C/C++ Concurrency
Happens-before \((\text{hb})\) is irreflexive. \((\text{irrHB})\)

Execution is coherent.

- \(\text{rf}; \text{hb}\) is irreflexive \((\text{CohHBRF})\)
- \(\text{mo}; \text{rf}; \text{hb}\) is irreflexive. \((\text{Coh-RW})\)
- \(\text{mo}; \text{hb}\) is irreflexive. \((\text{Coh-WW})\)
- \(\text{mo}; \text{hb}; \text{rf}^{-1}\) is irreflexive. \((\text{Coh-WR})\)
- \(\text{mo}; \text{rf}; \text{hb}; \text{rf}^{-1}\) is irreflexive. \((\text{Coh-RR})\)

Alternatively: \(\text{hb}; \text{eco}\) is irreflexive. \((\text{Coh})\)

where \(\text{eco}\) is extended-coherence-order such that
\(\text{eco} \triangleq (\text{rf} \cup \text{mo} \cup \text{fr})^+\)

Combining \((\text{irrHB})\) & \((\text{Coh})\) axioms: \(\text{hb}; \text{eco}^?\) is irreflexive.

\([\text{U}] \cap (\text{fr}; \text{mo}) = \emptyset\) \((\text{Atomicity})\)
Axioms

Original C11 model proposed (Ref: [POPL’15]):
\[ \forall a, b. \ rf(a, b) \land (isNA(a) \lor isNA(b)) \implies hb(a, b) \]  
(ConsRFna)

Example: What is value read by \( a \)?

\[ X = 0 \]

\[ X_{rlx} = 1; \quad \text{if} (X_{rlx} == 1) \]
\[ a = X_{na}; \quad // \ ? \]

(ConsRFna) conflicts with (Coh) axiom.
(ConsRFna) is problematic. Therefore dropped.
Axiom for SC accesses

- Execution has sc order between SC accesses.
- sc is total.
- Goes along with hb and mo.

\[(hb \cup mo) \cap ([SC] \times [SC]) \subseteq sc\]  \hspace{1cm} (ConsSC)

(SCread) SC reads are restricted to read only from the immediately preceding SC write to the same location in sc order or from a non-SC write that has not happened before any preceding SC write.

\[\forall a, b.\]
\[\left( (a, b) \in rf; [RU_{sc}] \Rightarrow sc_{imm}(a, b) \lor a \notin SC \land \nexists x. \ hb(a, x) \land x \in WU_{sc} \land sc(x, b) \right)\]
Exercise

Study the relevant examples from [POPL’11], [POPL’15], [POPL’16], and [PLDI’17].