

Tools for exploring and understanding memory models

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Joint work with

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Outline

- Memory models
- Lem
- Herd

Memory models

- Memory model:
 - which values might be read from memory
 - assembly code / higher-level language
 - operational / axiomatic

Axiomatic memory model

- Defines predicates over program executions
- Contract between programmer and language

The value of an atomic object M , as determined by evaluation B , shall be the value stored by some operation in the visible sequence of M with respect to B .

C standard §5.1.2.4:22

The execution of a program contains a *data race* if it contains two conflicting actions in different threads, at least one of which is not atomic, and neither happens before the other. Any such data race results in undefined behavior.

C standard §5.1.2.4:25

Lem

A *visible side effect* A on an object M with respect to a value computation B of M satisfies the conditions:

- A happens before B , and
- there is no other side effect X to M such that A happens before X and X happens before B .

C standard §5.1.2.4:19

```
let visible_side_effect_set actions hb =  
  { (A,B) | forall ((A,B) IN hb) |  
    is_write A && is_read B && (loc_of A = loc_of B) &&  
    not ( exists (X IN actions). not (X IN {A;B}) &&  
      is_write X && (loc_of X = loc_of B) &&  
      (A,X) IN hb && (X,B) IN hb ) }
```

Lem

Herd

A *visible side effect* A on an object M with respect to a value computation B of M satisfies the conditions:

- A happens before B , and
- there is no other side effect X to M such that A happens before X and X happens before B .

C standard §5.1.2.4:19

```
let hb_l = hb & loc
let vse = [W];hb_l;[R] & ~(hb_l;[W];hb_l)
```

Herd

$$\frac{(a, b) \in R \quad (b, c) \in S}{(a, c) \in R ; S}$$

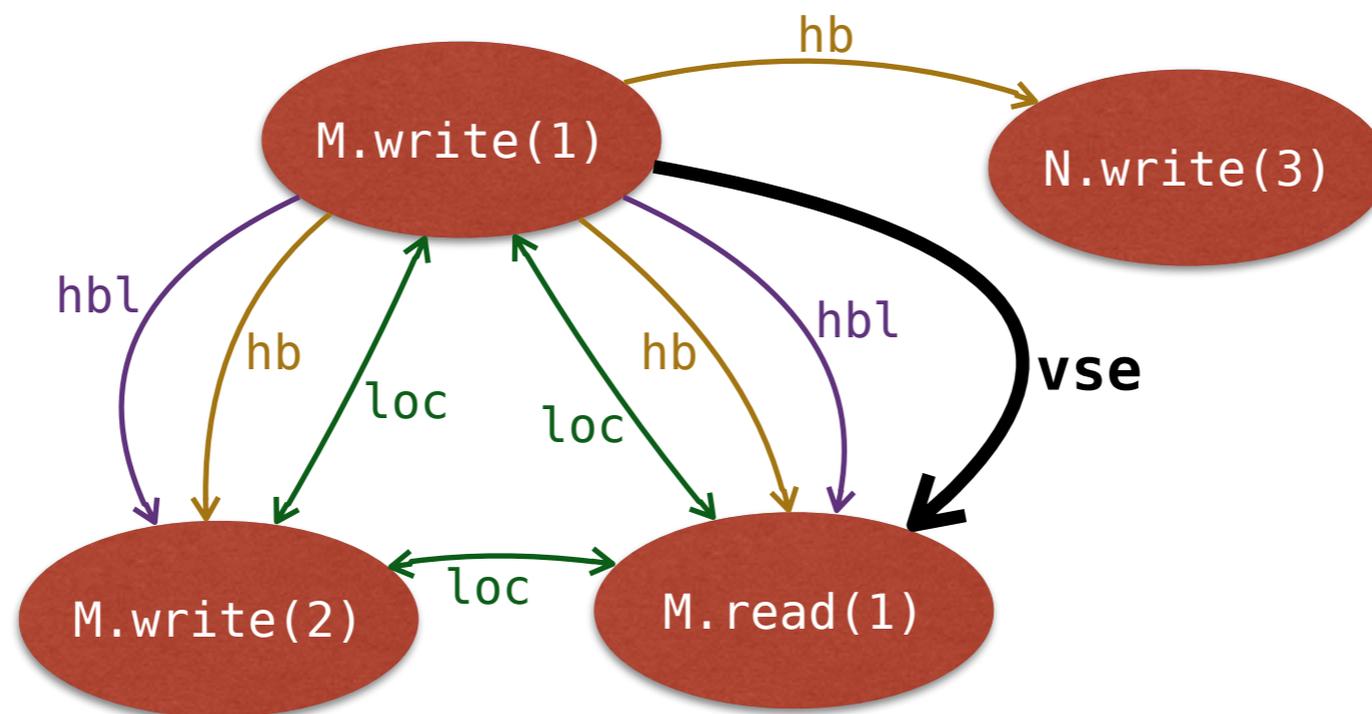
$$\frac{a \in s}{(a, a) \in [s]}$$

$R \ \& \ S$ $R \ | \ S$ $R \ ; \ S$ $[s]$

$\sim R$ R^{-1} R^* R^+ $R^?$

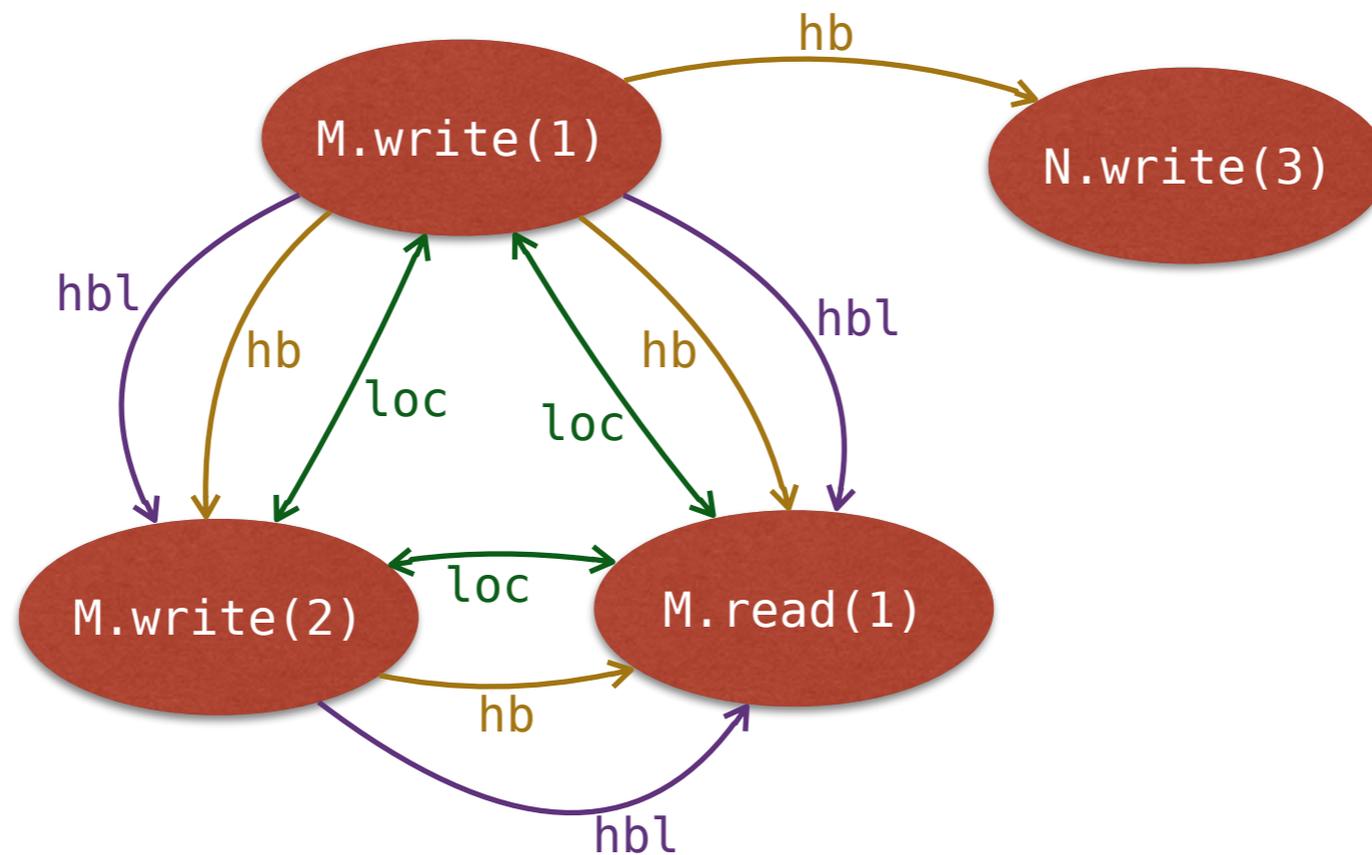
$[zone-4] ; northern ; [step-free] ; central ; [zone-6]$

Herd



```
let hb_l = hb & loc
let vse = [W];hb_l;[R] & ~(hb_l;[W];hb_l)
```

Herd



```
let hb\l = hb & \l oc
let vse = [W];hb\l;[R] & ~(hb\l;[W];hb\l)
```

The POWER of Herd

Lem vs. Herd

- Lem:
 - Expressive language → match prose
- Herd:
 - Concise → optimise model, compare models
 - Efficient simulation

Our work

- C/C++ memory model in Herd, prove equivalent to existing Lem version
- OpenCL memory model in Lem and Herd
- NVIDIA's PTX memory model

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