Parallel and Concurrent Programming Classical Problems, Data structures and Algorithms

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Outline

Introduction

Data and Algorithms

- Classical Algorithmic studies emphasis the importance of data structures against algorithms
- Parallel Algorithms share the same trade-off with a bit more stress on data structures
- Clever data structures are needed for performances but also for consistency and determinism
- We need to understand how to:
  - Correctly manage shared data (mutual exclusion)
  - Synchronize threads
  - Avoid as much as possible contention due to locks
- Once data structures are safe and efficient, we can study algorithms and how to smartly use multiple processors.

Locking techniques

How to lock ?

- Petterson's Algorithm ensure mutual exclusion and other properties but it's not the best choice.
- What are the available techniques for locking shared ressources ?
  - Memory and interruptions blocking;
  - *Low-level* primitives;
  - *API-level* locking routines;
  - *Higher-level* approach (semaphore, monitor . . .)

Lower level locks

Memory and interruptions blocking

- Interruptions blocking:
  - A way to ensure *atomicity* of operations is to prevent the current thread to leave active mode and other threads to be active.
  - Processors offer the ability to block interruptions, so a running thread won't be interrupted.
  - Such techniques can't be allowed in userland for obvious security and safety reasons.
  - Interruptions blocking are sometimes used in kernel-space (giant locks.)
  - With multiple processors, interruptions blocking doesn't solve all issues.
- Memory blocking:
  - Memory can also be locked by processor and/or threads.
  - Again, this is not permitted in userland.
- Anyway, locking interruptions or memory imply a *global* synchronization point.

Test and Set

Modern (relatively) processors offer atomic primitives to be used safely in userland like *Test and Set*.

Example:

Test and Set: is an atomic operation simulating the following code:

```
/* mem: a shared ressources
 * reg: a thread local variable (ie a register)
 */
void TS(unsigned *mem, unsigned reg)
{
  reg = *mem; // save the value
  *mem = 1;   // set to "true"
}
```

Since, this is performed atomically, we can implement simple *spin-lock*:

```
  TS(mem, reg);    // was it "false"
  while (reg)      // no ? -> loop
    TS(mem, reg); // test again ...
  /* CS */
  *mem = 0;        // set back to "false"
```

Compare and Swap (CAS)

- *Compare and Swap* is a better variation of *Test and Set*: it compare a memory location with a value and, if the test return true, it sets the memory location to a new value. *Compare and Swap* (as *Test and Set*) is atomic.
- *Compare and Swap* is often used for *lock* implementations, but is also primordial for most *lock-free* algorithms.

Example:

CAS mimic the following code:

```c
int CAS(int *mem, int testval, int newval)
{
  int                 res = *mem;
  if (*mem==testval)
    *mem = newval;
  return res;
}
```

The *ia32* architecture provides various implementation of *Compare And Swap* (for different sizes) but most higher level languages does not provide operators for it (this is changing with last C/C++ standard.) Here is an example on how to implement a CAS in C:

Example:

```
void volatile*
cas (void *volatile *mem,
     void *volatile  cmp,
     void *volatile  newval)
{
  void volatile         *old;
  __asm__ volatile ("lock cmpxchg %3, (%1)\n\t"
            :"=a"(old):"r"(mem),"a"(cmp),"r"(newval));
  return old;
}
```

Example: Operator Assign

- We can use CAS to implement an almost atomic kind of *Operator Assign* (OA) instruction like +=
- For OA weed need to fetch the value in a shared cell, perform our operation and store the new value, but only if cell content has not change.

Example:

```
int OpAssignPlus(int *mem, int val)
{
  int                   tmp;
  tmp = *mem;
  while (CAS(mem, tmp, tmp+val) != tmp)
    tmp = *mem;
  return (tmp + val);
}
```

Mutex and other usual locks

Mutex locking

- Mutex provides the simplest locking paradigm that one can want.
- Mutex provides two operations:
  - **lock**: if the mutex is free, lock-it, otherwise wait until it's free and lock-it
  - **unlock**: make the mutex free
- Mutex enforces mutual exclusion of critical section with only two basic operations.
- Mutex comes with several *flavors* depending on implementation choices.
- Mutex is the most common locking facility provides by threading API.

Mutex flavors

- When waiting, mutex can *spin* or *sleep*
- Spinning mutex can use *yield*
- Mutex can be fair (or not)
- Mutex can enforce a FIFO ordering (or not)
- Mutex can be reentering (or not)
- Some mutex can provide a *try lock* operation

To Spin Or Not, To Spin That is the Question

- Spin waiting is often considered as a bad practice:
  - Spin waiting often opens priority inversion issues
  - Spin waiting consumes ressources for doing nothing
  - Since spin waiting implies recurrent test (TS or CAS), it locks memory access by over using atomic primitives.
- On the other hand, passive waiting comes with some issues:
  - Passive waiting means *syscall* and process state modification
  - The cost (time) of putting (and getting it out of) a thread (or a process) in a sleeping state, is often longer than the waiting time itself.
- Spin waiting can be combine with *yield*. Using yield (on small wait) solves most of spin waiting issues.

Barrier

- While mutex prevent other threads to enter a section simultaneously, barriers will block threads until a sufficient number is waiting.
- Barrier offers a *phase* synchronization: every threads waiting for the barrier will be awaken simultaneously.
- When the barrier is initialized, we fix the number of threads required for the barrier to open.
- Barrier has one operation: *wait*.
- *Openning* the barrier won't let *latter* threads to pass directly.
- Barrier often provides a way to inform the *last thread* that is the one that make the barrier open.

Read/Write locks

- The problem: a set of threads are using a shared peace of data, some are only reading it (readers), while others are modifying it (writers.)
- We may let several readers accessing the data concurrently, but a writer must be alone when modifying the shared data.
- Read/Write locks offer a mechanism for that issue: a thread can acquire the lock, only for reading (letting other readers being able to do the same) or acquire for writing (blocking others.)
- A common issue (and thus a possible implementation choice) is whether writers have higher priority than reader:
  - When a writer asks for the lock, it will wait until no reader owns the lock;
  - When a writer is waiting, should the lock be acquired by new readers ?

Condition Variables

- Condition variables offers a way to put a thread in a sleeping state, until some events occurs.
- Condition offers two operations:
  - *wait*: the calling thread will pause until someone call *signal*;
  - *signal*: wake a thread waiting on the condition (if any.)
- A condition variable is always associated with a lock (mutex): we first lock to test, then if needed we wait. Moving to wait state will free the mutex which will be given back to it after the wait.
- The classical use of a condition variable is:

```
lock(mutex);                  // we need to be alone
while ( some conditions )     // do we need to wait
  wait(condvar, mutex);       // yes => sleep
...                           // we pass, do our job
unlock(mutex);                // we-re done
```

- Sometimes one can use a *broadcast* which will try to wake every thread waiting on the condition.

Condition variables: usecase

- Condition variables are used to solve producer/consumer problem:

Example:

```
void consumer () {
  for (;;) {
    void        *data;
    lock(mutex);
    while (q.is_empty())
      wait(cond, mutex);
    data = q.take();
    unlock(mutex);
    // do something
  }
}
```

Example:

```
void producer () {
  for (;;) {
    void        *data;
    // produce
    data = ... ;
    lock(mutex);
    q.push(data);
    unlock(mutex);
    signal(cond);
  }
}
```

Higher Level: Semaphore and Monitor

Semaphore: What the hell is that ?

- A semaphore is a shared counter with a specific semantics for the decrease/increase operations.
- Normally, a semaphore maintain a *FIFO* waiting queue.
- The two classic operations are:
  - **P**: if the counter is strictly positive, decrease it (by one), otherwise the calling thread is push to sleep, waiting for the counter be positive again.
  - **V**: increase the counter, waking the first waiting thread when needed.
- Since semaphores use a queue, synchronisation using semaphores can consider *fair*: each thread will wait a finite time for the protected ressource. The property is even more precise, since a waiting thread will see (at least) every other threads accessing the ressource exactly one time before it.

Semaphore's classics

- The counter value of the semaphore can be initialize with any positive integer (zero inclusive.)
- A semaphore with an initial value of 1 can act as a fair *mutex*.
- Semaphore can be used as a condition counter, simplifying classic problems such as *Producer/Consumer*.
- Operations' name **P** and **V** comes from Dijkstra's first Semaphores' presentation and probably mean something in dutch. But, implementations often use more explicit names like *wait* for **P** and *post* for **V**.

Producer/Consumer with semaphores

Example:

```
semaphore                 mutex = new semaphore(1);
semaphore                 size  = new semaphore(0);
```

Example:

```
void consumer () {
  for (;;) {
    void          *data;
    P(size);
    P(mutex);
    data = q.take();
    V(mutex);
    // do something
  }
}
```

Example:

```
void producer () {
  for (;;) {
    void          *data;
    // produce
    data = ... ;
    P(mutex);
    q.push(data);
    V(mutex);
  }
}
```

Draft Implementation of Semaphore

Example:

```
semaphore {
  unsigned          count;
  mutex             m;
  condition         c;
};
```

Example:

```
void P(semaphore sem){
  lock(sem.m);
  while (sem.count == 0)
    wait(sem.c, sem.m);
  sem.count--;
  unlock(sem.m)
}
```

Example:

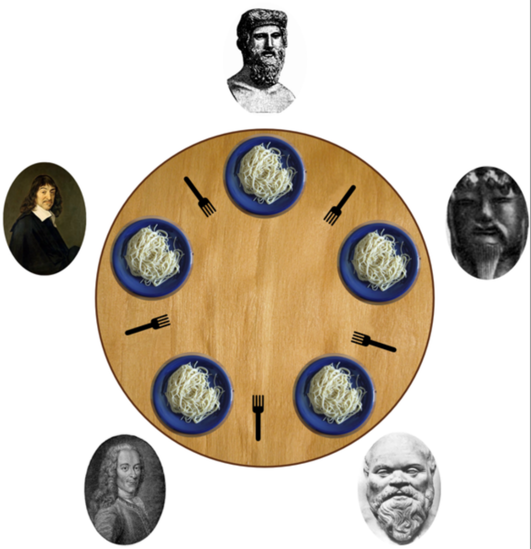
```
void V(semaphore sem){
  lock(sem.m);
  sem.count++;
  unlock(sem.m);
  signal(sem.c);
}
```

Monitors

- Monitors are abstraction of concurrency mechanism.
- Monitors are more Object Oriented than other synchronization tools.
- The idea is to provide objects where method execution are done in mutual exclusion.
- Monitors come with condition variables
- Modern OO languages integrate somehow monitors:
  - In Java every object is a monitor but only methods marked with `synchronized` are in mutual exclusion.
  - Java's monitor provide a simplified mechanism in place of condition variables.
  - C# and D follow Java's approach.
  - Protected objects in ADA are monitors.
  - ...

The Dining Philosophers Problem

The Dining Philosophers



The Dining Philosophers

- A great *classic* in concurrency by Hoare (in fact a *retold version* of an illustrative example by Dijkstra.)
- The first goal is to illustrate **deadlock** and **starvation**.
- The problem is quite simple:
  - N philosophers (originally $N = 5$) are sitting around a round table.
  - There's only N chopstick on the table, each one between two philosophers.
  - When a philosopher want to eat, he must acquire his left and his right chopstick.
- Naive solutions will cause deadlock and/or starvation.

mutex and condition based solution

```c
/* Dining Philosophers */
#define _XOPEN_SOURCE 600

#include <stdlib.h>
#include <unistd.h>
#include <stdio.h>
#include <time.h>
#include <errno.h>
#include <signal.h>
#include <pthread.h>

#define NPHI 5
#define LEFT(k) (((k)+(NPHI-1))%NPHI)
#define RIGHT(k) (((k)+1)%NPHI)

enum e_state {THINKING,EATING,HUNGRY};

typedef struct s_table *table;
struct s_table
{
  enum e_state states[NPHI];
  pthread_cond_t        can_eat[NPHI];
  pthread_mutex_t       *lock;
};

struct s_thparams
{
  table table;
  pthread_barrier_t     *sync;
  int id;
};
```

```c
/* return 1 after receiving SIGINT */
int is_done(int yes)
{
 static pthread_spinlock_t *lock=NULL;
 static int                 done=0;
 if (!lock) {
  lock=malloc(sizeof(pthread_spinlock_t));
  pthread_spin_init(lock,
        PTHREAD_PROCESS_PRIVATE);
 }
 pthread_spin_lock(lock);
 if (yes)
  done = yes;
 pthread_spin_unlock(lock);
 return done;
}

/* where all the magic is !  */
/* test if we are hungry and */
/* our neighbors do no eat   */
void test(table t, int k)
{
 if (t->states[k] == HUNGRY
     && t->states[LEFT(k)] != EATING
     && t->states[RIGHT(k)] != EATING){
  t->states[k] = EATING;
  pthread_cond_signal(&(t->can_eat[k]));
 }
}
```

mutex and condition based solution

```c
void pick(table t, int i)
{
 pthread_mutex_lock(t->lock);
 t->states[i] = HUNGRY;
 printf("Philosopher %d: hungry\n",i);
 test(t,i);
 while (t->states[i] != EATING)
  pthread_cond_wait(&t->can_eat[i],
                    t->lock);
 printf("Philosopher %d: eating\n",i);
 pthread_mutex_unlock(t->lock);
}

void put(table t, int i)
{
 pthread_mutex_lock(t->lock);
 t->states[i] = THINKING;
 printf("Philosopher %d: thinking\n",i);
 test(t,LEFT(i));
 test(t,RIGHT(i));
 pthread_mutex_unlock(t->lock);
}

void thinking()
{
 struct timespec        reg;
 reg.tv_sec = random()%6;
 reg.tv_nsec = 1000000*(random()%1000);
 if (nanosleep(&reg,NULL) == -1) {
  if (errno != EINTR || is_done(0))
  pthread_exit(NULL);
 }
}

void eating()
{
 struct timespec       reg;
 reg.tv_sec = random()%2;
 reg.tv_nsec = 1000000*(random()%1000);
 nanosleep(&reg,NULL);
}

void *philosopher(void *ptr)
{
 struct s_thparams    *p;
 p = ptr;
 pthread_barrier_wait(p->sync);
 printf("Philosopher %d:thinking\n",p->id);
 while (!is_done(0))
 {
  thinking();
  pick(p->table, p->id);
  eating();
  put(p->table, p->id);
 }
 pthread_exit(NULL);
}

void handle_int(int sig)
{
 is_done(1);
 signal(sig,handle_int);
}
```

mutex and condition based solution

```
int main(int argc, char *argv[])
{
 table                  t;
 struct s_thparams     *p;
 pthread_t              th[NPHI];
 pthread_mutex_t        lock;
 pthread_barrier_t      sync;
 size_t                 i, seed=42;

 signal(SIGINT, handle_int);

 if (argc>1)
  seed = atoi(argv[1]);
 srandom(seed);

 t = malloc(sizeof (struct s_table));
 pthread_barrier_init(&sync,NULL,NPHI);
 pthread_mutex_init(&lock,NULL);
 t->lock = &lock;
```

```
 for (i=0; i<NPHI; ++i)
 {
  t->states[i] = THINKING;
  pthread_cond_init(&t->can_eat[i],NULL);
 }

 for (i=0; i<NPHI; ++i)
 {
  p = malloc(sizeof (struct s_thparams));
  p->table = t;
  p->sync = &sync;
  p->id = i;
  pthread_create(th+i,NULL,philosopher,p);
 }

 for (i=0; i<NPHI; ++i)
  pthread_join(th[i], NULL);

 return 0;
}
```

Sharing Resources

- The dining philosophers problem emphasizes the need of synchronisation when dealing with shared resources.
- Even with a simple mutex per chopstick, the execution may not (will probably not) be correct, ending with either a global deadlock or some philosophers in starvation.
- It is easy to see that no more than half of the philosophers can eat at the same time: **sharing resources implies less parallelism !**
- This kind of situation is what we want to avoid: *a lot of dependencies between threads*.
- A good parallel program try to avoid shared resources when possible. A good *division* of a problem for parallel computing will divide the global task into *independant tasks*.

Data Structures

Concurrent Collections

Producers and Consumers Classical Problem

- When using a shared collection, we face two issues:
  - Concurrent accesses;
  - What to do when collection is empty.
- Usual solution for a queue (or any other *push-in/pull-out* collection) is to implement the Producers/Consumers model:
  - The collection is accessed in mutual exclusion;
  - When the collection is empty *pull-out* operations will block until data is available.
- Producers/Consumers is quite easy to implement using semaphores or using mutex and condition variables.
- Producers/Consumers can also be extended to support bounded collections (*push-in* operations may wait until a place is available.)

Producers and Consumers Seminal Solution

Example:

```c
void push(void *x, t_queue q)
{
  pthread_mutex_lock(q->m);
  q->q = _push(x,q->q);
  pthread_mutex_unlock(q->m);
  sem_post(q->size);
}

void *take(t_queue q)
{
  void                *x;
  sem_wait(q->size);
  pthread_mutex_lock(q->m);
  x = _take(&q->q);
  pthread_mutex_unlock(q->m);
  return x;
}
```

Locking Refinement

- Global locking of the collection implies more synchronisation (and thus, less parallelism !)
- Let's consider a *FIFO* queue:
  - Unless there's only one element in the queue, *push-in* and *pull-out* can occur at the same time (careful implementation can also accept concurrent accesses when there's only one element.) [2]
  - The traditionnal circular list implementation of queue can not be used here.
  - The solution is to build the queue using a structures with two pointers (head and tail) on a simple linked list.
- Better locking strategies leads to more parallelism, but as we can see usual implementations may not fit.

Loose Coupling Concurrent Accesses

- When using *map* collections (collections that map keys to values), we can again improve our locking model.
- When accessing such collection we have two kind of operations: read-only and create/update.
- The idea is to see a *map* as a collection of pairs: all operations on the *map* will get a pair (even the create operation) and locking will only impact the pair and not the whole collection.
- In ordrer to support concurrent read we prefer read/write lock.
- Insertion operations can also be seperated in two distinct activities:
  - We create the cell (our pair) give back the pointer to the caller (with appropriate locking on the cell itself.)
  - Independently, we perform the insertion on the structure using a tasks queue and a seperate worker.
- The later strategy minimize even more the need of synchronisation when accessing our collection.

Data Structures Concurrent Friendly

- Some data structures are more *concurrent friendly* than others.
- The idea is again to minimize the impact of locking: we prefer structures where modifications can be kept local rather than global.
- Tree structures based are good candidate: most modification algorithm (insertion/suppression/update) can be kept local to a sub-tree and during the traversal we can release lock on *unimpacted* sub-tree.
  - For example, in *B-tree*, it has been proved that read operations can be perfomed without any locks and Write locks are located to modified block [1].
- Doubly linked lists are probably the worst kind of data structures for concurrent accesses: the nature of linked lists implies global locking to all elements accessible from the cell, so any operations on doubly linked lists will lock the whole list.

Non blocking data structures

- Normally spin waiting is a bad idea, but careful use of spin waiting can increase parallelism in some cases.
- The idea of non-blocking data structures is to interleave the waiting loop with the operation we want to perform.
- Good algorithm for that kind of data structures are harder to implement (and to verify) but offers a more dynamic progression: no thread idle by the system should block another when performing the operation.
- Non blocking operations relies on hardware dependent atomic operations

Non Blocking Concurrent Queue

- We'll study an implementation of a non blocking queue describes in [2]
- The two classical operations provides progression and all expected safety
- The algorithm uses double CAS (see next slides) to solves the ABA problem.
- Basic idea: when accessing tail or head of the queue, we fetch the front pointer, and in order to update the structure we use a CAS, if it fails we retry from the begining.
- The second interesting point is to finish work of other threads when possible.

The ABA issue

- When manipulating value using CAS a particular issue can arise: the so called ABA problem.
- The idea is quite simple: the fetched pointer can change several time during between the original fetch and the CAS, and for example we can fetch a A, it can be replaced by a B then by a A again.
- When manipulating data structure this means that the fetched values are incoherent.
- The simpliest way to solve the issue is to use a *double-CAS*: the pointer is concatened to a counter incremented each time we perform a CAS.

Concurrent Data Model

Using Data in A Concurrent Context

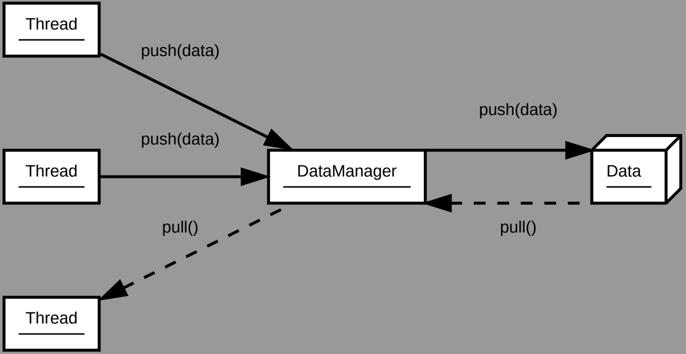
- Once we have chosen a good data structures, we need to manage concurrent accesses.
- Classical concurrent data structures define locking to enforce global data consistency but problem driven consistency is not considered.
- Most of the time, consistency enforcement provide by data structures are sufficient, but more specific cases requires more attention.
- Even with non-blocking or (almost) lock-free data structures, accessing shared data is a bottleneck (some may call it a *serialization point*.)
- When dealing with shared data, one must consider two major good practices:
  - Enforcing high level of abstraction;
  - Minimize locking by deferring operations to a *data manager* (*asynchronous upates*.)

- **Enforcing high level of abstraction:**
  - Encapsulation of the operations minimize exposition of the locking policy and thus enforce correct use of the data.
  - When possible, using *monitor* (object with native mutual exclusion) can simplify consistency and locking.
  - As usual, abstraction (and thus encapsulation) offers more possibility to use clever operations implementations.

Data Authority and Concurrent Accesses

- **Deferring operations to a kind of *data manager*:**
  - Deferring operations can improve parallelism by letting a different worker performs the real operations: the calling thread (the one that issue the operation) won't be blocked (if possible), the data manager will take care of performing the real operations.
  - Since the data manager is the only entity that can perfom accesses to the data, it can work without any lock, nor any blocking stage.
  - Data manager can *re-order* operations (or simply discard operations) to enforce algorithm specific constraint.

Data Manager



The Future Value Model

- Future are concurrent version of lazy evaluation in functionnal languages.
- Futures (or *promises* or *delays*) can be modeled in many various ways (depending on language model.)
- In short, a future is a variable whose value is computed independently. Here's a simple schematic example (pseudo language with *implicit future*):

```
// Defer computation to another thread
future int                v = <expr>;
// some computations
// ...
// We now need access to the future value
x <- 42 + v
```

Future for real . . .

- Java has future (see `java.util.concurrent.Future`);
- Futures will normaly be part of C++0x;
- Futures exists in sevral *Actor based* languages, functionnal languages (rather natively like in Haskell or AliceML, or byt the means of external libs like in OCaml) and pure object oriented languages (Smalltalk, AmbientTalk, E ...)
- Implementing simple future using pthread is quite simple: the future initialization create a new thread with a pointer to the operation to perform and when we really need the value we perform a *join* on the thread.
- One can also implements future using a tasks based systems.

Futures' issues

There are several issues when implementing futures. Those issues depend on the usage made of it:

- When we use futures to perform blocking operations or intensive computations, tasks systems may induce important penality.
- Creating a thread for each future induces important overhead.
- In object oriented languages, one have to solve whether message passes should wait on the futures result or not:

```
future int                v = acker(...);
// ...
v.add(1)
// we can block here waiting for v to complete
// but we can also send the message and let the
// future handle it in time.
```

Tasks Systems

Direct Manipulation of Physical Threads

- Physical (*system*) threads are not portable
- Most of the time, physical threads are almost independant process
- Creating, joining and cancelling threads is almost as expensive as process manipulations
- Synchronisation often implies kernel/user context switching
- Scheduling is under system control and doesn't take care of synchronisation and memory issues
- Data segmentation for parallel computing is problem **and** hardware driven:
  - Data must be split in order to respect memory and algorithm constraints
  - Number of physical threads needs to be dependant of the number of processors/cores to maximize performances
- ...

Light/Logical Threads

- One can implement threads in full user-space (*light threads*) but we loose physical parallelism.
- A good choice would be to implement *logical threads* with scheduling exploiting physical threads.
- Using logical threads introduces loose coupling between problem segmentation and hardware segmentation.
- *Local* scheduling increase code complexity and may introduce overhead.

Tasks based approach

- A good model for logical threads is a tasks system.
- A task is a sequential unit in a parallel algorithm.
- Tasks perform (*sequential*) computations and may spawn new tasks.
- The tasks system manage scheduling between *open* tasks and available physical threads.
- Tasks systems often use a *threads pool*: the system start a bunch of physical threads and schedule tasks on available threads dynamically.

Simple tasks system: waiting queue.

- *Producer* schedule new *tasks* by pushing it to the queue.
- *Consumer* take new *tasks* from the queue.
- *Producer* and *Consumer* are physical threads, we call them **worker**.
- Each worker may play both role (or not.)
- Tasks can be input values or data ranges for a fixed task's code.
- It is also possible to implement tasks description so producer can push any kinds of task.
- For most cases, we need to handle a kind of *join*: special task pushed when computation's results are ready, in order to closed unfinished tasks (think of a parallel reduce or parallel Fibonacci numbers computation.)

Tasks Sytems For Real

- Java `Executor` provides a task-based threading approach
- Intel's TBB (Threading Building Blocks) is completely based on this paradigm:
  - High level tools (such as parallel for) are based on a task and the librairy provides a scheduling mechanism to efficiently executes task.
  - You can also directly use the task system and build you're own partitionning.
  - TBB provides also pipeline mechanism

Algorithms and Concurrency

Easy Parallelism

Problems with simple parallel solutions

- A lot of problems can be solved easily with parallelism: for example when computing a Mandelbrot Set, we can perform the iteration for each pixel independently.
- The remaining issue of *easy parallelism* is scheduling: for our Mandelbrot set we can't start a new thread for each pixel.
- Using tasks systems and range based scheduling offers a good tradeoff between scheduling overhead and efficient usage of physical parallelism.
- Modern tools for parallel computing offers *intelligent* parallel loop constructions (*parallel for*, *parallel reduce* …) based on range division strategy statisfying hardware constraints (number of processors, cache affinity …)

Parallel *trap*

Parallel not so parallel

- Some times, parallel version are not so fast, even with multi-processor.
- It is important to keep in mind that speed-up is bound by the real degrees of parallism (Amdahl's law.) Take an example:
    - We have a set of vectors and want to compute the average of each vector;
    - Simple parallel version consiste of running a thread per vector;
    - This does not implies good speed-up (in fact, sequential version runs almost as fast);
    - A better solution is to perform (smart) parallel sums for each vector, the parallel part will be more significant and thus you can have a good speed-up.

Parallel or not, Parallel that is the question !

Parallelism and classical algorithms

- Some classical algorithms won't perform well in parallel context: for example depth first traversal is inherently not parallel.
- Optimizations in classical algorithms can also induce a lot of synchronisation points.
- Backtrack based algorithms can be improved with parallelism, but we must take care of scheduling: if the algorithms have a lot of backtrack point, we have to find a *strategy* to choose which point can be scheduled for parallel execution.

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