UNIVERSITY OF TWENTE.

VERIFICATION OF SHARED-READING SYNCHRONISERS

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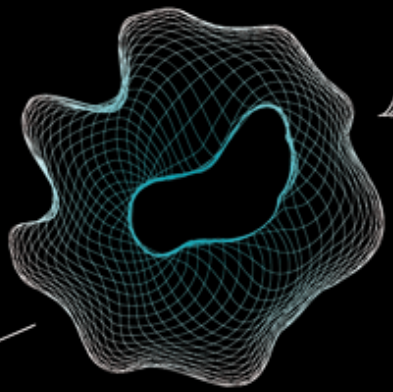

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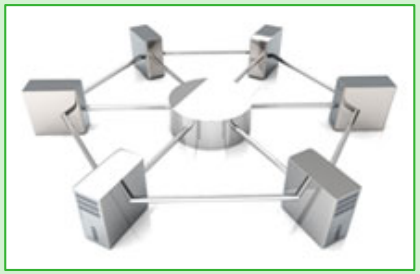
SOFTWARE RELIABILITY

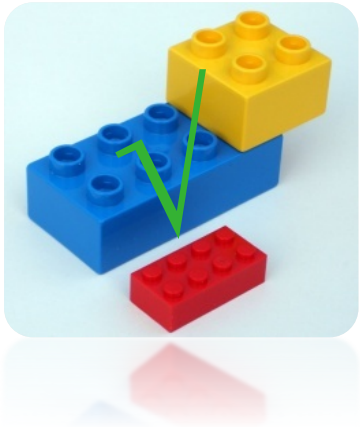
All software has errors!

Software failures can have enormous impact

An important challenge: Reliable software with parallel computations



SYNCHRONISERS



- Major building block for concurrent software
- Role:
  - Tame the inferences between threads
  - Prevent unwanted interleavings
- Well-known examples (in Java API):
  - Reentrant Locks
  - Barriers
  - Countdown Latch
  - Semaphore
- Exclusive Access vs Shared Reading

CHALLENGE: VERIFICATION OF SYNCHRONISER

- Implementation uses AtomicInteger
- Need to ensure that synchroniser protects access to shared resources
- Threads can have a different view on shared state
- Verification support for atomics

```
public class AtomicInteger {
   private volatile int value;

   public AtomicInteger(int v);

   public int get();
   public void set(int v);
   public boolean compareAndSet(int x, int n);
}
```

Atomics rule:

emp |- {P * I} C {Q * I}
I |- {P} atomic(C) {Q}

APLAS 2014: EXCLUSIVE ACCESS SYNCHRONISERS

- Identification of typical synchronisation patterns (using combinations of get, set and compareAndSet)
- Specification of AtomicInteger class
  - Value of the atomic variable (synchroniser state)
  - Views of the participating threads on the atomic variable
- Client specifies synchronisation protocol
  - Roles of the thread
  - Resource invariant: protected shared memory location
- Verification of various exclusive access synchroniser implementations

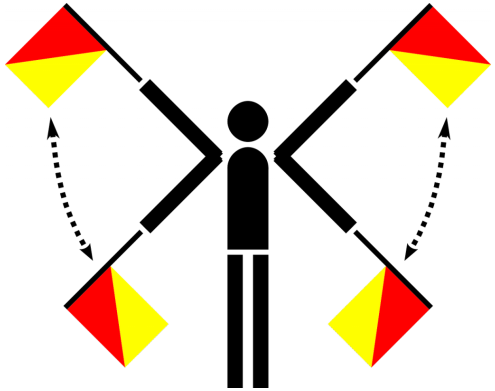
CONTRIBUTIONS

- Extension to shared-reading synchronisers
- Adaptation of AtomicInteger specification
  - Support both partial and exclusive access to shared state
- Verification of several synchroniser implementations
  - Semaphore
  - CountDown Latch
- Verification is tool-supported
  - VerCors tool set: http://www.utwente.nl/vercors

SEMAPHORE IMPLEMENTATION

```
public class Semaphore{
    private AtomicInteger sync;
    Semaphore(int n){
        sync = new AtomicInteger(n);
    }

    public void acquire() { ... }
    public void release() { ... }
}
```



SEMAPHORE ACQUIRE

```
public void acquire(){
    boolean stop = false;
    int c = 0;
    while(!stop) {
        c = sync.get(); // how many parts are still left
        if( c > 0 ){ // any part left?
            int nextc = c-1;
            stop = sync.compareAndSet(c,nextc); //try to obtain 1 part
        }
    }
}
```

SEMAPHORE RELEASE

```
public void release(){
    boolean stop = false;
    while(!stop) {
        int c = sync.get(); // how much space is left
        int nextc = c+1;
        stop = sync.compareAndSet(c,nextc); // try to increase this by 1
    }
}
```

SHARED-READING SYNCHRONISER CHARACTERISTICS

- Groups of threads involved in the synchronisation can be abstracted by their behavioural role
- If threads with identical role share a resource, they have to participate in a compare-and-set competition (for acquire and release)
- If threads have different roles access can be controlled by collaboration between get and set
- Internal volatile counter determines remaining portion of shared state

- CompareAndSet: obtain resources by competition
- Get: obtain resources as prescribed by the protocol
- Set: release resources

ATOMIC INTEGER SPECIFICATION

```
/*@  given Set<role> rs; // abstract thread roles
       given group (frac->group) inv; // protected shared resource
       given (role, int->frac) share; // relation counter and resource fraction
       given (role, int, int-> boolean) trans; // valid transitions
@*/
class AtomicInteger {
   private volatile int value;
   /*@  group handle(role r,int d,frac p); @*/ //token from last access

   /*@  requires inv(share(S,v));    // resources to be protected
        ensures (\forall* r in rs: handle(r,v,1));  // handle for all threads
   @*/
   AtomicInteger(int v);
   … }
```

ATOMIC INTEGER SPECIFICATION: GET AND SET

```
/*@  given role r, int d, frac p;
       requires handle(r,d,p) ** inv(share(r,d));
       ensures handle(r,\result,p) ** inv(share(r,\result));
@*/
public int get();

/*@  given role r, int d, frac p;
       requires handle(r,d,p) ** trans(r,d,v);
       requires inv(share(S,v)) ** inv(share(r,d));
       ensures handle(r,v,p);@*/
public void set(int v);
```

ATOMIC INTEGER SPECIFICATION: COMPARE-AND-SET

```
/*@  given role r, int m, frac p;
       requires handle(r,x,p) ** trans(r,x,n)
       requires inv(share(S,n)-share(S,x));
       ensures  \result==> (handle(r,n,p) ** inv(share(S,x) - share(S,n));
       ensures !\result==> (handle(r,x,p) ** inv(share(S,n) - share(S,x));
@*/
boolean compareAndSet(int x, int n);}
```

VERIFICATION OF SEMAPHORE IMPLEMENTATION

CLASS LEVEL SPECIFICATIONS

```
/*@  given group (frac -> resource) rinv; @*/
public class Semaphore{
   /*@  ghost final int num;
        ghost Set<role> roles = {T};
        group initialized(int d,frac p) = sync.handle(T,d,p);
        resource held(int d,frac p) = initialized(d,p);
        group inv(frac p) = rinv(p);
        frac share(role r, int c){
           return (r==S && c>=0 && c<num)?(c/num):0; }
        boolean trans(role r, int c, int n){
           return   (r==T && c>0 && n==c-1) ||
                    (r==T && c<max && n==c+1); } @*/
      private AtomicInteger /*@ <roles,inv,share,trans> @*/ sync;
```

CONSTRUCTOR

```
/*@  requires rinv(1) ** n>0;
       ensures initialized(n,1) ** num == n;
@*/
Semaphore(int n){
   /*@ set num = n;  fold sync.inv(share(n)); @*/
   sync=new AtomicInteger /*@<roles,inv,share,trans>@*/ (n);
   /*@ fold initialized(n,1); @*/
}
```

IF YOU READ THE PAPER

- More details about how the specification for AtomicInteger is derived
- Full verification (also acquire and release of Semaphore)
- CountDown Latch implementation with online verification

CONTRIBUTIONS

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