Critical sections in OpenMP

Paolo Burgio
paolo.burgio@unimore.it

Outline

- Expressing parallelism
  - Understanding parallel threads
- ~~Memory~~ Data management
  - Data clauses
- Synchronization
  - Barriers, locks, critical sections
- Work partitioning
  - Loops, sections, single work, tasks…
- Execution devices
  - Target

OpenMP synchronization

- OpenMP provides the following synchronization constructs:
  - `barrier`
  - `flush`
  - `master`
  - `critical`
  - `atomic`
  - `taskwait`
  - `taskgroup`
  - `ordered`
  - …and OpenMP locks

Exercise

Let's code!

- Spawn a team of (many) parallel Threads
  - Each incrementing a shared variable
  - What do you see?

Coherency problem

- When multiple workers concurrently access the same shared data
  - Data races
  - Read stale data
  - …
- (Luckily, does not happen with read-only data)

Data races, aka: the `a++` problem

- Intrinsic to the way computers are build
  - Leave out *Processor-in-memory*, ok?

- A shared variable `a`
- Incremented by two parallel threads
- Interleaved execution

- Eisen-bug vs Bohr-bug

The big problem

- a++ is not an unique instruction

src.cpp

```
a++;
```

obj.o

```
ld r1, [sp, -120] ; load from address of 'a'
add r2, r1, #1 ; add 1
st [sp, -120], r2 ; store in a
```

GCC

When things go well

T

a++;

11

```
ld r1, [sp, -120]
add r1, r1, #1
st [sp, -120] r1
```

12

T

a++;

12

```
ld r1, [sp, -120]
add r1, r1, #1
st [sp, -120] r1
```

13

t

When things go less well

T

a++;

11

```
ld r1, [sp, -120]
add r1, r1, #1
```

```
st [sp, -120] r1
```

12

T

a++;

11

```
ld r1, [sp, -120]
add r1, r1, #1
st [sp, -120] r1
```

12

t

OpenMP locks

- Defined at the OpenMP runtime level
  - Symbols available in code including `omp.h` header

- General-purpose locks
  1. Must be initialized
  2. Can be set
  3. Can be unset

- Each lock can be in one of the following states
  1. Uninitialized
  2. Unlocked
  3. Locked

Locking primitives

omp.h

```c
/* Initialize an OpenMP lock */
void omp_init_lock(omp_lock_t *lock);

/* Ensure that an OpenMP lock is uninitialized */
void omp_destroy_lock(omp_lock_t *lock);

/* Set an OpenMP lock. The calling thread behaves
   as if it was suspended until the lock can be set */
void omp_set_lock(omp_lock_t *lock);

/* Unset the OpenMP lock */
void omp_unset_lock(omp_lock_t *lock);
```

- The `omp_set_lock` has <u>blocking semantic</u>
- `omp_set/unset_lock` are <u>thread safe</u>
- <u>Opaque data type</u> `omp_lock_t`

OMP locks: example

- Locks **must** be
  - Initialized
  - Destroyed
- Locks can be
  - set
  - unset
  - tested
- Very simple example

```c
/*** Do this only once!! */
/* Declare lock var */
omp_lock_t lock;
/* Init the lock */
omp_init_lock(&lock);



/* If another thread set the lock,
   I will wait */
omp_set_lock(&lock);


/* I can do my work being sure that no-
   one else is here */


/* unset the lock so that other threads
   can go */
omp_unset_lock(&lock);



/*** Do this only once!! */
/* Destroy lock */
omp_destroy_lock(&lock);
```

Exercise

Let's code!

- Spawn a team of (many) parallel Threads
  - Each incrementing a shared variable
  - What do you see?
- Protect the variable using OpenMP locks
  - What do you see?
- Now, comment the call to `omp_unset_lock`
  - What do you see?

Non-blocking lock set

omp.h

```
/* Set an OpenMP lock but do not suspend the execution of the thread.
   Returns TRUE if the lock was set */

int omp_test_lock(omp_lock_t *lock);
```

- Extremely useful in some cases. Instead of blocking
  - we can do useful work
  - we can increment a counter (to profile lock usage)

- Reproduce blocking set semantic using a loop
  - `while (!omp_test_lock(lock)) /* ... */;`

The omp_lock_t type

omp.h

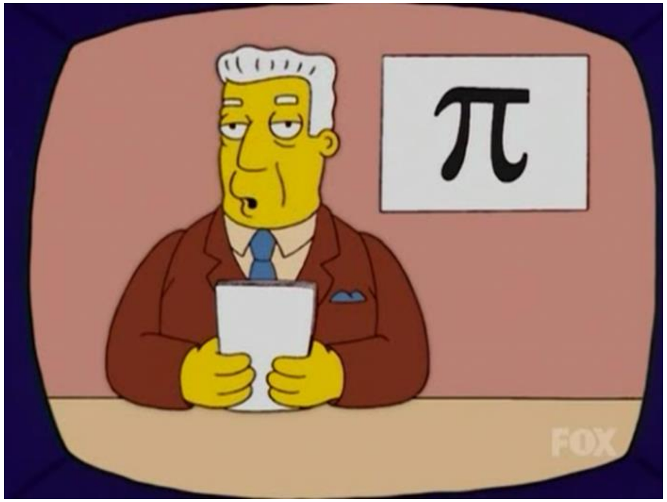
```
/* (1) Our implementation @UniBo (few years ago) */
typedef unsigned long omp_lock_t;

/* (2) ROSE compiler */
typedef void * omp_lock_t;

/* (3) GCC-OpenMP (aka Libgomp) */
typedef struct {
  unsigned char _x[@OMP_LOCK_SIZE@]
          __attribute__((__aligned__(@OMP_LOCK_ALIGN@)));
} omp_lock_t;
```

- Opaque data type
- Implementation-defined, it represents a lock type
  - Different implementations, different optimizations
- C routines for OMP lock are thread-safe, and accept a pointer to an `omp_lock_t` type
  - (at least)

Exercise

Let's code!

- Modify the "PI Montecarlo" exercise
  - Replace the variable in the `reduction` clause with a `shared` variable
  - Protect it using an OpenMP lock



Let's do more

- Locks are extremely powerful
  - And low-level
- We can use them to build complex semantics
  - Mutexes
  - Semaphores..
- But they are a bit "cumbersome" to use
  - Need to initialize before, and release after
  - We can definitely do more!

pragma-level synchronization constructs

The `critical` construct

```
#pragma omp critical [(name) [hint(hint-expression)] ] new-line
  structured-block
```

Where *`hint-expression`* is an integer constant expressioon that evaluates to a valid lock hint

- "Restricts the execution of the associated structured block to a single thread at a time"
  - The so-called Critical Section
- Binding set: all threads everywhere (also in other teams/parregs)
- Can associate it with a "hint"
  - `omp_lock_hint_t`
  - Also locks can
  - We won't see this

The critical section

- From this...

```
/* Declare lock var */
omp_lock_t lock;
/* Init the lock */
omp_init_lock(&lock);


/* If another thread set the lock,
   I will wait */
omp_set_lock(&lock);

/* I can do my work being sure that no-
   one else is here */

/* unset the lock so that other threads
can go */
omp_unset_lock(&lock);


/* Destroy lock */
omp_destroy_lock(&lock);
```

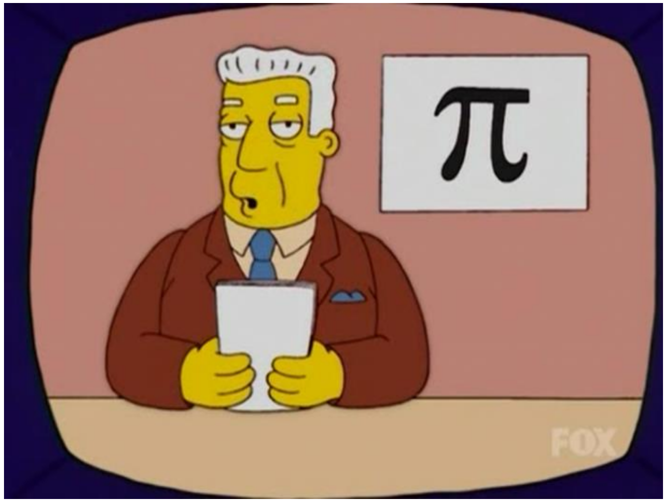
- ...to this

```
/* If another thread is in, I must wait */

#pragma omp critical
{
  /* _Critical Section_
     I can do my work being sure
     that no- one else is here */

}

/* Now, other threads can go */
```

Exercise

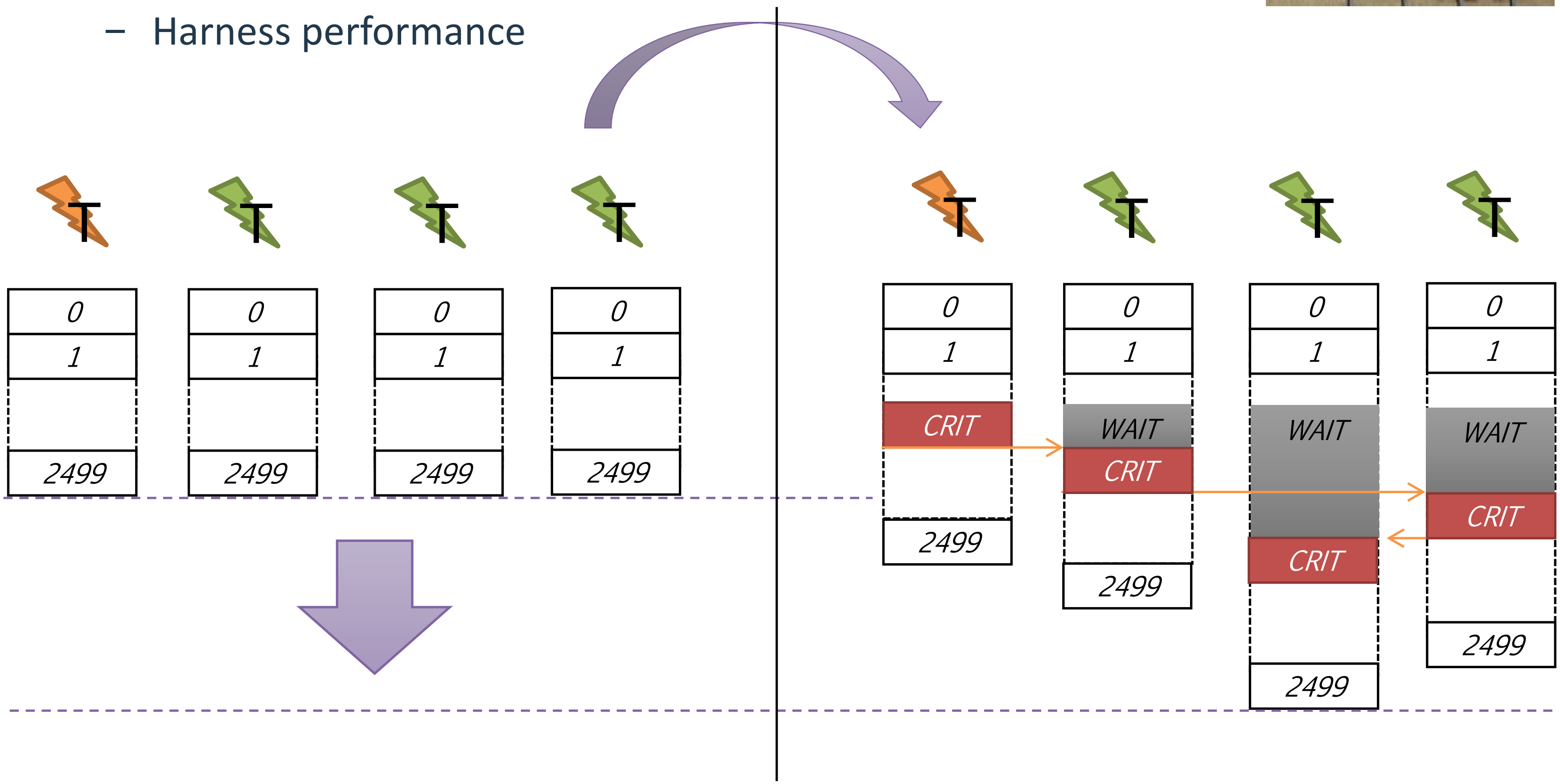
Let's code!

- Modify the "PI Montecarlo" exercise
  - Using critical section instead of locks



The risk of sequentialization

› Critical sections should be kept small as possible
  - They force code portions sequentialization
  - Harness performance



Even more flexible

- (Good) parallel programmers manage to keep critical sections small
  - Possibly, away from their code!
- Most of the operations in a critical section are always the same!
  - "Are you really sure you can't do this using `reduction` semantics?"
  - Modify a shared variable
  - Enqueue/dequeue in a list, stack..
- For single (C/C++) instruction we can definitely do better

The `atomic` construct

```
#pragma omp atomic [seq_cst] new-line
expression-stmt
```

- The atomic construct ensures that a specific storage location is accessed atomically
  - We will see only its simplest form
  - Applies to a single instruction, not to a structured block..

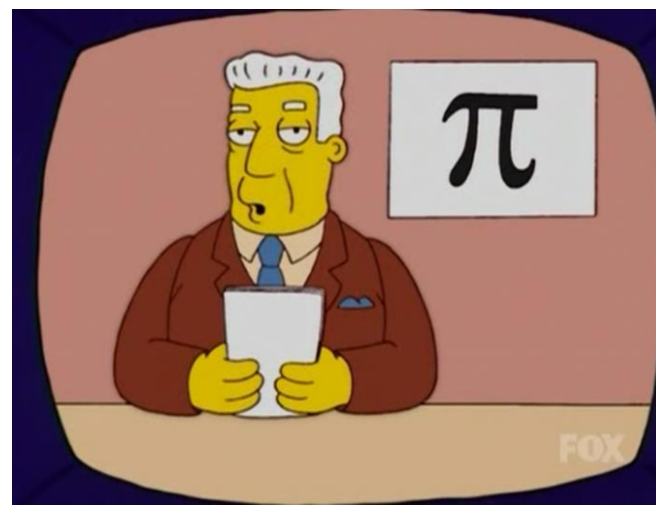
- Binding set: all threads <u>everywhere</u> (also in other teams/parregs)

- The `seq_cst` clause forces the atomically performed operation to include an implicit `flush` operation without a list
  - Enforces memory consistency
  - Does not avoid data races!!

Exercise

Let's code!

- Modify the "PI Montecarlo" exercise
  - Implementing the critical section with the `atomic` construct
  - (If possible)



How to run the examples

Let's code!

- Download the `Code/` folder from the course website

- Compile
- `$ gcc -fopenmp code.c -o code`

- Run (Unix/Linux)

```
$ ./code
```

- Run (Win/Cygwin)

```
$ ./code.exe
```

References

- "Calcolo parallelo" website
  - http://hipert.unimore.it/people/paolob/pub/Calcolo_Parallelo/
- My contacts
  - paolo.burgio@unimore.it
  - http://hipert.mat.unimore.it/people/paolob/
- Useful links
  - http://www.google.com
  - http://www.openmp.org
  - https://gcc.gnu.org/
- A "small blog"
  - http://www.google.com