Shared Memory Concurrency 2

CS 62 - Spring 2016
Michael Bannister

Some slides based on those from Dan Grossman, U. of Washington

Weekly Assignments

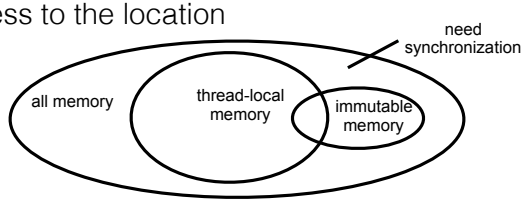
- Lab: Parallel Sorting
- Weekly Assignment: Operating System Simulator
  - Due: 4/10
  - First partner assignment
  - Open design
- Final Darwin tournament pushed to Friday 4/1

Reentrant Locks

- If thread holds lock when executing code, then further method calls within block don't need to reacquire same lock.
  - E.g., Methods m and n are both synchronized with same lock (e.g., with *this*), and execution of m results in calling n. Then once thread has the lock executing m, no delay in calling n.
- Very important for recursive functions!

Providing Safe Access

- For every memory location (e.g., object field) in your program, you must obey at least one of the following:
  - Thread-local: Don't access the location in > 1 thread
  - Immutable: Don't write to the memory location
  - Synchronized: Use synchronization to control access to the location



Thread-Local

- Whenever possible, don't share resources
  - Easier to have each thread have its own thread-local copy of a resource than to have one with shared updates
  - This is correct only if threads don't need to communicate through the resource
    - That is, multiple copies are a correct approach
    - Example: Random objects
  - Note: Since each call-stack is thread-local, never need to synchronize on local variables
- *In typical concurrent programs, the vast majority of objects should be thread-local: shared-memory should be rare – minimize it*

Immutable

- Whenever possible, don't update objects
  - Make new objects instead
- One of key tenets of functional programming
  - Hopefully you study this in 52
  - Generally helpful to avoid side-effects
  - Much more helpful in a concurrent setting
- If a location is only read, never written, no synchronization is necessary!
  - Simultaneous reads are not races and not a problem
- *Programmers over-use mutation – minimize it*

Dealing with the Rest

- Guideline: No data races
  - Never allow two threads to read/write or write/write the same location at the same time
- Necessary: In Java or C, a program with a data race is almost always wrong
- Use locks to eliminate race conditions

Worse Than You Think!

```
class C {
  private int x = 0;
  private int y = 0;

  void f() {
    x = 1;
    y = 1;
  }
  void g() {
    int a = y;
    int b = x;
    assert(b >= a);
  }
}
```

- Assertion always true w/single threaded.
- Looks always true for multithreaded.
  - OK if f not called at all
  - OK after f completes
  - Looks OK if in middle of f
- But have race condition

Memory Reordering

- For performance reasons, compiler and hardware reorder memory operations.
- But, but, ...
  - Compiler/hardware will never perform a memory reordering that affects the result of a single-threaded program
  - The compiler/hardware will never perform a memory reordering that affects the result of a data-race-free multi-threaded program
- So: If no interleaving of your program has a data race, then need not worry: result will be equivalent to some interleaving

Lock Granularity

- Coarse-grained: Fewer locks, i.e., more objects per lock
  - Example: One lock for entire data structure (e.g., array)
  - Example: One lock for all bank accounts
- Fine-grained: More locks, i.e., fewer objects per lock
  - Example: One lock per data element (e.g., array index)
  - Example: One lock per bank account
- "Coarse-grained vs. fine-grained" is really a continuum.

Trade-Offs

- Coarse-grained advantages
  - Simpler to implement
  - Faster/easier to implement operations that access multiple locations (because all guarded by the same lock)
  - Much easier: ops that modify data-structure shape
- Fine-grained advantages
  - More simultaneous access (performance when coarse-grained would lead to unnecessary blocking)
- Guideline:
  - Start with coarse-grained (simpler) and move to fine-grained (performance) only if contention on the coarser locks becomes an issue. Alas, often leads to bugs.

Critical-section granularity

- A second, orthogonal granularity issue is critical-section size
  - How much work to do while holding lock(s)
- If critical sections run for too long:
  - Performance loss because other threads are blocked
- If critical sections are too short:
  - Bugs because you broke up something where other threads should not be able to see intermediate state
- Guideline: Don't do expensive computations or I/O in critical sections, but also don't introduce race conditions

Deadlock

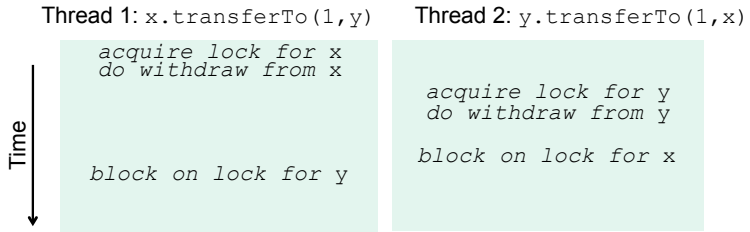
Deadlock

```
class BankAccount {
   ...
   synchronized void withdraw(int amt) {...}
   synchronized void deposit(int amt) {...}
   synchronized void transferTo(int amt, BankAccount a) {
      this.withdraw(amt);
      a.deposit(amt);
   }
}
```

- What locks are held at a.deposit(amt)?
- Is this a problem?

Deadlock

- Suppose have separate threads, each transferring to each others' account



Deadlock

- A deadlock occurs when there are threads T_1, …, T_n such that:
  - For i=1,..,n-1, T_i is waiting for a resource held by T_{i+1}
  - T_n is waiting for a resource held by T_1
- In other words, there is a cycle of waiting
  - Formalize as a graph of dependencies with cycles bad
- Deadlock avoidance in programming amounts to techniques to ensure a cycle can never arise