Recursive read deadlocks and Where to find them

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Agenda

- Deadlock cases
- Lockdep
- Flavors of read/write locks
- More deadlock cases
- (Recursive) read deadlock detection

Deadlock cases

- self deadlock

```
P0

spin_lock(&A);
...
spin_lock(&A);
```

- ABBA deadlock

```
P0                  P1

spin_lock(&A);      spin_lock(&B);
...                 ...
spin_lock(&B);      spin_lock(&A);
```

Deadlock cases (cont.)

- IRQ safe->unsafe deadlocks
  - IRQs bring more "code combinations"

```
P0

<irq enabled>
spin_lock(&A);
...
<in irq handler>
 spin_lock(&A);
```

```
P0                      P1

<irq enabled>           <irq disabled>
spin_lock(&A);          spin_lock(&B);
...                     ...
<in irq handler>
 spin_lock(&B);         spin_lock(&A);
```

Deadlock cases (cont.)

- ABBCCA deadlocks
  - or more

P0	P1	P2
`spin_lock(&A);`	`spin_lock(&B);`	`spin_lock(&C);`
`...`	`...`	`...`
`spin_lock(&B);`	`spin_lock(&C);`	`spin_lock(&A);`

Lockdep

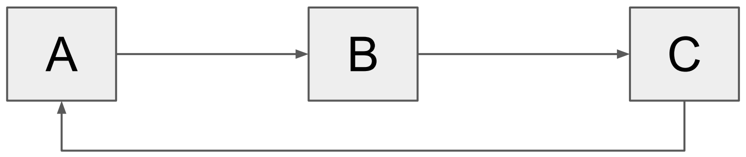
- Locks are grouped by classes
- Lock dependency
    - A -> B

```
P0

spin_lock(&A);
...
spin_lock(&B);
```

- Dependency graph

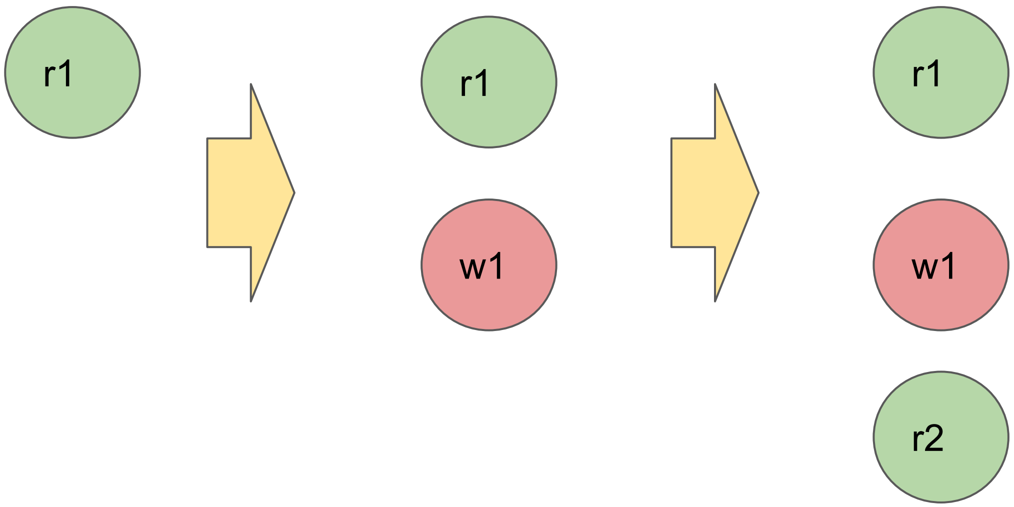
Lockdep (cont.)

- Deadlock detection
    - A closed path (circle) in the dependency graph



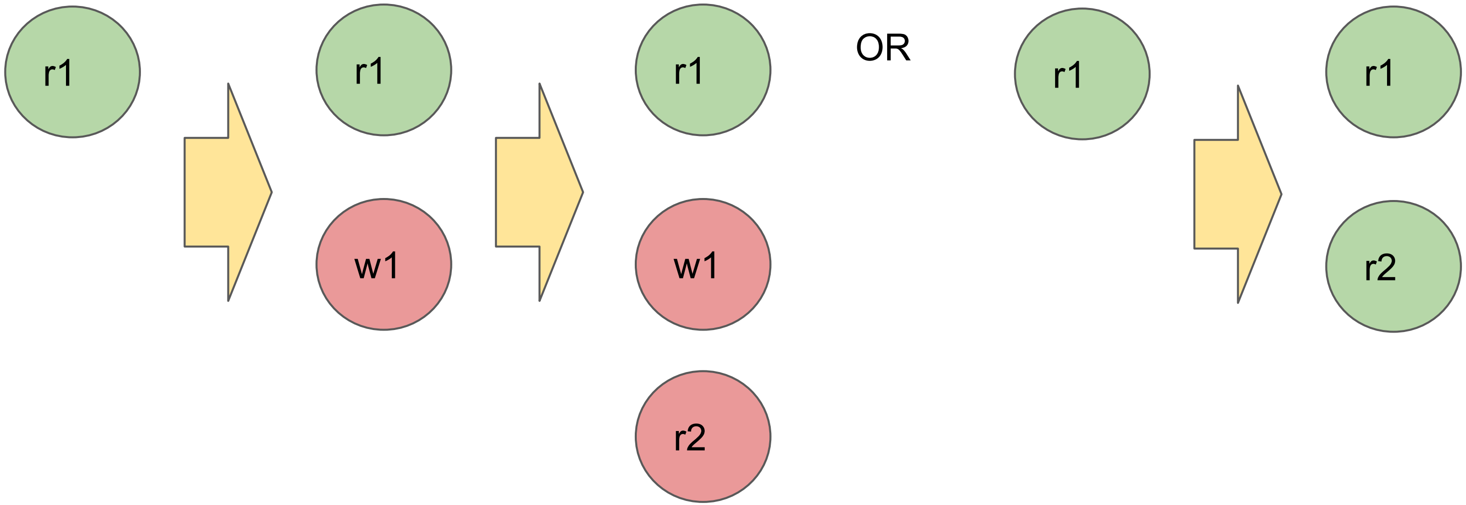
Flavors of read/write locks

- Recursive/unfair rwlocks
  - readers are preferable



Flavors of read/write locks (cont.)

- Non-recursive/fair rwlocks



Flavors of read/write locks (cont.)

flavors	multiple readers	recursive c.s	a reader blocks another reader
recursive	Y	Y	N
non-recursive	Y	N	Y* (via a waiting writer)

Flavors of read/write locks (cont.)

- Block condition
  - Recursive readers can get blocked by writers
  - Non-recursive readers can get blocked by non-recursive readers (via a waiting writer) or writers

	reader(recursive or not)	writer
recursive reader	N	Y
non-recursive(r & w)	Y	Y

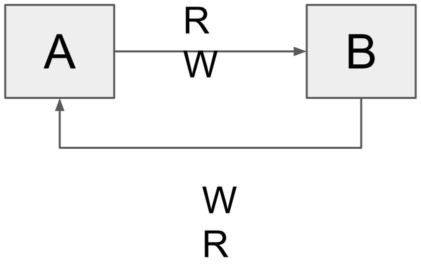
More deadlock cases

- For non-recursive read/write locks
  - Same as spinlocks, since readers can block each other via a waiting writer

P0	P1	P2
read_lock(&A);	**spin_lock(&B);**	
...	**...**	**write_lock(&A);**
spin_lock(&B);	**read_lock(&A);**	

More deadlock cases

- For recursive locks, things get interesting:
    - This is not a deadlock

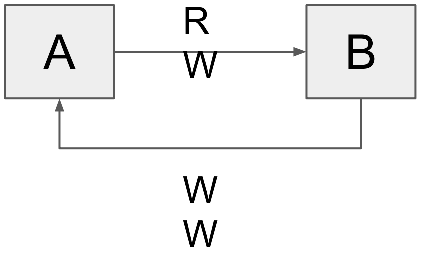



```
P0                    P1

read_lock(&A);        spin_lock(&B);
...                   ...
spin_lock(&B);        read_lock(&A);
```

More deadlock cases

- But this is a deadlock

```
P0                          P1

read_lock(&A);              spin_lock(&B);
...                         ...
spin_lock(&B);              write_lock(&A);
```

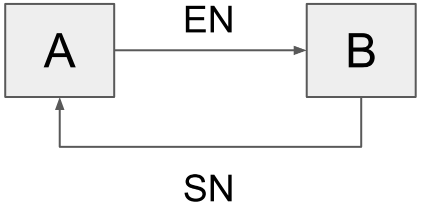


More deadlock cases

- Things get complicated when we mixed recursive and non-recursive read locks
- queued rwlock
  - non-recursive read lock in process context
  - recursive read lock in irq context

More deadlock cases

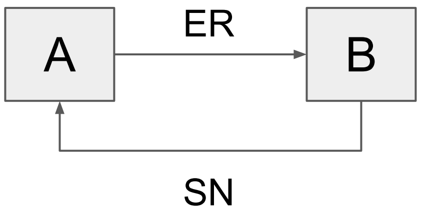
- Recursive deadlock case




```
P0                      P1                      P2

<in irq handler>
 read_lock(&B);         spin_lock_irq(&A);
                                                write_lock_irq(&B);
 spin_lock(&A);         read_lock(&B);
```

More deadlock cases

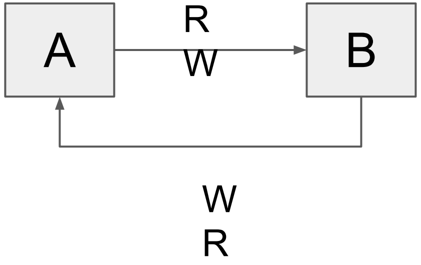
- Recursive *not* deadlock case




```
P0                        P1                       P2

<in irq handler>
 spin_lock(&A);           read_lock(&B);
                                                   write_lock_irq(&B);
 read_lock(&B);           spin_lock_irq(&A);
```

Recursive read deadlock detection

- Limitation of current lockdep
  - circles mean deadlocks
  - while not all the circles mean deadlocks if we consider recursive readers.



Recursive read deadlock detection

- Goals
  - Compatible with original lockdep detection.
  - Handle qrwlock semantics.
  - No false positive.

Recursive read deadlock detection

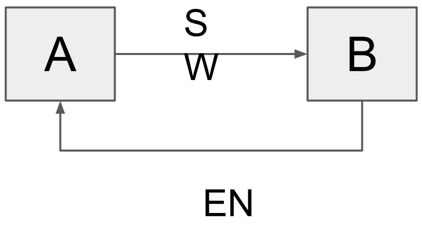
- Overview
    - Classification for lock dependencies
    - Definition of "strong" dependencies
    - Deadlock Condition
    - Informal Proof

Classification of lock dependencies

- We used to treat all lock dependencies as the same
- but they are really not.
- {R reader, reader, writer} -> {R reader, reader, writer} : 9 combinations

Classification of lock dependencies

- Groups things into 4
    - {R reader, reader} -> {reader, writer}: -(SN)->
    - {R reader, reader} -> {R reader}: -(SR)->
    - {writer} -> {reader, writer}: -(EN)->
    - {writer} -> {R reader}: -(ER)->
- Why? Because for a dependency A -> B, we cares:
    - Whether A can block anyone
    - Whether B can get blocked by anyone



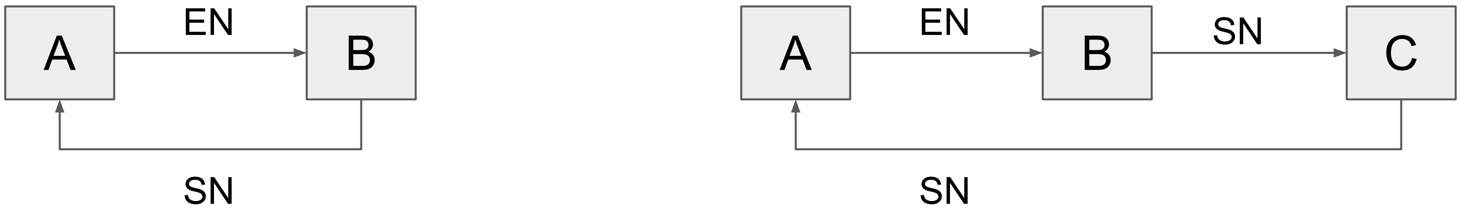

```
P0                        P1

read_lock(&A);            spin_lock(&B);
...                       ...
spin_lock(&B);            write_lock(&A);
```

Definition of "strong" dependencies

- Chaining lock dependencies via block conditions
- For dependencies A -> B and B -> C
  - A -> B -> C is a "strong" dependency path iff
    - A -> B : -(*R)-> and B -> C : -(E*)->, or
    - A -> B : -(*N)-> and B -> C : -(S*)->, or
    - A -> B : -(*N)-> and B -> C : -(E*)->
  - IOW, -(*R)-> -(S*)-> will break the dependency
- works for "A -> B, B -> C and C -> D" case, and so on

Deadlock condition

- A strong dependency chain/path forms a circle




```
P0                      P1                      P2

spin_lock(&A);          read_lock(&B);          read_lock(&C);
...                     ...                     ...
write_lock(&B);         write_lock(&C);         spin_lock(&A);
```

Informal Proof

- We want to prove:
  - A strong dependency circle is equivalent to deadlock possibility
- Necessary condition
  - a strong dependency circle => deadlock possibility
  - Easy, because a strong dependency circle means we can build a combination of locking sequences that cause deadlock.

Informal Proof (cont.)

- Sufficient condition
  - deadlock possibility => a strong dependency circle
  - My trick
    - deadlock possibility => circular wait (deadlock necessary condition according to wikipedia)
    - circular wait => a strong dependency circle

Implementation

- Extend __bfs() to walk on strong dependency path
- Make LOCK*_STATE* part of the chainkeys
- Add test cases
  - also unleash irq_read_recursion2
- Enable this for srcu
- Code
  - git.kernel.org/pub/scm/linux/kernel/git/boqun/linux.git arr-rfc-wip