CS 33

Final Words

Malloc and Threads

- Multiple threads
- One heap

Bottleneck?

Solution 1

- Divvy up the heap among the threads
  – each thread has its own heap
  – no mutexes required
  – no bottleneck
- How much heap does each thread get?
- What if one thread mallocs something and another thread frees it?

Solution 2

- **Multiple “arenas”**
  - each with its own mutex
  - thread allocates from the first one it can find whose mutex was unlocked
    - » if none, then creates new one
  - deallocations go back to original arena

Solution 3

- Global heap plus per-thread heaps
  - threads pull storage from global heap
  - freed storage goes to per-thread heap
    - » unless things are imbalanced
      - then thread moves storage back to global heap
  - mutex on only the global heap
- What if one thread allocates and another frees storage?

Malloc/Free Implementations

- **ptmalloc**
  - based on solution 2
  - in glibc (i.e., used by default)
- **tcmalloc**
  - based on solution 3
  - from Google
- **Which is best?**

Test Program

```
const unsigned int N=64, nthreads=32, iters=10000000;
int main() {
  void *tfunc(void *);
  pthread_t thread[nthreads];
  for (int i=0; i<nthreads; i++) {
    pthread_create(&thread[i], 0, tfunc, (void *)i);
    pthread_detach(thread[i]);
  }
  pthread_exit(0);
}
void *tfunc(void *arg) {
  long i;
  for (i=0; i<iters; i++) {
    long *p = (long *)malloc(sizeof(long)*((i%N)+1));
    free(p);
  }
  return 0;
}
```


Compiling It …

```
% gcc -o ptalloc alloc.cc -lpthread
% gcc -o tcalloc alloc.cc -lpthread -ltcmalloc
```


Running It (2014) …

```
$ time ./ptalloc
real    0m5.142s
user    0m20.501s
sys     0m0.024s
$ time ./tcalloc
real    0m1.889s
user    0m7.492s
sys     0m0.008s
```


What's Going On?

```
$ strace -c -f ./ptalloc
 …
% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
100.00    0.040002          13      3007       520 futex
 …


$ strace -c -f ./tcalloc
 …
% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
 …
  0.00    0.000000           0        59        13 futex
 …
```


Test Program 2, part 1

```
#define N 64
#define npairs 16
#define allocsPerIter 1024
const long iters = 8*1024*1024/allocsPerIter;
#define BufSize 10240
typedef struct buffer {
  int *buf[BufSize];
  unsigned int nextin;
  unsigned int nextout;
  sem_t empty;
  sem_t occupied;
  pthread_t pthread;
  pthread_t cthread;
} buffer_t;
```


Test Program 2, part 2

```
int main() {
  long i;
  buffer_t b[npairs];
  for (i=0; i<npairs; i++) {
    b[i].nextin = 0;
    b[i].nextout = 0;
    sem_init(&b[i].empty, 0, BufSize/allocsPerIter);
    sem_init(&b[i].occupied, 0, 0);
    pthread_create(&b[i].pthread, 0, prod, &b[i]);
    pthread_create(&b[i].cthread, 0, cons, &b[i]);
  }
  for (i=0; i<npairs; i++) {
    pthread_join(b[i].pthread, 0);
    pthread_join(b[i].cthread, 0);
  }
  return 0;
}
```


Test Program 2, part 3

```
void *prod(void *arg) {
  long i, j;
  buffer_t *b = (buffer_t *)arg;
  for (i = 0; i<iters; i++) {
    sem_wait(&b->empty);
    for (j = 0; j<allocsPerIter; j++) {
      b->buf[b->nextin] = malloc(sizeof(int)*((j%N)+1));
      if (++b->nextin >= BufSize)
        b->nextin = 0;
    }
    sem_post(&b->occupied);
  }
  return 0;
}
```

Test Program 2, part 4

```
void *cons(void *arg) {
  long i, j;
  buffer_t *b = (buffer_t *)arg;
  for (i = 0; i<iters; i++) {
    sem_wait(&b->occupied);
    for (j = 0; j<allocsPerIter; j++) {
      free(b->buf[b->nextout]);
      if (++b->nextout >= BufSize)
        b->nextout = 0;
    }
    sem_post(&b->empty);
  }
  return 0;
}
```


Running It (2014) …

```
$ time ./ptalloc2
real    0m1.087s
user    0m3.744s
sys     0m0.204s
$ time ./tcalloc2
real    0m3.535s
user    0m11.361s
sys     0m2.112s
```


What's Going On?

```
$ strace -c -f ./ptalloc2
 …
% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
 94.96    2.347314          44     53653     14030 futex
…
$ strace -c -f ./tcalloc2
 …
% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
 93.86    6.604632          36    185731     45222 futex
 …
```


Running it (2015) ...

```
sphere $ time ./ptalloc

real    0m2.373s
user    0m9.152s
sys     0m0.008s
sphere $ time ./tcalloc

real    0m4.868s
user    0m19.444s
sys     0m0.020s
```


Running it (2015) ...

```
kui $ time ./ptalloc

real    0m2.787s
user    0m11.045s
sys     0m0.004s
kui $ time ./tcalloc

real    0m1.701s
user    0m6.584s
sys     0m0.004s
```


Running it (2015) ...

```
cslab0a $ time ./ptalloc

real    0m2.234s
user    0m8.468s
sys     0m0.000s
cslab0a $ time ./tcalloc

real    0m4.938s
user    0m19.584s
sys     0m0.000s
```


What's Going On?

- On kui:
  - `libtcmalloc.so -> libtcmalloc.so.4.1.0`
- On other machines:
  - `libtcmalloc.so -> libtcmalloc.so.4.2.2`

However (2015) ...

```
cslab0a $ time ./ptalloc2

real    0m0.466s
user    0m1.504s
sys     0m0.212s
cslab0a $ time ./tcalloc2

real    0m1.516s
user    0m5.212s
sys     0m0.328s
```


It's 2019

- tcmalloc no longer exists
  - no explanation from Google, it's simply gone
- ptmalloc continues to improve

Thread Scheduling

- The OS multiplexes threads on the available processors/cores
  - share the processors equally
    - » time slicing: each thread gets a fixed amount of time before it's forced to yield the processor to another thread (if there is one)
  - some threads are more important than others
    - » priorities: higher-priority threads get the processor in preference to lower-priority threads

A Scheduling Issue

- You and four friends each contribute $1000 towards a server
  - you, rightfully, feel you own 20% of it
- Your friends are into threads, you're not
  - they run 5-threaded programs
  - you run a 1-threaded program
- The scheduler treats all threads equally
- Their programs each get 5/21 of the processor
- Your programs get 1/21 of the processor
  - (you should have paid more attention to the fractal threads lab)

Lottery Scheduling

- 25 lottery tickets are distributed equally to you and your four friends
  - you give 5 tickets to your one thread
  - they give one ticket each to their threads
- A lottery is held for every scheduling decision
  - your thread is 5 times more likely to win than the others

Metered Processors

Algorithm

- Each thread has a meter, which runs only when the thread is running on the processor
- At every clock tick
  - give processor to thread that's had the least processor time as shown on its meter
  - in case of tie, thread with lowest ID wins

Issue

- Some threads may be more important than others

Metered Processors
(RI Variation)

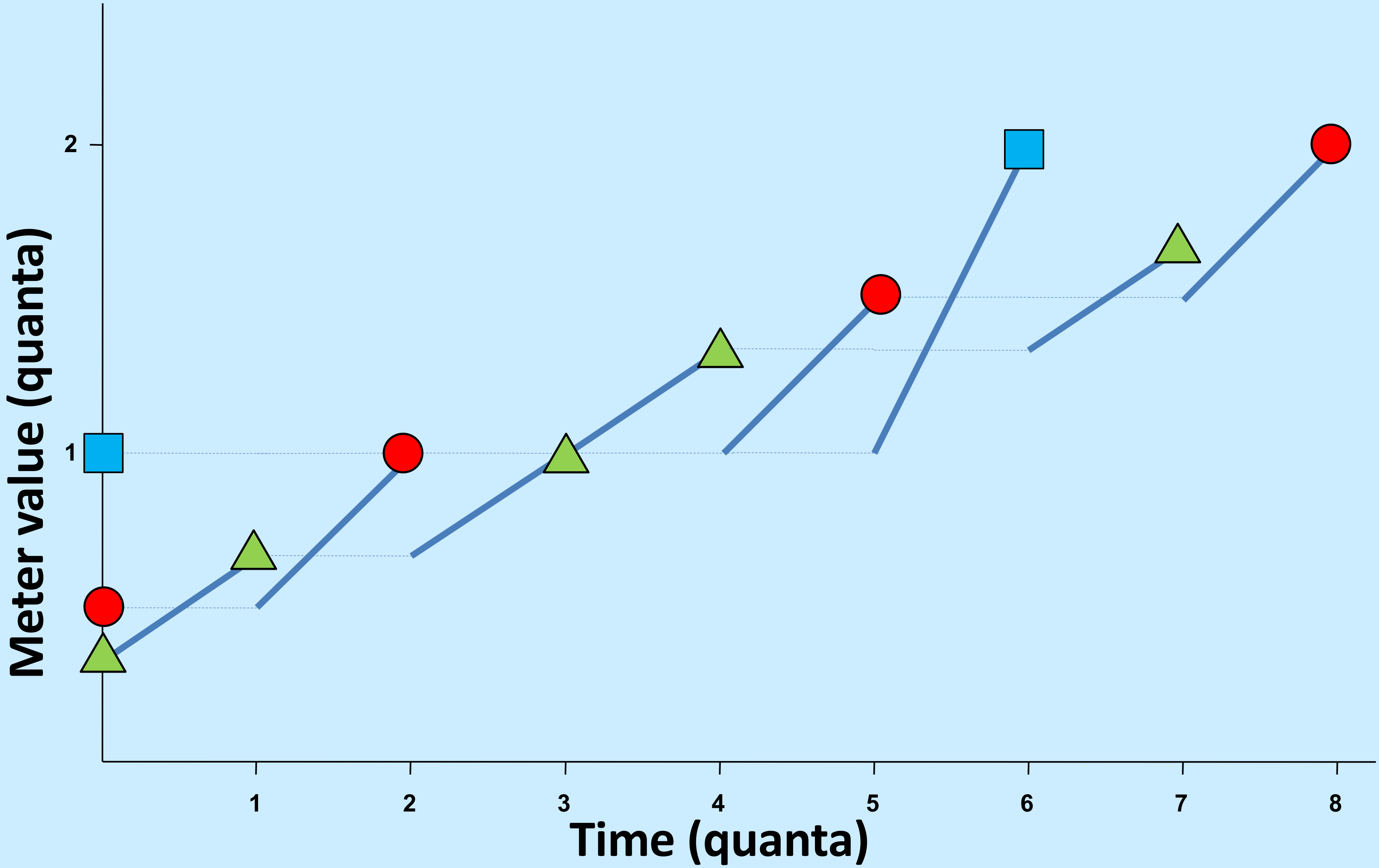
Details …

- Each thread pays a bribe
  - the greater the bribe, the slower the meter runs
  - to simplify bribing, you buy “tickets”
    - » one ticket is required to get a fair meter
    - » two tickets get a meter running at half speed
    - » three tickets get a meter running at 1/3 speed
    - » etc.

New Algorithm

- Each thread has a *(possibly crooked)* meter, which runs only when the thread is running on the processor
- At every clock tick
  – give processor to thread that's had the least processor time as shown on its meter
  – in case of tie, thread with lowest ID wins

Example



You'll Soon Finish CS 33 …

- You might
  - celebrate

  - take another systems course
    - » 32
    - » 131
    - » 138
    - » 166
    - » 167

  - become a 33 TA

Systems Courses Next Semester

- CS 32 (Intro to Software Engineering)
  - you've mastered low-level systems programming
  - now do things at a higher level
  - learn software-engineering techniques using Java, XML, etc.
- CS 131 (Fundamentals of Computer Systems)
  - an overview of how computer systems work
- CS 138 (Distributed Systems)
  - you now know how things work on one computer
  - what if you've got lots of computers?
  - some may have crashed, others may have been taken over by your worst (and smartest) enemy
- CS 166 (Computer Systems Security)
  - liked buffer?
  - you'll really like 166
- CS 167/169 (Operating Systems)
  - still mystified about what the OS does?
  - write your own!

Critical Review

- **Do it online**
  - https://brown.co1.qualtrics.com/jfe/form/SV_cOBf7p7gocbkCI5
  - password: KLFDS

The End

Well, not quite …

Database is due on 12/13.

The TAs and I will hold hours all this week.

I'll hold hours 3-4 today, 2-4 Wednesday, 2-5 Friday

Happy coding and happy holidays!

