Critical sections in OpenMP

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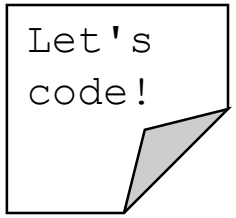
Outline

- 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



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

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

```
/* 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);
```

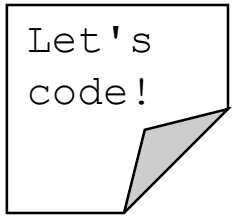
› The `omp_set_lock` has blocking semantic

OMP locks: example

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

```
/*** 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



- 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?

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;
```

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

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);
```

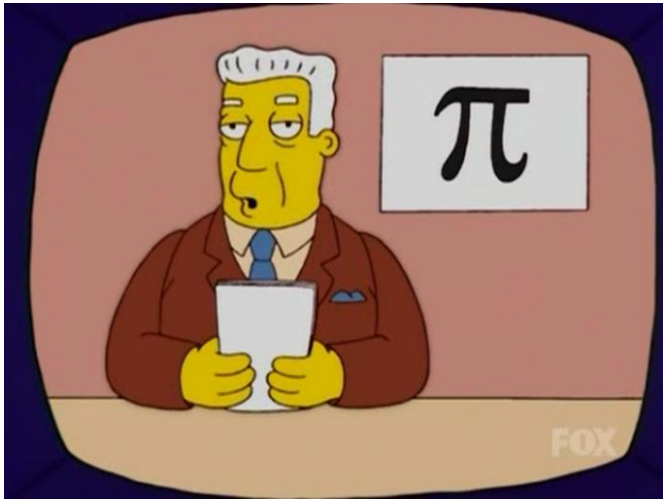
- Extremely useful in some cases. Instead of blocking
  - we can do useful work
  - we can increment a counter (to profile lock usage)

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

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
```

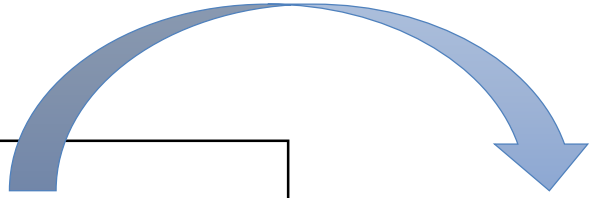
Where *hint-expression* is an integer constant expressioon that evaluates to a valid lock hint

- "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);
```



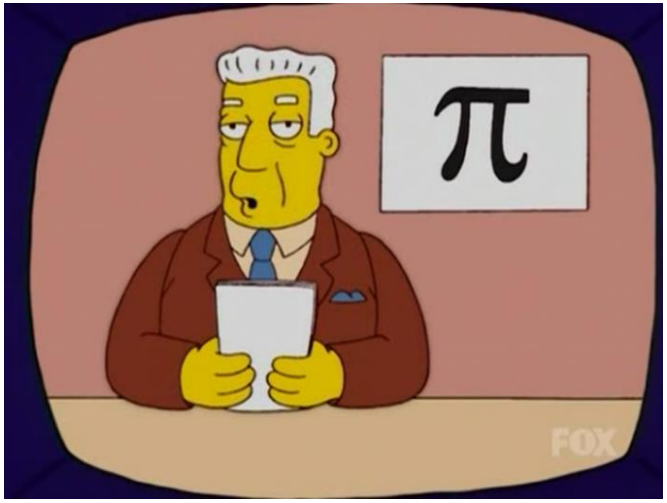
› …to this

```
/* 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

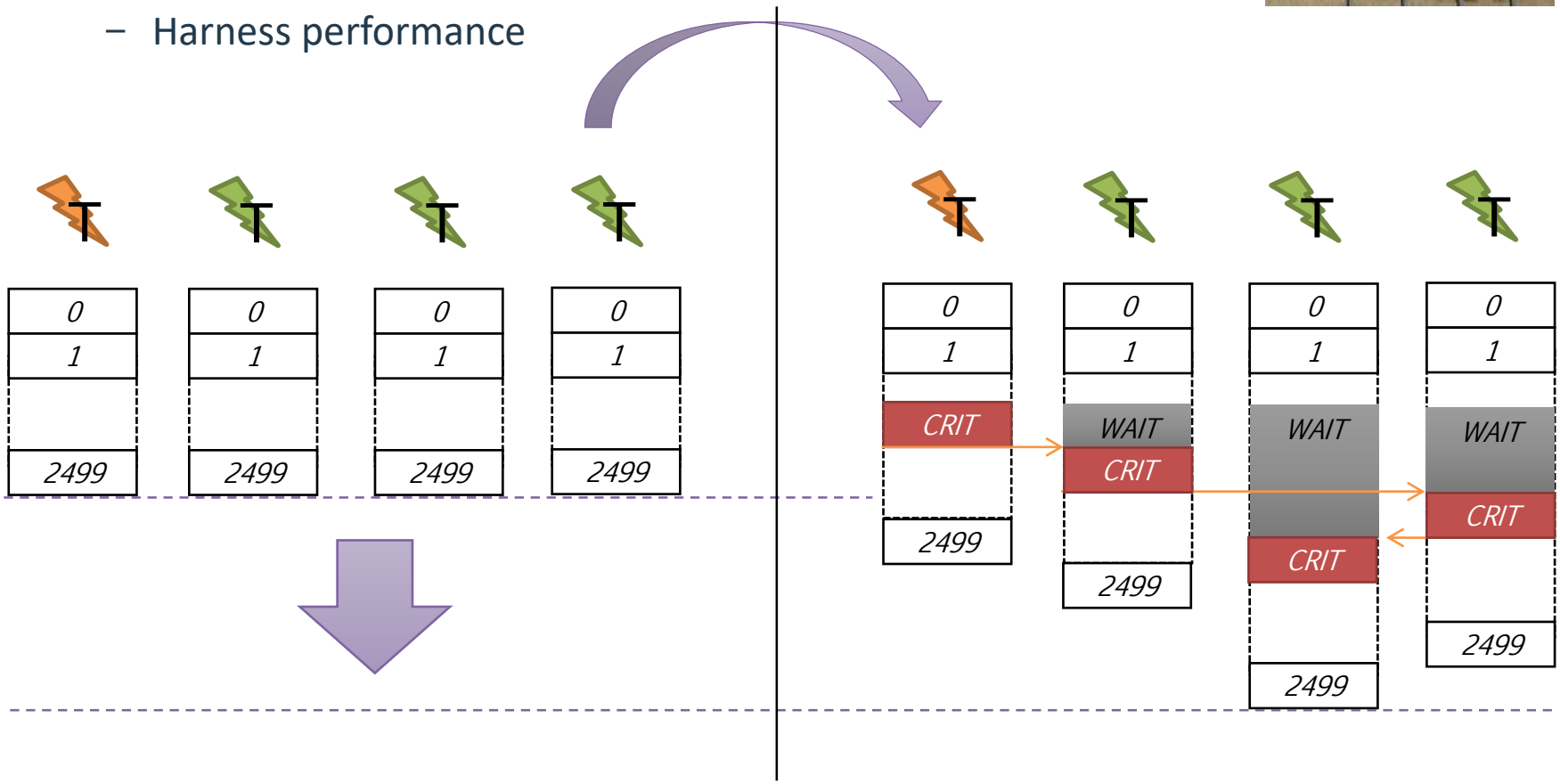
Let's code!

- 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

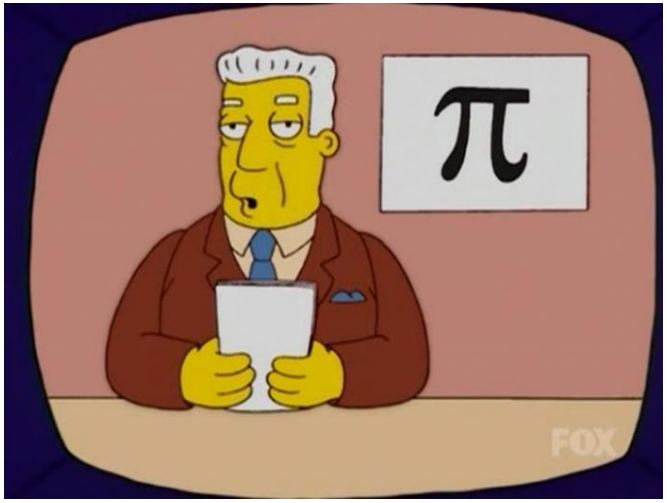
```
#pragma omp atomic [seq_cst] new-line
expression-stmt
```

- 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 everywhere (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!!

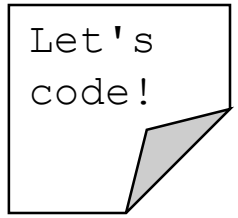
Exercise

Let's code!

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



How to run the examples



- 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/PhD/index.html
- 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