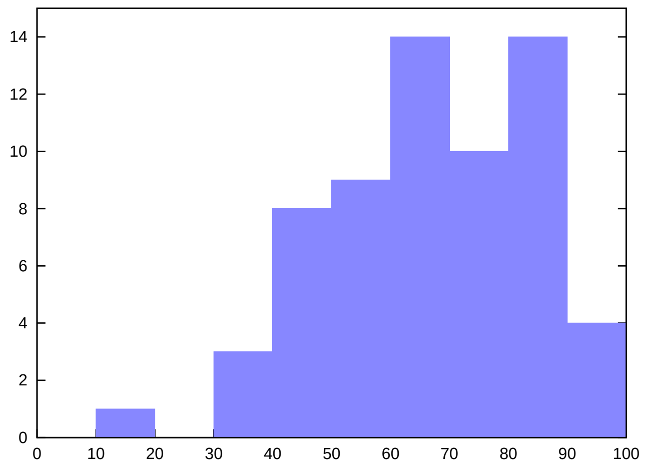
Department of Electrical Engineering and Computer Science

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

6.828 Fall 2012

Quiz I Solutions

Mean 65 Median 66 Std. dev 17.5214



I Shell

The xv6 shell creates new processes to run a command as follows:

```
if(fork1() == 0)
  runcmd(parsecmd(buf));
wait();
```

1. [5 points]: It is possible that the child process that runs the command exits before the parent calls `wait`. Give a scenario in which that can happen.

Answer: Yes. After the parent forked the child, the kernel may decide to run the child first. It may execute the command and exit before the kernel runs the parent again.

2. [6 points]: How does xv6 ensure that `wait` returns correctly even if the child already has exited before the parent called `wait`?

Answer: The kernel keeps track of processes that have exited but for which the parent hasn't called `wait`. Such processes are in the zombie state.

II Locks

In the in-class exercises on locking you modified a hash table to work correctly under concurrent lookup and insert by adding `acquire` and `release` statements for a global lock. The code we handed out for `put` is as follows:

```
static void
insert(int key, int value, struct entry **p, struct entry *n)
{
  struct entry *e = malloc(sizeof(struct entry));
  e->key = key;
  e->value = value;
  e->next = n;
  *p = e;
}

static
void put(int key, int value)
{
  struct entry *n, **p;
  for (p = &table[key%NBUCKET], n = table[key % NBUCKET];
                       n != 0; p = &n->next, n = n->next) {
    if (n->key > key) {
      insert(key, value, p, n);
      goto done;
    }
  }
  insert(key, value, p, n);
 done:
  return;
}
```

3. [4 points]: In your solutions for the in-class exercise, you added in the above code `acquire` and `release` calls to ensure correct operation of concurrent `put` invocations. Indicate where in the above code they should be added.

Answer: Put an acquire for a lock before the for loop and put the corresponding release after done but before the return statement.

To avoid the overhead of locks, Alyssa suggests use of atomic operations, which are guaranteed to perform their multiple step operation as a single atomic operation. In particular, Alyssa suggests use of the following atomic operation:

```
bool __sync_bool_compare_and_swap (type *ptr, type oldval, type newval)
```

This builtin function performs an atomic compare and swap. If the current value of `*ptr` is `oldval`, it writes `newval` into `*ptr`, and returns `true`. Otherwise it returns `false`. The compiler turns the builtin function into the atomic instruction sequence that's appropriate for the target architecture; on the x86, it might use `lock cmpxchg`.

An example:

```
char *p;
  ...
  if(__sync_bool_compare_and_swap(&p, 0, 1))
    ....  // success: p was set to 1
  else
    ...   // failure: p was not set to 1, because p wasn't equal to 0
```

This code will set `p` to `1` only if `p` previously held `0`. If two cores execute the code at the same time, and `p` held `0`, only one of the two cores will see a `true` return value from the call.

4. [8 points]: Complete the `put` below using `__sync_bool_compare_and_swap` so that concurrent invocations will run correctly without using locks:

```
static
void put(int key, int value)
{
  struct entry *n, **p;
  struct entry *e = malloc(sizeof(struct entry));
  e->key = key;
  e->value = value;




  for (p = &table[key%NBUCKET], n = table[key % NBUCKET]; n != 0;
                                      p = &n->next, n = n->next) {


    if (n->key > key) {






    }
  }






 done:
  return;
}
```

Answer: Replace the above code as follows:

```
again:
  for(p = &table...){
    if(n->key > key){
      e->next = n;
      if(__sync_bool_compare_and_swap(p, n, e) == 0)
        goto again;
      else
        goto done;
    }
  }
  e->next = 0;
  if(__sync_bool_compare_and_swap(p, 0, e) == 0)
    goto again;
```

5. [8 points]: For the lock-free implementation, give an example of a workload for which `put`'s throughput scales linearly with an increasing number of cores.

Answer: A workload in which puts use keys that hash to different buckets. These puts can run concurrently. In the lock-based implementation they will be serialized.

III Logical Logging

Alyssa is unhappy that xv6 logging writes an entire sector to the log even if the file system only needs to modify a few bytes in the sector. She observes that log records would be much shorter if they described the operation to be performed, rather than containing the entire modified sector. Alyssa modifies the xv6 logging system to use this idea, called "logical logging." For example, when her `balloc()` allocates a data block, it logs the setting of the bit in the block allocation bitmap with a "set bit" record. A "set bit" record contains a constant indicating the record type, and the block number that was allocated. Alyssa's recovery code for this type of log record sets the relevant bit in the block allocation bitmap on disk. The "set bit" record takes up only a few bytes in the log, rather than an entire sector.

While the "set bit" record works, it turns out that correct recovery from logical log records is not possible for some operations.

6. [8 points]: Alyssa defines a "create file" log record containing the parent directory i-number and the new file's name. Recovery for this kind of record calls a version of create() (sysfile.c) that does everything but the initial nameiparent(), and that uses bwrite for all modifications. Explain why use of this "create file" log record will incorrectly handle some failure scenarios that the current xv6 handles correctly.

Answer: One problem: if the system crashes during recovery for a "create file" log record, an i-node may be left allocated but not used. When the system re-starts and recovery is run again, recovery will allocate a different i-node, and the first one will never be freed.

7. [8 points]: Consider a "delete directory entry" log record that contains the parent i-number and the entry's name. Recovery finds the named entry in the parent directory and overwrites it with nulls. Explain if this works; if not, briefly explain why not.

Answer: This works. If there's a crash during recovery, it happens either before or after the disk write of the zeroed directory entry. If before, the re-run of recovery after system re-start will zero out the directory entry again, which is OK. If after, the entry will be missing, and recovery will not change the directory entry, which is also OK. This argument depends on directory entries not spanning sector boundaries, which is the case in xv6.

IV Page Tables

Consider the following 32-bit x86 page table setup.

`%cr3` holds 0x00001000.

The Page Directory Page at physical address 0x00001000:

```
PDE 0: PPN=0x00002, PTE_P, PTE_U, PTE_W
PDE 1: PPN=0x00003, PTE_P, PTE_U, PTE_W
PDE 2: PPN=0x00002, PTE_P, PTE_U, PTE_W
... all other PDEs are zero
```

The Page Table Page at physical address 0x00002000 (which is PPN 0x00002):

```
PTE 0: PPN=0x00005, PTE_P, PTE_U, PTE_W
PTE 1: PPN=0x00006, PTE_P, PTE_U, PTE_W
... all other PTEs are zero
```

The Page Table Page at physical address 0x00003000:

```
PTE 0: PPN=0x00005, PTE_P, PTE_U, PTE_W
PTE 1: PPN=0x00005, PTE_P, PTE_U, PTE_W
... all other PTEs are zero
```

8. [8 points]: List all virtual addresses that map to physical address 0x00005555.

Answer: 0x00000555, 0x00400555, 0x00401555, 0x00800555

9. [8 points]: Given the above page table, what virtual address (if any) should the kernel store to in order to modify the mapping for virtual address 0x402000 (that's 4*1024*1024 + 8192)?

Answer: There is no address to which the kernel can store in order to modify the page table, because the PPNs of the page directory and page table pages are not mentioned in any PTE. Loads and stores can only refer to virtual addresses, not physical addresses, so with this page table's mappings there's no way to refer to the memory storing the page table.

10. [8 points]: Explain exactly what the above page table should contain in order to to allow the kernel to write to the page directory page. There is more than one answer; you only have to explain one.

Answer: One possibility: PTE number 2 of the page table page at 0x00002000 should contain `PPN=0x00001, PTE_P, PTE_W`

V JOS memory mapping and fork

Here is a code snippet from Ben Bitdiddle's lab 4. Ben is struggling to get user-mode `fork` to work. In his `fork`, Ben invokes `duppage` for every virtual page number (`vpn`) below `UTOP` that is present in the current environment's address space, except for the exception stack.

```
static int duppage(envid_t envid, unsigned vpn) {
    void *addr = (void *)(vpn << PGSHIFT);
    pte_t pte = uvpt[vpn];
    int r;
    // if the page is just read-only, just map it in.
    if (!(pte & (PTE_W|PTE_COW))) {
        if ((r = sys_page_map(0, addr, envid, addr, pte & PTE_SYSCALL)) < 0)
            panic("sys_page_map␣in␣child␣failed:␣%e", r);
        return 0;
    }
    if ((r = sys_page_map(0, addr, 0, addr, PTE_P|PTE_U|PTE_COW)) < 0)
        panic("sys_page_map␣in␣parent␣failed:␣%e", r);
    if ((r = sys_page_map(0, addr, envid, addr, PTE_P|PTE_U|PTE_COW)) < 0)
        panic("sys_page_map␣in␣child␣failed:␣%e", r);
    return r;
}
```

11. [8 points]: Ben Bitdiddle could not pass the `forktree` test because the above code has a bug. While debugging, he printed out the value of `uvpt[vpn]` at the end of the function, and found that the parent environment's user stack was not marked copy-on-write. Explain why this is happening, and describe how to fix the bug. You should assume that his other code is free of bugs.

Answer: After marking its own stack COW with the first `sys_page_map` call, the environment page faults on the stack when it tries to push arguments for the next `sys_page_map`. The page fault handler for fork allocates a new page, copies the data over, and marks it not-COW. The same physical page is then installed (COW) in the child environment by the second `sys_page_map`, but because it is not COW in the parent, the child sees all updates to the parent's stack until it tries to write to its own stack and switches to a copy. This puts the stack in an invalid state by the time the child environment is run. To fix the bug, Ben should map a page COW in the child before in the parent.

VI Exokernel `exec`

Ben Bitdiddle has chosen to implement UNIX-style `exec` as his challenge exercise for lab 5. `exec` replaces the current environment's memory with the desired executable, sets up a stack, and jumps to the entry point of the executable.

Alyssa P. Hacker proposes the following design for `exec` in the user-space library operating system:

1. Unmap all pages in the current environment except for the stack and the code for `exec`.
2. Map in the pages (loaded from the ELF file on disk) for the new environment.
3. Unmap the code page for `exec`.
4. Jump to the new environment's entry point.

12. [8 points]: Ben Bitdiddle sees a problem with Alyssa's first and second steps. What might go wrong? Assume the code for `exec` fits in a single page and doesn't make any function calls (other than system calls).

Answer: If the ELF file has a section whose mapping overlaps the code for `exec`, this will not work. A workaround is to scan the ELF file for conflicts and remap the `exec` code to a new location if necessary.

13. [8 points]: There are a few other problems with Alyssa's plan. Please describe a new plan for a working `exec` in user space. Your solution shouldn't modify the kernel.

Answer: One issue is that after unmapping the code for `exec`, the environment will pagefault. A solution involves setting up and jumping to a small piece of trampoline code on the stack to issue the final unmapping syscall, perform final initialization, and jump to the entry point.

VII 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]: This year we posted an improved draft of the xv6 commentary at the beginning of the semester. Did you find the chapters useful? What should we do to improve them?

Answer: Yes, they were very useful. They could use more figures.

15. [2 points]: This year we continued code reviews and added rebuttals. Did you find them useful? What should we do to improve them?

Answer: Yes. Reading other people's code was as helpful as getting reviews.

16. [1 points]: Did you find the in-class exercises useful? How would you suggest improving them?

End of Quiz