5118020-03 Operating System

Lock-based Concurrent Data Structures

OSTEP Chapter 29

Shin Hong

Performance of Concurrent Algorithm

- Amdahl's law
  - Upper bound of performance gains by adding additional cores to an application that has both serial and parallel components
    - *S* is serial portion, *N* processing cores

$$speedup \leq \frac{1}{S + \frac{(1-S)}{N}}$$

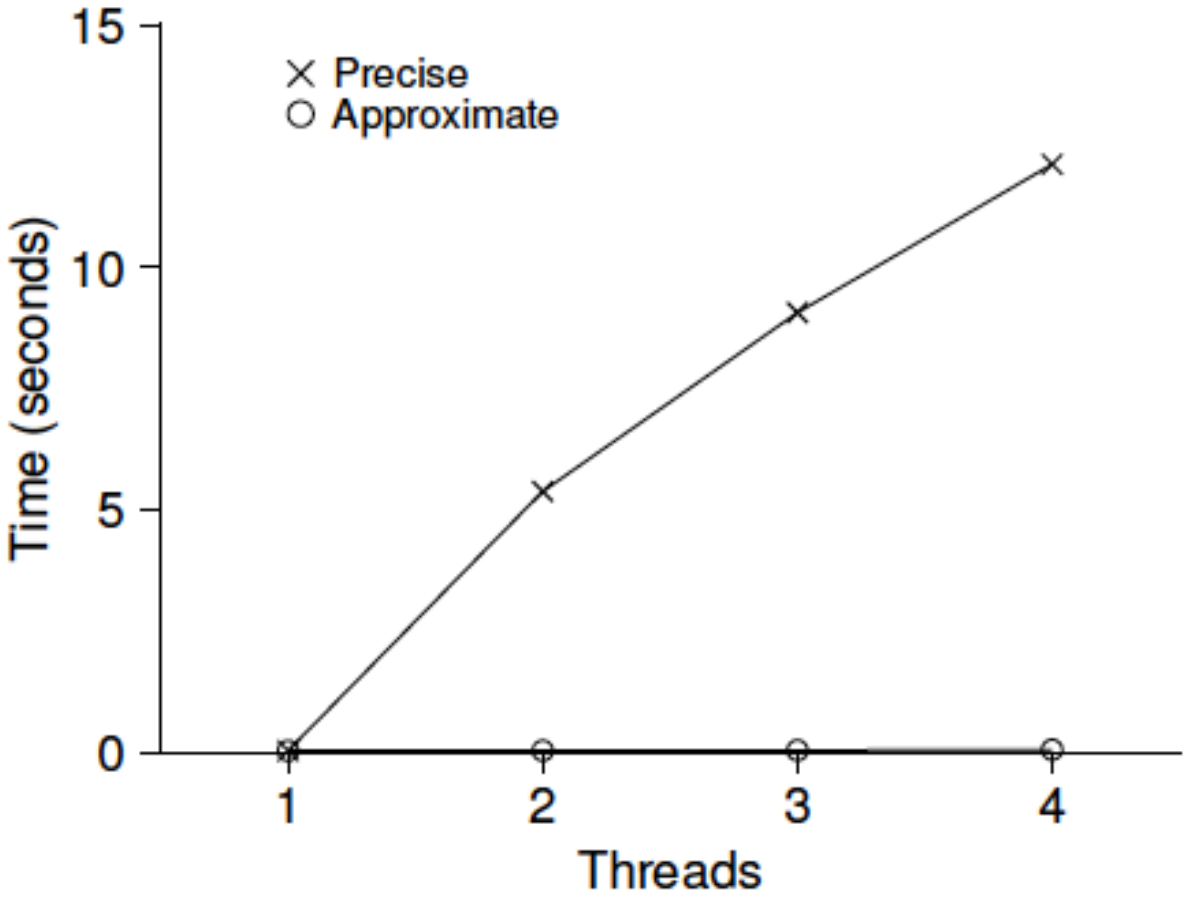
    - That is, if application is 75% parallel / 25% serial, moving from 1 to 2 cores results in speedup of 1.6 times
    - As *N* approaches infinity, speedup approaches 1 / *S*
  - Serial portion of an application has disproportionate effect on performance gained by adding additional cores
- Cost of context-switching and synchronization operation

Concurrent Counter – Naïve Thread Safe Version


```c
typedef struct __counter_t {
    int value;
} counter_t;

void init(counter_t *c) {
    c->value = 0;
}

void increment(counter_t *c) {
    c->value++;
}

void decrement(counter_t *c) {
    c->value--;
}

int get(counter_t *c) {
    return c->value;
}
```

```c
typedef struct __counter_t {
    int             value;
    pthread_mutex_t lock;
} counter_t;

void init(counter_t *c) {
    c->value = 0;
    Pthread_mutex_init(&c->lock, NULL);
}

void increment(counter_t *c) {
    Pthread_mutex_lock(&c->lock);
    c->value++;
    Pthread_mutex_unlock(&c->lock);
}

void decrement(counter_t *c) {
    Pthread_mutex_lock(&c->lock);
    c->value--;
    Pthread_mutex_unlock(&c->lock);
}

int get(counter_t *c) {
    Pthread_mutex_lock(&c->lock);
    int rc = c->value;
    Pthread_mutex_unlock(&c->lock);
    return rc;
}
```

Concurrent Counter – Scalability Issue



Approximate Counter

- Each thread updates on a local counter and periodically synchronize it with the global counter

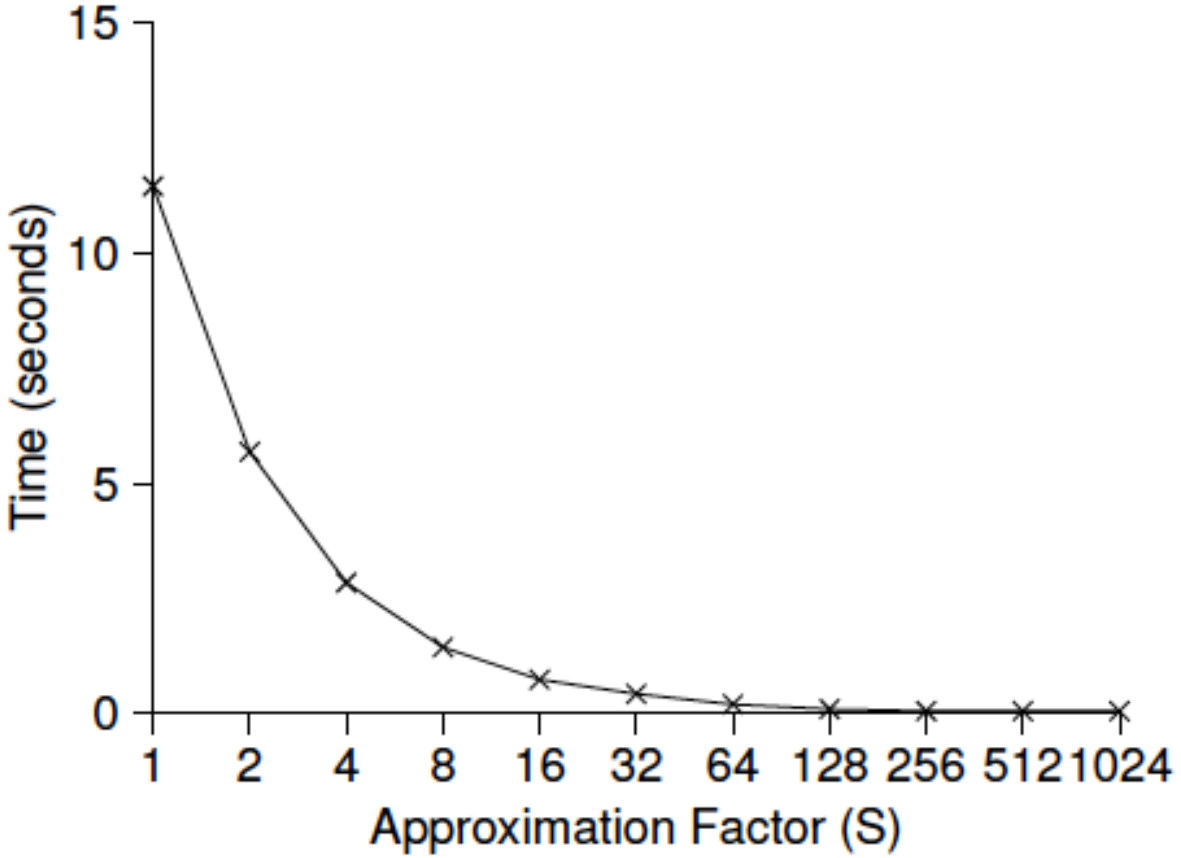
```
1  typedef struct __counter_t {
2      int             global;
3      pthread_mutex_t glock;
4      int             local[NUMCPUS];
5      pthread_mutex_t llock[NUMCPUS];
6      int             threshold;
7  } counter_t;
```

```
11 void init(counter_t *c, int threshold) {
12     c->threshold = threshold;
13     c->global = 0;
14     pthread_mutex_init(&c->glock, NULL);
15     int i;
16     for (i = 0; i < NUMCPUS; i++) {
17         c->local[i] = 0;
18         pthread_mutex_init(&c->llock[i], NULL);
19     }
20 }
```

```
25 void update(counter_t *c, int threadID, int amt) {
26     int cpu = threadID % NUMCPUS;
27     pthread_mutex_lock(&c->llock[cpu]);
28     c->local[cpu] += amt;
29     if (c->local[cpu] >= c->threshold) {
30         // transfer to global (assumes amt>0)
31         pthread_mutex_lock(&c->glock);
32         c->global += c->local[cpu];
33         pthread_mutex_unlock(&c->glock);
34         c->local[cpu] = 0;
35     }
36     pthread_mutex_unlock(&c->llock[cpu]);
```

```
40 int get(counter_t *c) {
41     pthread_mutex_lock(&c->glock);
42     int val = c->global;
43     pthread_mutex_unlock(&c->glock);
44     return val; // only approximate!
45 }
```

Scaling Approximate Counter



Concurrent Linked List – First Version


```
1  // basic node structure
2  typedef struct __node_t {
3      int                 key;
4      struct __node_t         *next;
5  } node_t;
6
7  // basic list structure (one used per list)
8  typedef struct __list_t {
9      node_t                *head;
10     pthread_mutex_t     lock;
11 } list_t;
12
13 void List_Init(list_t *L) {
14     L->head = NULL;
15     pthread_mutex_init(&L->lock, NULL);
16 }
```

```
18 int List_Insert(list_t *L, int key) {
19     pthread_mutex_lock(&L->lock);
20     node_t *new = malloc(sizeof(node_t));
21     if (new == NULL) {
22         perror("malloc");
23         pthread_mutex_unlock(&L->lock);
24         return -1; // fail
25     }
26     new->key  = key;
27     new->next = L->head;
28     L->head   = new;
29     pthread_mutex_unlock(&L->lock);
30     return 0; // success
31 }
32
33 int List_Lookup(list_t *L, int key) {
34     pthread_mutex_lock(&L->lock);
35     node_t *curr = L->head;
36     while (curr) {
37         if (curr->key == key) {
38             pthread_mutex_unlock(&L->lock);
39             return 0; // success
40         }
41         curr = curr->next;
42     }
43     pthread_mutex_unlock(&L->lock);
44     return -1; // failure
45 }
```

Scaling Linked List

- Reduce locking scope

- Use finer-grained lock
  - Add a lock per node, instead of one global lock
  - Hand-over-hand locking

```
6  void List_Insert(list_t *L, int key) {
7      // synchronization not needed
8      node_t *new = malloc(sizeof(node_t));
9      if (new == NULL) {
10         perror("malloc");
11         return;
12     }
13     new->key = key;
14
15     // just lock critical section
16     pthread_mutex_lock(&L->lock);
17     new->next = L->head;
18     L->head   = new;
19     pthread_mutex_unlock(&L->lock);
20 }
```

Concurrent Queue


```
1  typedef struct __node_t {
2      int                 value;
3      struct __node_t     *next;
4  } node_t;
5
6  typedef struct __queue_t {
7      node_t              *head;
8      node_t              *tail;
9      pthread_mutex_t     head_lock, tail_lock;
10 } queue_t;
```

```
12 void Queue_Init(queue_t *q) {
13     node_t *tmp = malloc(sizeof(node_t));
14     tmp->next = NULL;
15     q->head = q->tail = tmp;
16     pthread_mutex_init(&q->head_lock, NULL);
17     pthread_mutex_init(&q->tail_lock, NULL);
18 }
```

```
20 void Queue_Enqueue(queue_t *q, int value) {
21     node_t *tmp = malloc(sizeof(node_t));
22     assert(tmp != NULL);
23     tmp->value = value;
24     tmp->next  = NULL;
25
26     pthread_mutex_lock(&q->tail_lock);
27     q->tail->next = tmp;
28     q->tail = tmp;
29     pthread_mutex_unlock(&q->tail_lock);
30 }
```

```
32 int Queue_Dequeue(queue_t *q, int *value) {
33     pthread_mutex_lock(&q->head_lock);
34     node_t *tmp = q->head;
35     node_t *new_head = tmp->next;
36     if (new_head == NULL) {
37         pthread_mutex_unlock(&q->head_lock);
38         return -1; // queue was empty
39     }
40     *value = new_head->value;
41     q->head = new_head;
42     pthread_mutex_unlock(&q->head_lock);
43     free(tmp);
44     return 0;
45 }
```

Producer-Consumer


```
int buffer[MAX];
int fill_ptr = 0;
int use_ptr  = 0;
int count    = 0;

void put(int value) {
    buffer[fill_ptr] = value;
    fill_ptr = (fill_ptr + 1) % MAX;
    count++;
}

int get() {
    int tmp = buffer[use_ptr];
    use_ptr = (use_ptr + 1) % MAX;
    count--;
    return tmp;
}
```

```
void *producer(void *arg) {
    int i;
    int loops = (int) arg;
    for (i = 0; i < loops; i++) {
        put(i);
    }
}

void *consumer(void *arg) {
    while (1) {
        int tmp = get();
        printf("%d\n", tmp);
    }
}
```

```
cond_t empty, fill;
mutex_t mutex;

void *producer(void *arg) {
    int i;
    for (i = 0; i < loops; i++) {
        Pthread_mutex_lock(&mutex);
        while (count == MAX)
            Pthread_cond_wait(&empty, &mutex);
        put(i);
        Pthread_cond_signal(&fill);
        Pthread_mutex_unlock(&mutex);
    }
}

void *consumer(void *arg) {
    int i;
    for (i = 0; i < loops; i++) {
        Pthread_mutex_lock(&mutex);
        while (count == 0)
            Pthread_cond_wait(&fill, &mutex);
        int tmp = get();
        Pthread_cond_signal(&empty);
        Pthread_mutex_unlock(&mutex);
        printf("%d\n", tmp);
    }
}
```