Debugging Multithreaded Programs

Debugging
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Deadlocks

- threads T1, T2, synchronization m1, m2
  - T1 waits to synchronize with T2 on m1
  - T2 waits to synchronize with T1 on m2
  - m1 can only be established by T2 after m2
  - m2 can only be established by T1 after m1
- a deadlock *freezes* a system
- may only occur in rare corner cases
  - hard to find and debug

Finding Deadlocks

- models
  - either build or extract abstract model
  - model checking or unit testing
  - goal is exhaustive simulation of all schedules
- search for cyclic dependencies
  - priority inversion (static lock/mutex order)
  - cycles in lock dependency graph
- generate massif *load,* insert *jitter*
  - wait for random time between locks/unlocks
  - add artificial work

Debugging Deadlocks

- access to program state of all threads
  - either through debugging/logging thread
  - or with symbolic debuggers
- *attaching* symbolic debuggers
  - after program seemed to be *frozen*
  - `gdb program.exe` *`pid`*
  - `threads`, `thread 2`, `bt`
- trade-off between *printf style* debugging and symbolic debugging
- use external tools that monitor locking order
  - for instance *helgrind* (which uses sand boxing)
- programming discipline
  - add wrappers around locking instead of directly calling pthread_...
  - add checker code that looks incompatible invalid locking order

Proper Lock Protection

THREAD1	THREAD2
lock (mu);	
v = v + 1;	
unlock (mu);	
	lock (mu);
	v = v + 1;
	unlock (mu);

Happens-Before Relation

- dependency between events
- events in the same thread/process ordered by execution order
- synchronization among threads/processes
  - sending/receiving message
  - locking/unlocking (of one particular lock)
  - waiting for a condition/enabling a condition
- shared access events should be ordered by happens before relation
  - otherwise data races
  - non deterministic behavior
  - usually also incorrect

Improper Lock Protection 1

m1 != m2

THREAD1

```
lock (m1);
v = v + 1;
unlock (m1);
```

THREAD2

```
lock (m2);
v = v + 1;
unlock (m2);
```

Improper Lock Protection 2

THREAD1	THREAD2
y = y + 1;	
lock (mu);	
v = v + 1;	
unlock (mu);	
	lock (mu);
	v = v + 1;
	unlock (mu);
	y = y + 1;

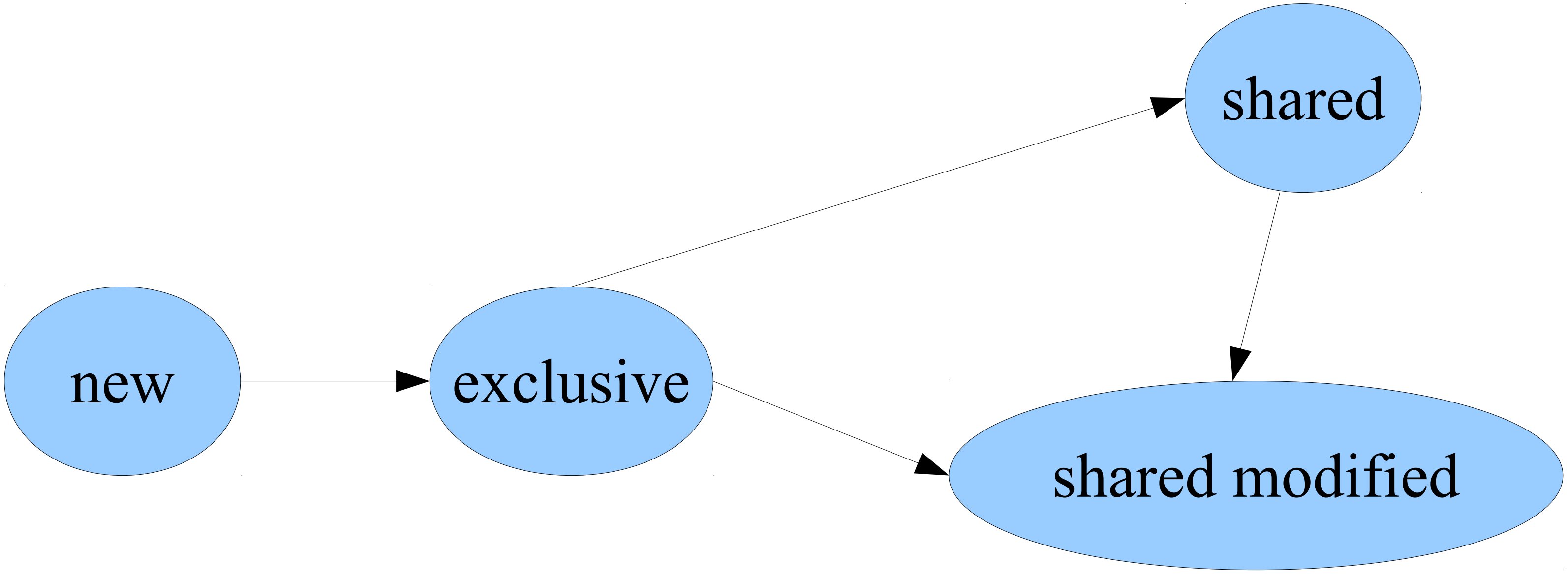
But access events to y still in *happens-before* relation!

Eraser/Lock Set Algorithm

- check for *locking discipline*
  - shared access protected by at least one lock
  - collect lock sets at access events
  - check intersection of lock sets non empty
- if a lock set becomes empty
  - either improper locking
  - even though no problem in *this* run
- some cases of *false positives / warnings*
  - for instance if threads work in phases
  - phases are scheduled properly
  - objects are exclusively own by a certain thread such a phase

Eraser False Warnings

- initialization / collection example
  - data is initialized by boss thread
  - work is spawned off to worker threads
  - results are collected and displayed by boss
- read / read vs read / write
  - attach state to data



High-Level Data Races

- *view* on protected data consistent
  - data X and Y accessed *together* in thread 1
  - access to X alone in thread 2 is fine
  - but it is not *view consistent* to access Y in thread 3 alone
- similar refinements as with Eraser
  - same problems with false positives
  - needs more programming discipline

Debugging Data-Races

- tools that implement Eraser algorithm
  - example again is *helgrind*
  - usually need sand boxing and thus
  - much slower than actual code
  - danger of *Heisenbugs*
- alternatively: programming discipline
  - wrap access to shared data
  - add checker for locking discipline
  - still potential for Heisenbugs
- much more difficult than debugging deadlocks
  - need to check *all accesses* to data
  - compared to just checking lock/unlock of a mutex in debugging deadlocks
  - even worse than debugging pointer related bugs
- schedule steering: massif load and/or random jitter