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A Promising Semantics for Relaxed-Memory Concurrency

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Relaxed-Memory Concurrency

- **Semantics of multi-threaded programs?**
  - Sequential consistency (SC): simple but **expensive**
- **Relaxed memory models (C/C++, Java)**
  - Many consistency modes (cost vs. consistency tradeoff)
  - **Open problem: what is the "right" semantics?**

“Right” Concurrency Semantics?

- **Conflicting goals** of “masters”
- **Compiler/hardware**: validating optimizations (e.g. reordering, merging)
- **Programmer**: supporting reasoning principles (e.g. DRF theorem, program logic)

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Key problem: “out-of-thin-air”

"Out-of-thin-air" problem (1/3)

Load-Buffering (LB)

Thread 1	Thread 2
a = X	b = Y
Y = a	X = 42

(a=b=42?)

"Out-of-thin-air" problem (1/3)

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Registers

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Shared Locations

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Thread 2

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C11 Relaxed

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Allowed by reordering (Power/ARM)

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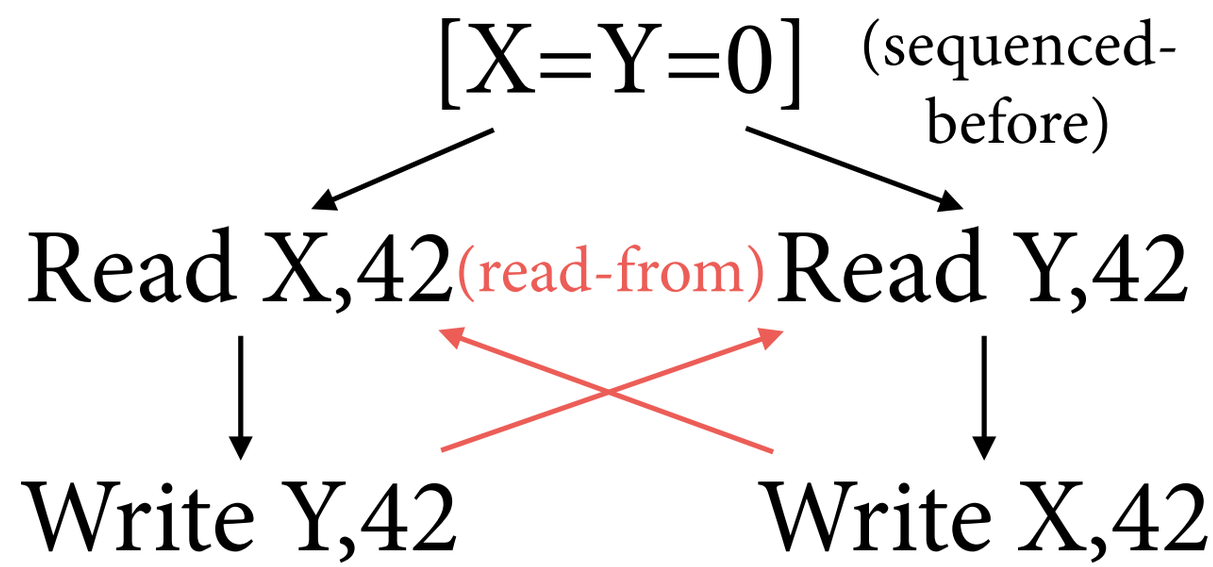

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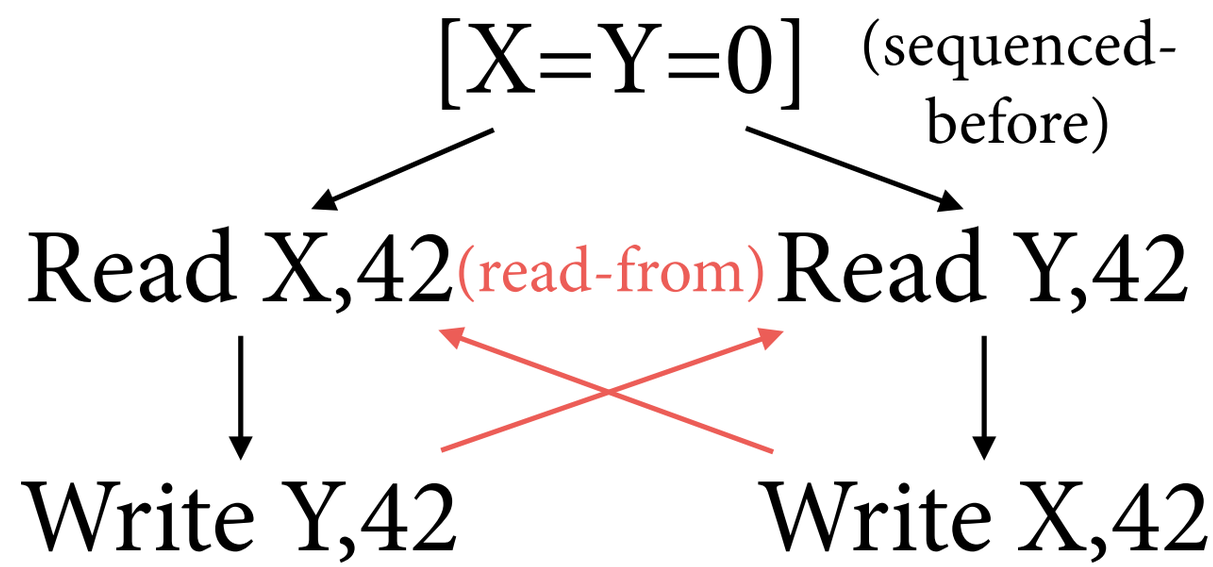

Allowed by justification (C/C++)

Justification is too loose!

"Out-of-thin-air" problem (2/3)

Classic Out-of-thin-air (OOTA)

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should be forbidden
42 is out-of-thin-air!

Reasoning principles
(e.g. invariant a=b=X=Y=0)

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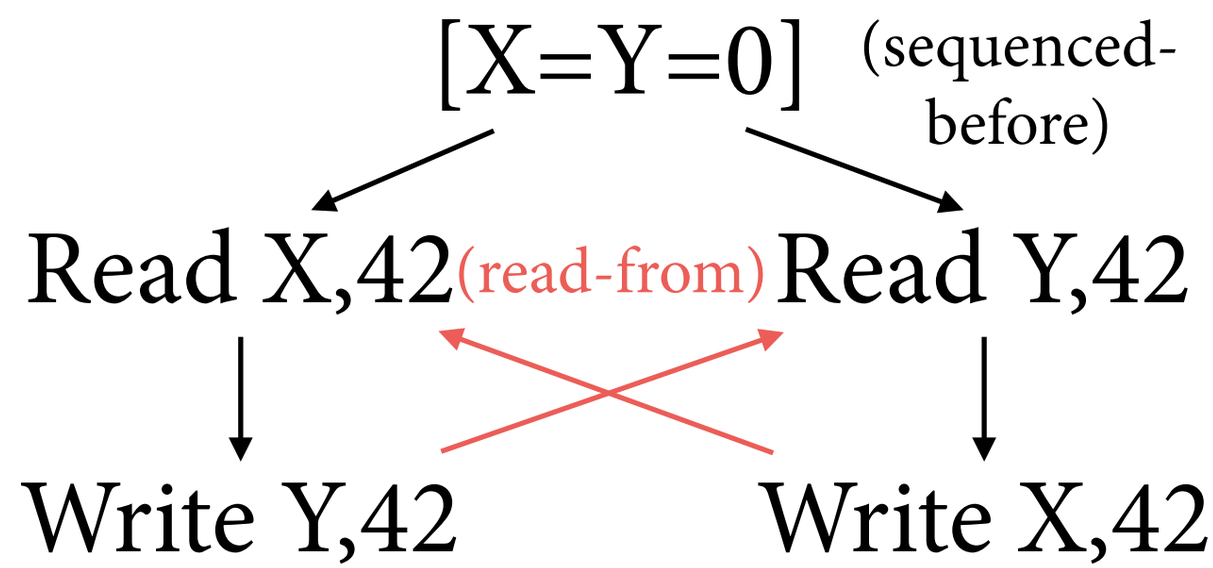

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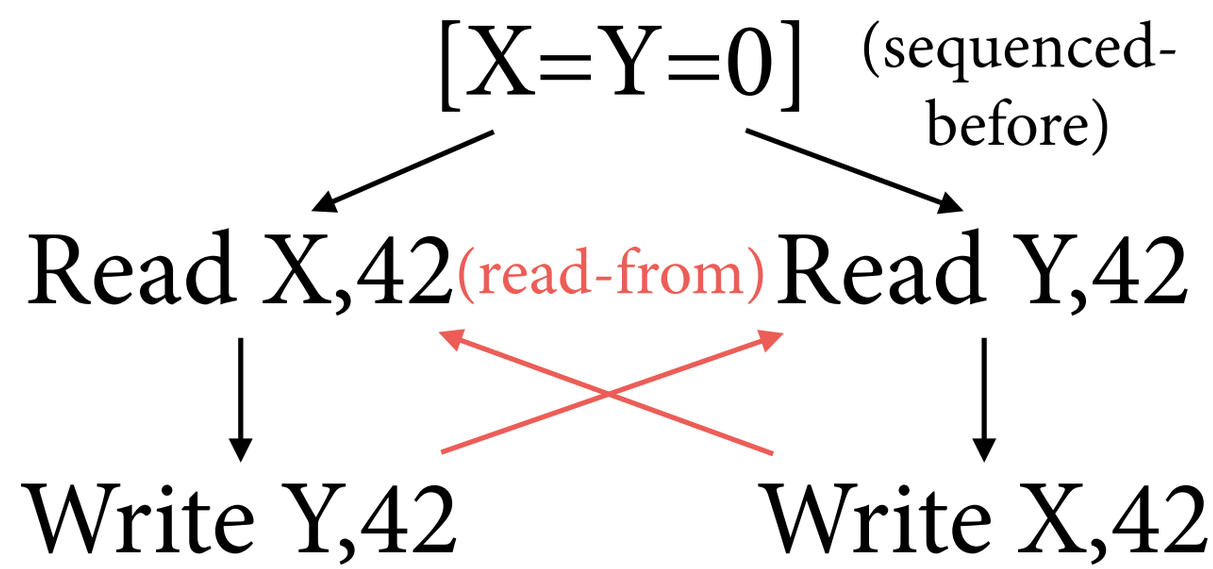

Allowed by justification
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What does
hardware do?

"Out-of-thin-air" problem (3/3)

Tracking Syntactic Dependency?

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allowed in hardware

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forbidden in hardware

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Tracking Syntactic Dependency?

Thread 1	Thread 2
a = X	b = Y
Y = a	X = b+42-b

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Syntactic approach doesn't work for PL!

"Out-of-thin-air" problem (3/3)

"A major open problem for PL semantics"
(Batty et al. ESOP 2015)

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Promising Semantics

- Solving the **out-of-thin-air problem**
- Supporting **optimizations & reasoning principles**
- Covering most **C/C++ concurrency** features
- **Operational semantics w/o undefined behavior**

- Most results are **verified in Coq**
  http://sf.snu.ac.kr/promise-concurrency

Key Idea: Promises

- A thread can **promise** to write X=V in the future, after which **other threads can read** X=V.
- To avoid OOTA, the promising thread must **certify** that it can write X=V **in isolation**.

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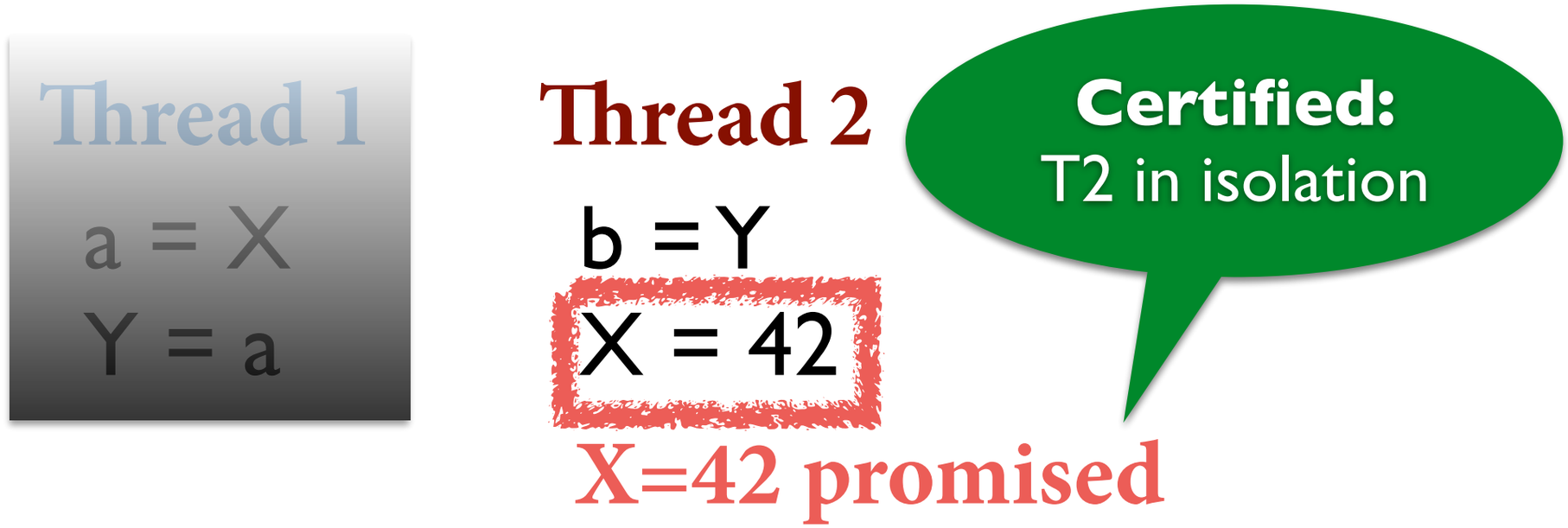

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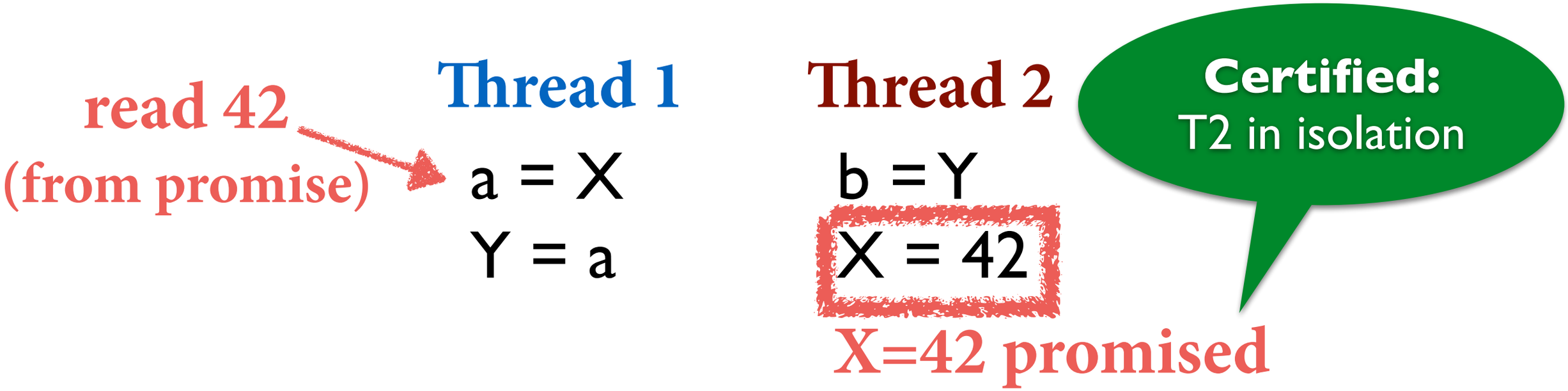

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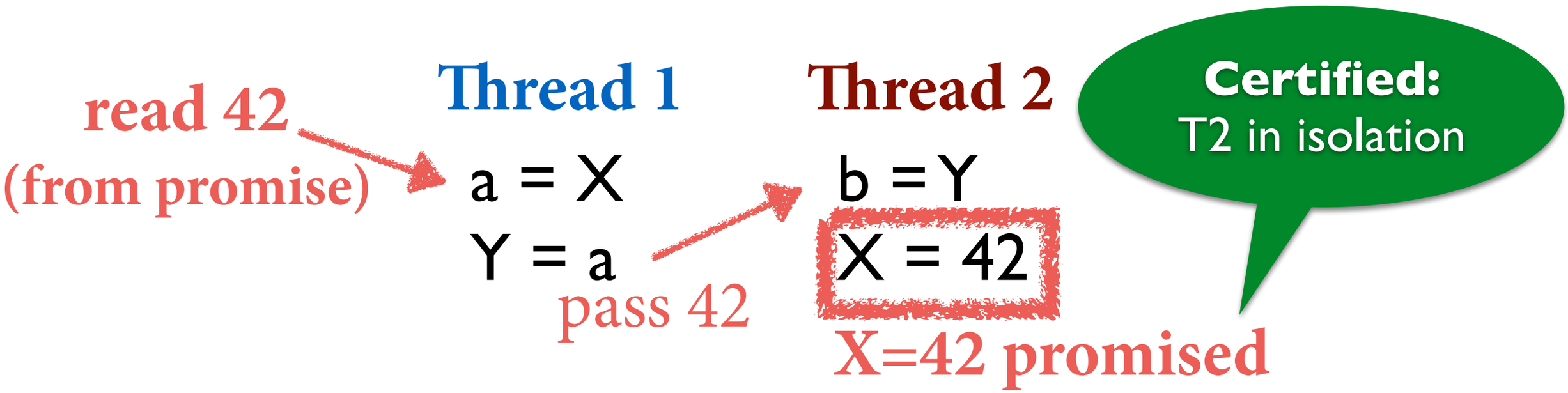

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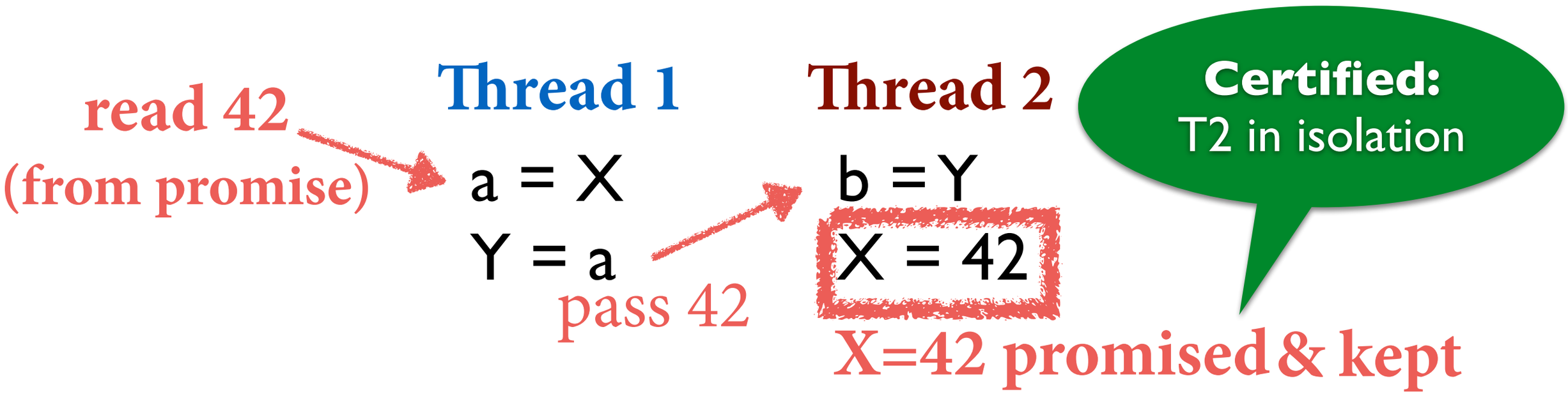

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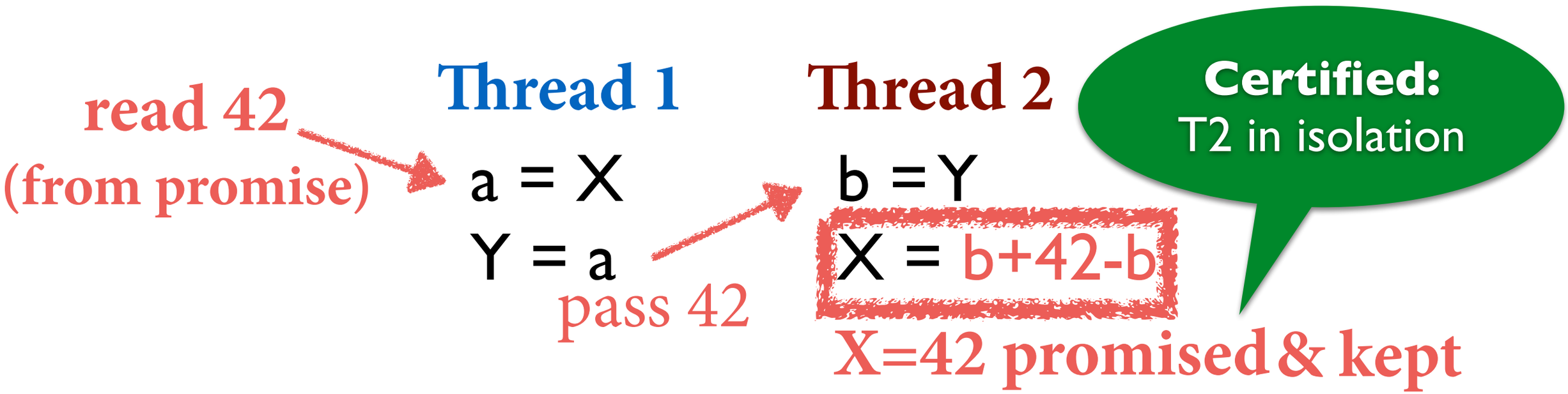

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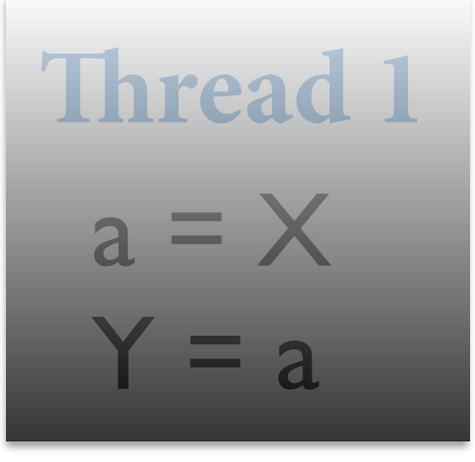

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cannot promise X=42

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Promises: "Semantic Solution" to OOTA

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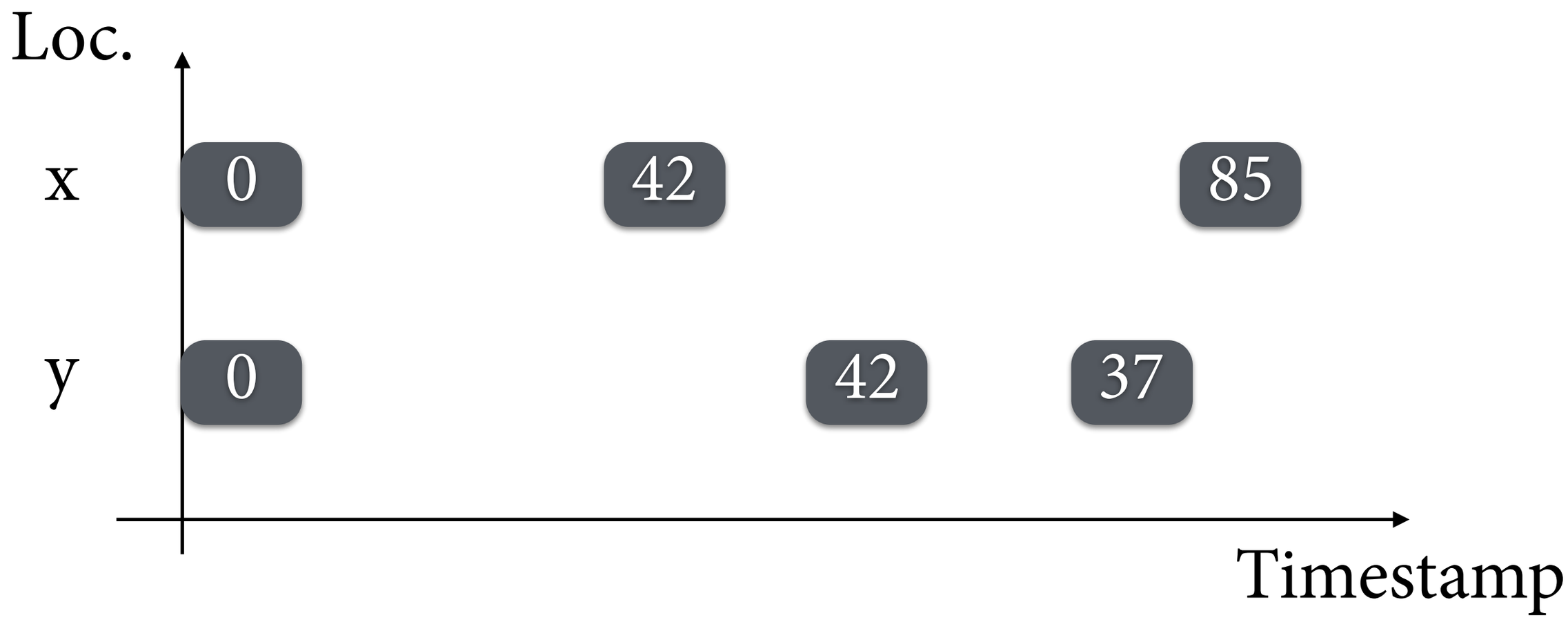
Basis: Operational Semantics

- Memory: pool of **messages** (loc, val, timestamp)
- Per-thread **view** on the memory



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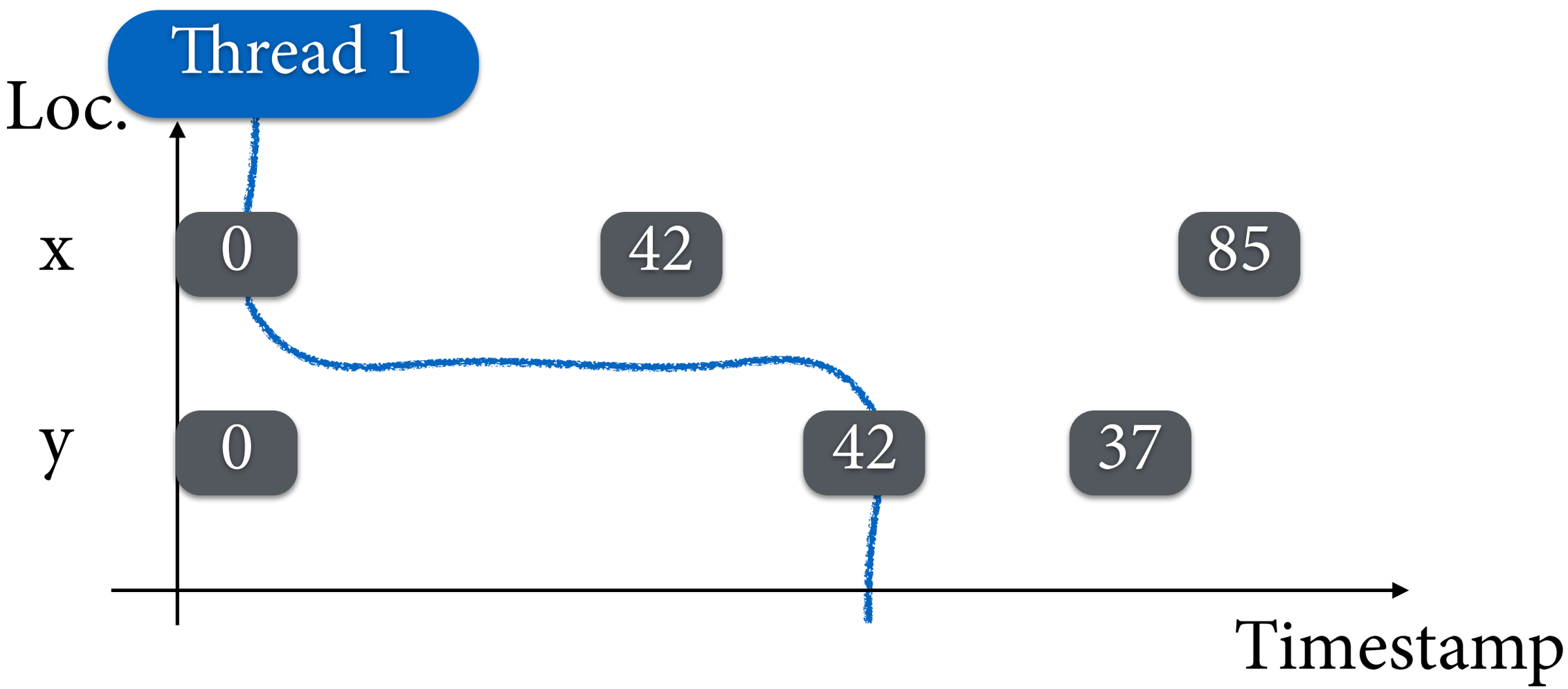

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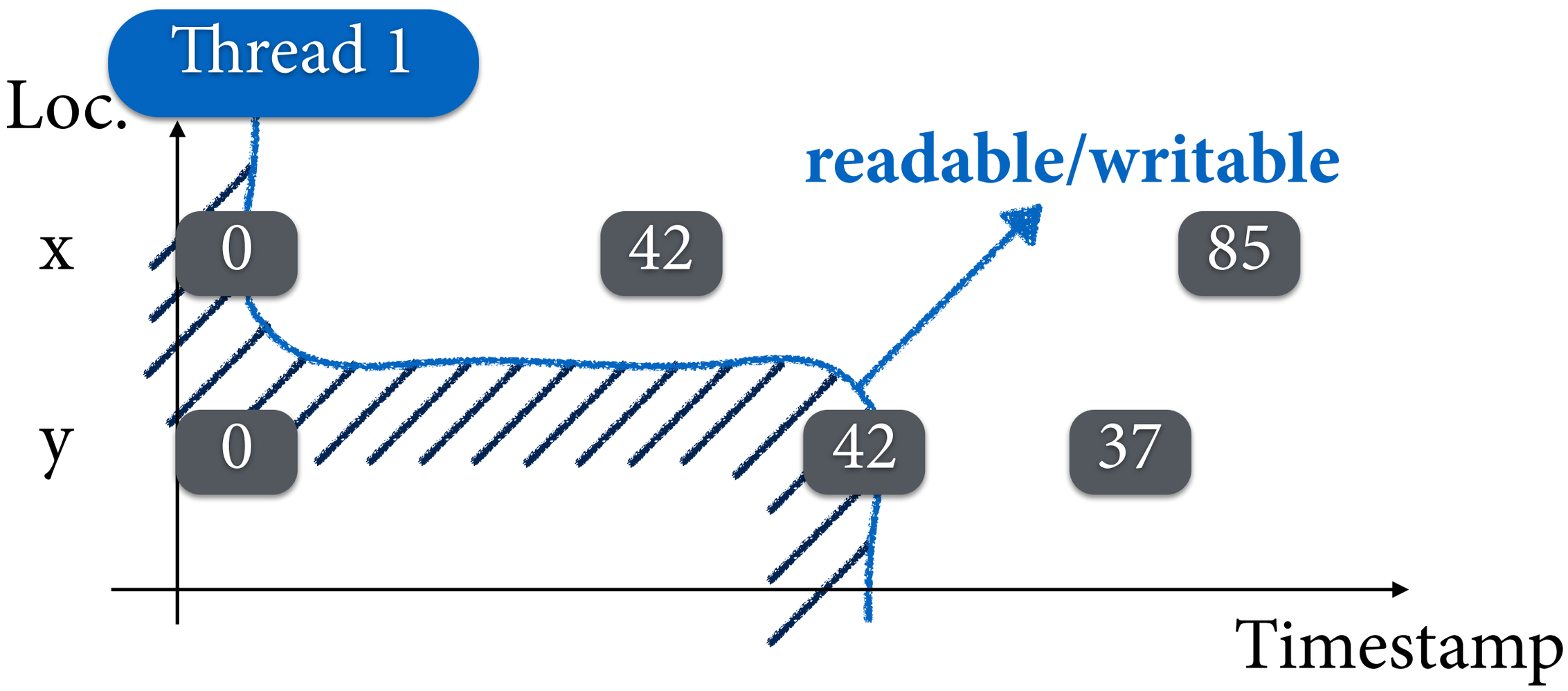

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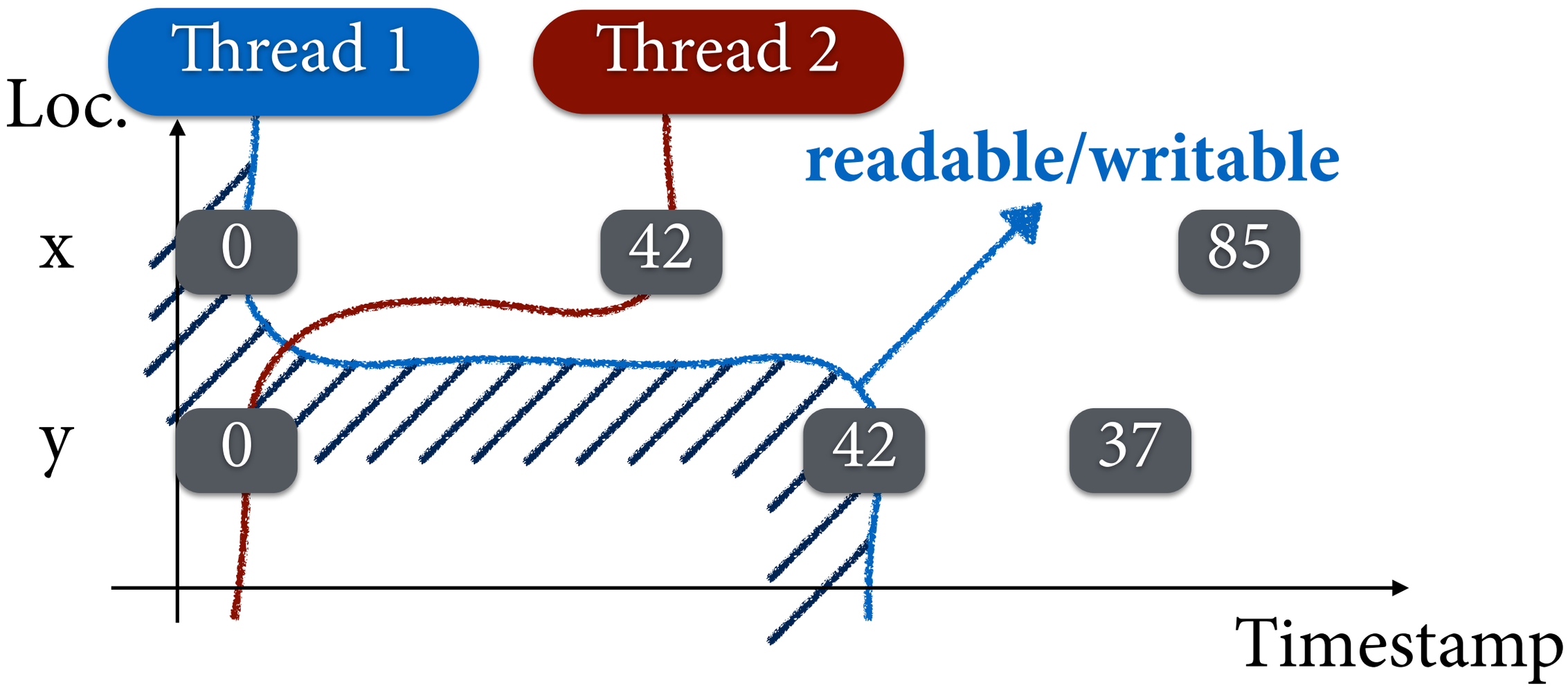

Example (1/3)

Store Buffering

Thread 1

Y = 42
a = X

Thread 2

X = 42
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(allowed: a=b=0)

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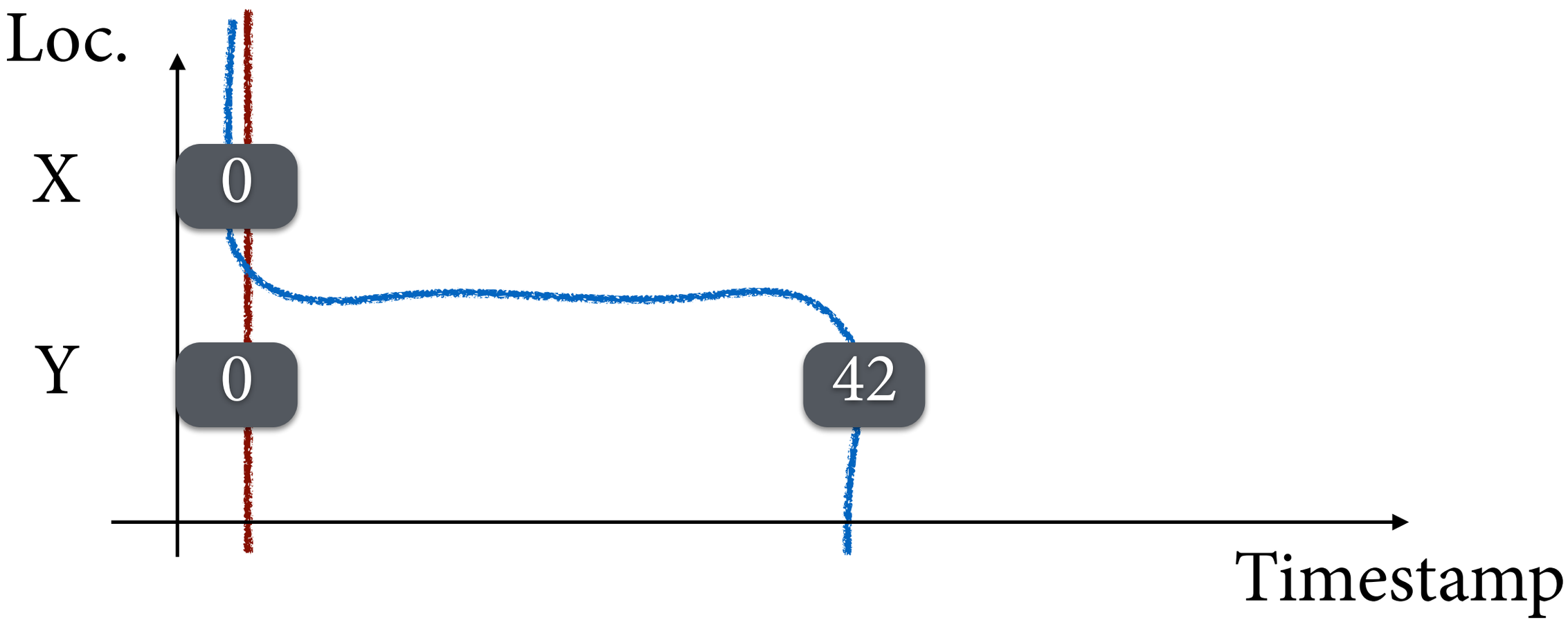

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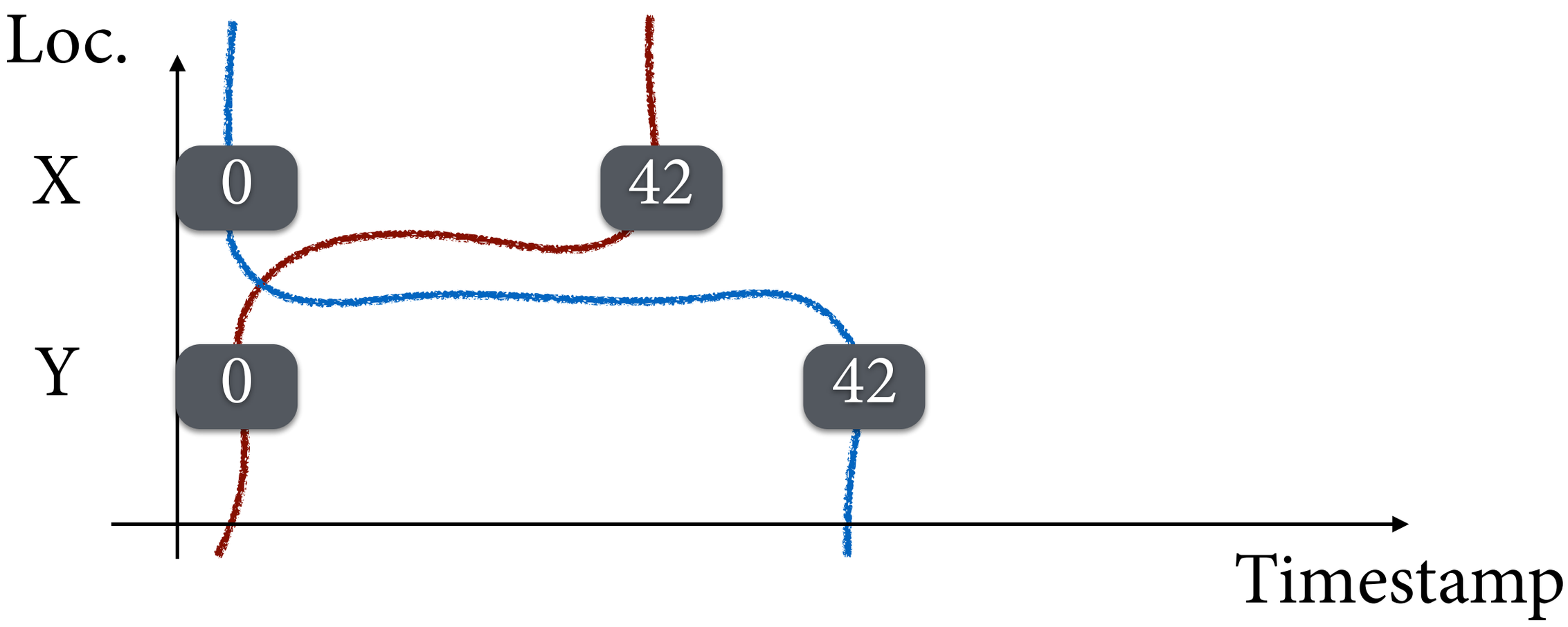

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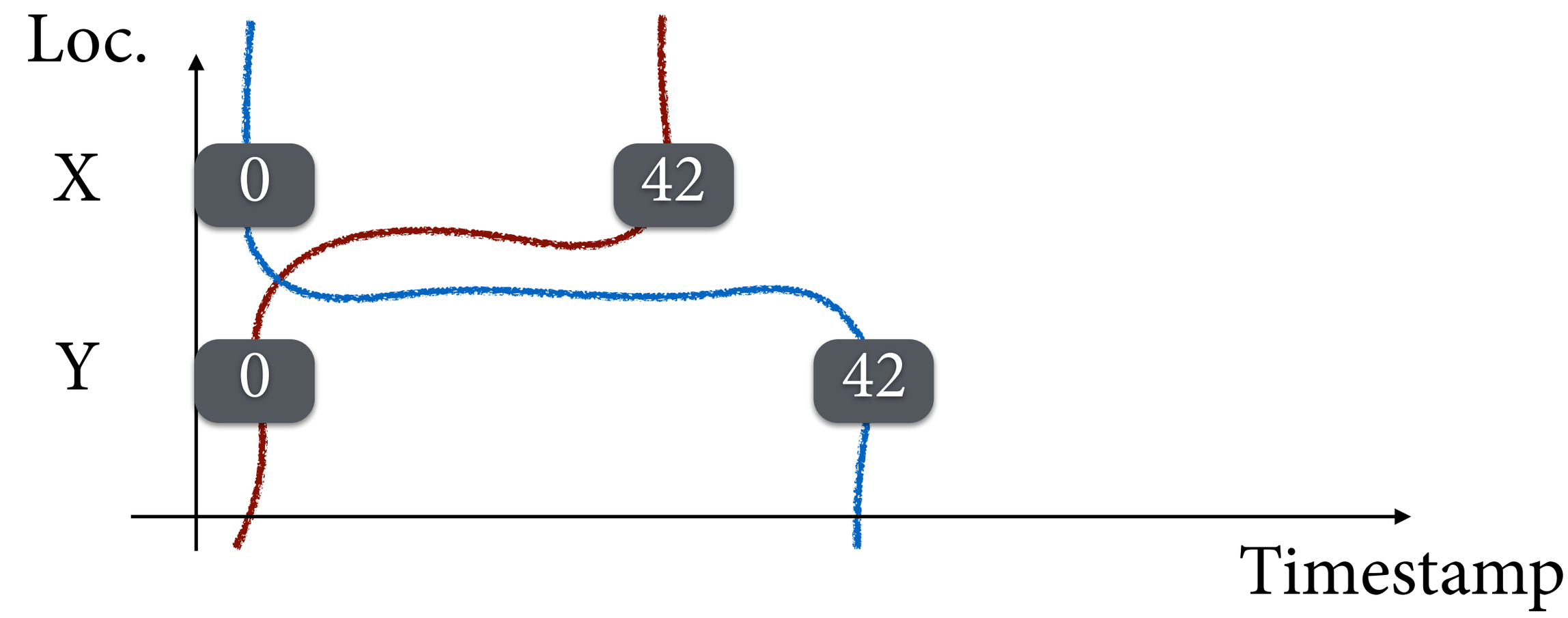

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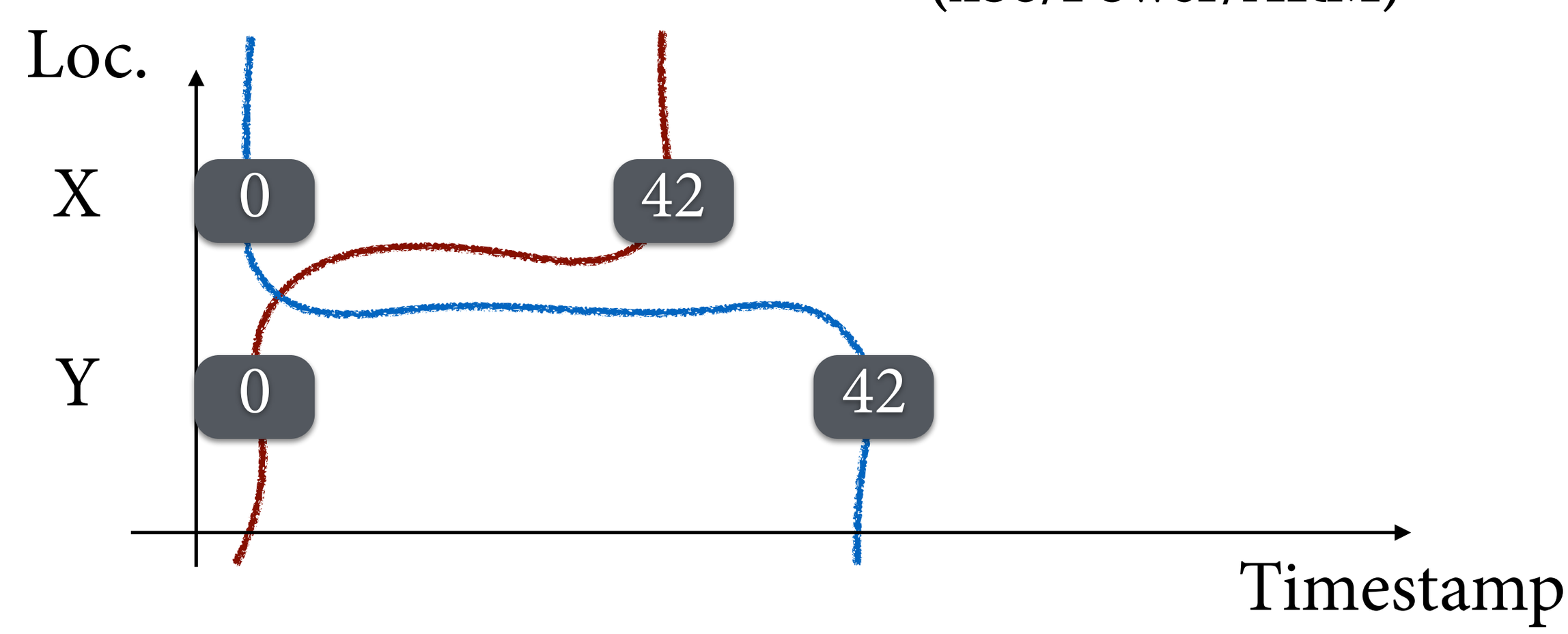

Example (2/3)

Load Buffering (LB)

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Thread 2

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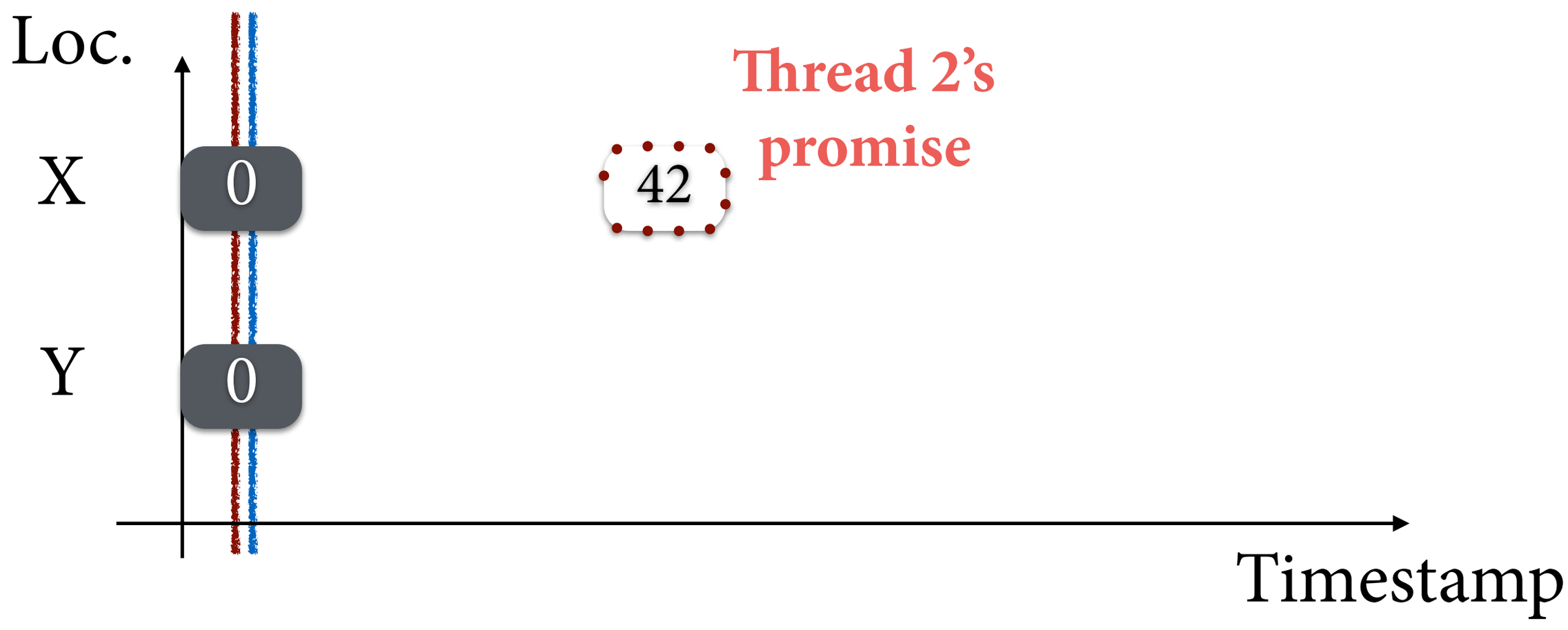

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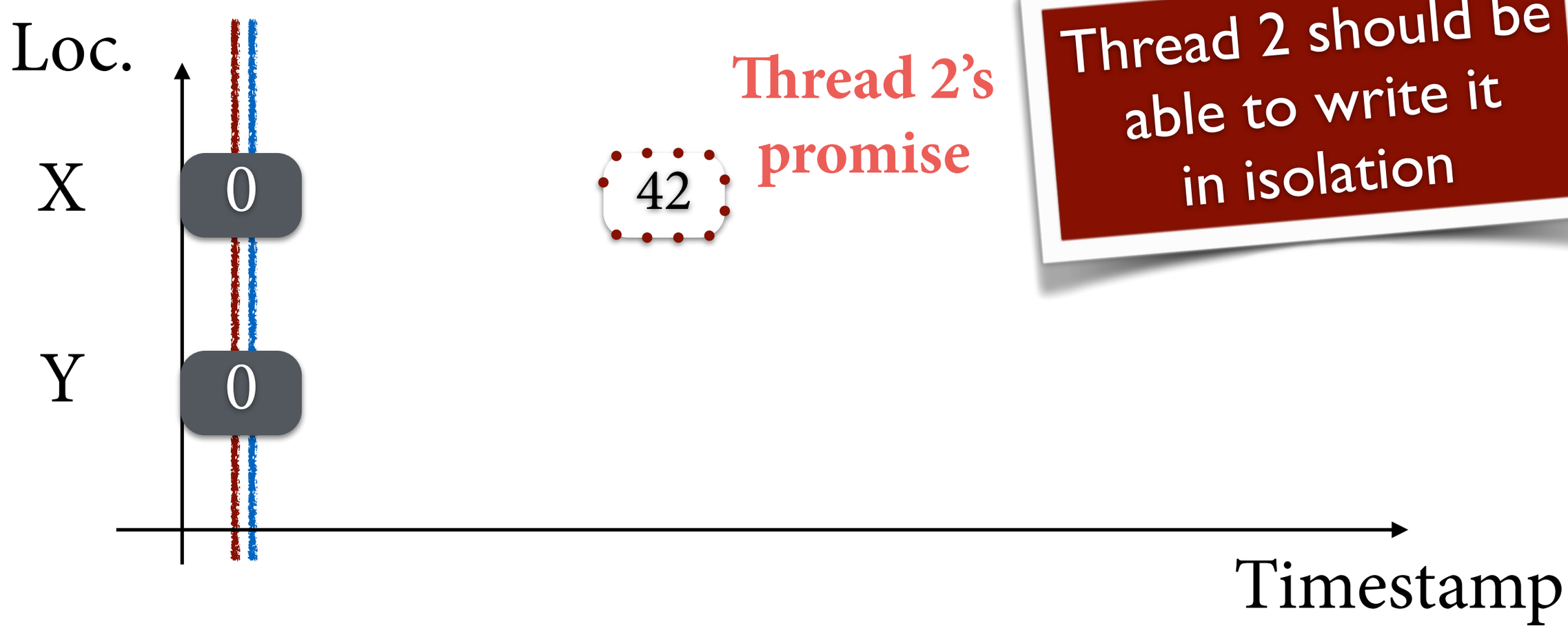

Thread 2 should be able to write it in isolation

Example (2/3)
Certification

Thread 2

```
b = Y
X = 42
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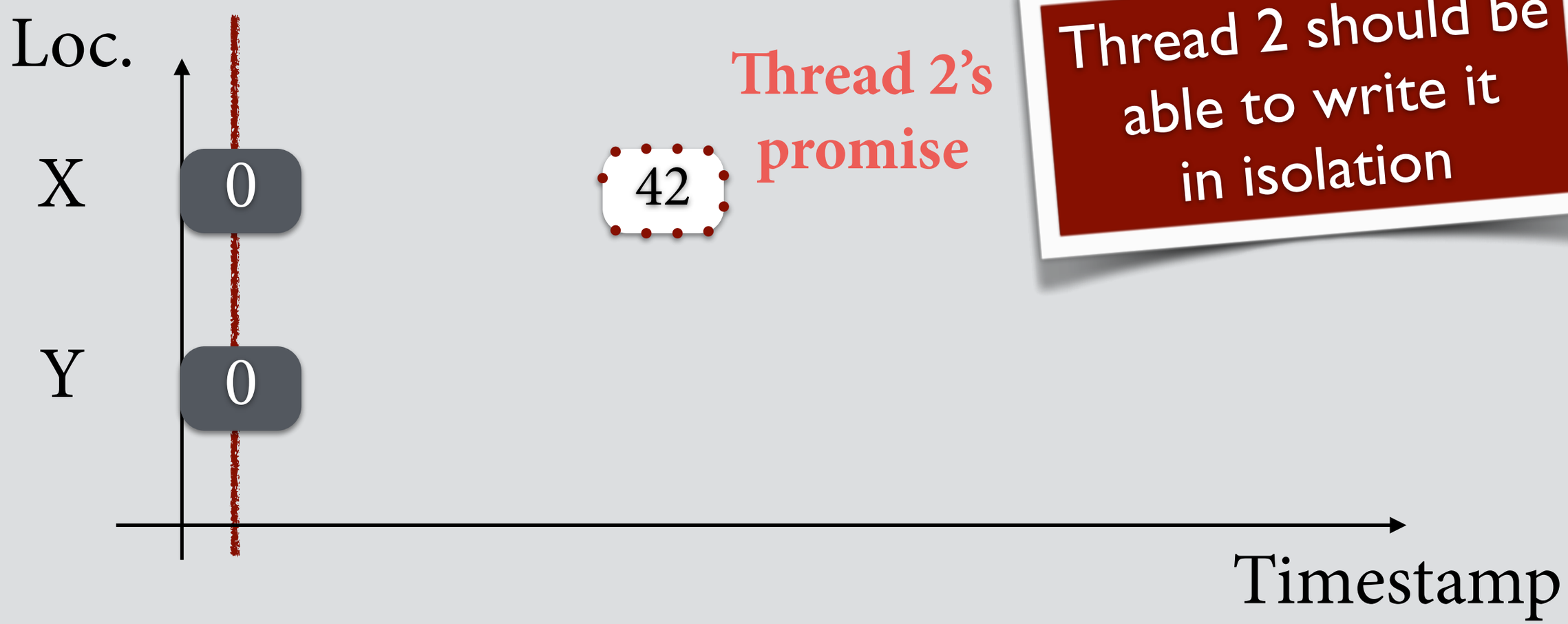

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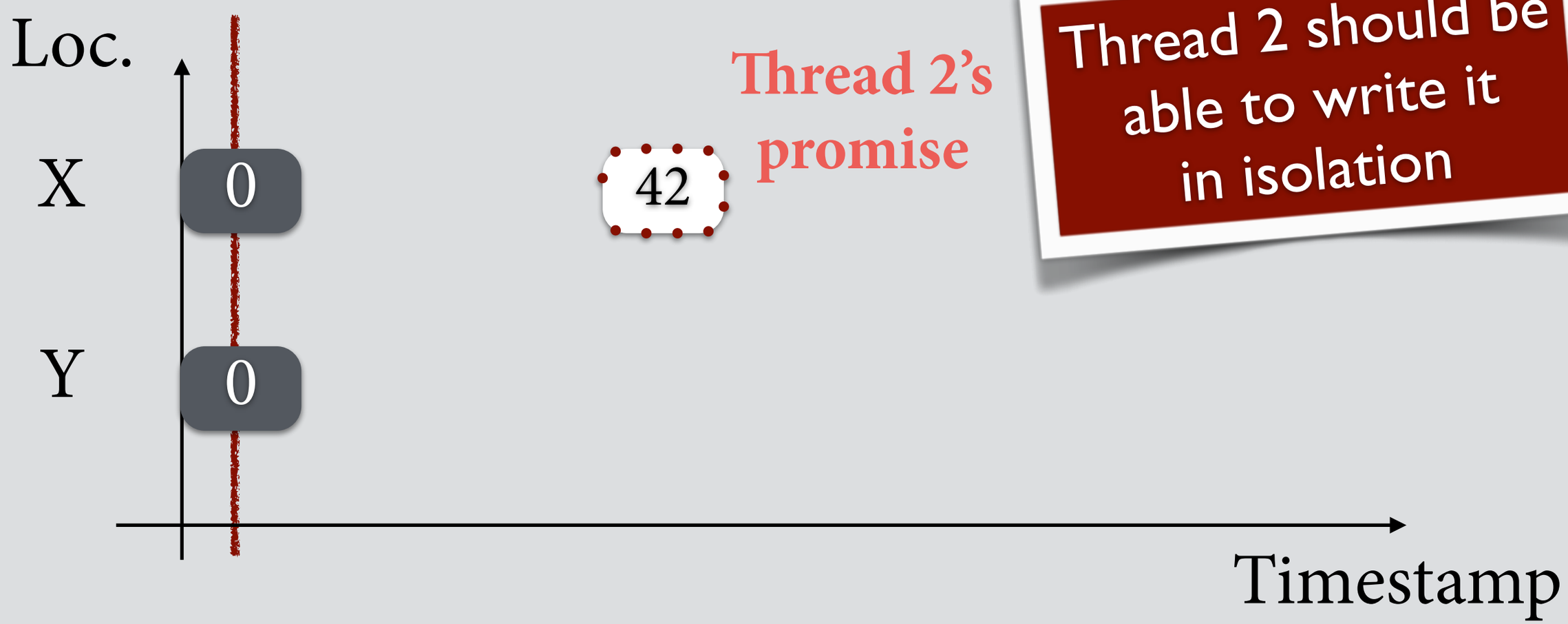

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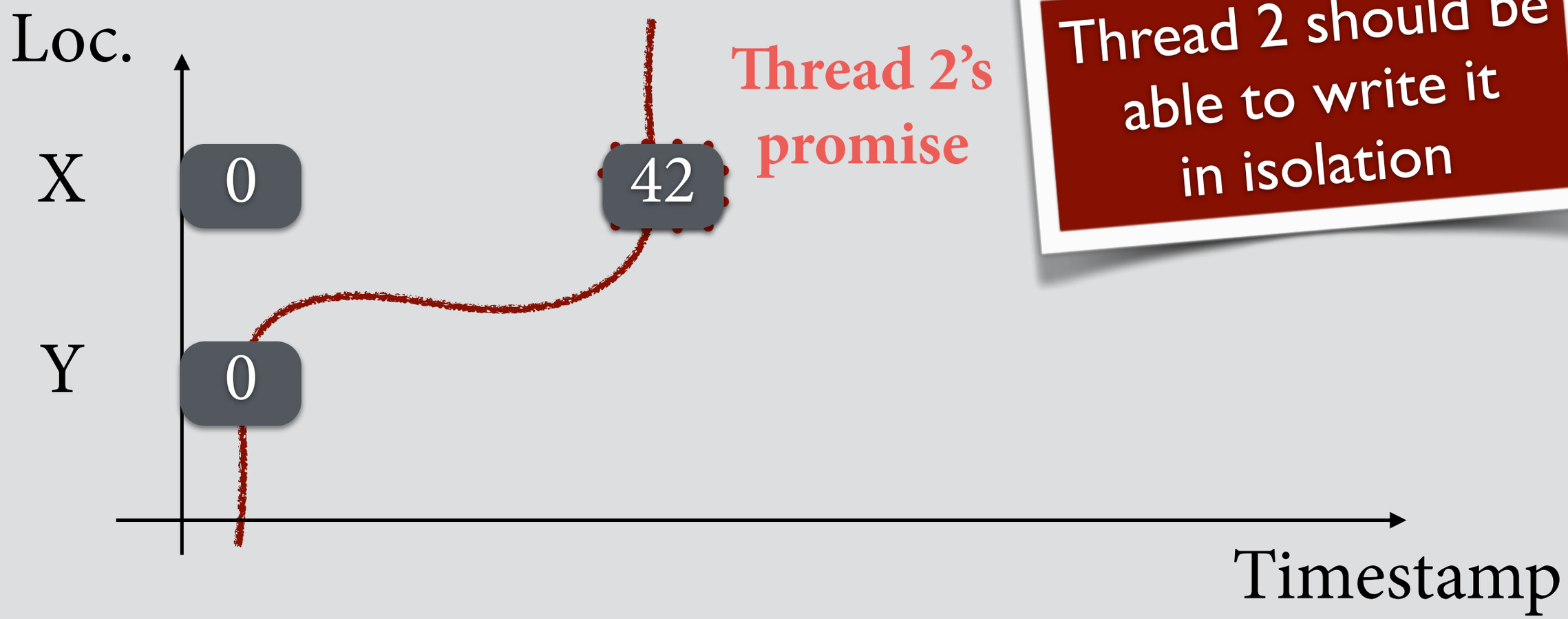

Thread 2's promise

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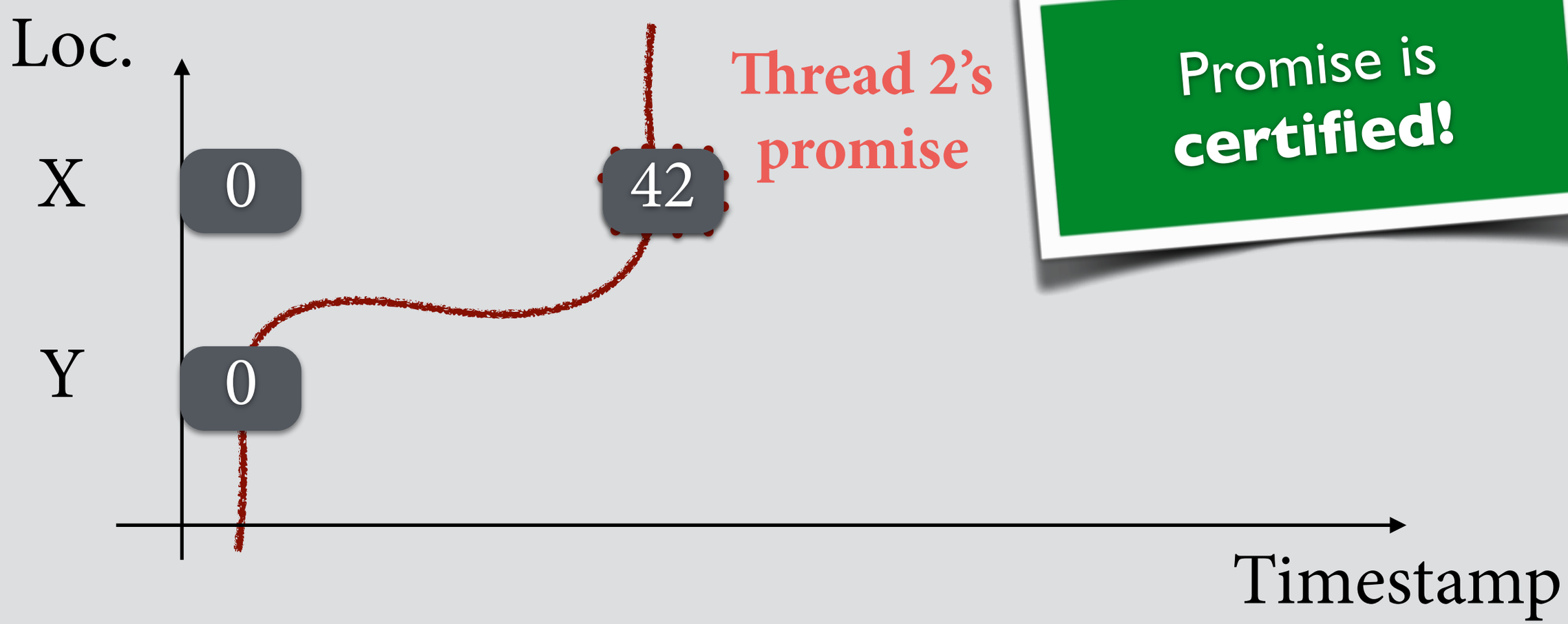

Thread 2's promise

Promise is **certified!**

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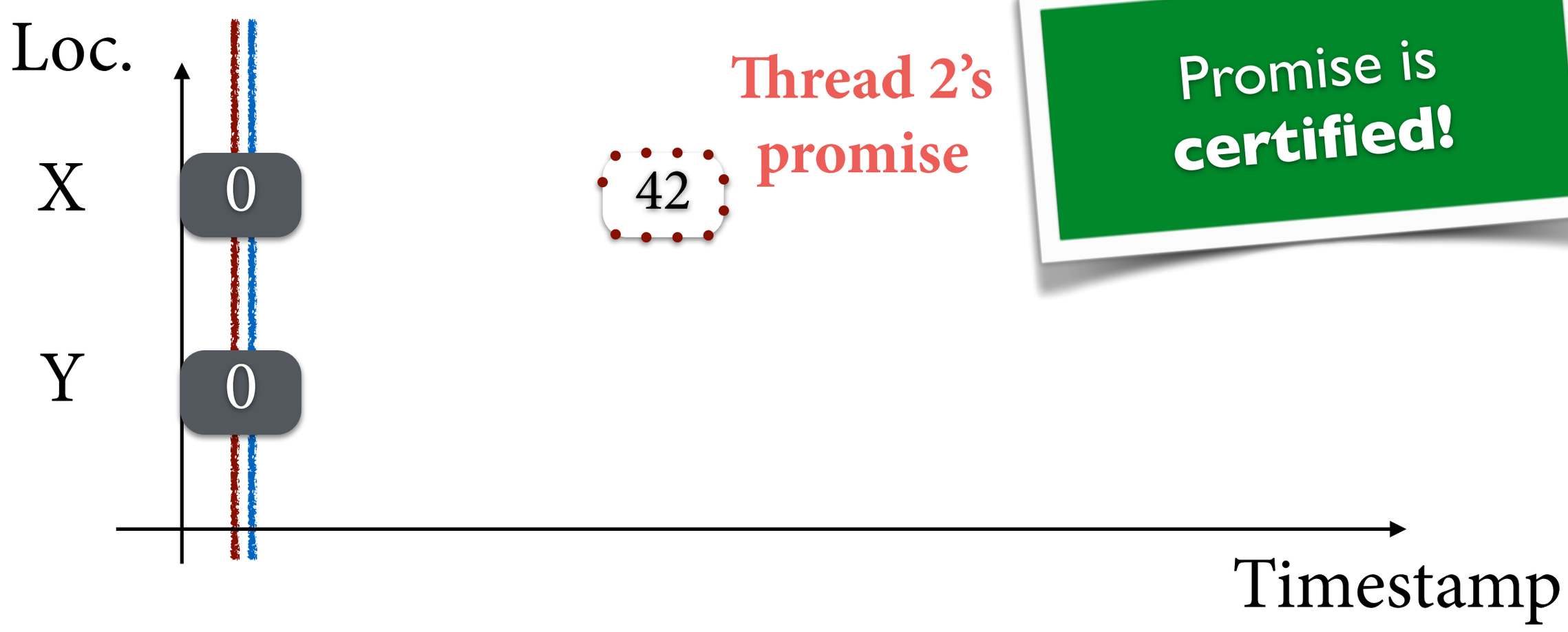

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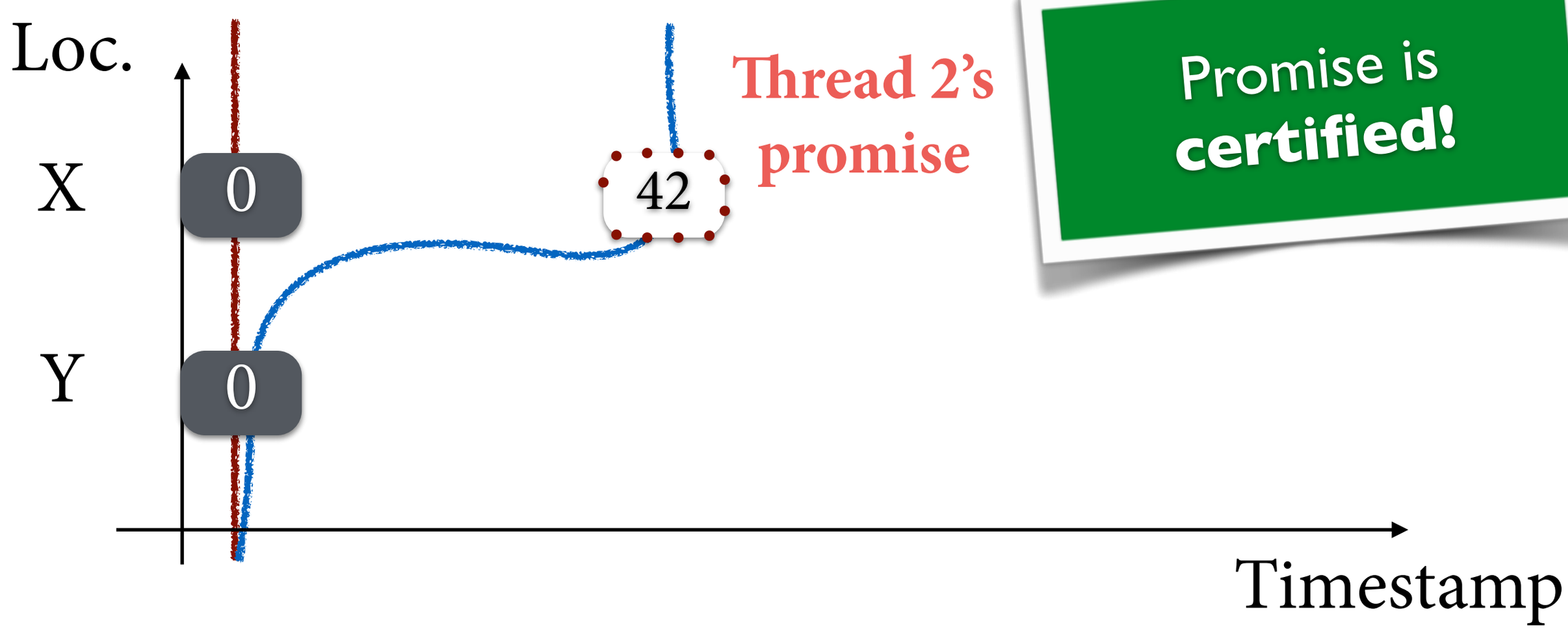

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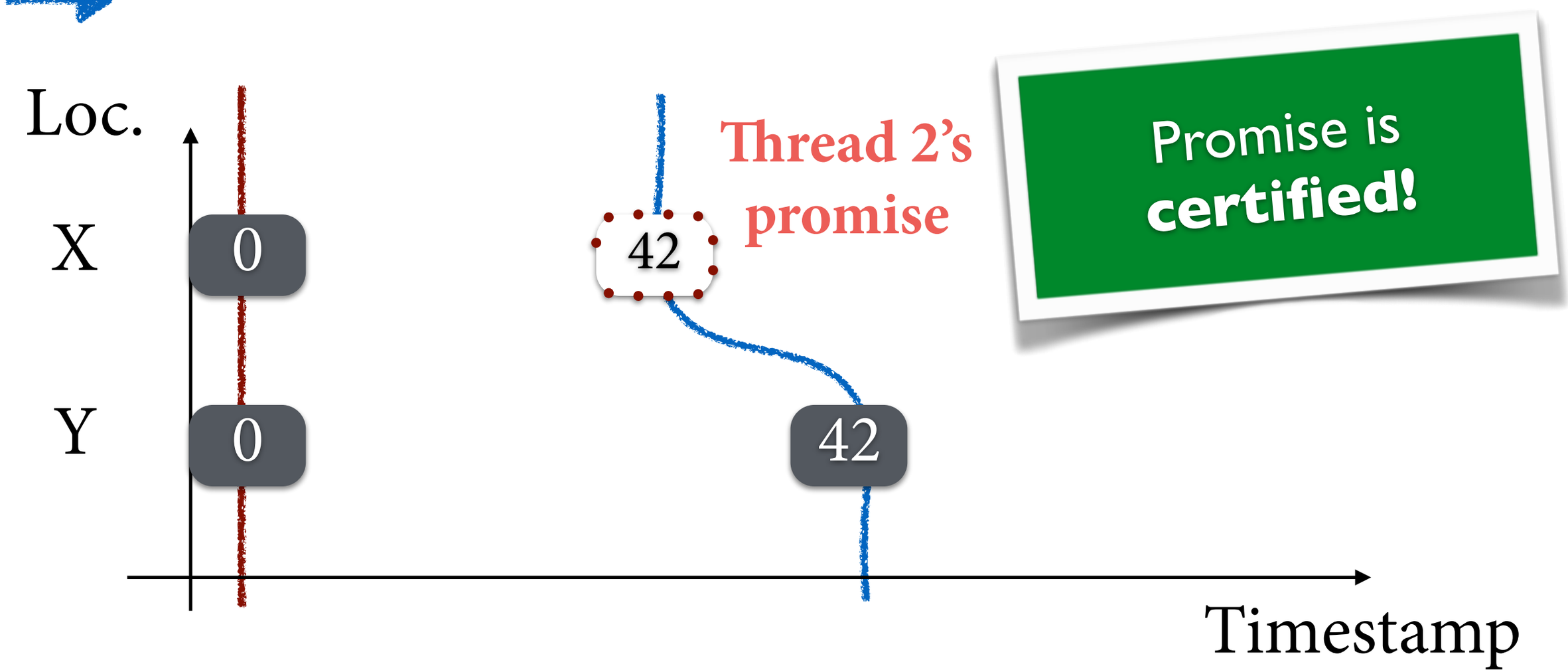
X = 42

(allowed: a=b=42)



Example (2/3)

Load Buffering (LB)

Thread 1

a = X

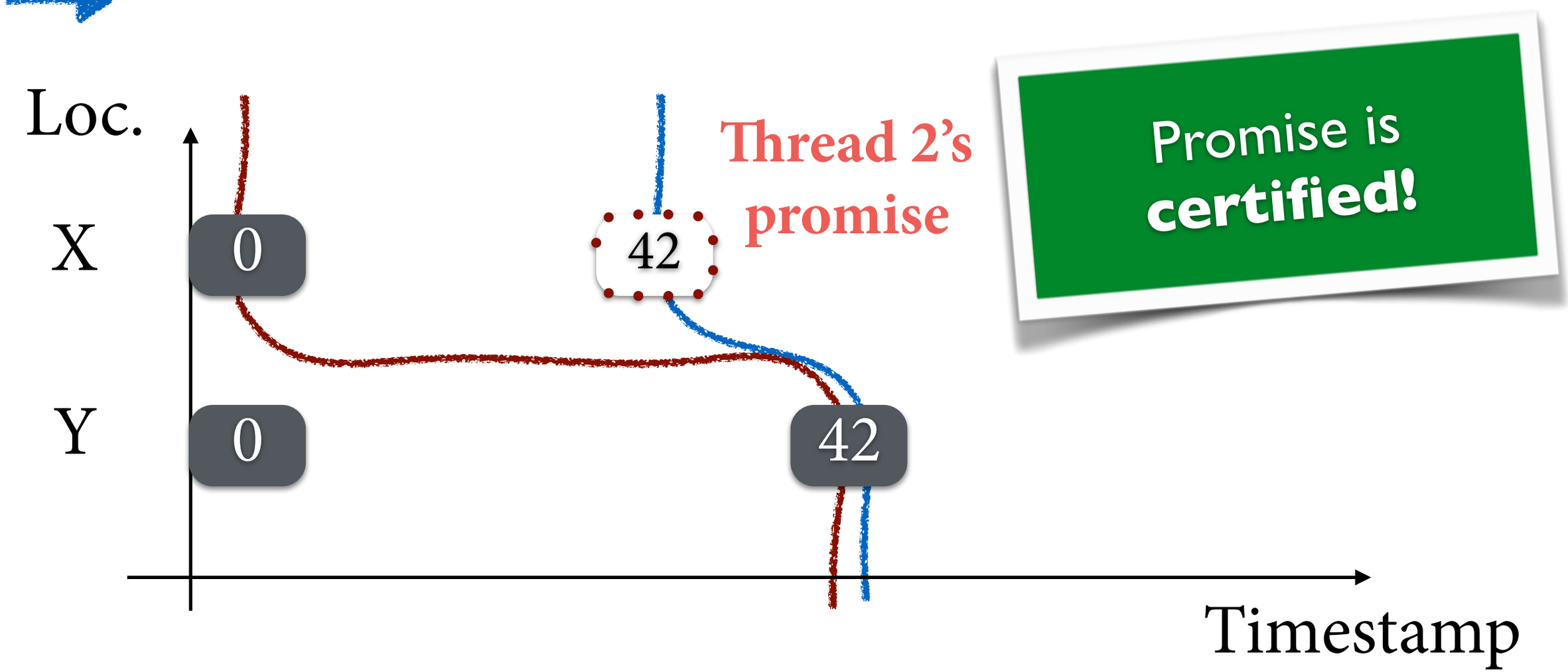
Y = a

Thread 2

b = Y

X = 42

(allowed: a=b=42)



Example (2/3)

Load Buffering (LB)

Thread 1

a = X

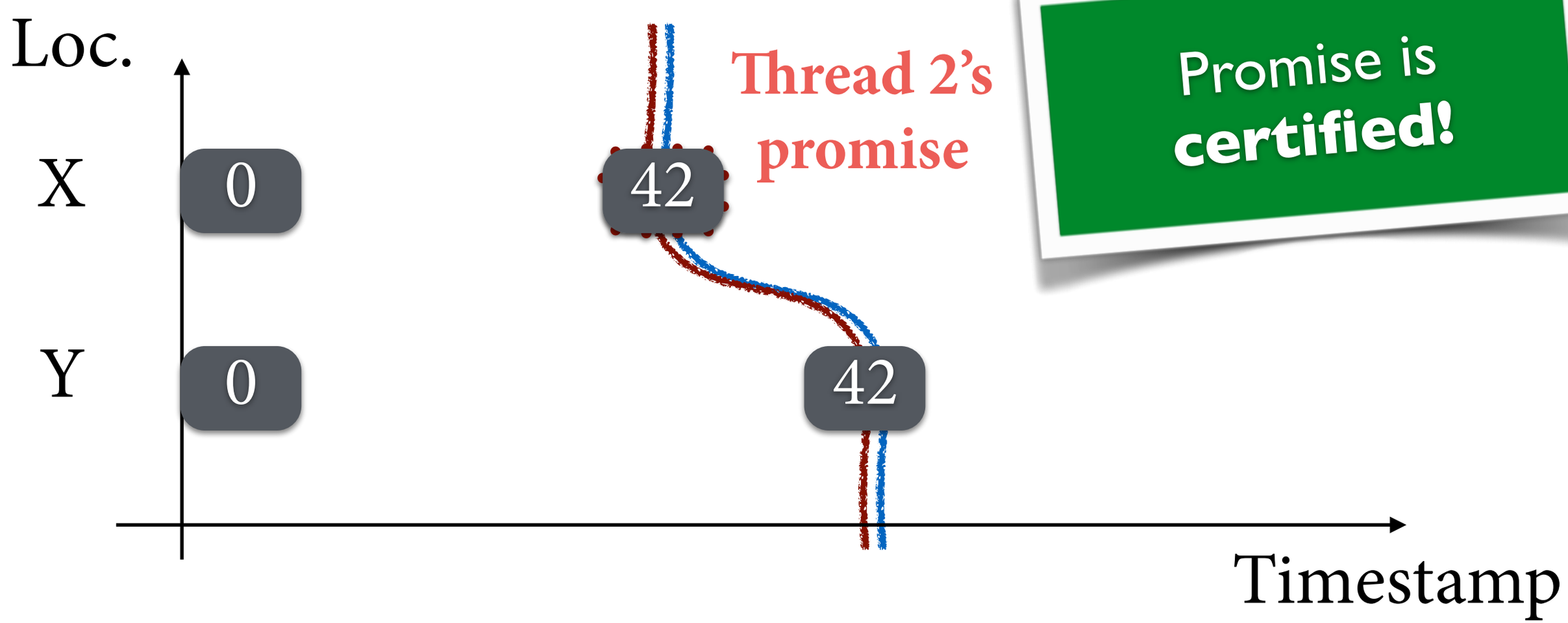
Y = a

Thread 2

b = Y

X = 42

(allowed: a=b=42)



Promise is **certified!**

Example (2/3)

Load Buffering (LB)

Thread 1

a = X

Y = a

Thread 2

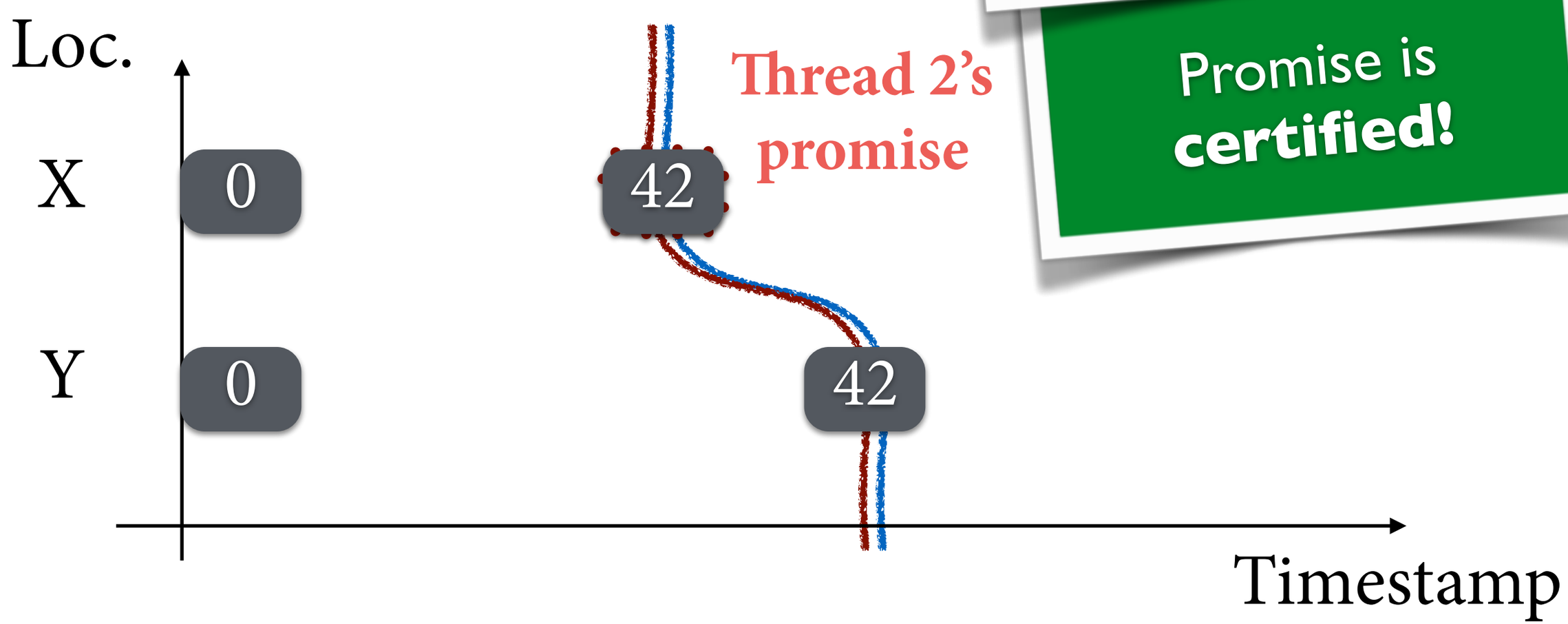
b = Y

X = b+42-b

(allowed: a=b=42)

false dependency makes no difference!

Promise is **certified!**



Example (3/3)

Classic Out-of-thin-air (OOTA)

Thread 1

a = X
Y = a

Thread 2

b = Y
X = b

(forbidden: a=b=42)

Example (3/3)

Classic Out-of-thin-air (OOTA)

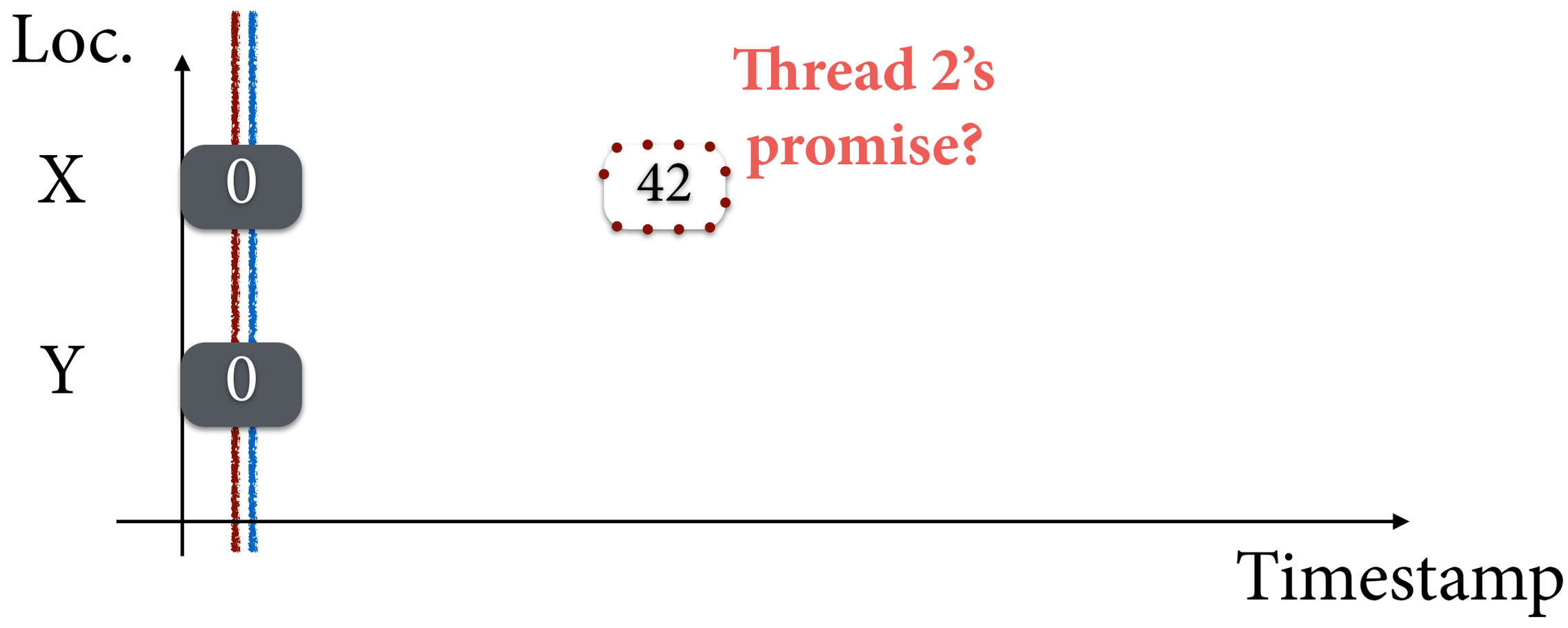
Thread 1

a = X
Y = a

Thread 2

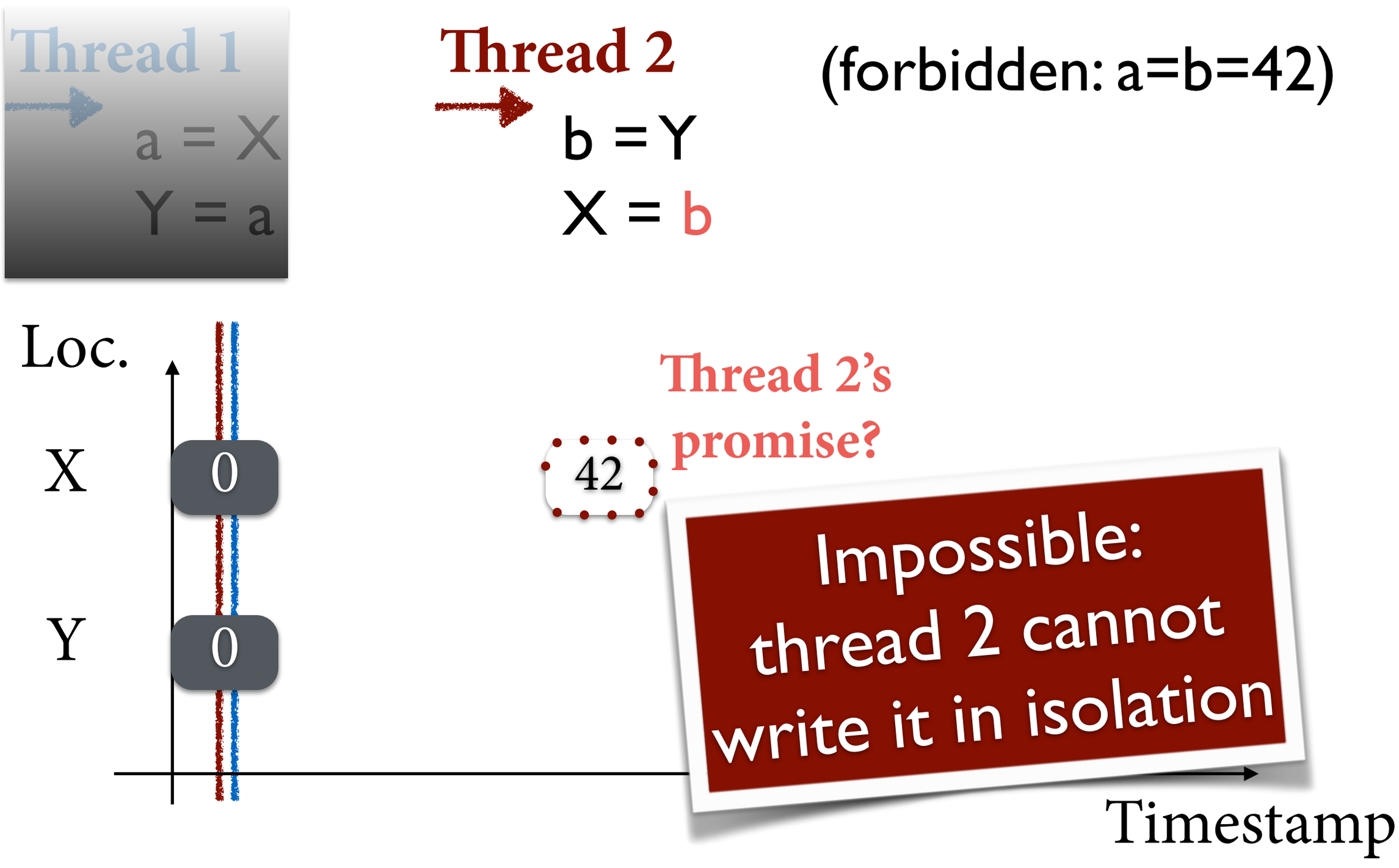
b = Y
X = b

(forbidden: a=b=42)



Example (3/3)

Classic Out-of-thin-air (OOTA)



Promises: "Semantic Solution" to OOTA

Thread 1

a = X

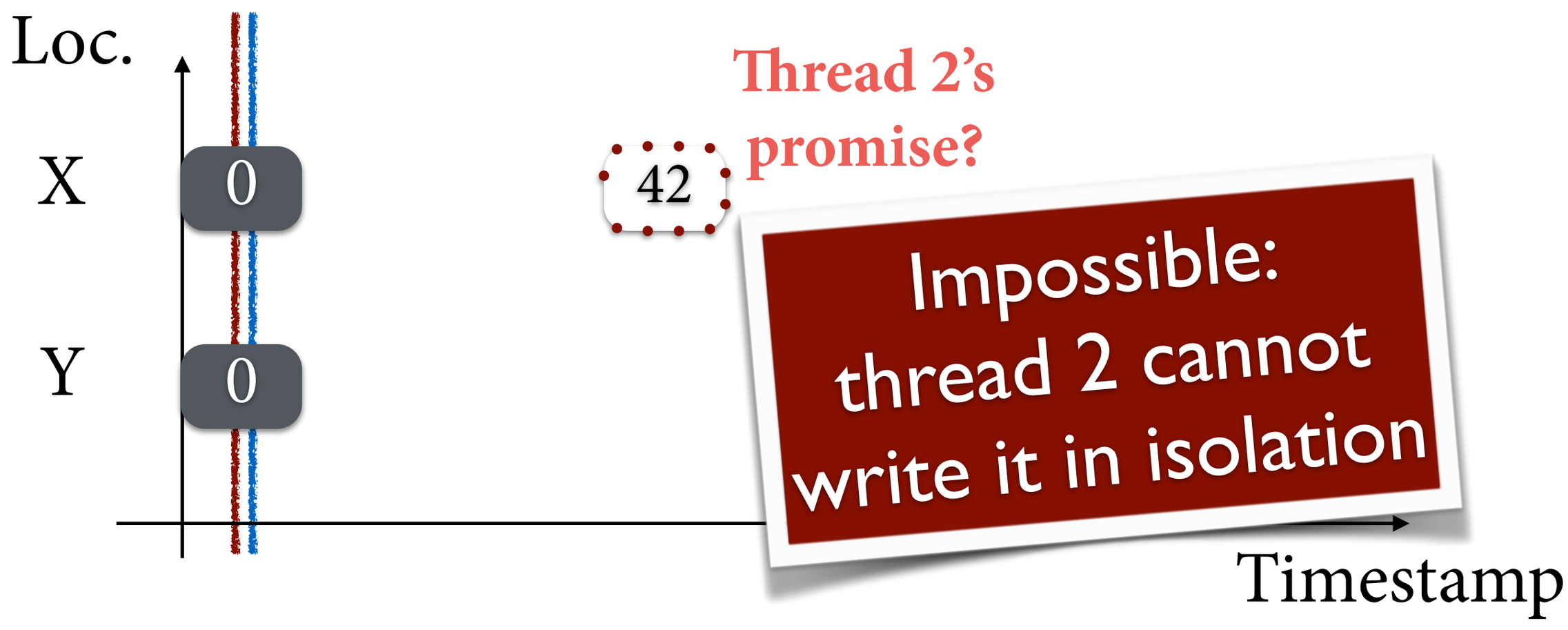
Y = a

Thread 2

b = Y

X = b

(forbidden: a=b=42)



Impossible: thread 2 cannot write it in isolation

Results (1/2)

Compiler/HW Optimizations

- **Operational semantics** for C/C++ concurrency: plain/relaxed/release/acquire r/w/u/fence, SC fence
- **Compiler optimizations** 
  (reordering, merging, dead code elim., …)
- **Compilation** to x86  & Power 

Results (2/2)
Reasoning Principles

- **DRF: D**ata **R**ace **F**reedom ⇒ SC 
  - DRF-PromiseFree: DRF ⇒ semantics w/o promises 
- **Invariant-based logic:** 
  soundness of global invariant (e.g. a=b=X=Y=0)

- http://sf.snu.ac.kr/promise-concurrency 

More comprehensive semantics for C/C++ concurrency

- **DRF: Data Race Freedom** ⇒ SC 
  - DRF-PromiseFree: DRF ⇒ semantics w/o promises 
- **Invariant-based logic:** 
  soundness of global invariant (e.g. a=b=X=Y=0)

- http://sf.snu.ac.kr/promise-concurrency 

Future Work

- Supporting **SC reads & writes**
  (We found a **flaw in C/C++11 on SC**)
- Supporting **consume** reads
- Compilation to **ARMv8**
- Developing a rich **program logic** &
  Verifying fine-grained concurrent programs