LOCKING PROTOCOLS & SOFTWARE TRANSACTIONAL MEMORY

Why Study (Software) Transactions

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1. Transactions are good abstractions
2. Design choices and issues can guide your concurrent data structures

Coarse/Fine Grained Locking

- Locking discipline enforce protection
  - Each object is protected by some lock
  - One lock protects a set of objects
- Lock leveling for deadlock avoidance
  - Assign a partial ordering to locks, Level(X)
  - After acquiring a lock X, the transaction is only allowed to acquire locks Y with Level(Y) > Level(X)
- Enforce locking discipline and lock leveling using static analysis tools

Two Phase Locking (Revisited)

1. Transactions acquire a lock on an object before accessing the object
2. Transactions cannot acquire a lock once the transaction has released some lock

- Works with shared/exclusive locks
- Deadlock avoidance

Use Hardware Primitives

```
Lock (L);
x = x + 1;
Unlock(L);
```

```
InterlockedIncrement(&x);
```

- Interlocked operations are implemented by low-level locking by the hardware

```
asm{
  lock inc [x];
}
```

Using Compare And Exchange

- If you need to protect more than one logical variables
- But the variables can be compressed into a 32/64 bits

```
Lock(L); // protects x and y

x = f(x, y);
y = g(x, y);

Unlock(L);
```

Using Compare and Exchange

- Compress x and y into a single 'state' variable

```
retry:
s = state; // compress state into 64 bits

x = s.x; y = s.y;
x = f(x,y); y = g(x,y)
t.x = x; t.y = y;

if(! CompareAndExchange(&state, t, s))
  goto retry;
```

Progress Guarantees

- Wait freedom
  - Every thread makes progress in the presence of conflicts
- Lock freedom
  - Some thread makes progress in the presence of conflicts
- Obstruction freedom
  - A thread makes progress when all other threads are suspended

What is the progress guarantee?

```
Lock(L);

x = f(x, y);
y = g(x, y);

Unlock(L);
```

```
Lock(L);

x = f(x, y);
y = g(x, y);

Unlock(L);
```

What is the progress guarantee?

```
retry:
s = state;
x = s.x; y = s.y;
x = f(x,y);
y = g(x,y)
t.x = x; t.y = y;

if(!CAS(&state,t,s))
  goto retry;
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if(!CAS(&state,t,s))
  goto retry;
```

Sophisticated Fine Grained Locking Protocols

- Locking protocols for guaranteeing linearizability
  - Even when not following the 2-phase locking discipline
- Allows early release of locks for more concurrency
- Proof of correctness is complicated
  - Never roll out your own

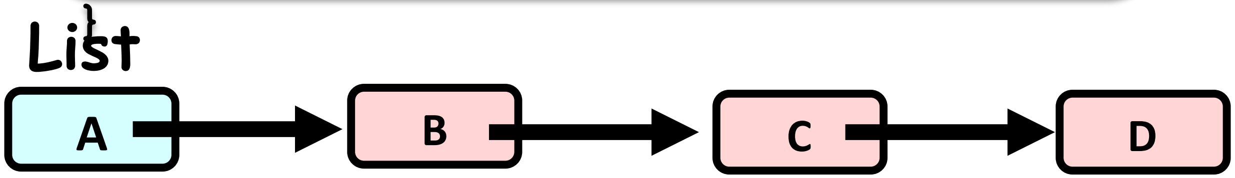
Tree Locking

- The objects form a tree
- Transactions acquire a lock on an object before accessing the object
  - Henceforth not state this constraint explicitly

1. A transaction may begin executing by locking any object
2. Can acquire a lock on X only if already holding the lock on parent of X
3. Can acquire a lock on X at most once
4. (Can otherwise release locks in arbitrary order)

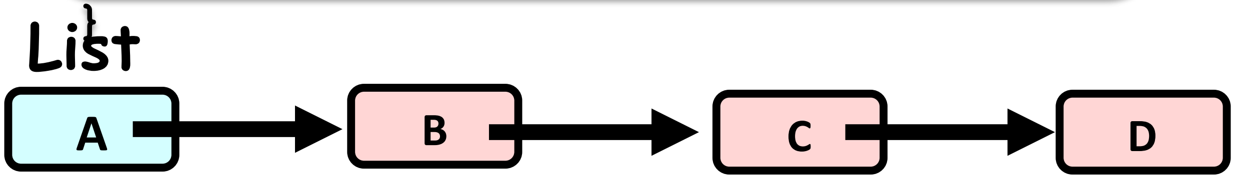
"Hand Over Hand" Locking

```
void IncrementAll(List list, int k)
{
  Node c = list;

  while( c != null ) {
    c.data += k;


    c = c.next ;

  }
}
```



"Hand Over Hand" Locking

```
void IncrementAll(List list, int k)
{
  Node c = list;
  Lock(c);
  while( c != null ) {
    c.data += k;
    if(c.next != null)
       Lock(c.next);
    c = c.next ;
    Unlock(c);
  }
}
```



Proof of Tree Locking

- If two transactions conflict, one of the two acquires all shared locks before the other
- This ordering enforces the serialization order
  - => Serializability
- Is this protocol linearizable?

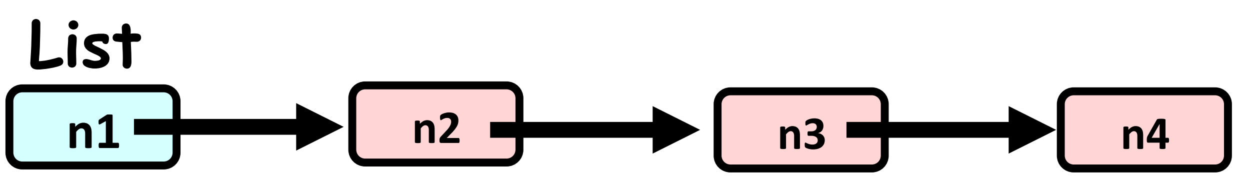
DAG Locking

- The objects form a DAG

1. A transaction may begin executing by locking any object
2. Can acquire a lock on X only if
    1. already holding the lock on some parent of X
    2. Has previously acquired locks on all parents of X
3. Can acquire a lock on X at most once
4. (Can otherwise release locks in arbitrary order)

Domination Locking

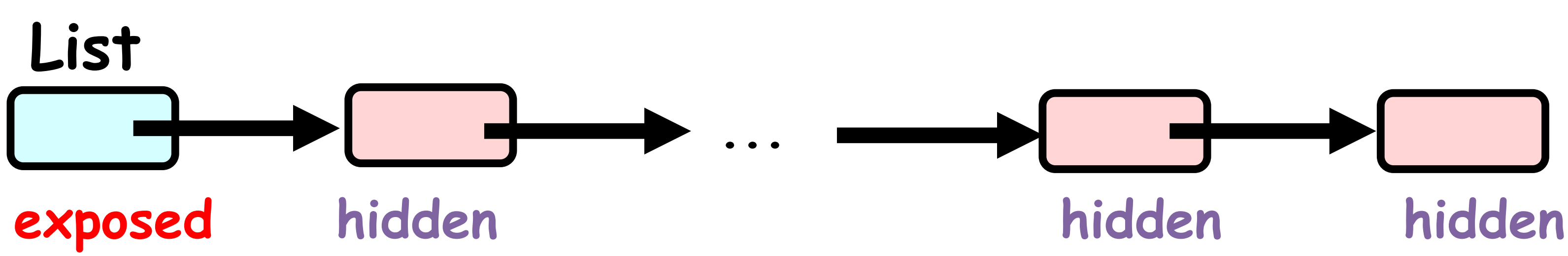
- Leverages the restricted semantics of software modules
  - thread can access n3 only after n1 & n2
- Allows early release
- Allows for dynamic modification to the underlying struture



Two types of objects

- Distinguishes between exposed and hidden objects
- Exposed objects
  - “roots” of data structures
  - may be pointed by transaction arguments
- Hidden objects
  - may not be pointed by transaction arguments
  - may be reachable via exposed objects

void insert(List l, int k) {…}



Domination Protocol Rules

1. A hidden object u can be acquired by t only if every path between an exposed object to u includes an object which is locked by t
2. Perform leveled two phase locking on exposed objects

Software Transactional Memory

- Different tradeoffs than database transactions
- Disk access ~10ms vs Memory access ~10ns
- Durability (the D in ACID is not necessary)
- Databases can control all access to the data, while STMs should deal with non-transactional accesses

Pessimism vs Optimism

- Pessimistic concurrency control
  - Expect conflict
  - Prevent conflict (by holding locks)
  - Need to avoid deadlocks
  - Useful when conflicts are frequent
- Optimistic concurrency control
  - Expect no conflicts
  - Rollback and retry
  - Need to avoid livelocks, wasted work on retry
  - Useful when conflicts are rare
- Combination possible

What is the concurrency control in TL2?

Version Management : How to perform writes

- "Eager" writes
  - Perform writes in place
  - Maintain undo-logs to revert writes on abort
- "Lazy" writes
  - Perform writes in a local log
  - Write to memory at commit time
  - Need to guarantee read-your-own-writes

Dealing with inconsistent reads

```
atomic {
  X = 1;



  Y = 1;
}
```

```
atomic {
  if(X != Y)
    while(1);
}
```

Obstruction Freedom: Is it acceptable to hold locks?

- Long running transactions can block progress ?
- A switched out thread can block progress ?
- A failed thread can block progress ?
- Priority inversion?

Optimisitic Concurrency For Reads

- Work loads tend to be read mostly
- Should allow efficient concurrent reads
- Look out for writes introduced in a read-only transaction

TL2 Algorithm

```
read_ver = global_clock;
on_read(x):
  (x_ver, x_locked) = version(x);
  validate_read(x):
     if(x_locked || x_ver > read_ver) abort;
on_write(x):
   write (x,v) to log

forall w in write_set lock(w);
atomic{ write_ver = ++global_clock; }
forall r in read_set valid_read(r);
forall w in write_set{
      version(w) = write_ver;
      unlock(w);
}
```