System Level Programming

Daniel Gruss

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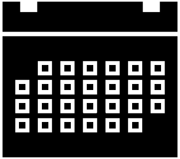
My Code



```c
void fun(size_t x)
{
  for (size_t i = 0; i < 1000000ULL; ++i)
    counter += (size_t)x;
}

int main()
{
  pthread_t t;
  pthread_create(&t,0,(void*(*)(void*))&fun,(void *)1);
  pthread_create(&t,0,(void*(*)(void*))&fun,(void *)2);
  mypause();
  printf("counter = %zu\n",counter);
  return 0;
}
```


I MULTITHREADED MY PROGRAM
THAT COMPUTES 1000000 + 2000000
THE RESULT IS 2999994
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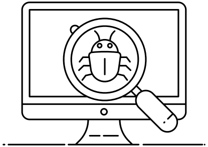
With printf debugging



```
T1 adds 1 to 550209
T1 adds 1 to 550210
T1 adds 1 to 550211
T1 adds 1 to 550212
T1 adds 1 to 550213
T1 adds 1 to 550214
T1 adds 1 to 550215     <-- look
    T2 adds 2 to 550122 <-- at
    T2 adds 2 to 550125 <-- these
    T2 adds 2 to 550127
    T2 adds 2 to 550129
    T2 adds 2 to 550131
    T2 adds 2 to 550133
```

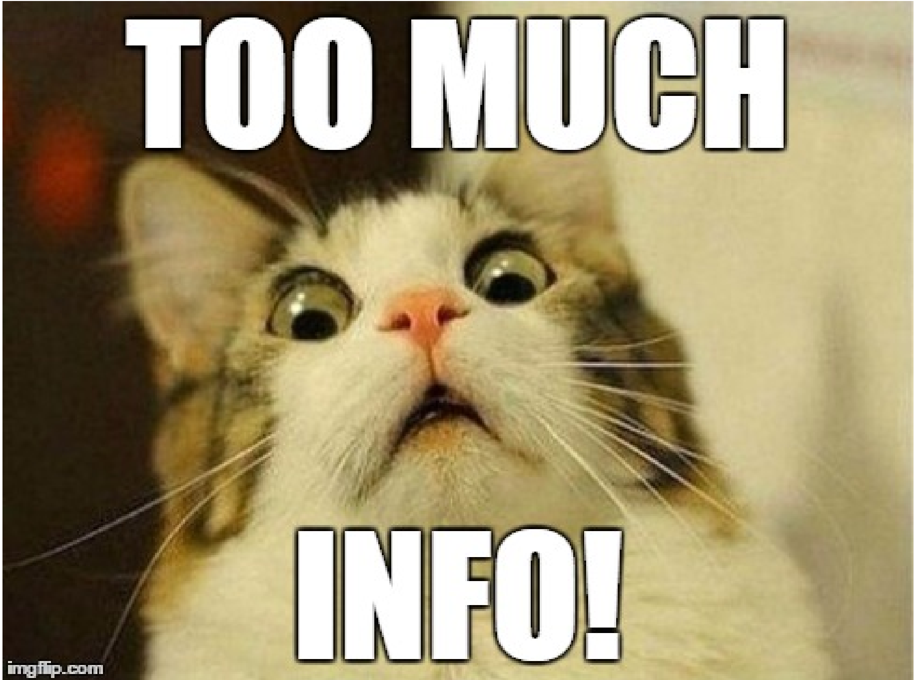
Intel® 64 and IA-32 A
Volumes: 1, 2A, 2B, 2

Last updated: November 16, 2020

› **File:**
325462-sdm-vol-1-2abcd-3abcd.pdf

› **Size:**
56.59 MB

Download


TOO MUCH
INFO!
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8.1.1 Guaranteed Atomic Operations

The Intel486 processor (and newer processors since) guarantees that the following basic memory operations will always be carried out atomically:

- Reading or writing a byte
- Reading or writing a word aligned on a 16-bit boundary
- Reading or writing a doubleword aligned on a 32-bit boundary

The Pentium processor (and newer processors since) guarantees that the following additional memory operations will always be carried out atomically:

- Reading or writing a quadword aligned on a 64-bit boundary
- 16-bit accesses to uncached memory locations that fit within a 32-bit data bus

The P6 family processors (and newer processors since) guarantee that the following additional memory operation will always be carried out atomically:

- Unaligned 16-, 32-, and 64-bit accesses to cached memory that fit within a cache line


INCREMENTS ARE NOT ATOMIC?
...
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How toilet locks work

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1. Enter public toilet room

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2. Use toilet door

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   2.1 Check color indicator (is it free?)

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     - 2.2.1 Pass through door + **lock** door

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2. Use toilet door
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    - 2.3 Else → back to step **2.1**

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4. Use toilet door again

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   - 2.3 Else $\rightarrow$ back to step **2.1**
3. Use toilet
4. Use toilet door again
   - 4.1 Pass through door + **unlock** door

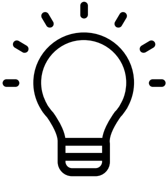
Let's code this!

Use toilet door (entry):

1. Check color indicator (is it free?)
2. If toilet is free:
   2.1 Pass through door + **lock** door
3. Else → back to step **2.1**

```
while (toilet_indicator != FREE)
{
  // busy wait - doing nothing
  // ugh, it's really urgent!
  // + i'm wasting time here
}
toilet_indicator = IN_USE;
```

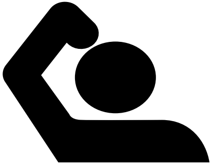
Spinlock



```
// return 0 if locking was successful
size_t lock(size_t* lock) {
  if (*lock == 0) // not locked
  {
    *lock = 1; // now locked
    return 0;
  }
  return 1;
}
```

POSIX: 0 means success!

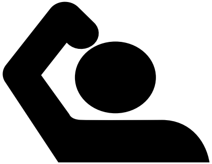
Spinlock



```
size_t lock(size_t* lock) {
  if (*lock == 0) // not locked
  {
    *lock = 1; // now locked
    return 0;
  }
  return 1;
}
```

Any problems here?

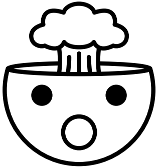
Spinlock



```
size_t lock(size_t* lock) {
  if (*lock == 0) // not locked
  {
    *lock = 1; // now locked
    return 0;
  }
  return 1;
}
```

Any problems here? It's not spinning!

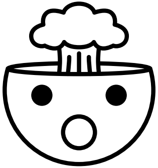
Spinlock



```
size_t lock(size_t* lock) {
  while (*lock == 1) // not locked
  {
    // busy wait
  }
  *lock = 1; // now locked
  return 0;
}
```

Any problems here?

Spinlock



```
size_t lock(size_t* lock) {
  while (*lock == 1) // not locked
  {
    // busy wait
  }
  *lock = 1; // now locked
  return 0;
}
```

Any problems here? It's not atomic!

POSIX to the rescue

```
#include <pthread.h>
int pthread_spin_lock(pthread_spinlock_t *lock);
int pthread_spin_unlock(pthread_spinlock_t *lock);
```

POSIX to the rescue

```c
#include <pthread.h>
int pthread_spin_lock(pthread_spinlock_t *lock);
int pthread_spin_unlock(pthread_spinlock_t *lock);
```

The `pthread_spin_lock()` function **locks** the spin lock referred to by `lock`. If the spin lock is currently unlocked, the calling thread acquires the lock immediately. If the spin lock is currently **locked** by another thread, the calling thread **spins**, testing the lock until it becomes available, at which point the calling thread acquires the lock.

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Idea: Instead of busy waiting,

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- wake up a sleeping thread when unlocking.

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- put thread to **sleep**,
- keep a **list of sleeping threads**,
- wake up a sleeping thread when unlocking.

→ We call this a Mutex!

Mutexes

```
#include <pthread.h>
int pthread_mutex_lock(pthread_mutex_t *mutex);
int pthread_mutex_unlock(pthread_mutex_t *mutex);
```

Mutexes

```c
#include <pthread.h>
int pthread_mutex_lock(pthread_mutex_t *mutex);
int pthread_mutex_unlock(pthread_mutex_t *mutex);
```

The mutex object referenced by `mutex` shall be locked by a call to `pthread_mutex_lock()` that returns zero. If the mutex is already locked by another thread, the calling thread shall **block until** the mutex becomes available. This operation shall return with the mutex object referenced by mutex in the locked state with the calling thread as its **owner**.

How to implement events?

```
while (go_eat == 0)
{
  pthread_mutex_lock(&food_ready_mutex);
  if (food_ready)
    go_eat = 1;
  pthread_mutex_unlock(&food_ready_mutex);
}
goEat();
```

Wait, that's busy wait AGAIN!

Condition Variables

- Synchronization mechanism

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- Not inherently thread-safe:

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Condition Variables

- Synchronization mechanism
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  - Using mutex to make it thread-safe!
- Three main operations:
  1. `wait` - wait for an event
  2. `signal` - wake up 1 waiting thread
  3. `broadcast` - wake up ALL waiting threads

Condition Variables

```
#include <pthread.h>
int pthread_cond_wait(pthread_cond_t *restrict cond, pthread_mutex_t *restrict
    mutex);
```

Condition Variables

```
#include <pthread.h>
int pthread_cond_wait(pthread_cond_t *restrict cond, pthread_mutex_t *restrict
    mutex);
```

The `pthread_cond_wait()` functions shall block on a condition variable. The application shall ensure that these functions are called with `mutex` locked by the calling thread. These functions atomically release `mutex` and cause the calling thread to block on the condition variable `cond`. Upon return, the mutex shall have been locked and shall be owned by the calling thread.

pthread_cond_wait pseudo code

```
int pthread_cond_wait(pthread_cond_t *restrict cond, pthread_mutex_t *restrict
    mutex)
{
  // atomic begin
  add_myself_to_sleepers_list();
  pthread_mutex_unlock(mutex);
  go_to_sleep();
  // atomic end
  // wait to be woken up
  pthread_mutex_lock(mutex);
}
```

Condition Variables

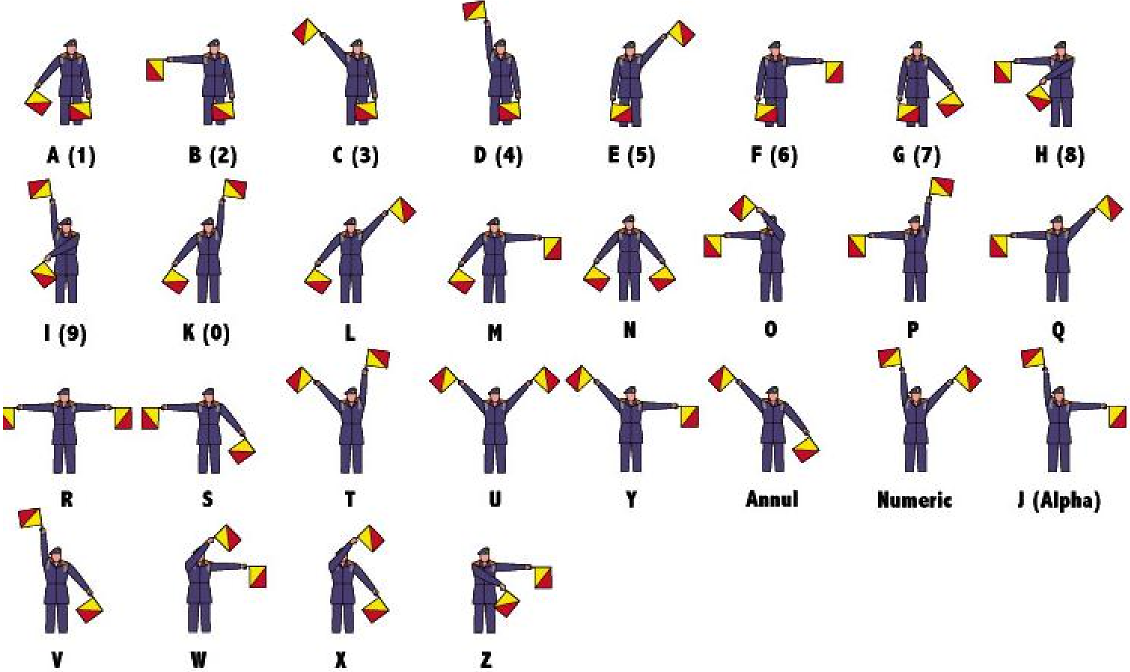
```
#include <pthread.h>
int pthread_cond_broadcast(pthread_cond_t *cond);
int pthread_cond_signal(pthread_cond_t *cond);
```

Condition Variables

```
#include <pthread.h>
int pthread_cond_broadcast(pthread_cond_t *cond);
int pthread_cond_signal(pthread_cond_t *cond);
```

The `pthread_cond_broadcast()` function shall unblock all threads currently blocked on the specified condition variable `cond`.

The `pthread_cond_signal()` function shall unblock at least one of the threads that are blocked on the specified condition variable `cond` (if any threads are blocked on `cond`).


A (1)
B (2)
C (3)
D (4)
E (5)
F (6)
G (7)
H (8)
I (9)
K (0)
L
M
N
O
P
Q
R
S
T
U
Y
Annul
Numeric
J (Alpha)
V
W
X
Z

Semaphores

- stores a numerical value ≥ 0

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- two operations:

Semaphores

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  1. `wait` $=$ decrement

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$\rightarrow$ what happens when decrementing at value 0?

Semaphores

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$\rightarrow$ what happens when decrementing at value 0?

$\rightarrow$ semaphore blocks

Semaphore vs Mutex

Mutex is basically a semaphore with

- numerical values 0 (locked) or 1 (free)

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- numerical values 0 (locked) or 1 (free)
    1. `wait` = `lock`

Semaphore vs Mutex

Mutex is basically a semaphore with

- numerical values 0 (locked) or 1 (free)
  1. `wait` = `lock`
  2. `post` = `unlock`

Semaphore vs CVs

Synchronization of events with semaphores:

- semaphores are not *owned/held* by any thread

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    1. `wait` $\approx$ `cond_wait`

Semaphore vs CVs

Synchronization of events with semaphores:

- semaphores are not *owned/held* by any thread
    1. `wait` ≈ `cond_wait`
    2. `post` ≈ `cond_signal`