C++ Concurrency - Formalised

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Mutex Algorithms

- At most one thread is in the critical section at any time.

Dekker's Mutex Algorithm [2]

Initialisation

```
x = 0; y = 0;
```

Thread 1

```
x = 1;
if (y == 1) {
  ... //Busy Wait
}
// Critical Section
```

Thread 2

```
y = 1;
if (x == 1) {
  ... //Busy Wait
}
// Critical section
```

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MOV [x] <- 1
MOV r1 <- [y]
```

Thread 2

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y = 1;
if (x == 1) {
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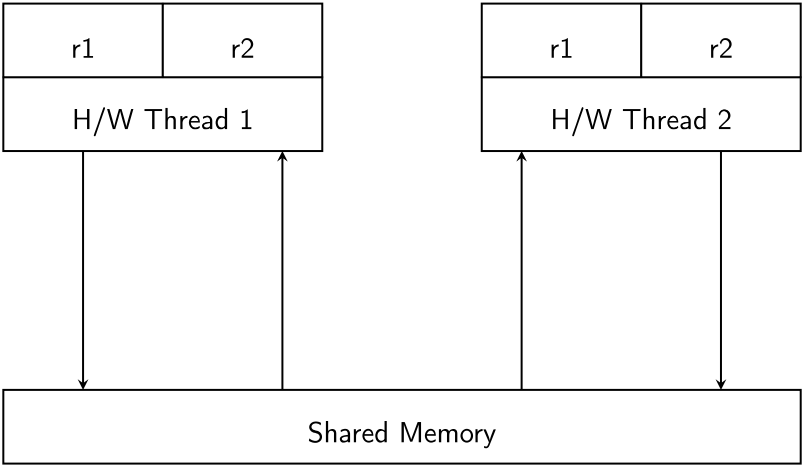
}
// Critical section
```

```
MOV [y] <- 1
MOV r2 <- [x]
```

Modern x86 Multiprocessors - simplified (based on [4])



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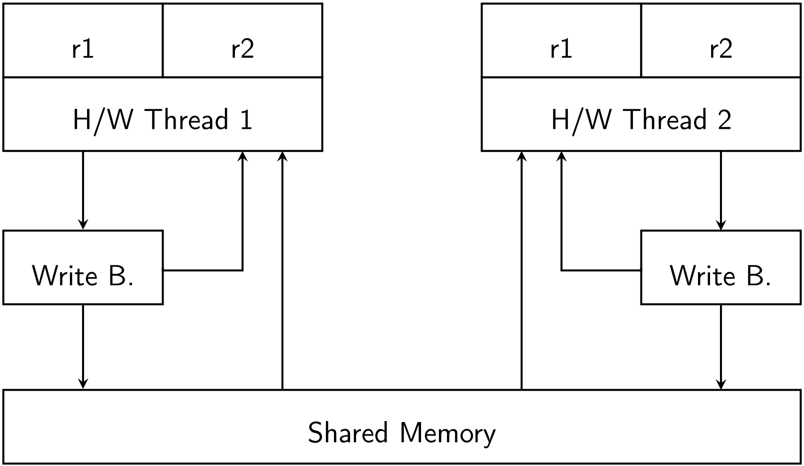
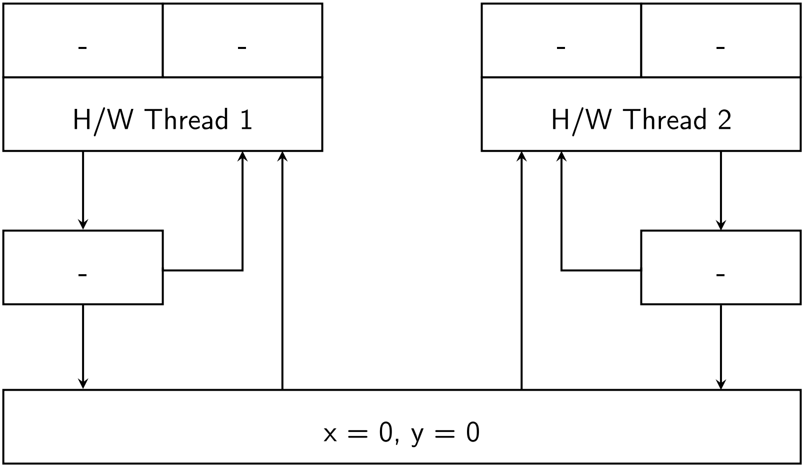


Modern x86 Multiprocessors and Dekker's Algorithm



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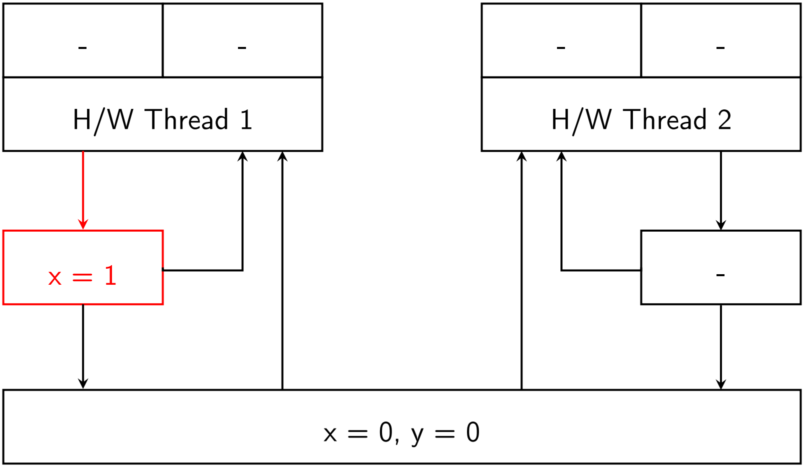

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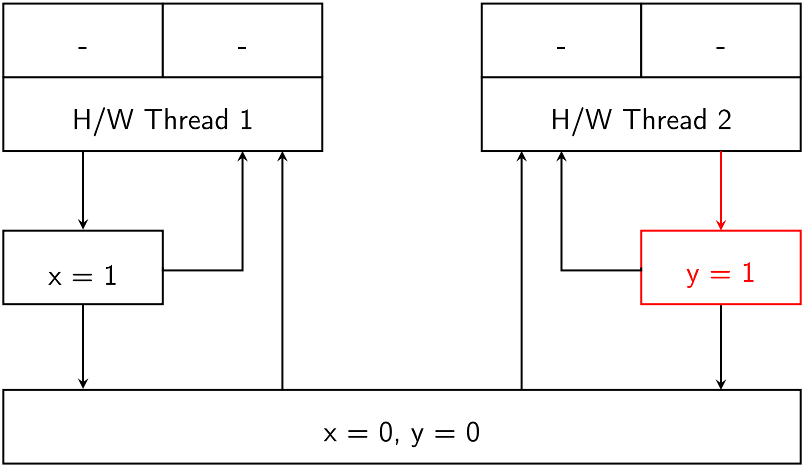

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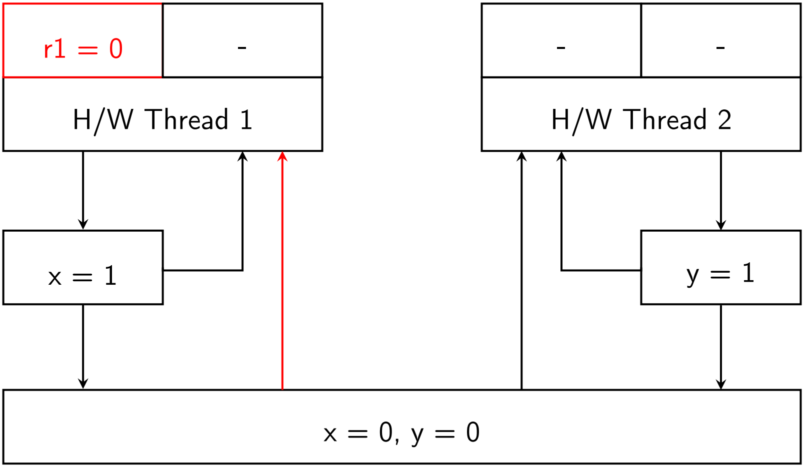

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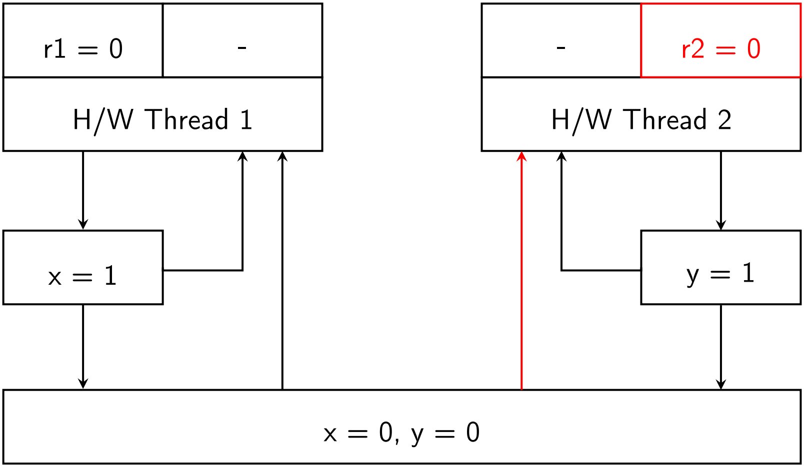

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- Sequential consistency is restored by paying a performance penalty.
- Some Non-x86 architectures exhibit even weaker models, e.g ARM.

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  2. Find all $X_{witness}$ consistent with X_{opsem}.
     - Loosely speaking: Different executions of the program.
  3. Check for undefined behaviour.
     - Reading from uninitialized variables
     - Unsequenced Races (e.g. x == (x = 2))
     - Data Races
     - ...

X_{opsem}: An Example

```
int main() {
  int x, y, z, a;
  {{{  x = 1;
  |||  y = 2;
  }}};
  a = 1;
  z = (x == y);
  return 0;
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a:W a=1

c:R y=?

b:R x=?

d:W z=(x? == y?)

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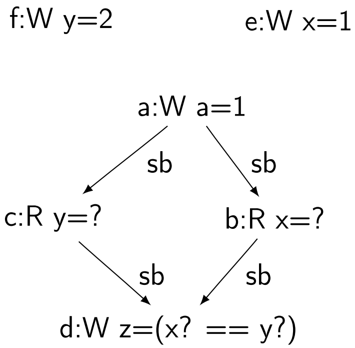

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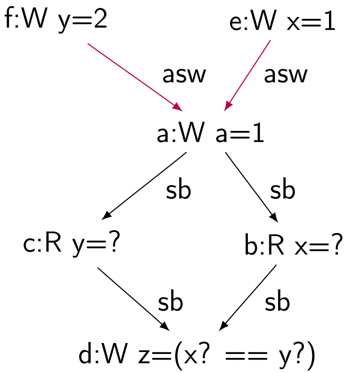

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  - Binary relations:
    - $\xrightarrow{sequenced-before}$ (sb)
    - $\xrightarrow{additional-synchronized-with}$ (asw)
- In this special case: $\xrightarrow{simple-happens-before} = (\xrightarrow{sequenced-before} \cup \xrightarrow{additional-synchronized-with})^+$

$X_{witness}$: An Example

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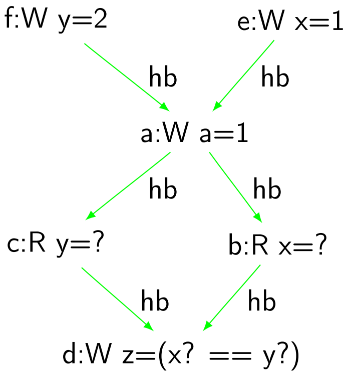

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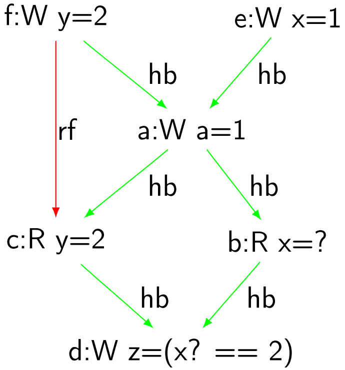

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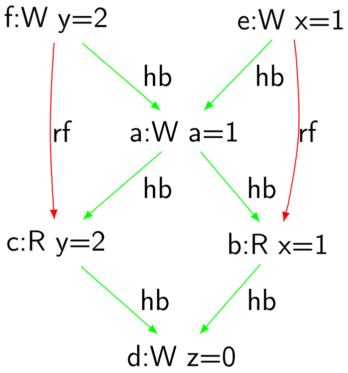

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    - $\xrightarrow{reads-from}$ (rf)
    - $\xrightarrow{sequentialconsistency}$ (sc) (not applicable in the example)
    - $\xrightarrow{modificationorder}$ (mo) (not applicable in the example)

$X = (X_{opsem}, X_{witness})$: An execution candidate

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int main() {
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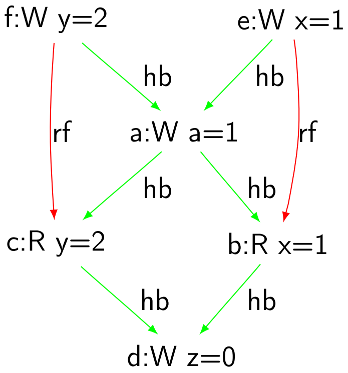

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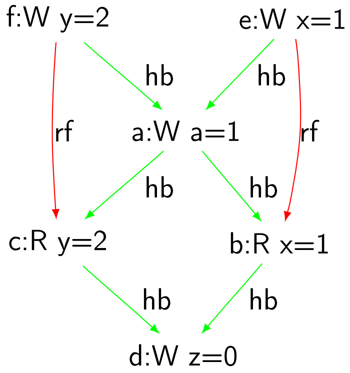

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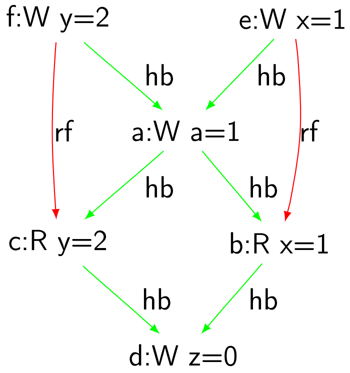

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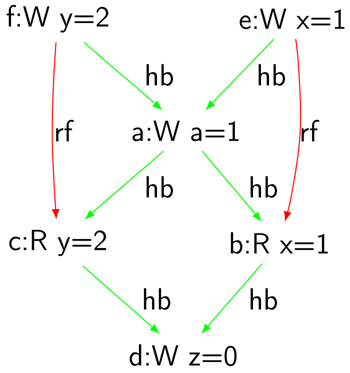

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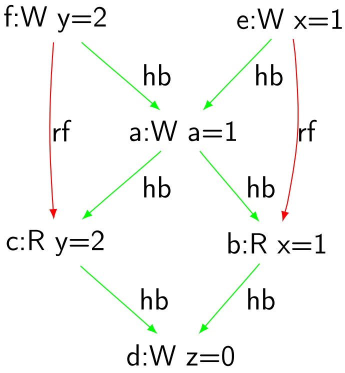

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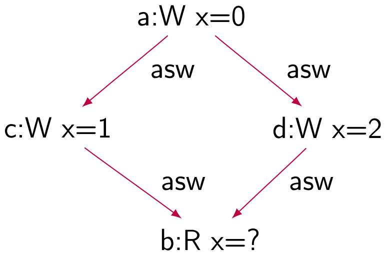

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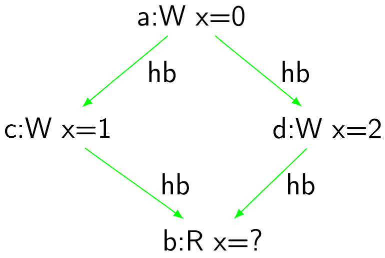

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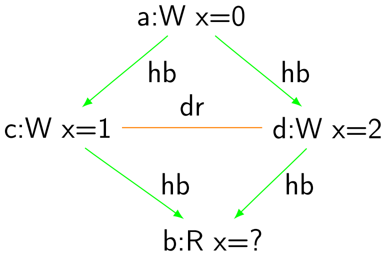

The Formalised C++ Memory Model

$$
\begin{array}{l}
\text{cpp\_memory\_model } \textit{opsem } (p : \text{program}) = \\
\quad \textbf{let } \text{pre\_executions} = \{(X_{opsem}, X_{witness}) \mid \\
\qquad \textit{opsem } p\ X_{opsem} \wedge \text{consistent\_execution } X_{opsem}\ X_{witness}\} \textbf{ in} \\
\quad \textbf{if } \exists X \in \text{pre\_executions}.\ \text{undefined\_behaviour } X \\
\quad \textbf{then } \text{NONE} \\
\quad \textbf{else } \text{SOME pre\_executions}
\end{array}
$$

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Concurrency Idioms (**Atomics**, Mutexes, Threads)

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C++11

- A memory model for multi-threaded code
- Concurrency Idioms in are part of the language (std::atomic<T> [1], std::mutex, std::thread)
  - Similar to Java
- Benefits: Compiler is able to produce correct code.

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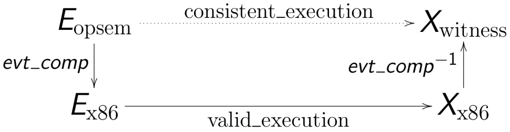

Figure: Figure taken from [3]

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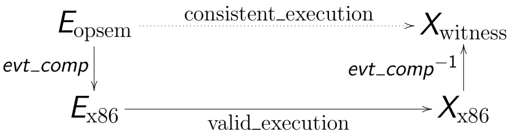

Figure: Figure taken from [3]

- Developer support.

Questions?

Bonus: Atomics vs. Mutexes - short presentation

salomon@sputnik:~/Documents/Studium/Semester 8/Master Seminar Software Verification/code

File Edit View Search Terminal Help

```
[salomon@sputnik code]$ ./non_atomic.o
Final counter value is 8785553
Elapsed Time is 70000
[salomon@sputnik code]$ ./atomic.o
Final counter value is 10000000
Elapsed Time is 370000
[salomon@sputnik code]$ ./mutex.o
Final counter value is 10000000
Elapsed Time is 3.47e+06
[salomon@sputnik code]$
```

Bonus: Dekker's algorithm in CppMem

http://svr-pes20-cppmem.cl.cam.ac.uk/cppmem/index.html

References

- C++ atomic types and operations, http://www.open-std.org/jtc1/sc22/wg21/docs/papers/2007/n2427.html.
- Dekker's algorithm, http://www.cs.utexas.edu/users/ewd/transcriptions/ewd01xx/ewd123.
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- Peter Sewell, Susmit Sarkar, Scott Owens, Francesco Zappa Nardelli, and Magnus O. Myreen.
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