section 7.4 of “A Comparison of Software and Hardware for x86 Virtualization.” As usual, guest VMs create *guest page tables* that translate from guest virtual addresses to guest physical addresses. However, with MMU virtualization, guest physical addresses are then further translated through a *nested page table*, created by the VMM, which maps guest physical addresses to host physical addresses.

When preparing a VM to run, the VMM must allocate physical pages for the guest’s memory and initialize this nested page table. Write the code to do this below. Your implementation should allocate `npages` host physical pages and map them in the page table `pgdir` starting at guest physical address 0. Return 0 from the function on success, or return a negative value on an error.

```
/* Helper functions from JOS */
int    page_insert(pde_t *pgdir, struct Page *pp, void *va, int perm);
int    page_alloc(struct Page **pp_store);
physaddr_t page2pa(struct Page *pp);

/* Guest permission bits */
#define PTE_GUEST      (PTE_P|PTE_W|PTE_U)

int
vm_init_mem(unsigned int npages, pde_t *pgdir)
{
```

Answer:

```
int i, r;
for (i = 0; i < npages; i++) {
    if ((r = page_alloc(&p)) < 0)
        return r;
    if ((r = page_insert(pgdir, p, (void*)(i*PGSIZE), PTE_GUEST)) < 0)
        return r;
}
return 0;

}
```

IV High-performance JOS

12. [10 points]: Ben, a little sleep-deprived from the network lab, dreams of turning JOS into the next big, high-performance web serving platform. He took the easy route in his network lab and made his receive syscall always return immediately, even if no packet is available, which is less than ideal for CPU utilization. He starts by making his receive syscall block, much like `sys_ipc_recv`.

Ben keeps around his old non-blocking receive function for use in the new implementation. Now that he's no longer polling, he configures the `e100` to generate an interrupt whenever it puts a packet in the receive ring and installs `e100_rx_intr` as the interrupt handler. Finally, since only one environment can receive at a time, he adds a few global variables to track the currently receiving environment.

```
// Copy the next packet into dst and return the length of the packet.
// If the receive ring is empty, return 0.
int e100_recv_nonblocking(void *dst);

// Environment currently blocked on receive, or NULL if none.
struct Env *e100_receiver;
// Packet buffer of the currently receiving environment.
void *e100_receiver_dst;
```

Give pseudo-code for the new blocking syscall implementation and for `e100_rx_intr`. You can assume `dst` is a valid pointer to a sufficiently large buffer.

```
int sys_e100_recv(void *dst) {
```

Answer:

```
if (e100_receiver)
    return -EINVAL;
if ((r = e100_recv_nonblocking(dst)) > 0)
    return r;
e100_receiver = curenv;
e100_receiver_dst = dst;
curenv->env_status = ENV_NOT_RUNNABLE;
sched_yield();
}
```

```
void e100_rx_intr(void) {
    // Acknowledge the interrupt. Otherwise, the e100 blocks further interrupts.
    e100_ack_rx();
}
```

Answer:

```
if (!e100_receiver) return;
lcr3(e100_receiver->cr3);
e100_receiver->env_tf.tf_regs.tf_eax =
    e100_recv_nonblocking(e100_receiver_dst);
e100_receiver->env_status = ENV_RUNNABLE;
e100_receiver = NULL;
lcr3(curenv->cr3);
}
```

13. [6 points]: Is your solution susceptible to receive livelock? If so, give a scenario that demonstrates the livelock. If not, explain why not.

Answer: No. If the user environment isn't keeping up with the incoming packets, the receive ring will fill up, the e100 will start dropping packets, and will stop generating interrupts until space is freed up in the ring. Packets are only removed from the receive ring when the user environment is ready to process them, which puts back-pressure on card. At most one interrupt will be generated per packet fully processed by the user environment.

V 6.828

We'd like to hear your opinions about 6.828, so please answer the following questions. (Any answer, except no answer, will receive full credit.)

14. [2 points]: The network lab took more time on average than we had intended. What would have saved you the most time? If it's test cases, which test cases would you add? If it's documentation, what would you like documentation on?

15. [2 points]: What is the best aspect of 6.828?

16. [2 points]: What is the worst aspect of 6.828?

End of Quiz

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