Active Testing for Concurrent Programs

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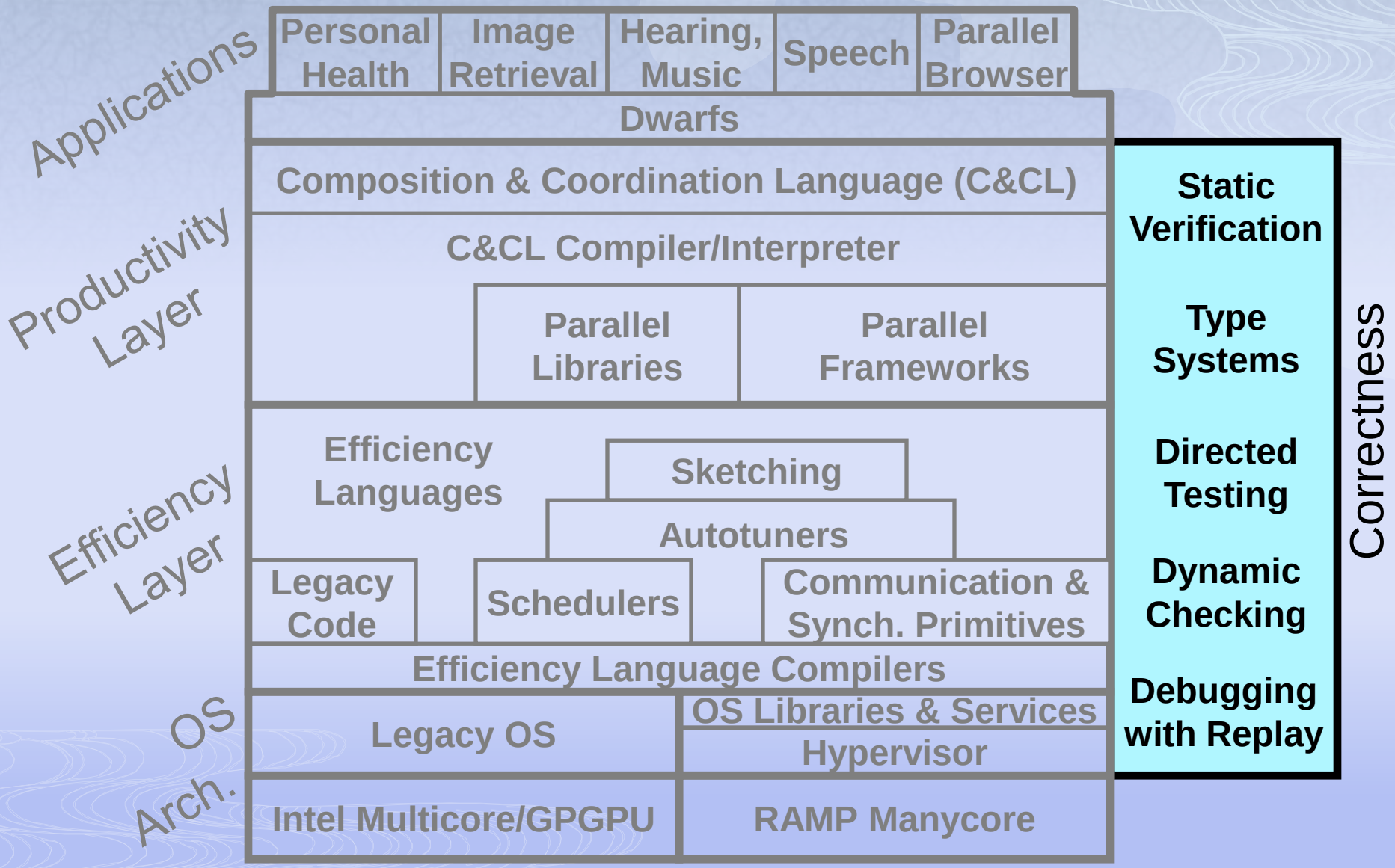
★ ParLab, UC Berkeley ‡ Intel Research

Overview

- Checking correctness of concurrent programs
- Active testing directed by
  - Data races
  - Atomicity violations
  - Deadlocks
- Programmer directed active testing
  - “Breakpoints” for parallel programs
- Conclusion


Applications
Personal Health
Image Retrieval
Hearing, Music
Speech
Parallel Browser
Dwarfs
Productivity Layer
Composition & Coordination Language (C&CL)
C&CL Compiler/Interpreter
Parallel Libraries
Parallel Frameworks
Efficiency Layer
Efficiency Languages
Sketching
Autotuners
Legacy Code
Schedulers
Communication & Synch. Primitives
Efficiency Language Compilers
OS
Legacy OS
OS Libraries & Services
Hypervisor
Arch.
Intel Multicore/GPGPU
RAMP Manycore
Static Verification
Type Systems
Directed Testing
Dynamic Checking
Debugging with Replay
Correctness

Checking Correctness of Concurrent Programs

- Multiple threads of execution with shared memory
- Want correctness for
  - All executions
  - All inputs need to be checked
- Interference among threads introduces non deterministic bugs
  - All schedules need to be checked

Checking All Schedules

- Model checking
  - Check all schedules systematically
  - Does not scale to large programs
- Focus on potentially buggy schedules
  - Schedules that may expose bugs
  - “Boundary case” schedules
- What are those “potentially buggy schedules”?

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  - “Boundary case” schedules
- What are those “potentially buggy schedules”?
  - Schedules exhibiting data races, atomicity violations, deadlocks

Active Testing

- Check the “potentially buggy schedules”
  - Practical and efficient
  - Find many bugs quickly
  - Create an **actual** execution showing a bug
- How?

Active Testing

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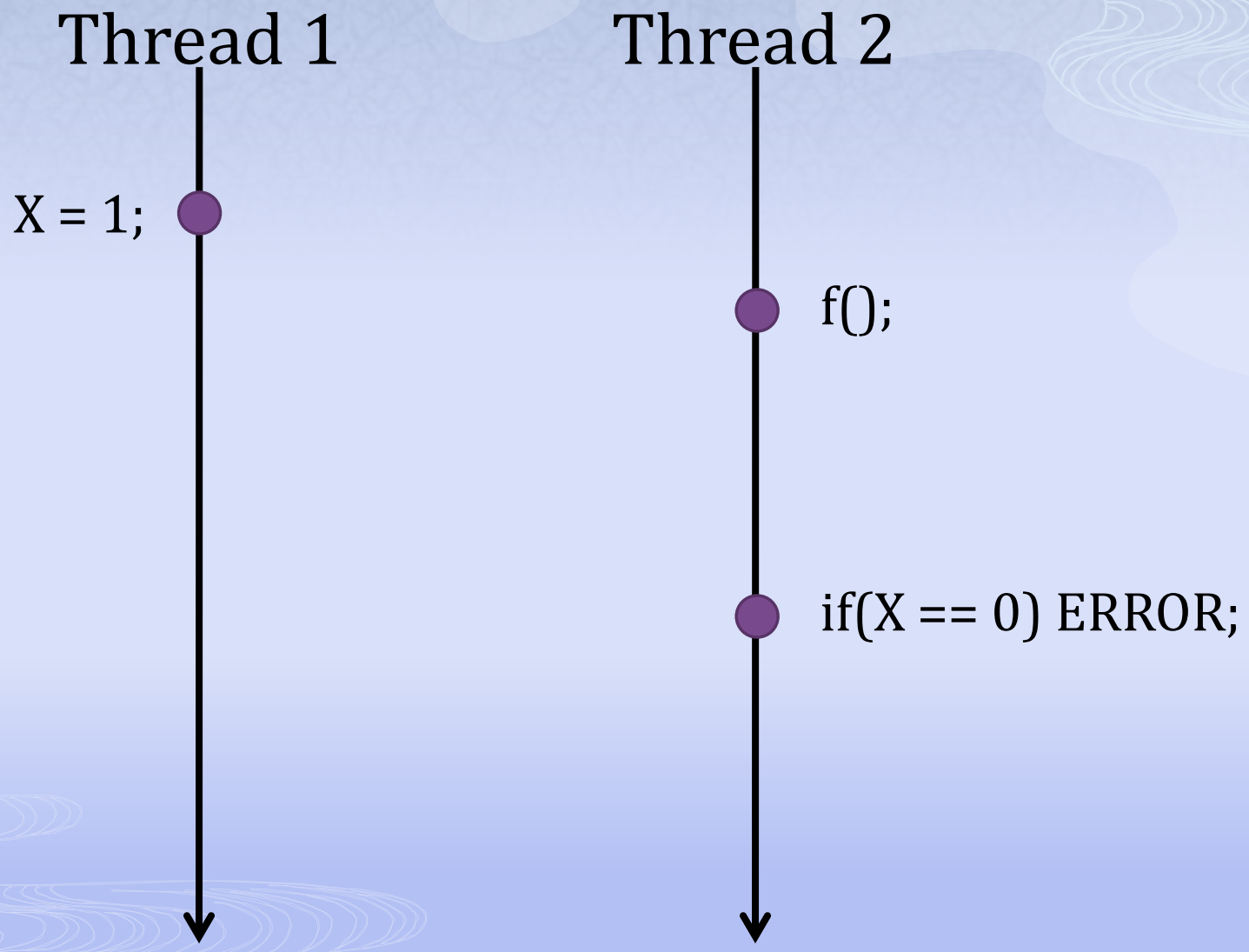
- Actively control scheduler
  - Explore schedules systematically or randomly
  - But, preempt threads at "appropriate" states
    - so that buggy schedules get created
  - Observe execution for any abnormal behavior (e.g. uncaught exceptions, assertion failures)

Preempting at "Appropriate" States: Race Directed



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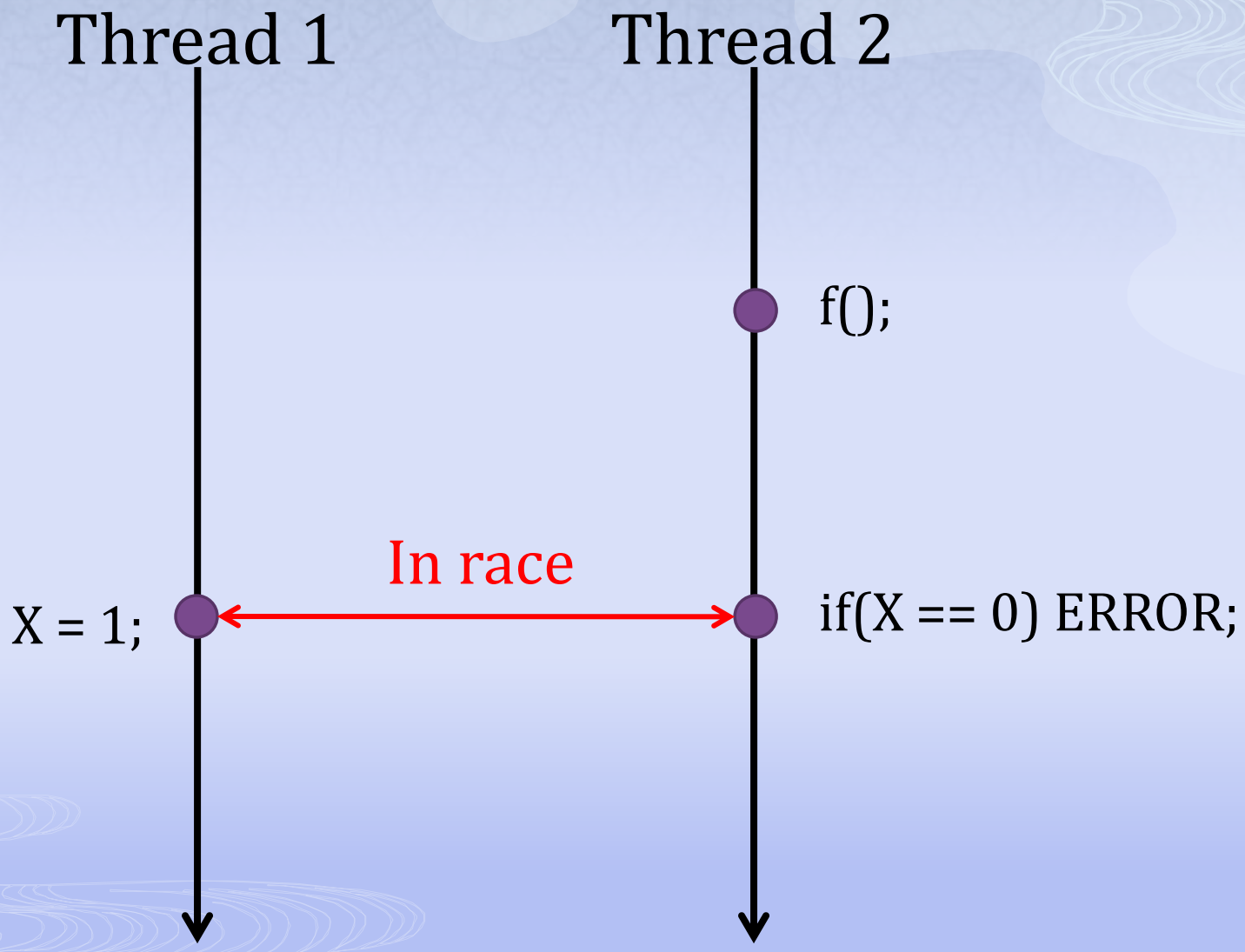

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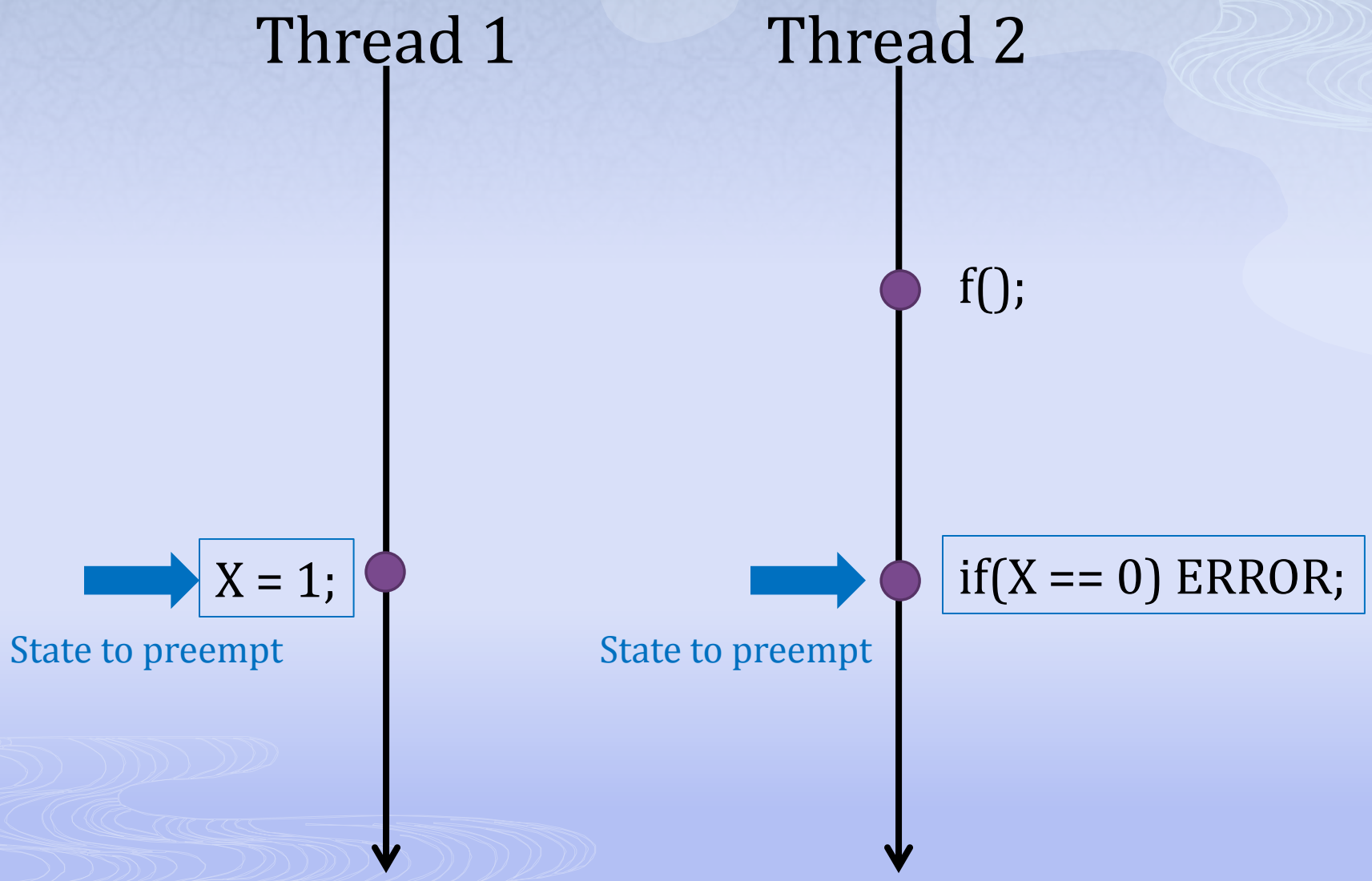

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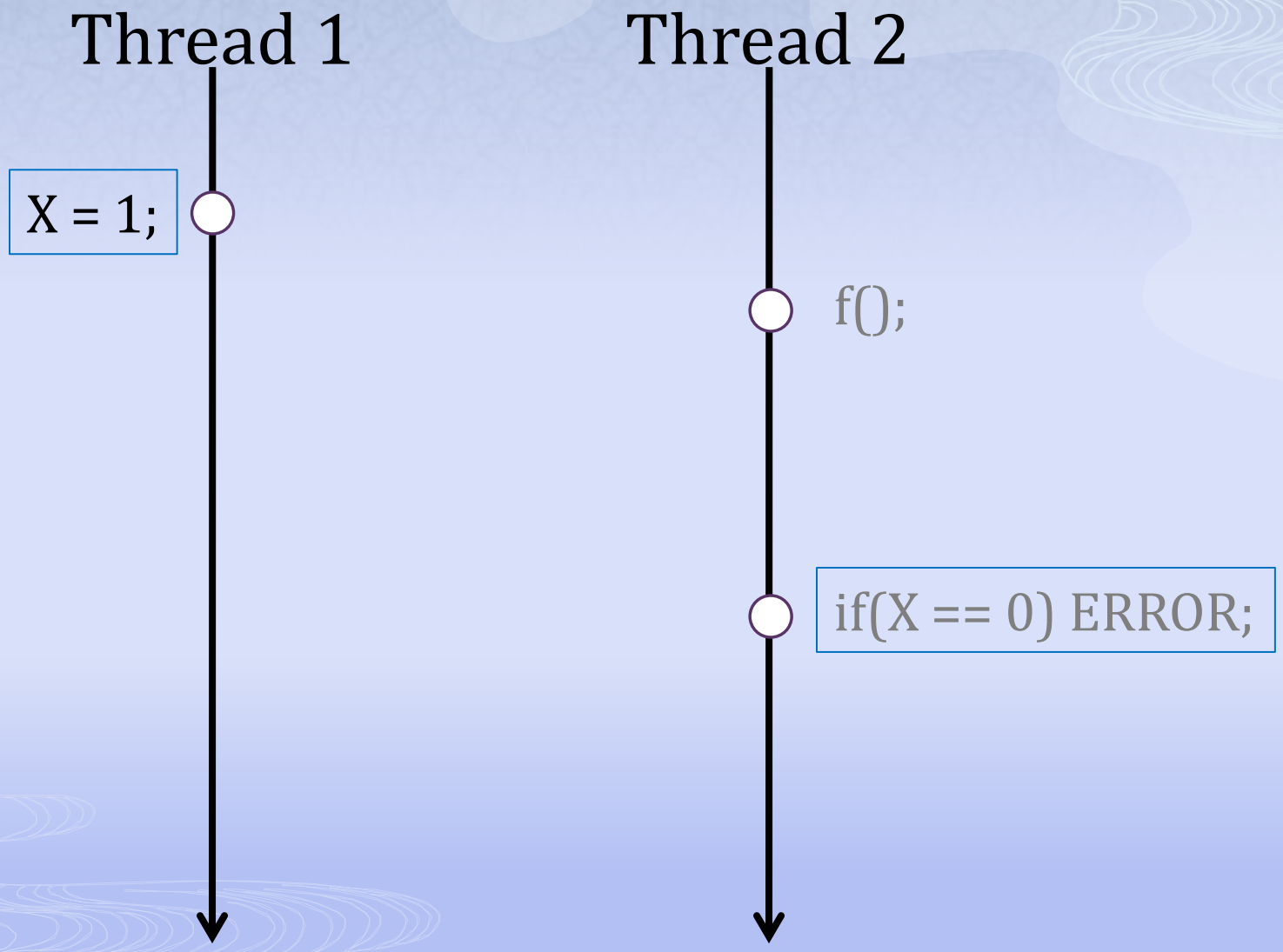

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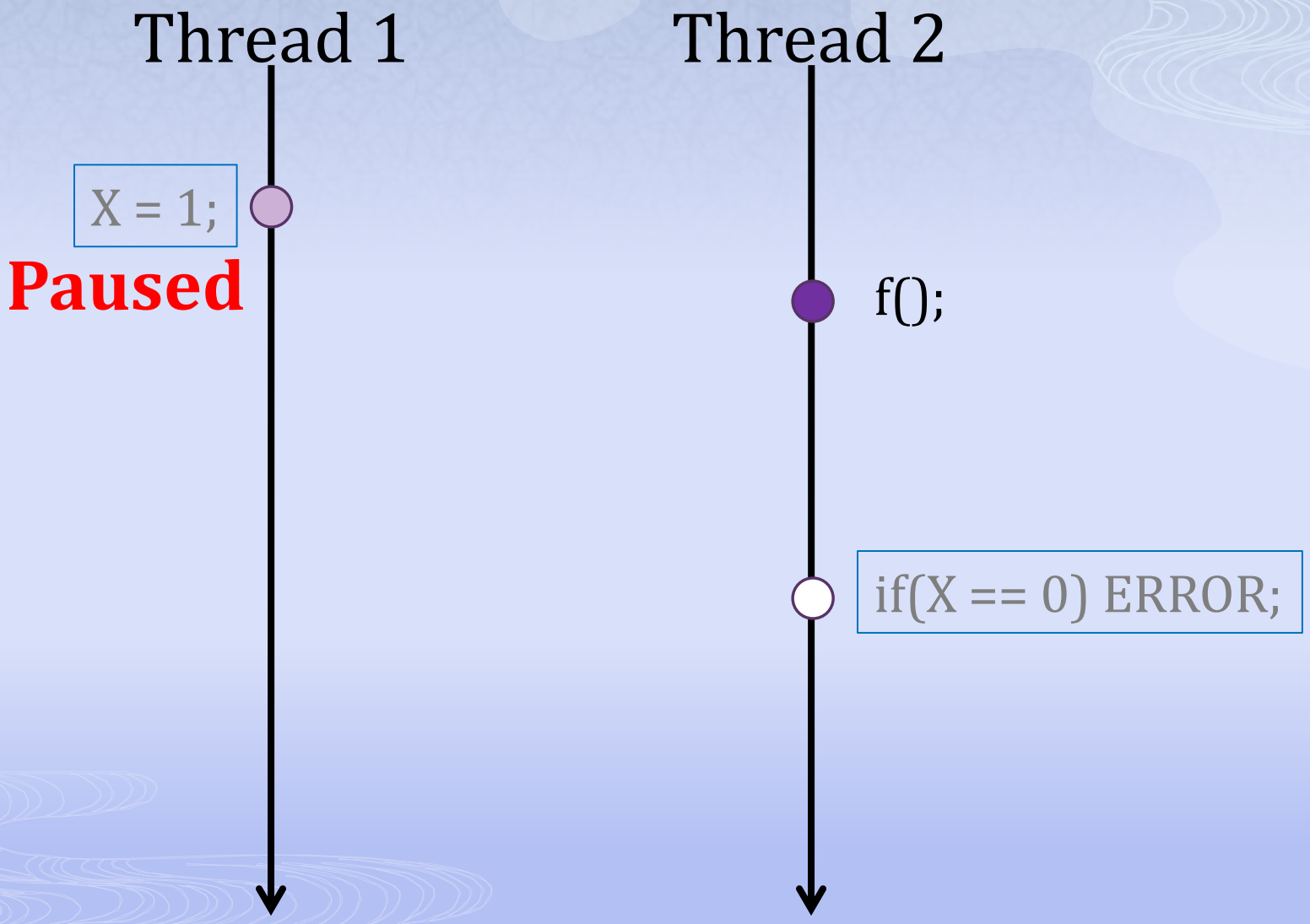

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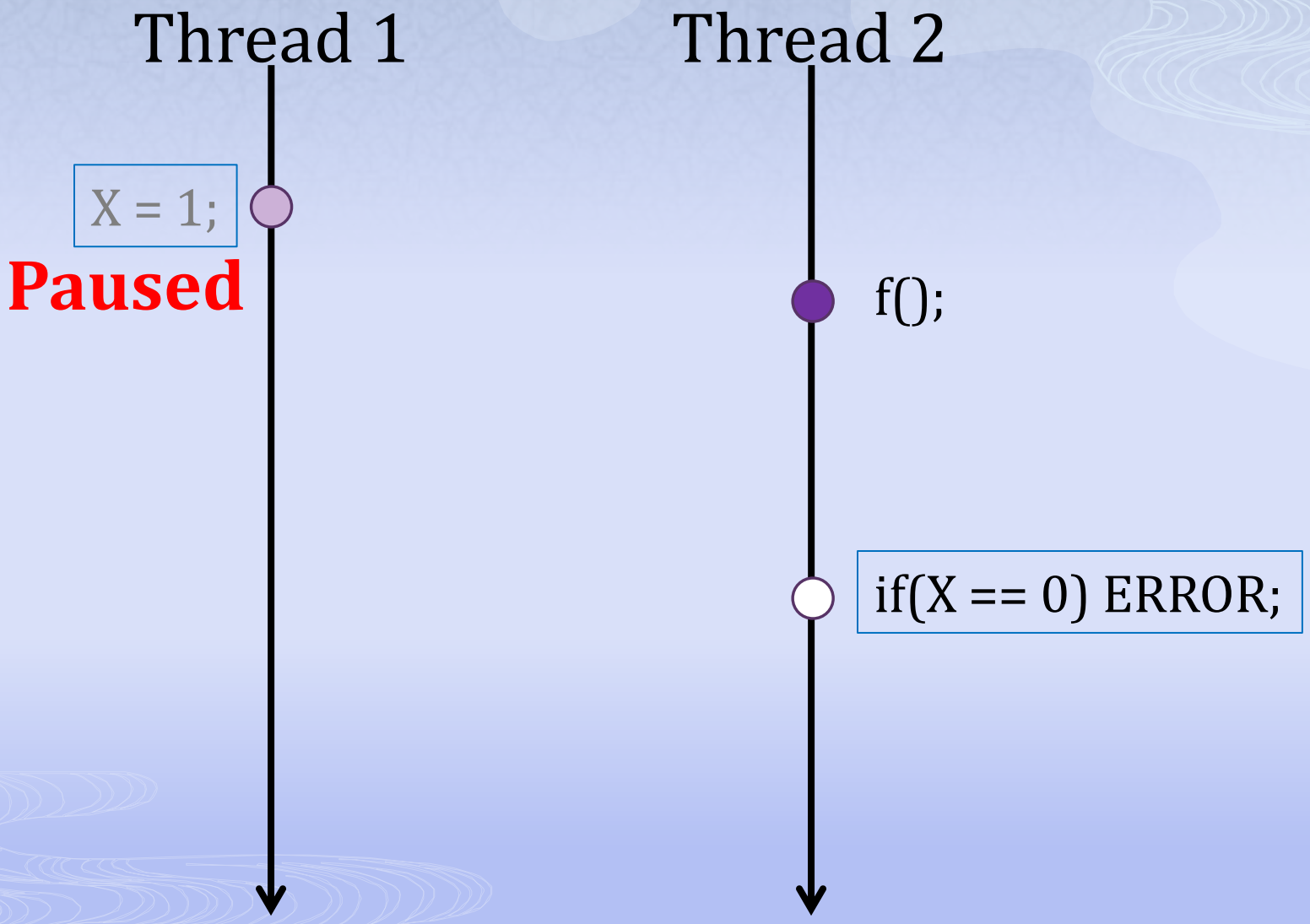

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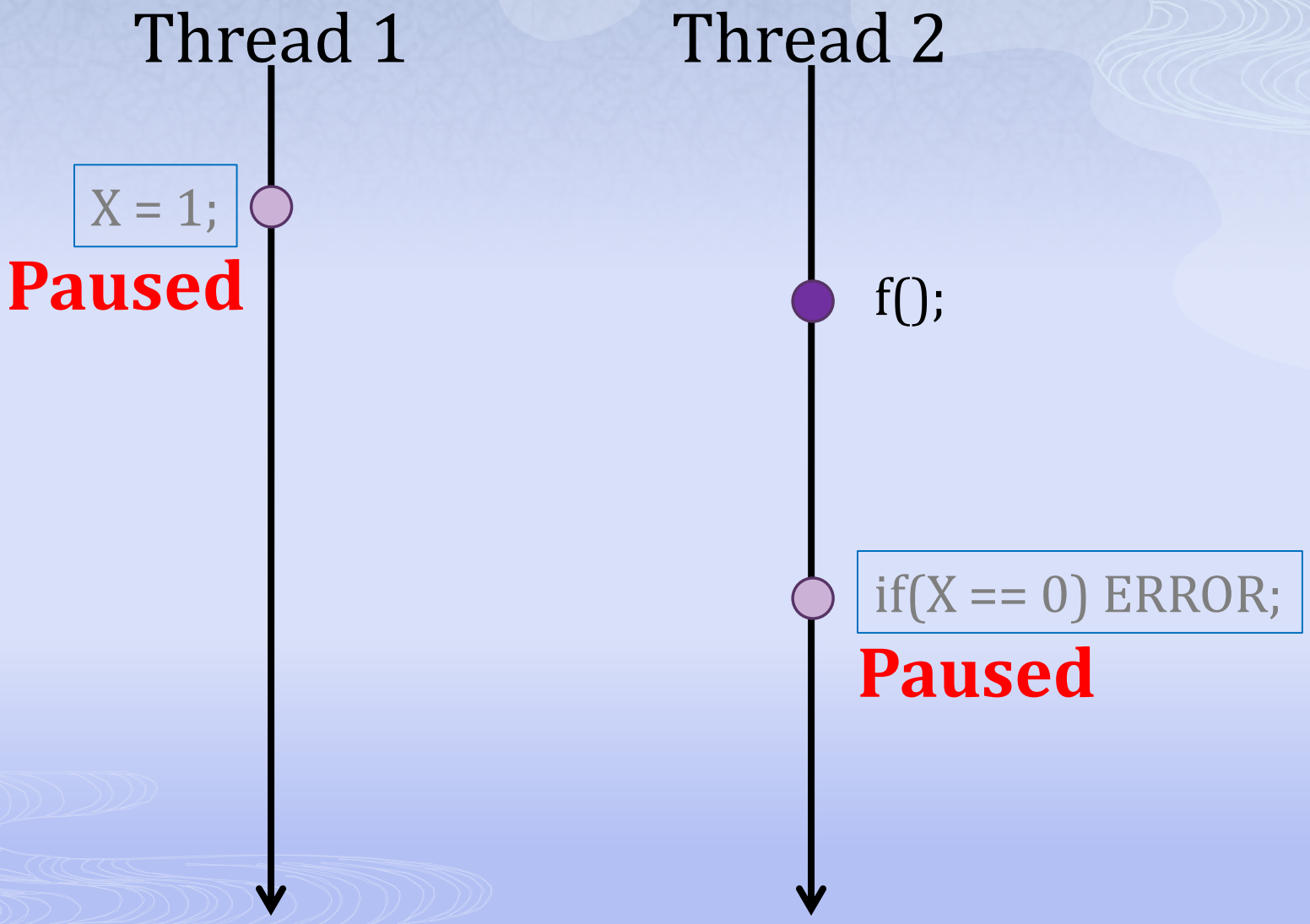

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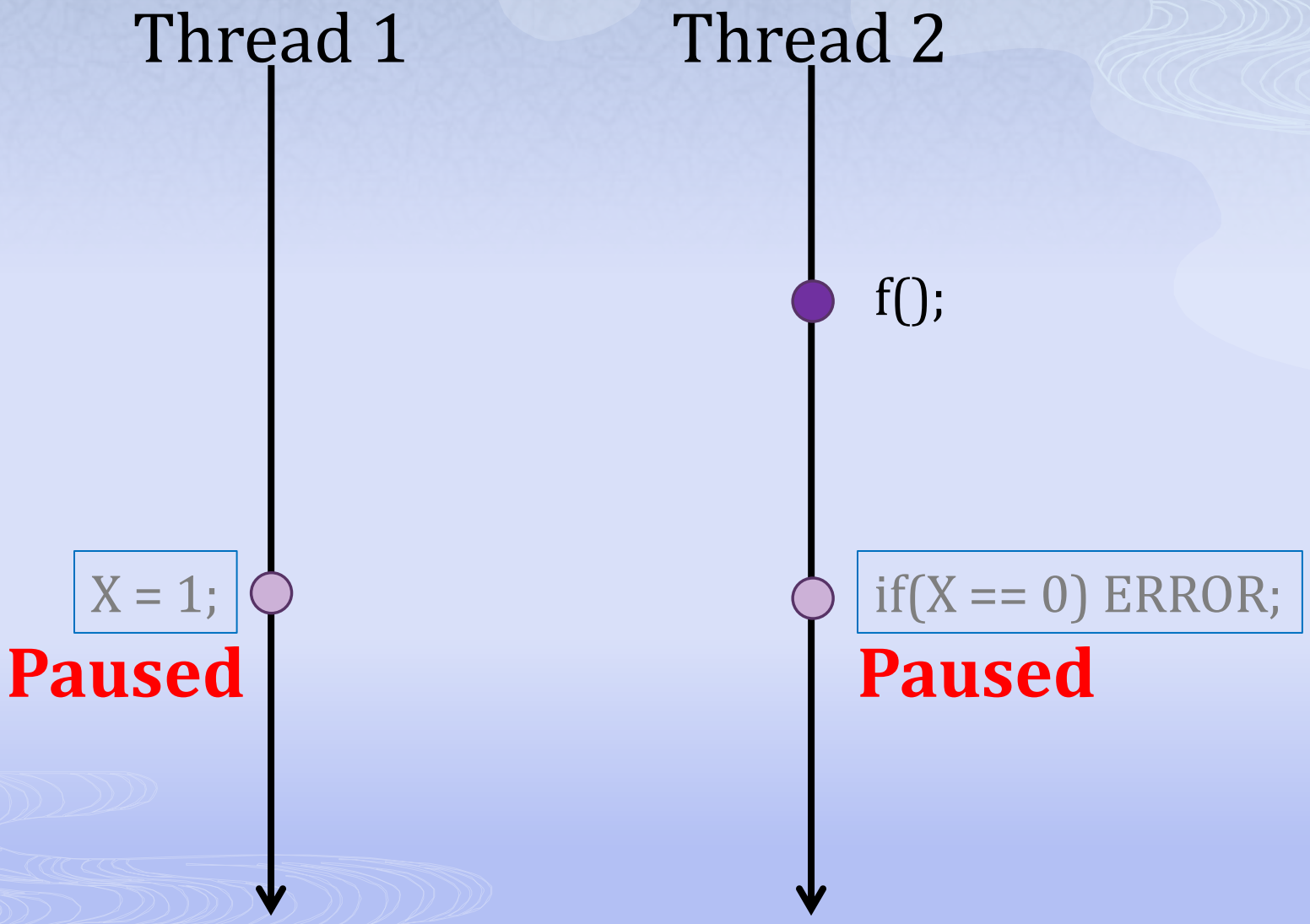

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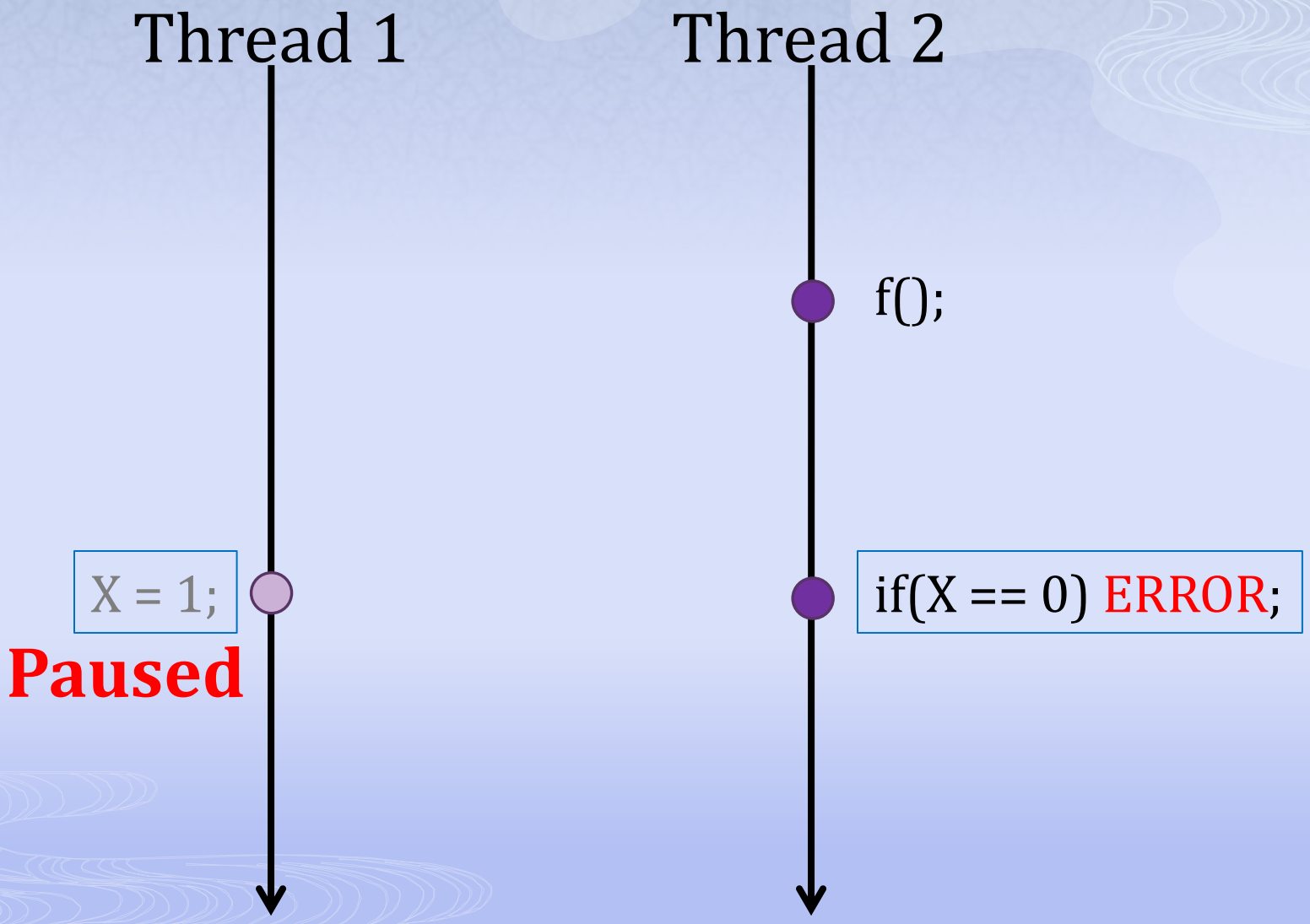

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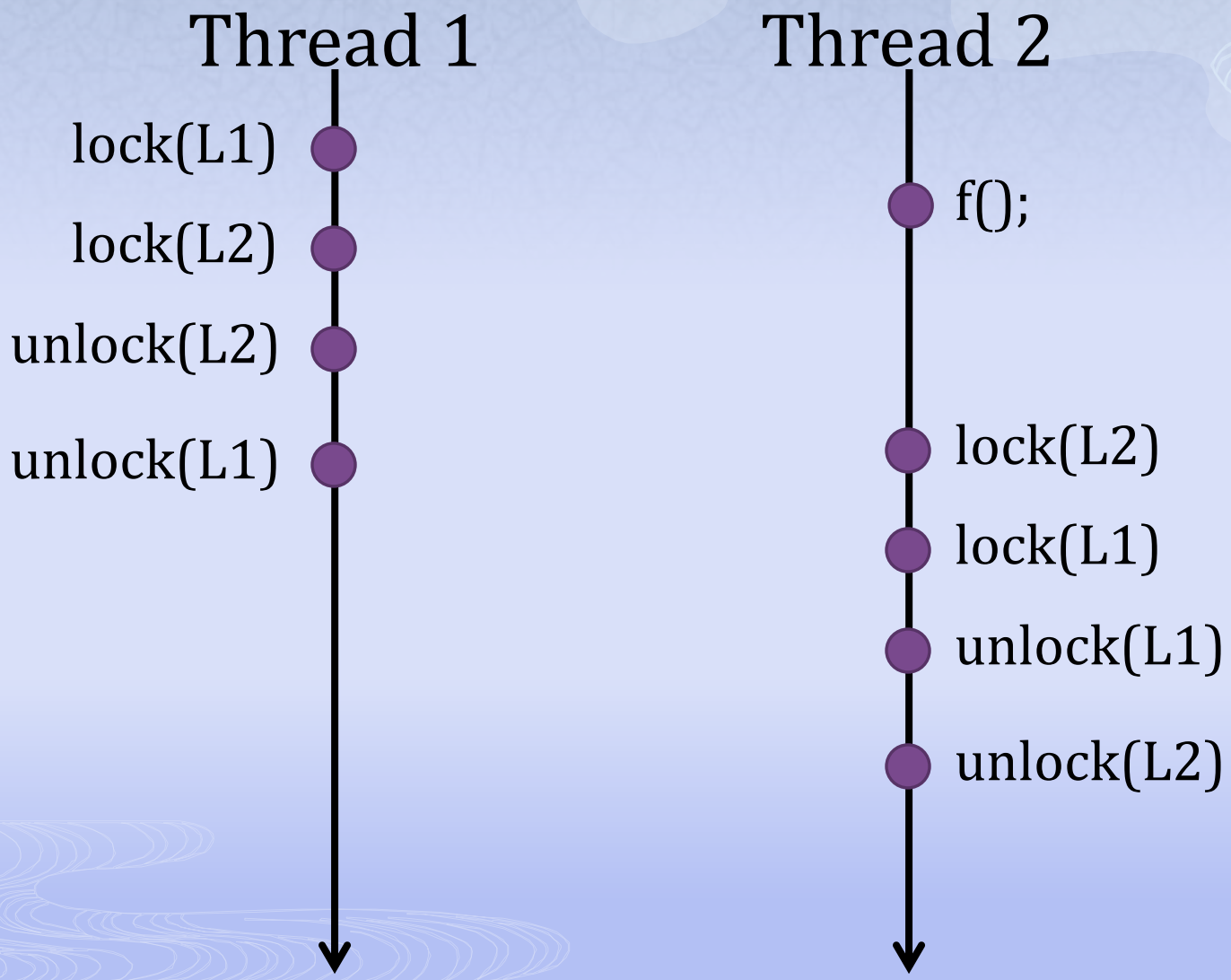

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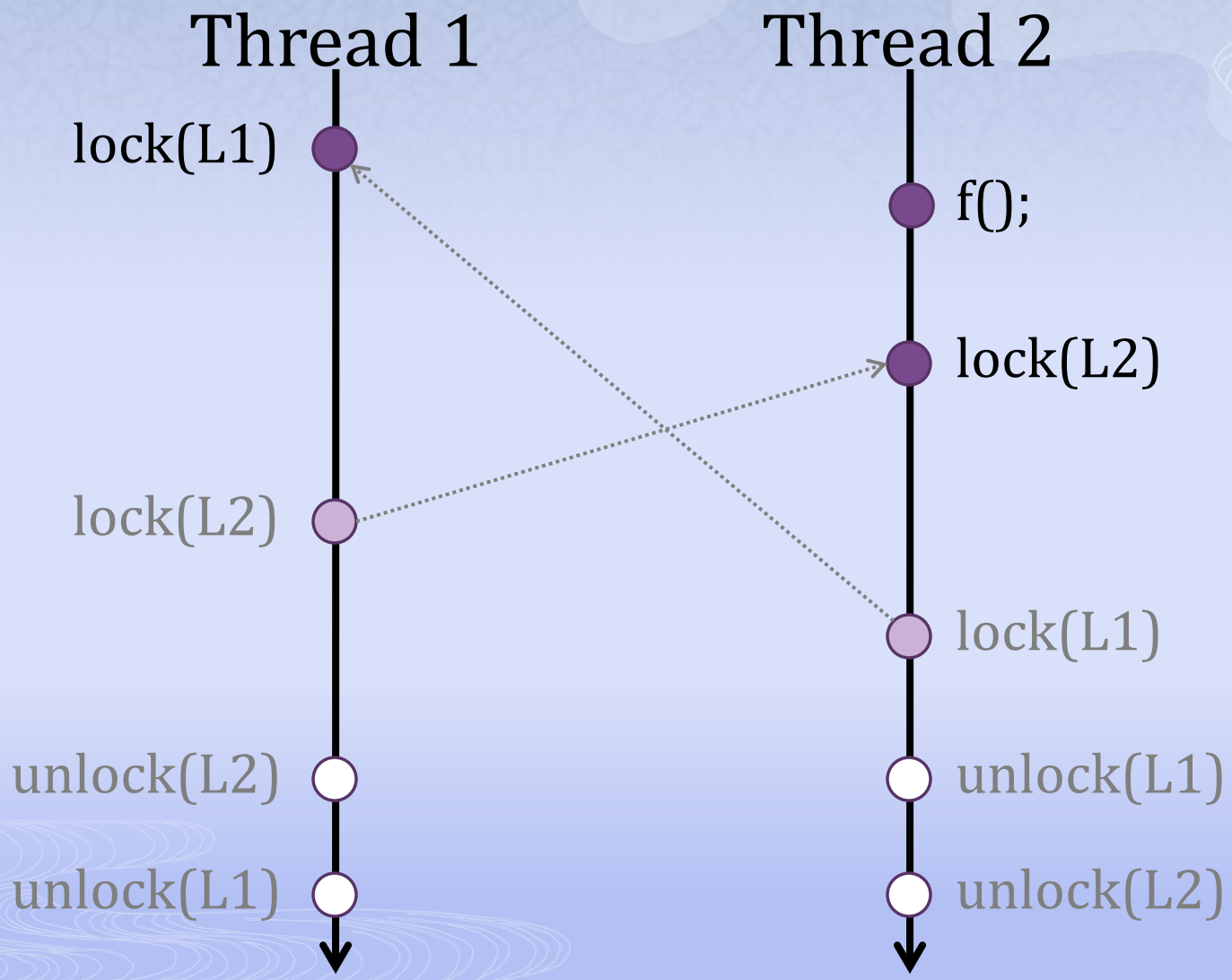

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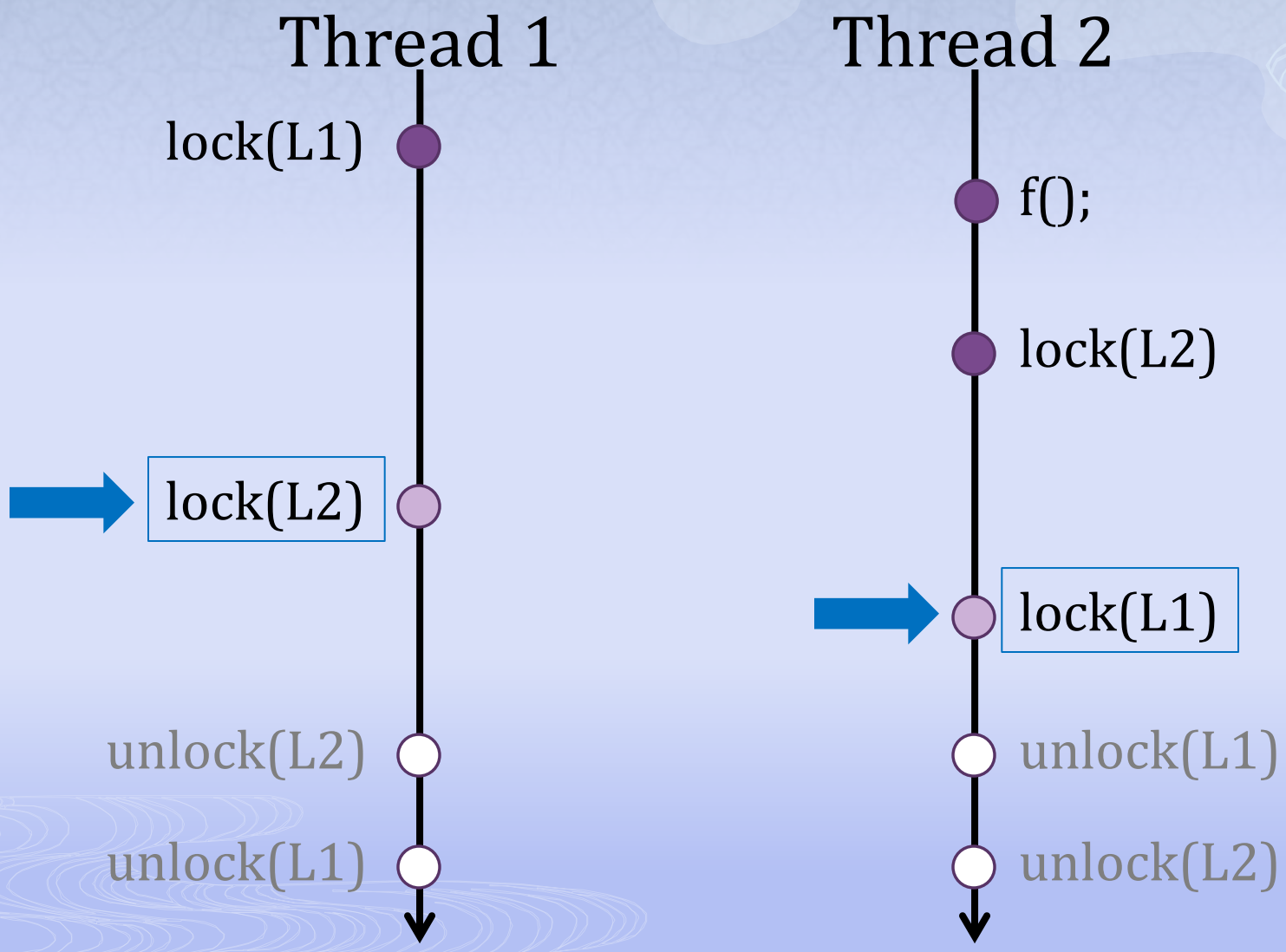

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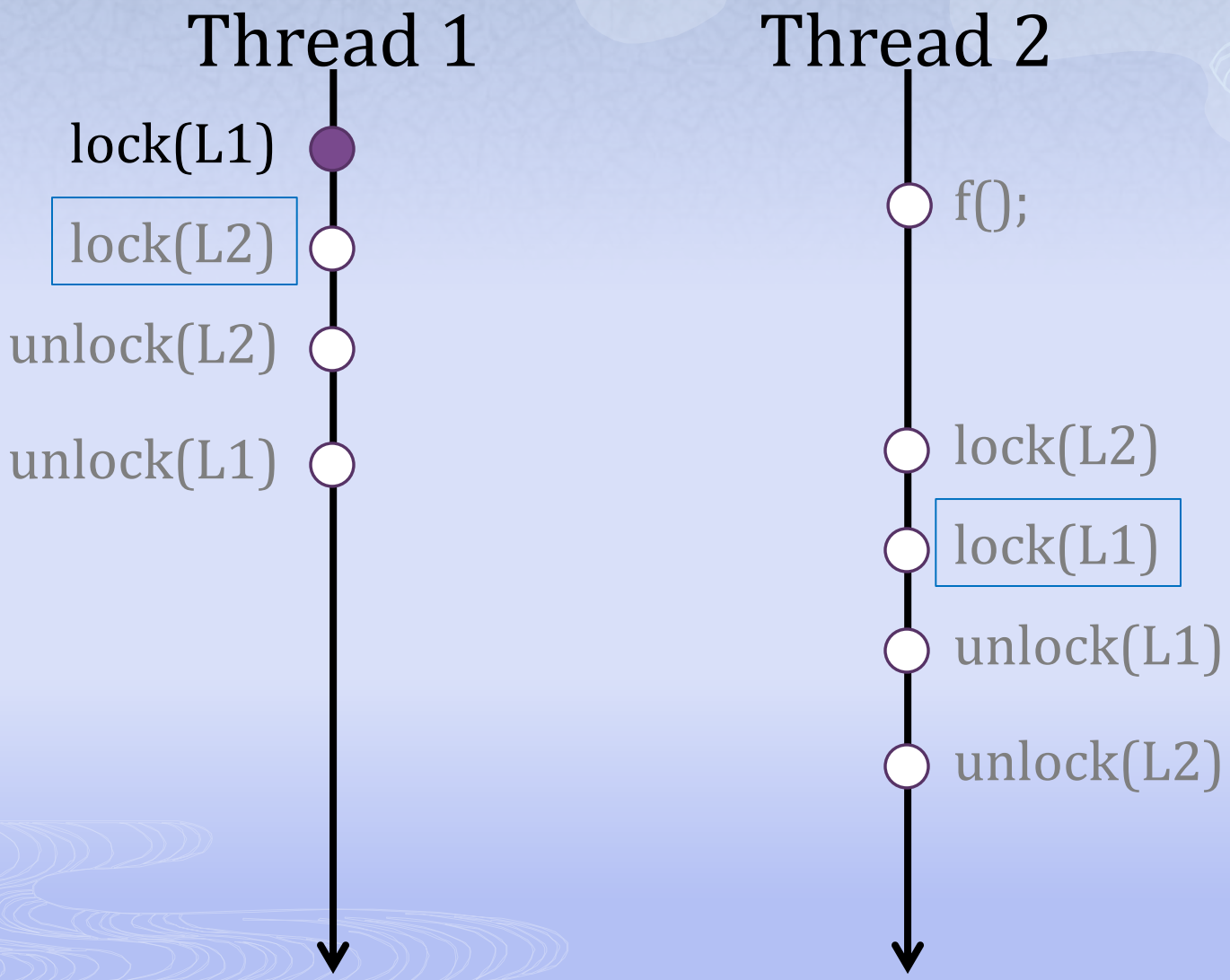

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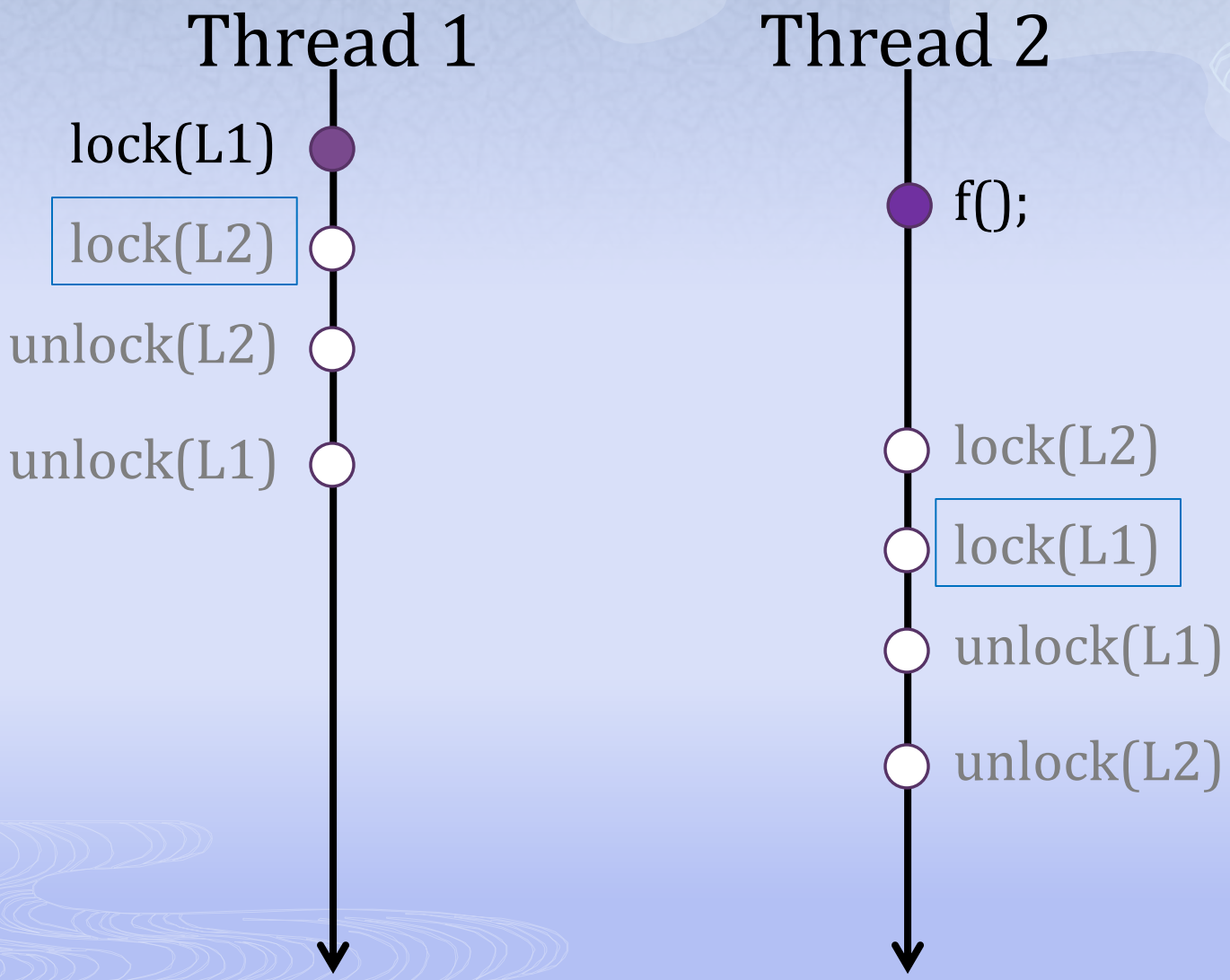

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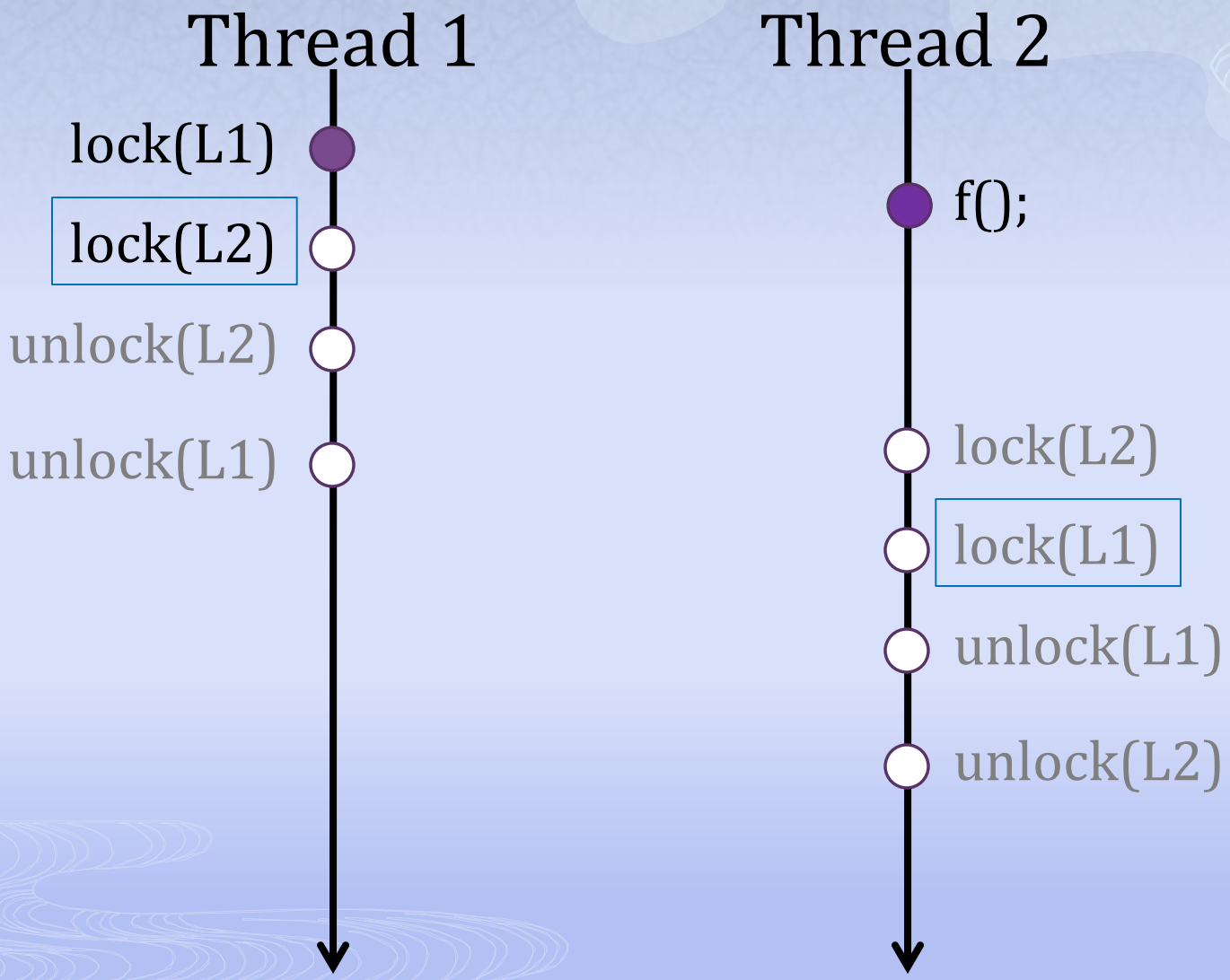

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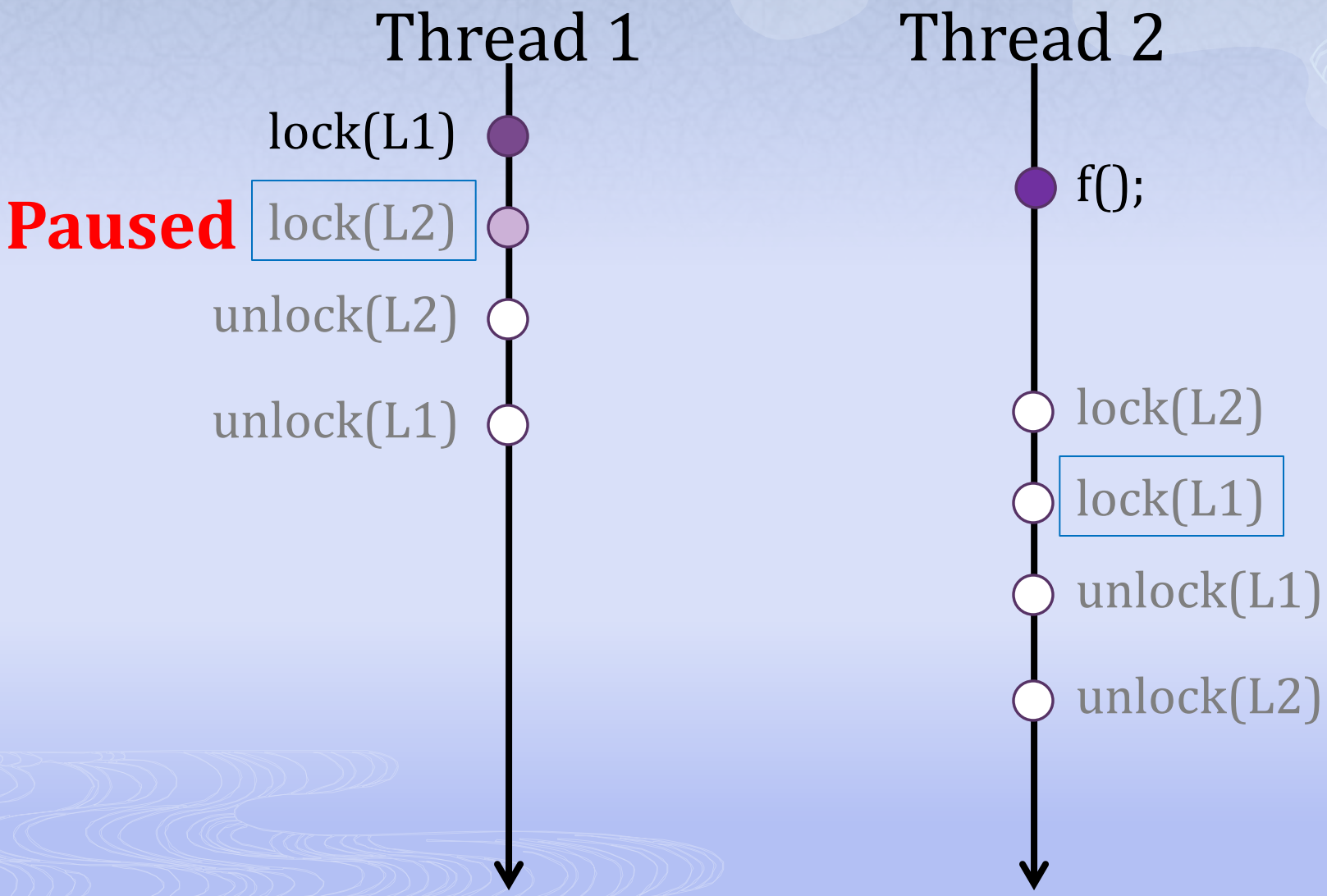

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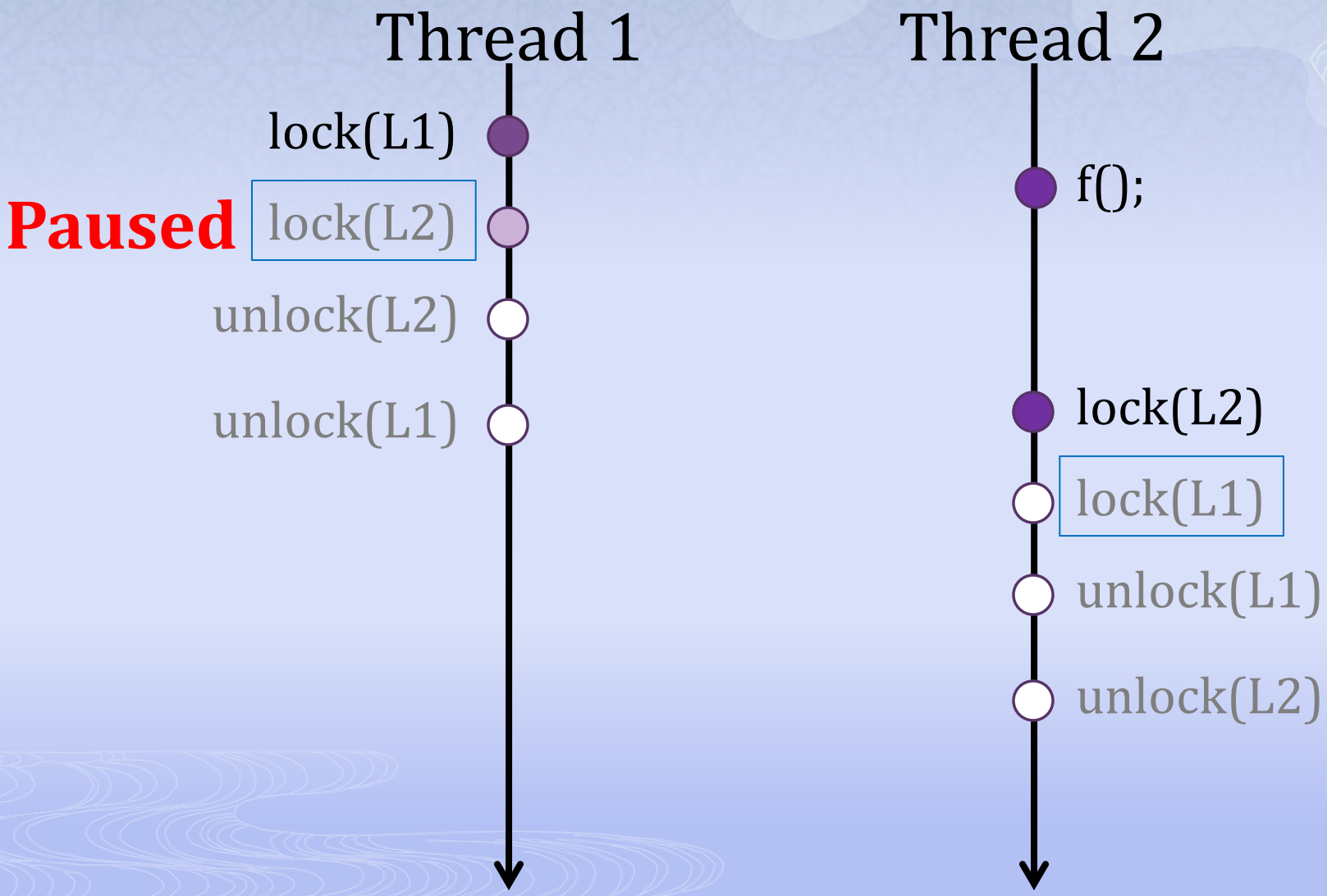

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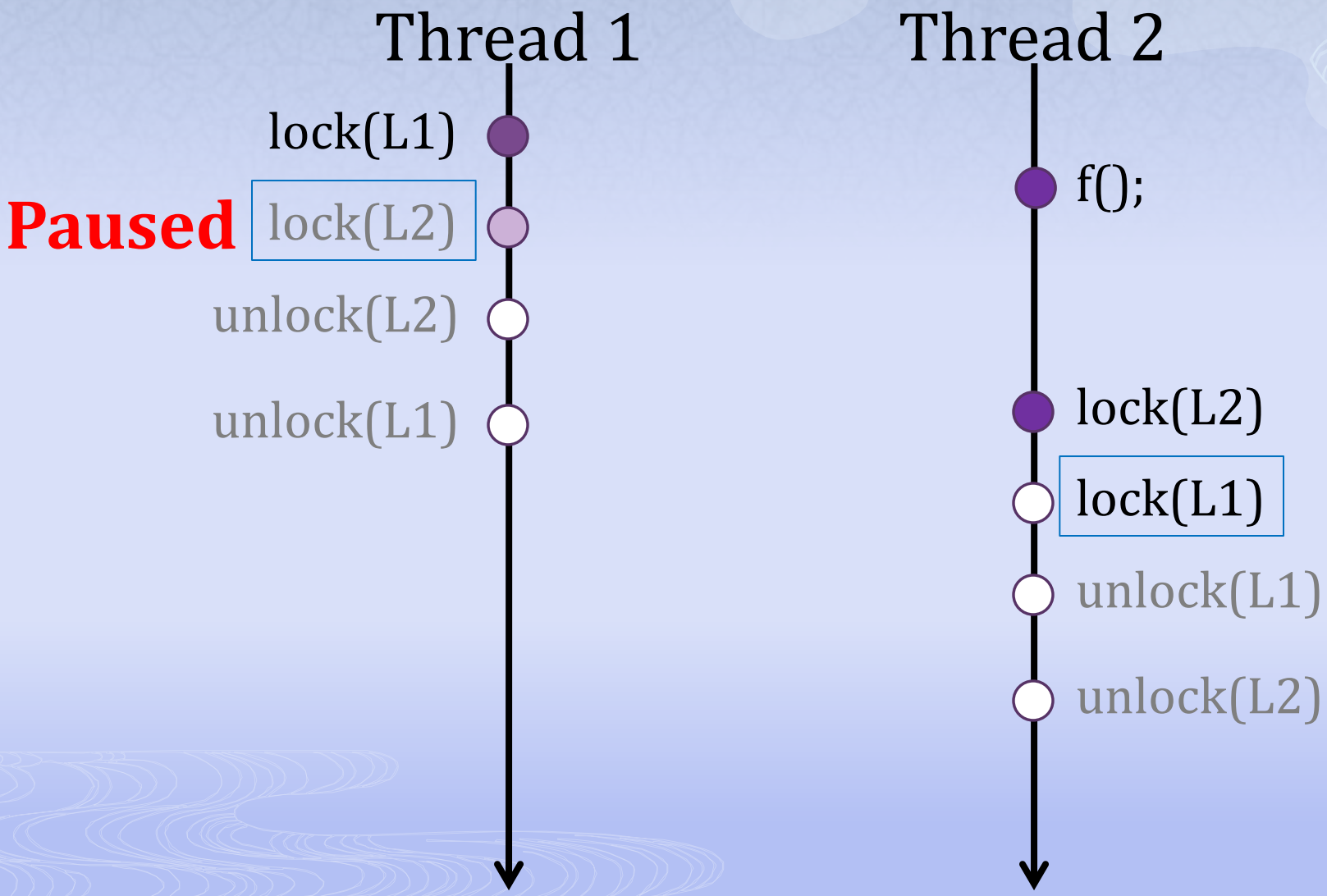

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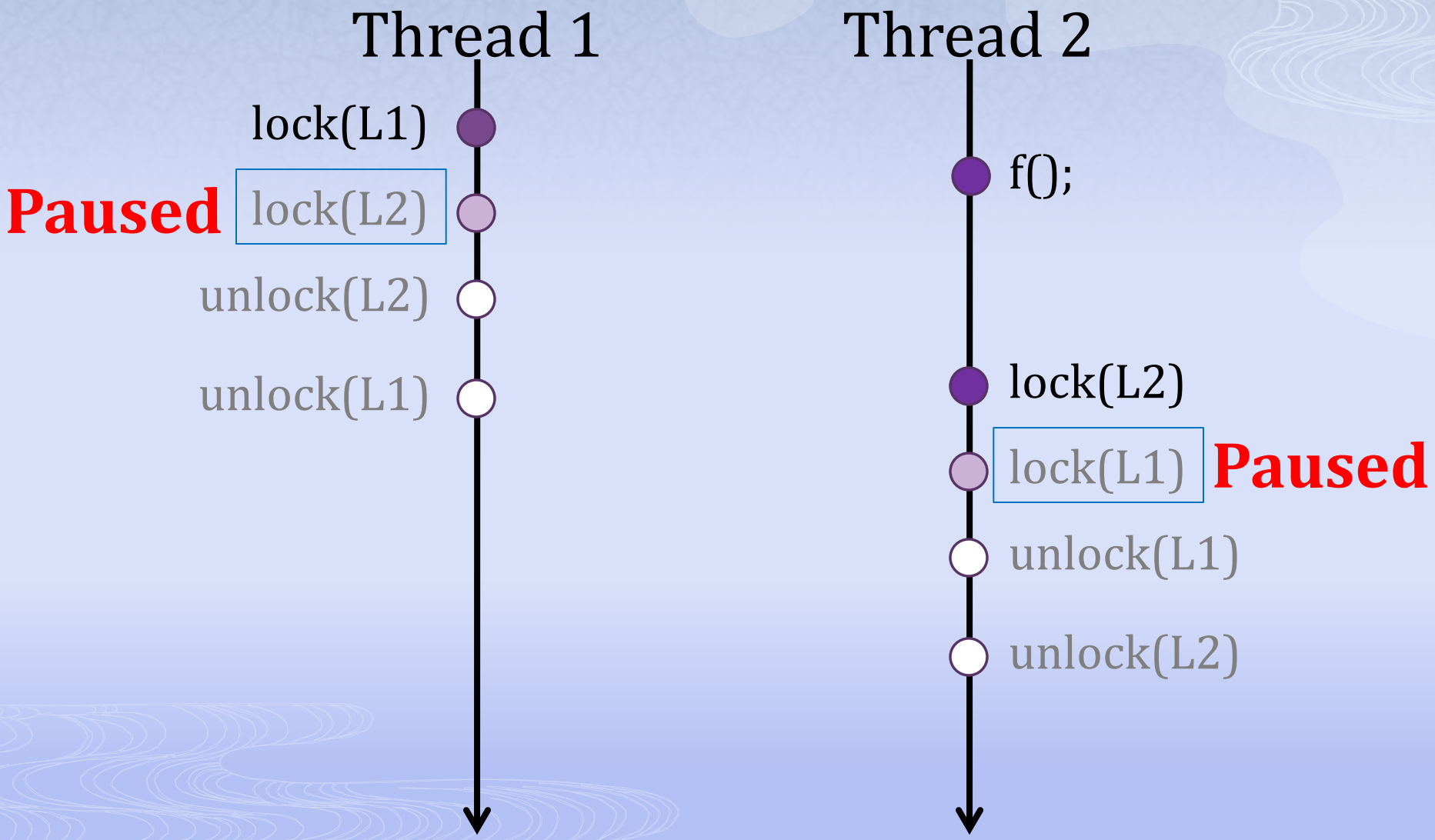

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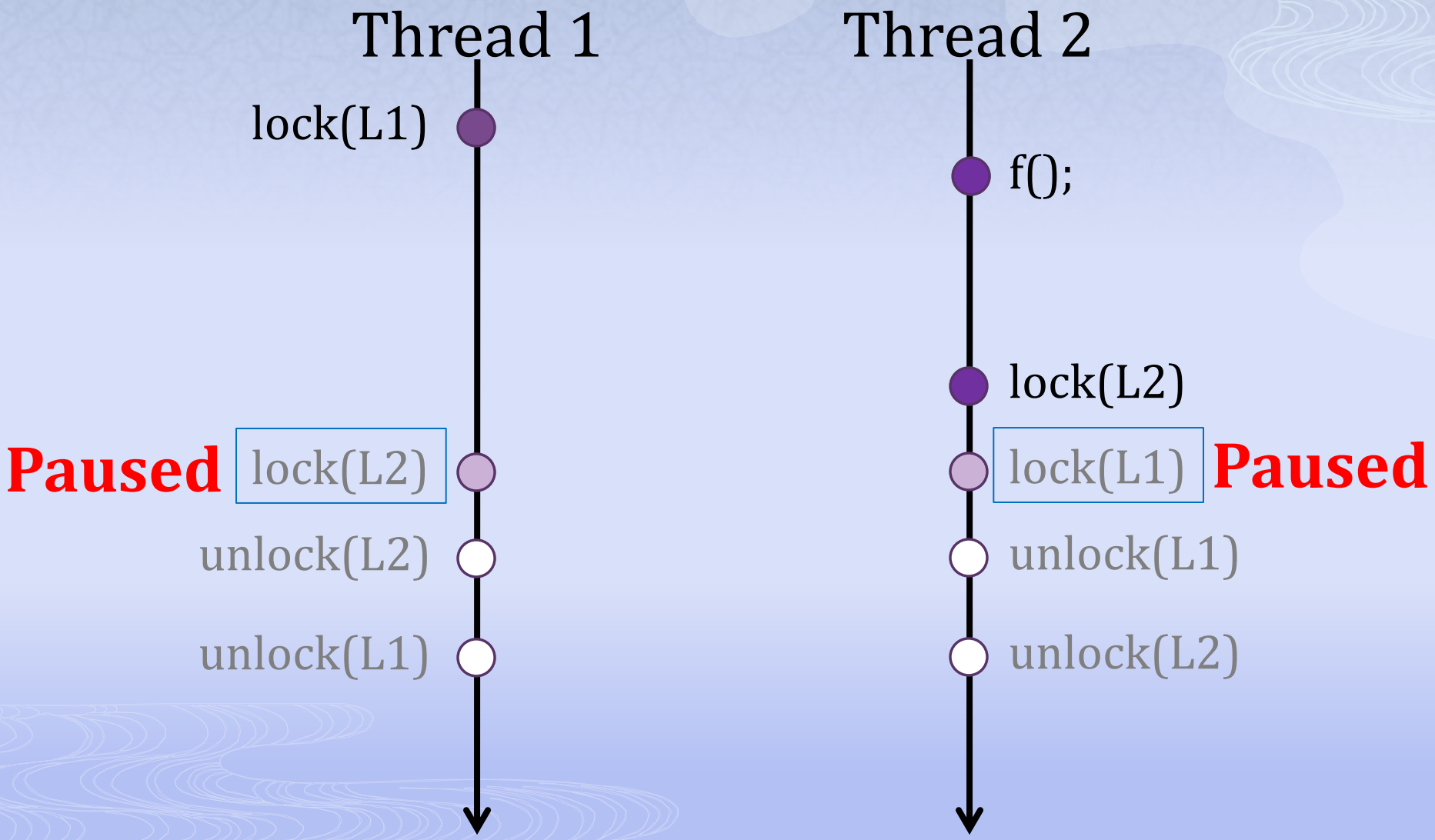

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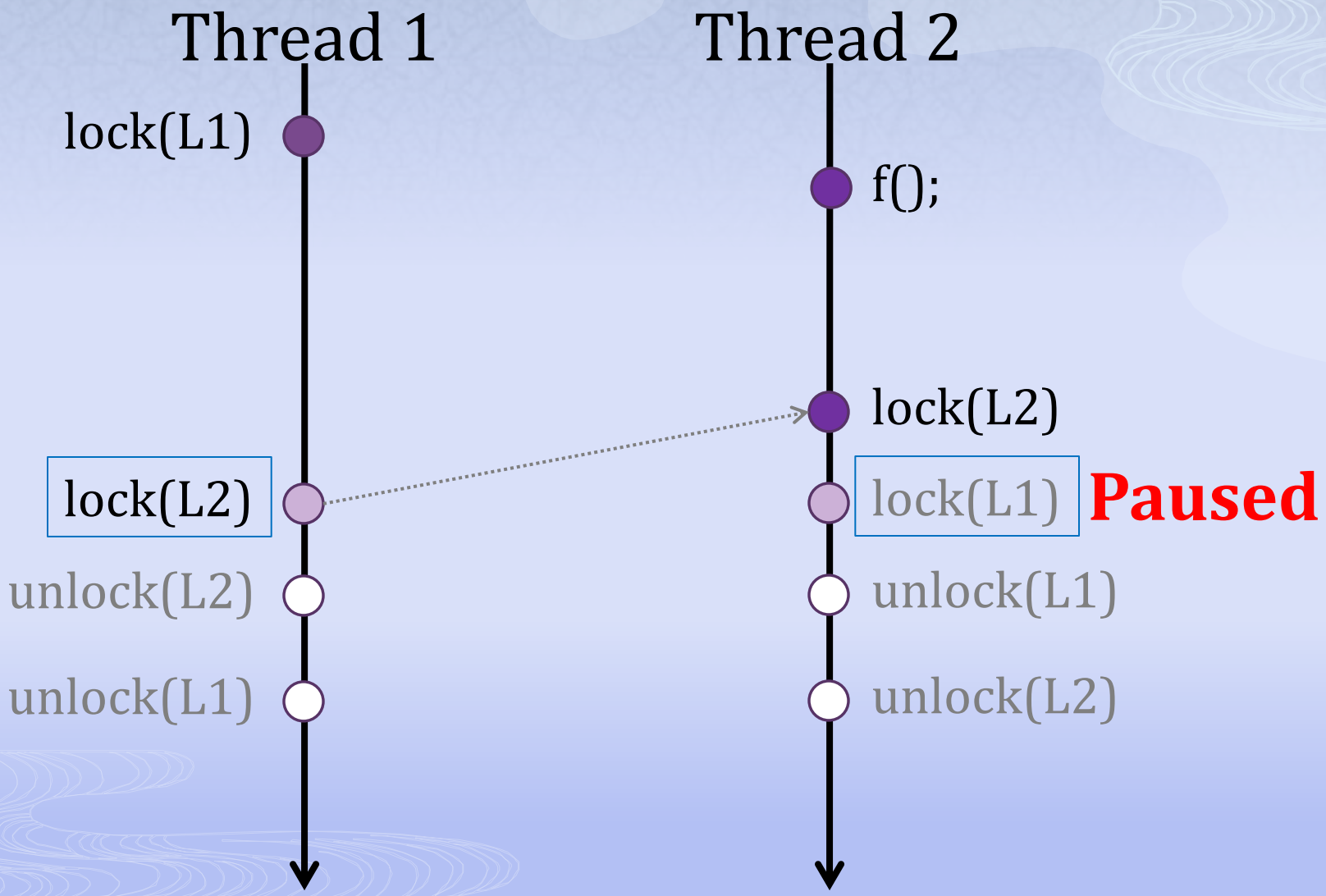

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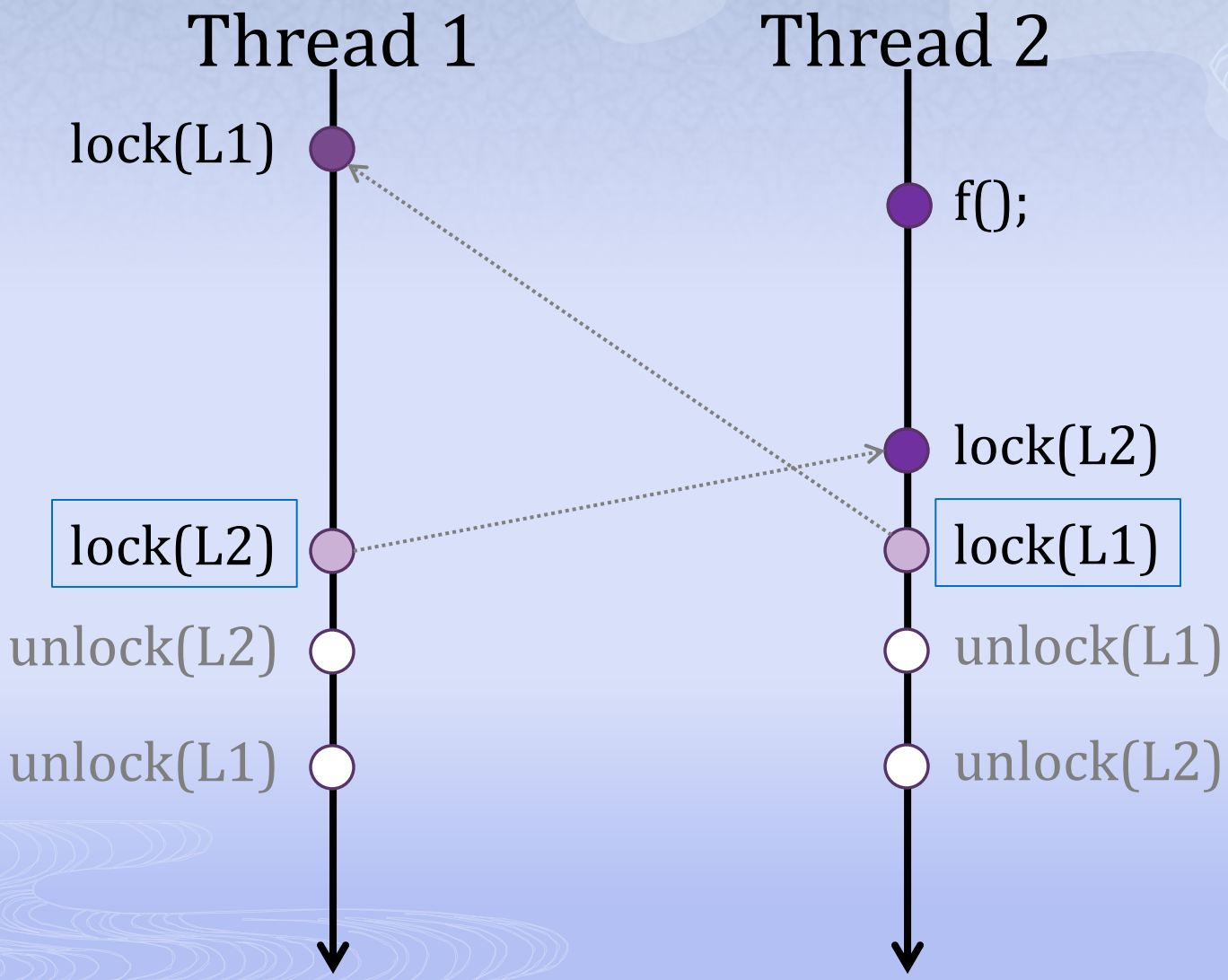

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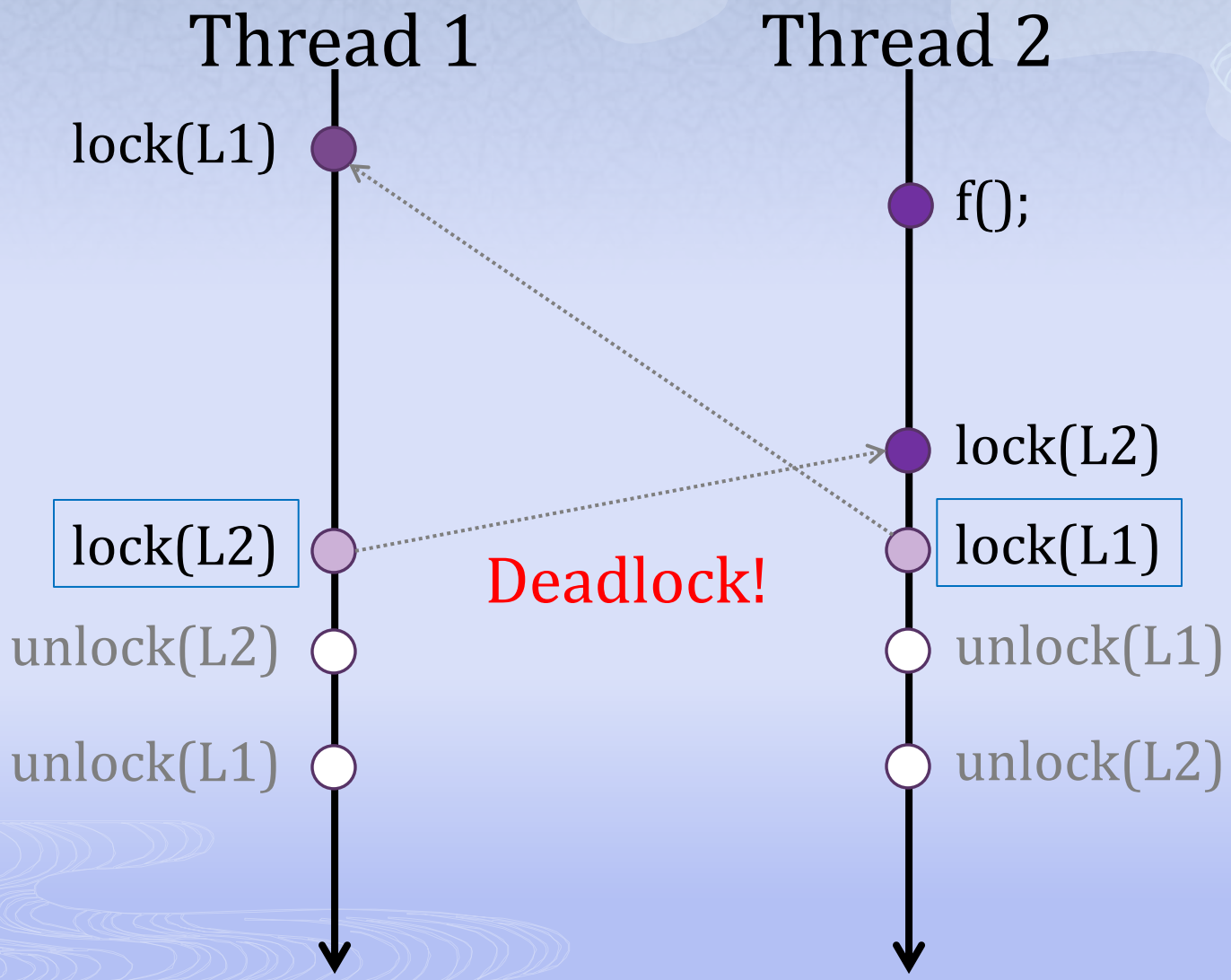

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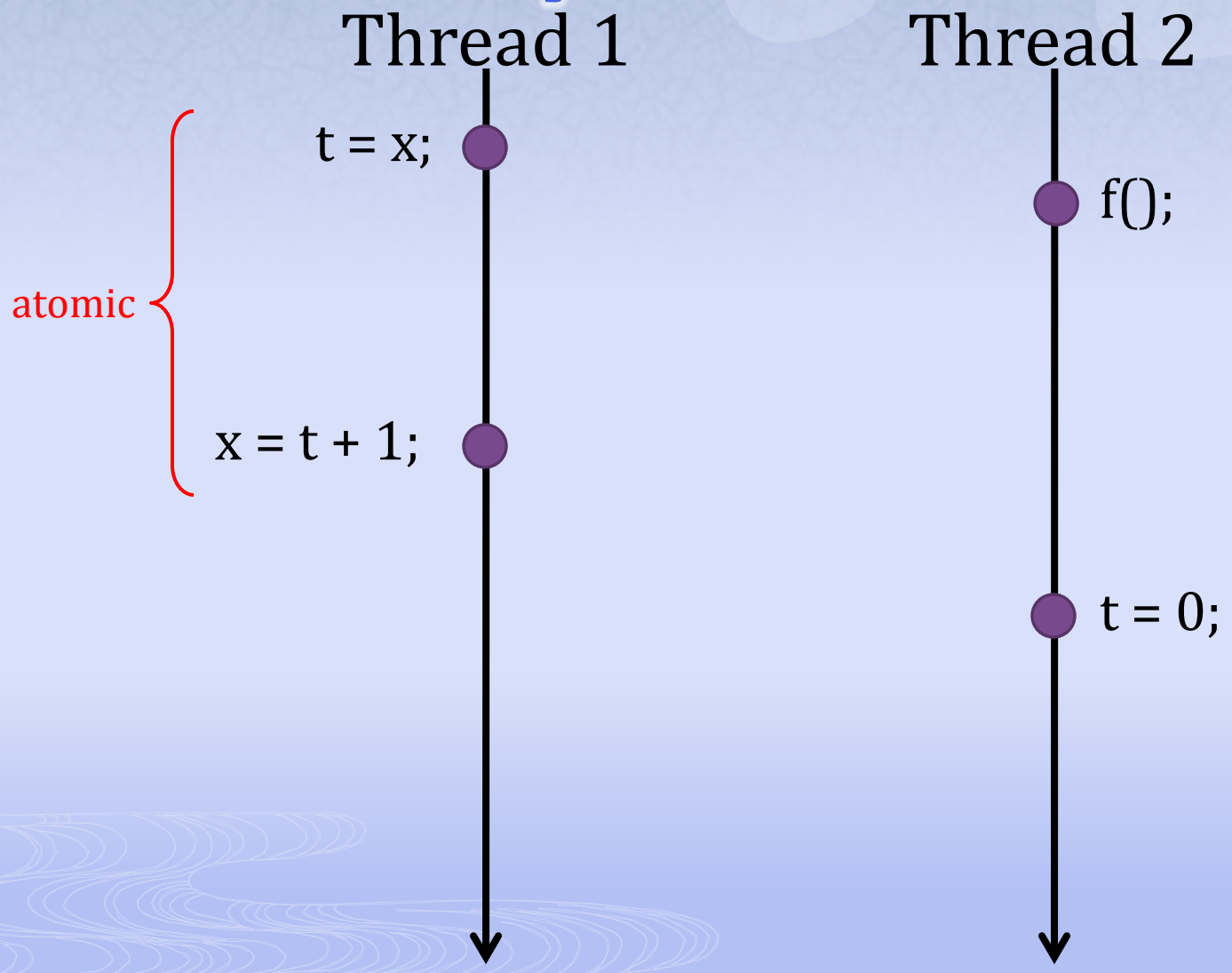

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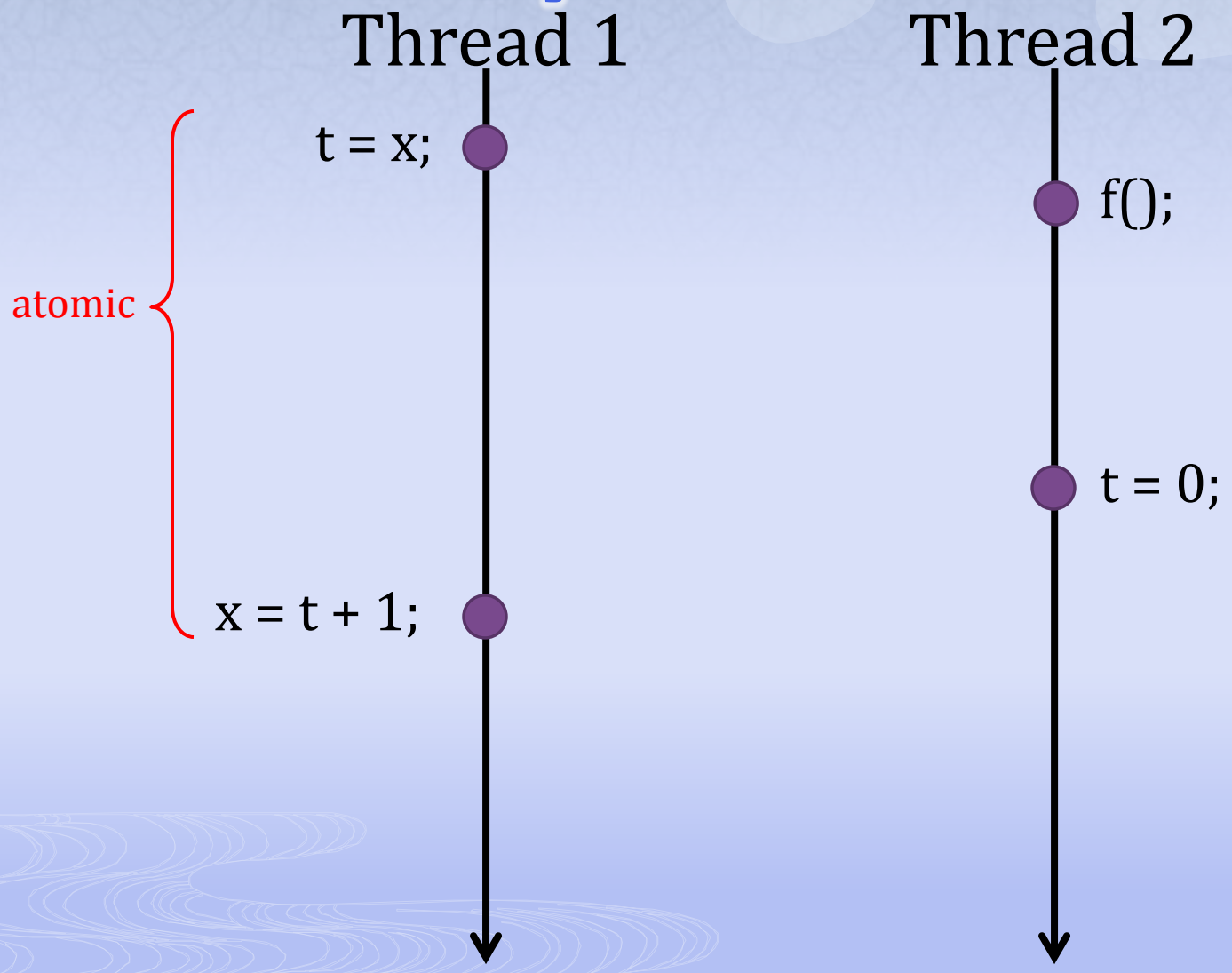

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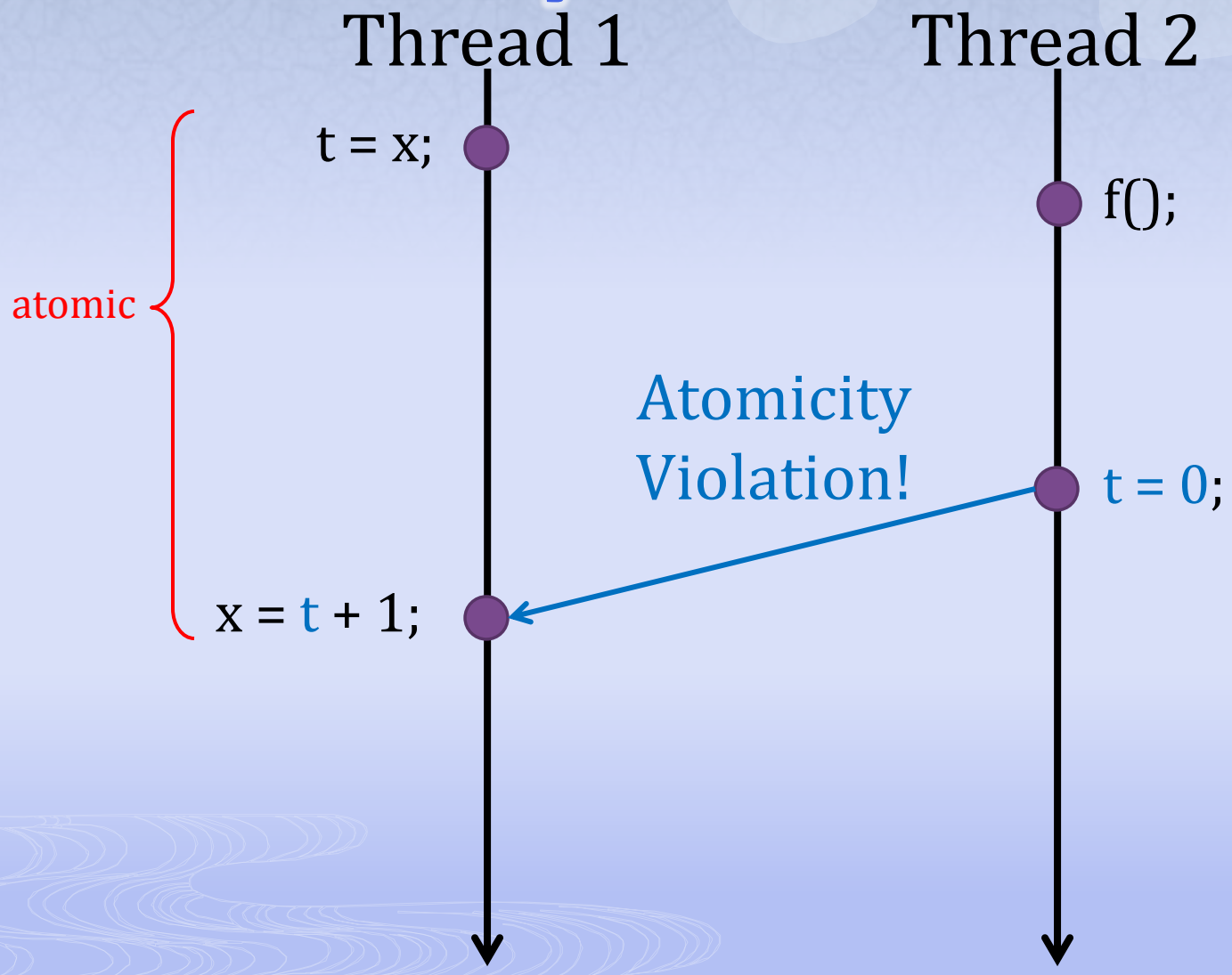

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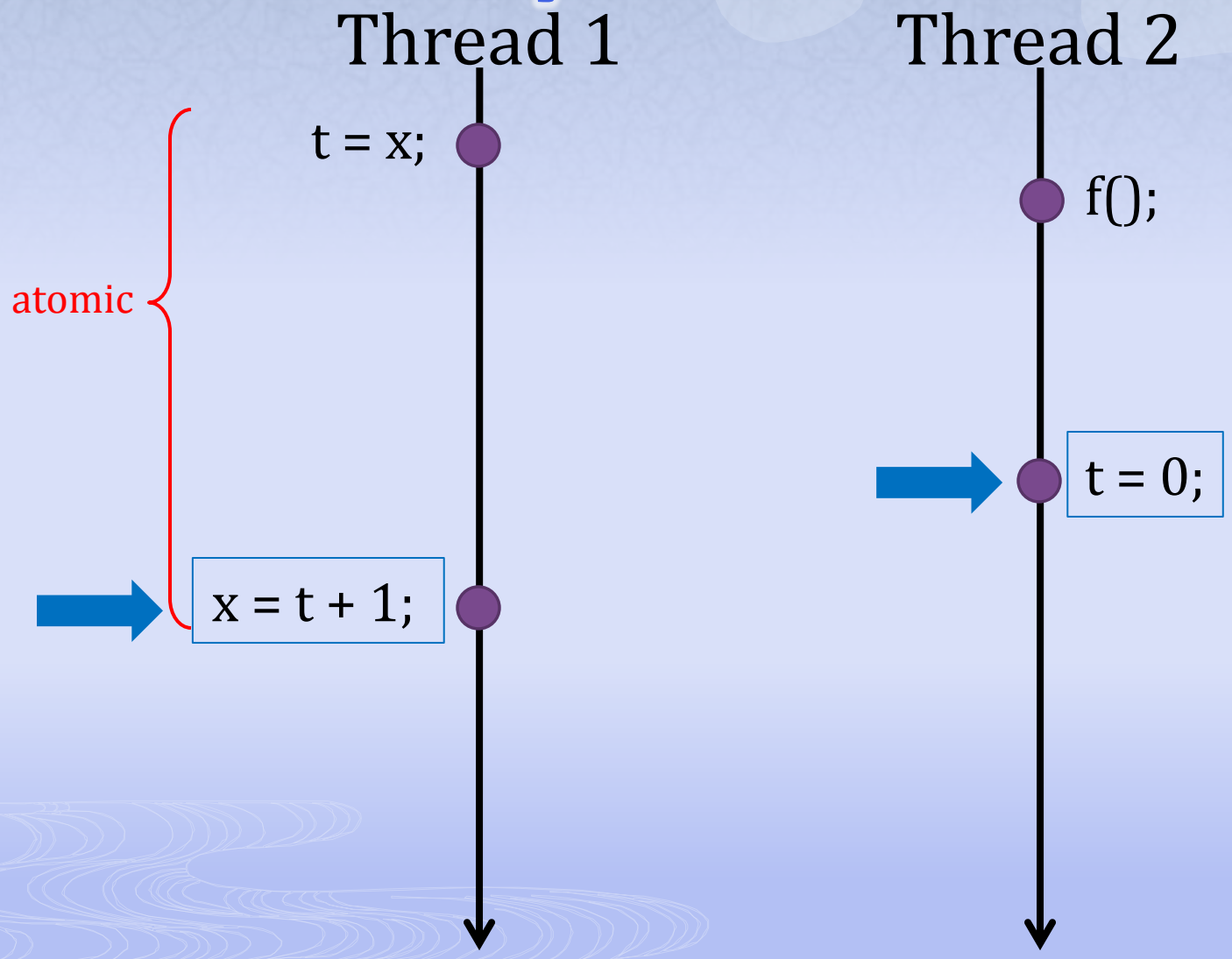

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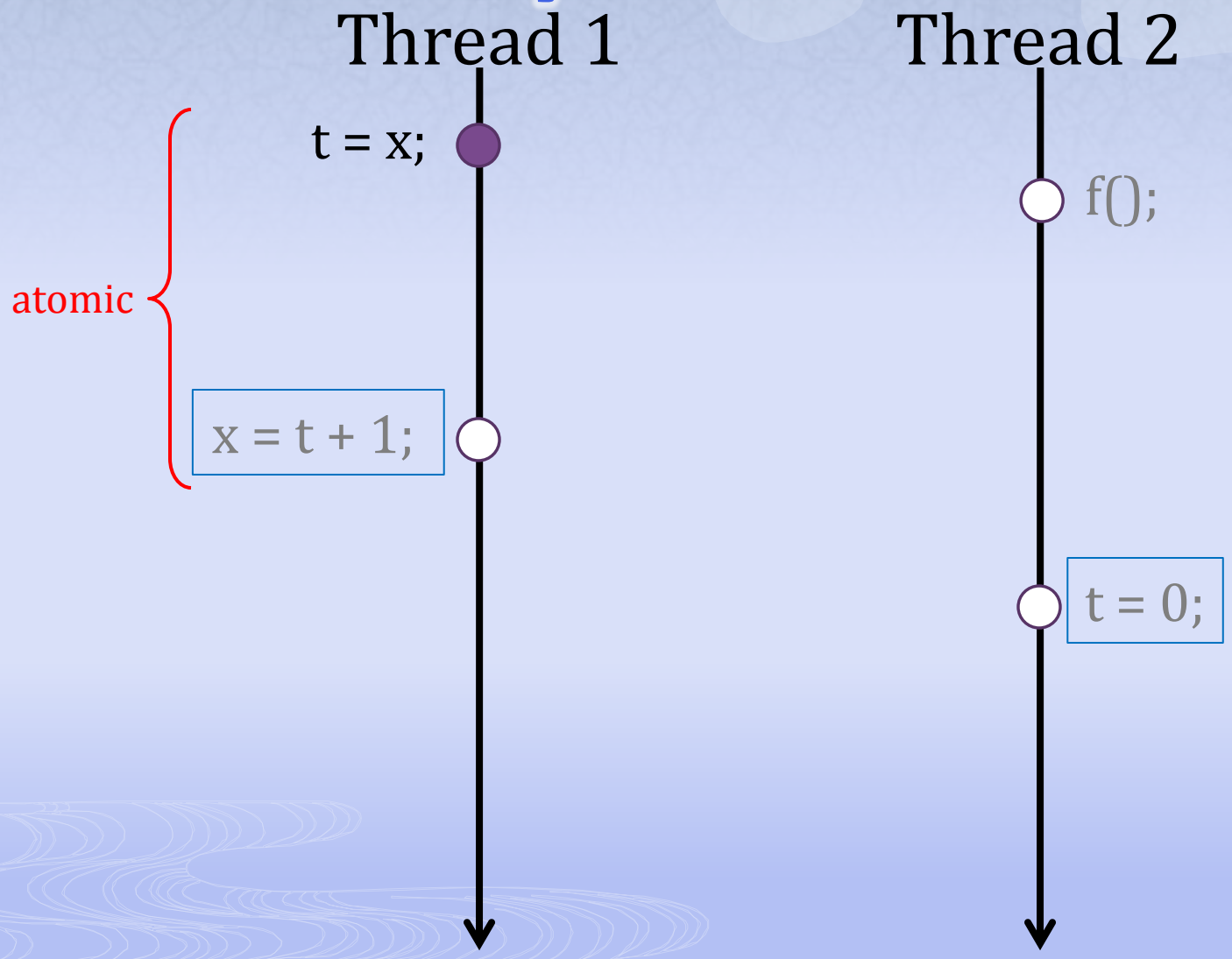

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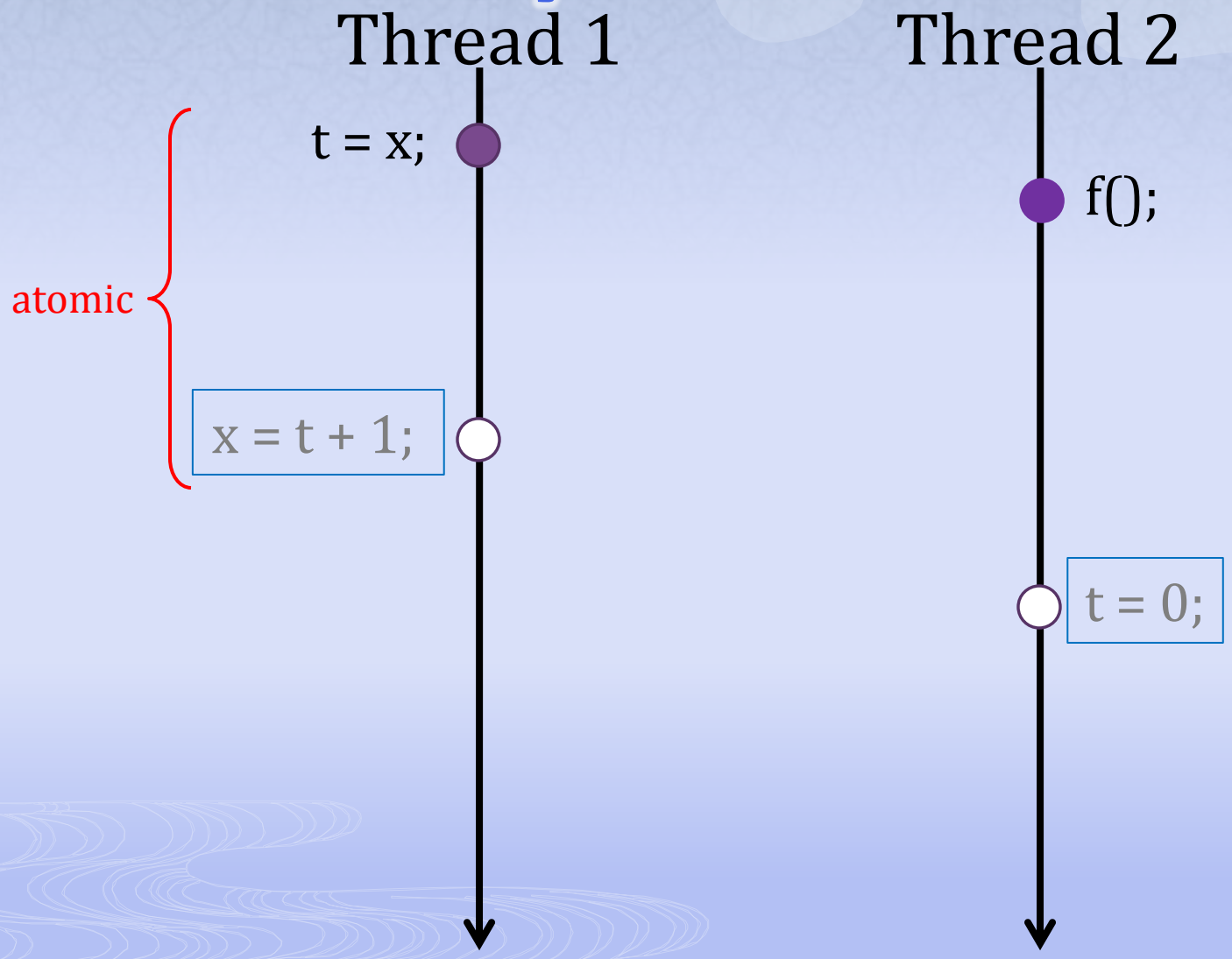

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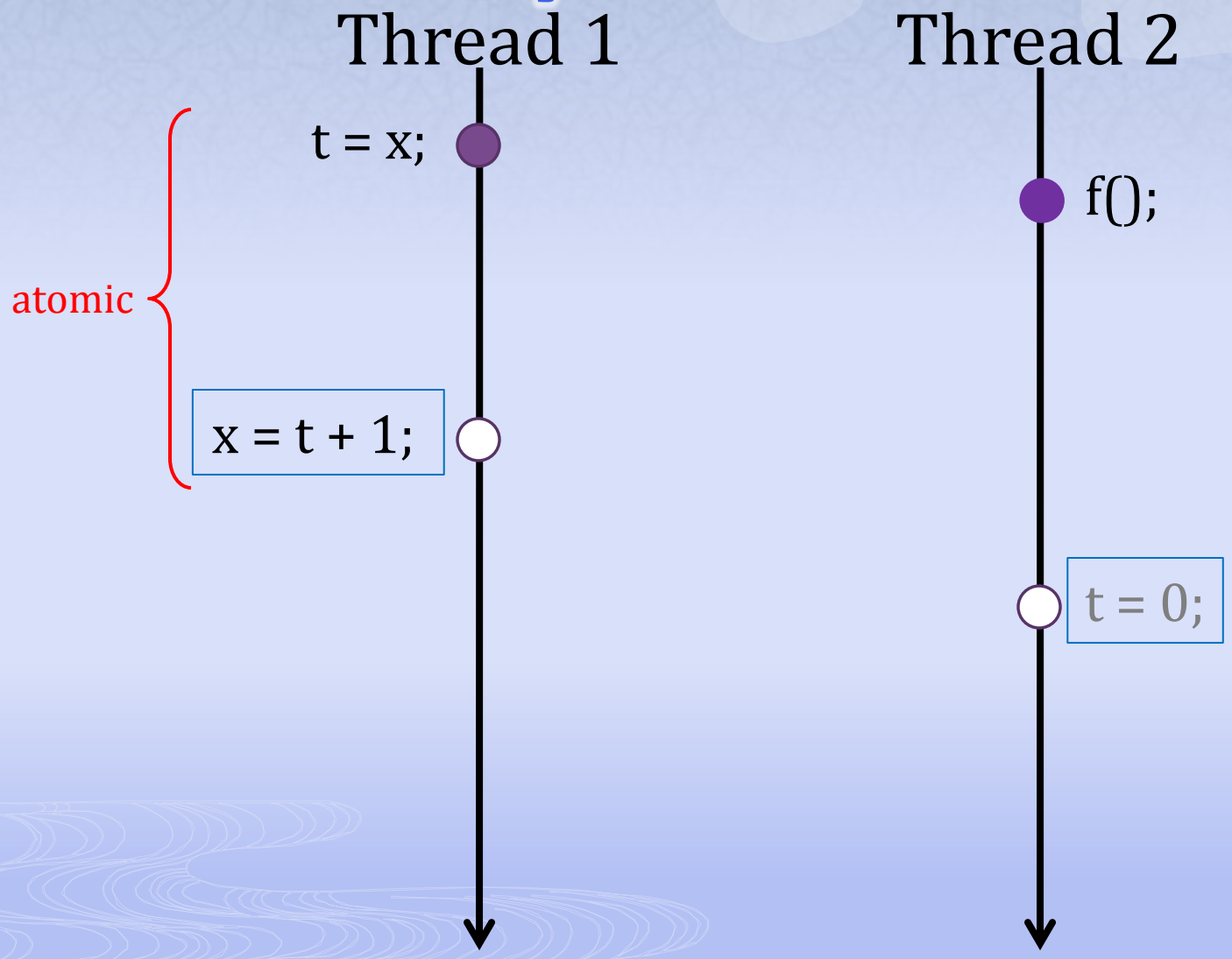

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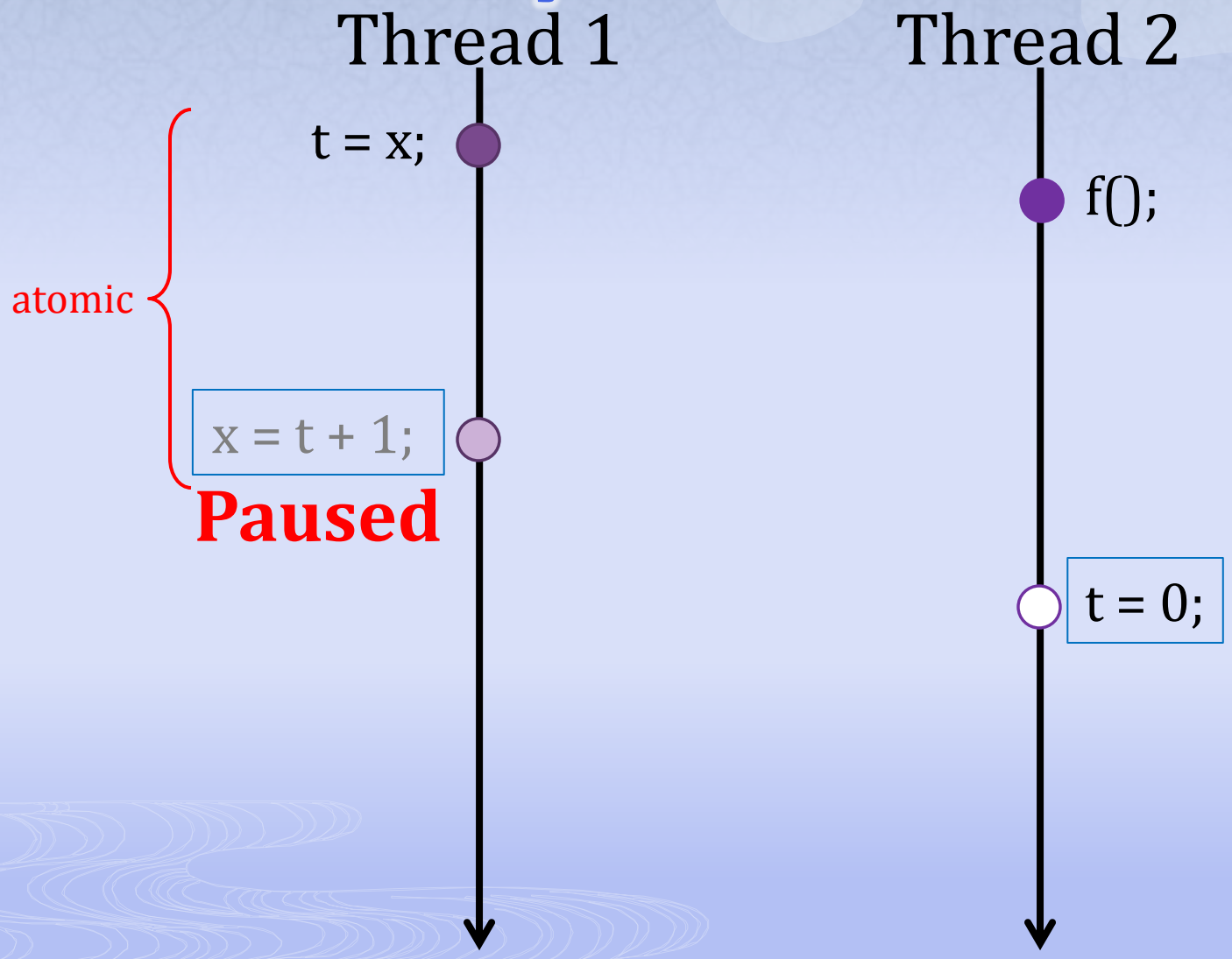

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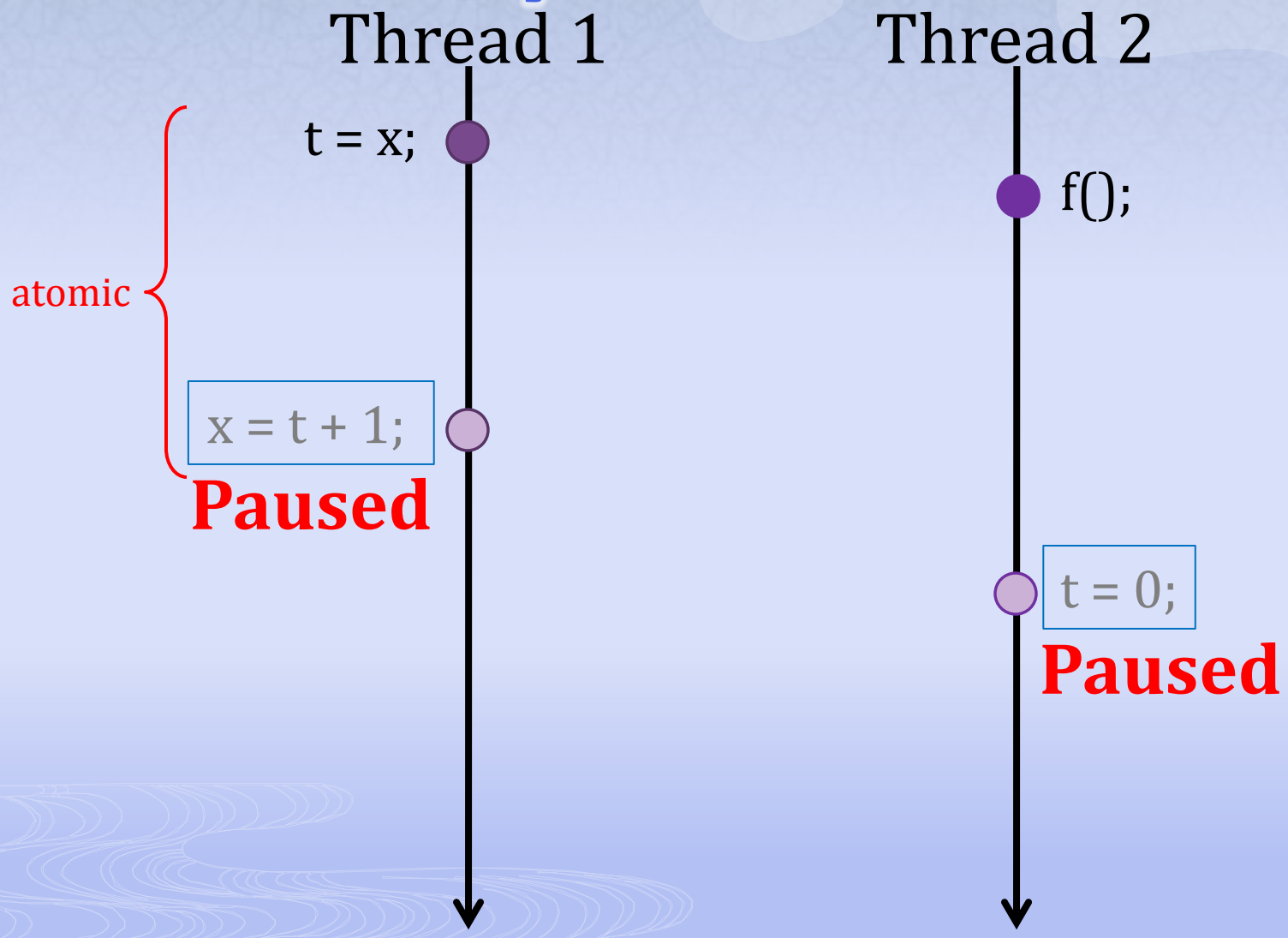

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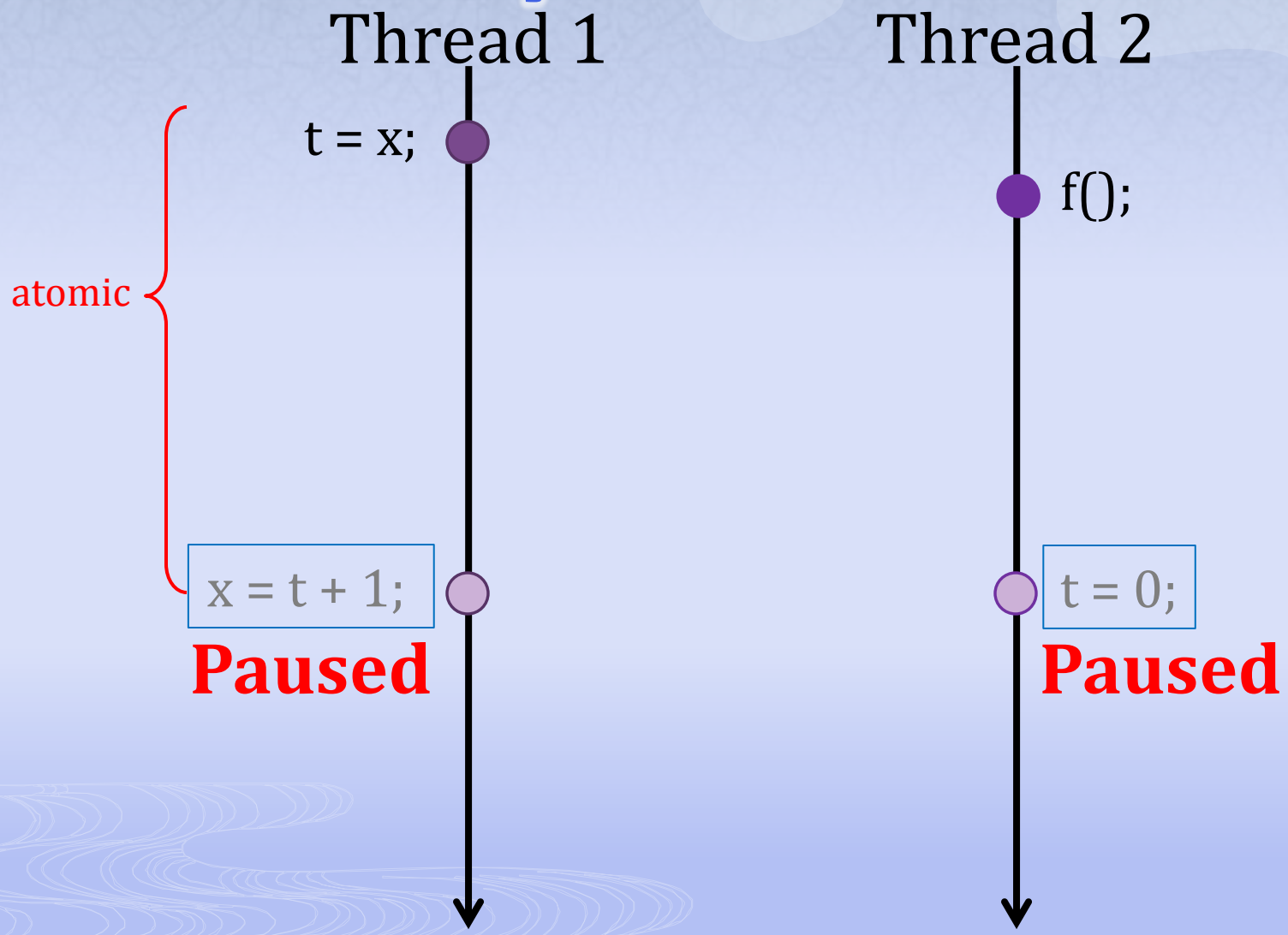

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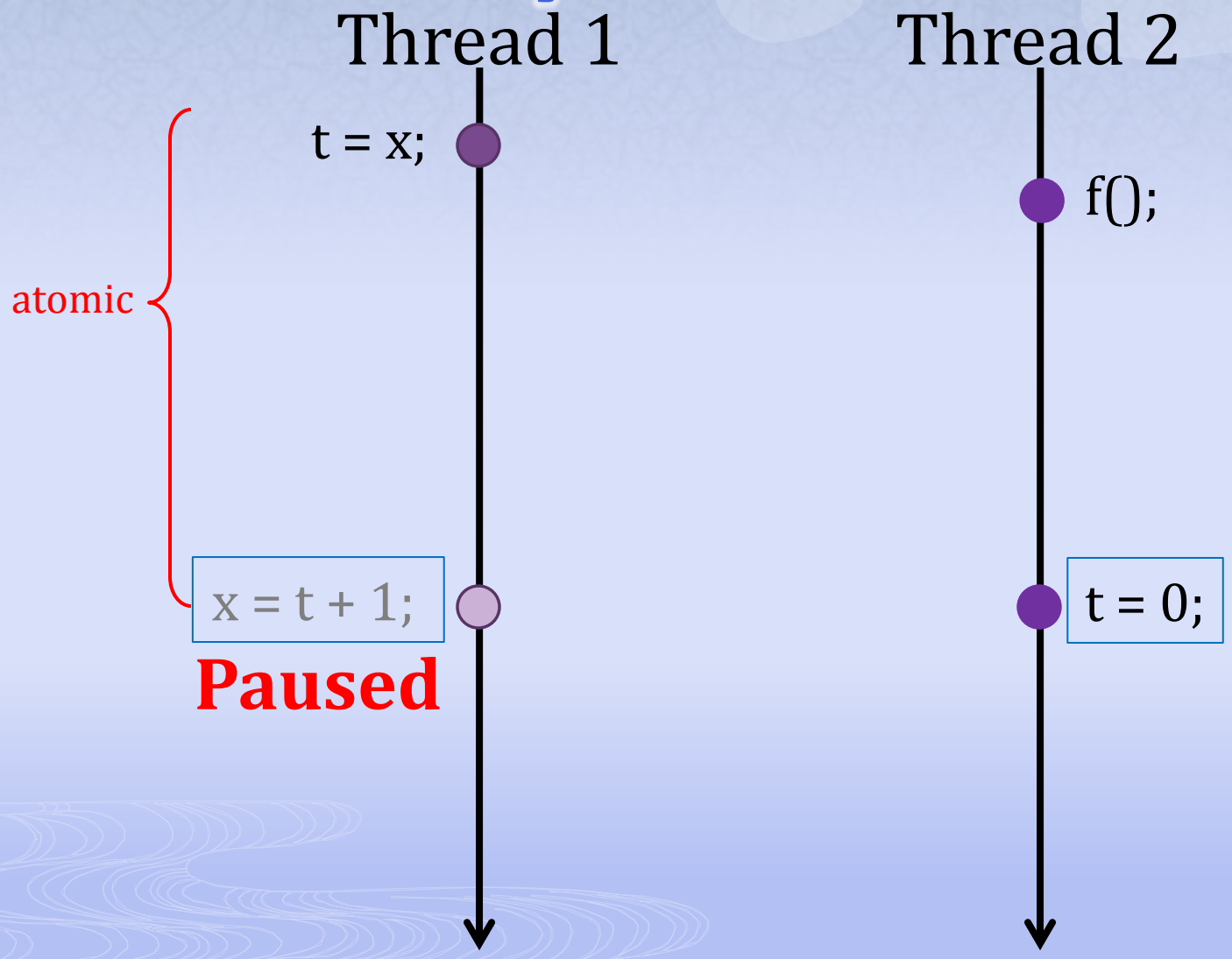

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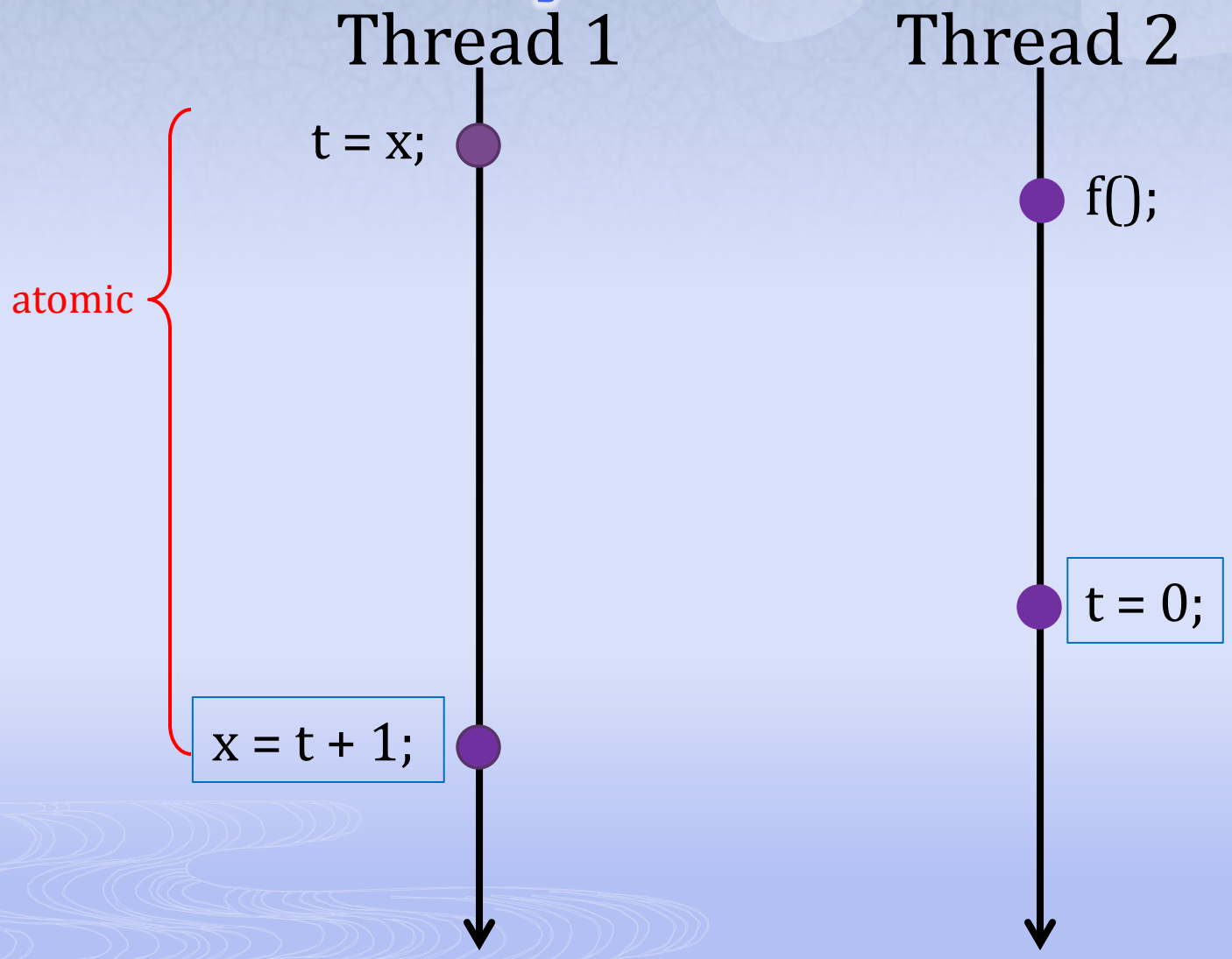

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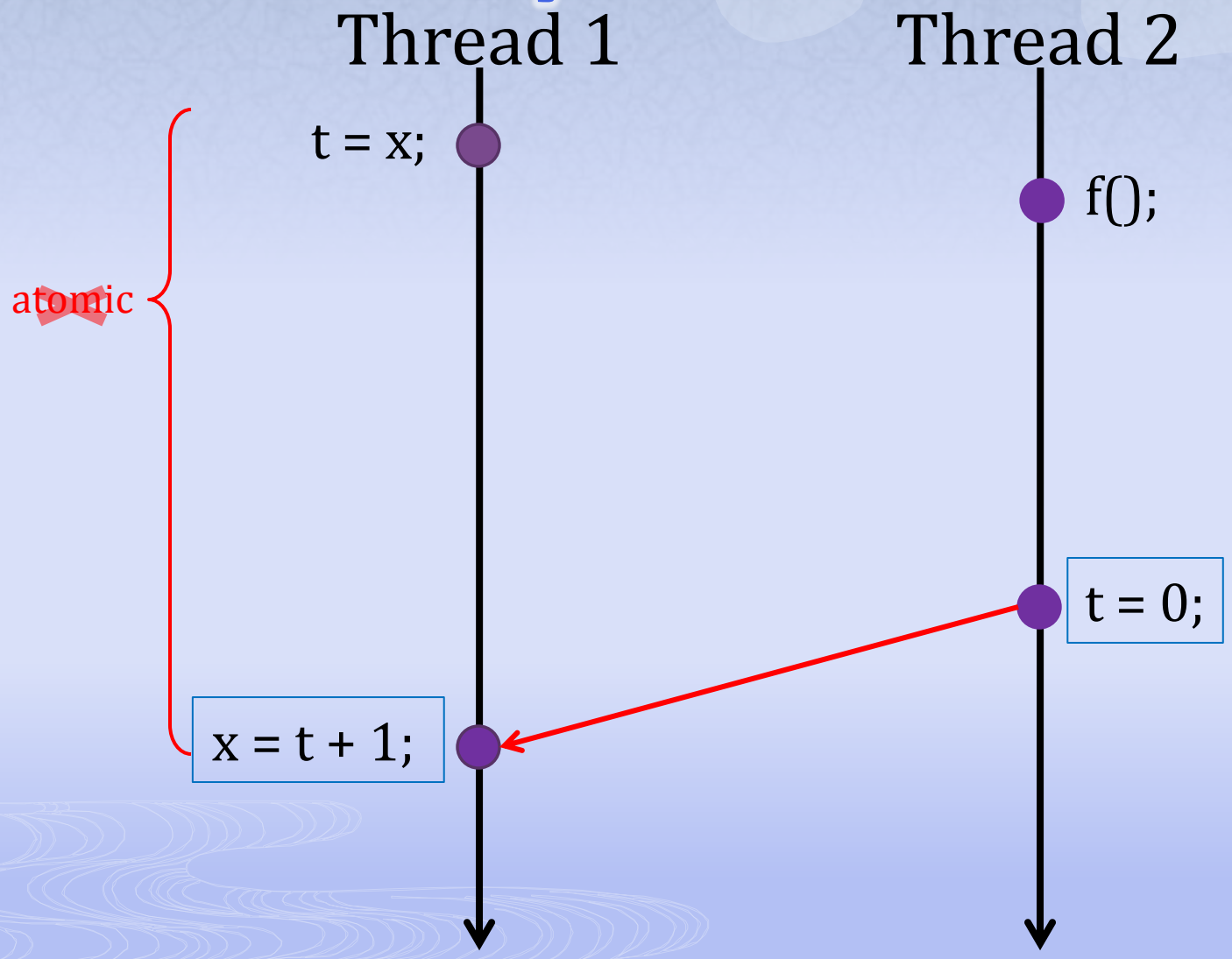

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Bugs Found

- Tool implemented for Java
- Races, deadlocks, atomicity violations in
  - Java Collections Framework
- Deadlocks found and reproduced in
  - Jigsaw web server
  - Java Swing GUI framework
  - Java Database Connectivity (JDBC)
- Atomicity violations in
  - Apache Commons Collections

Lessons Learned

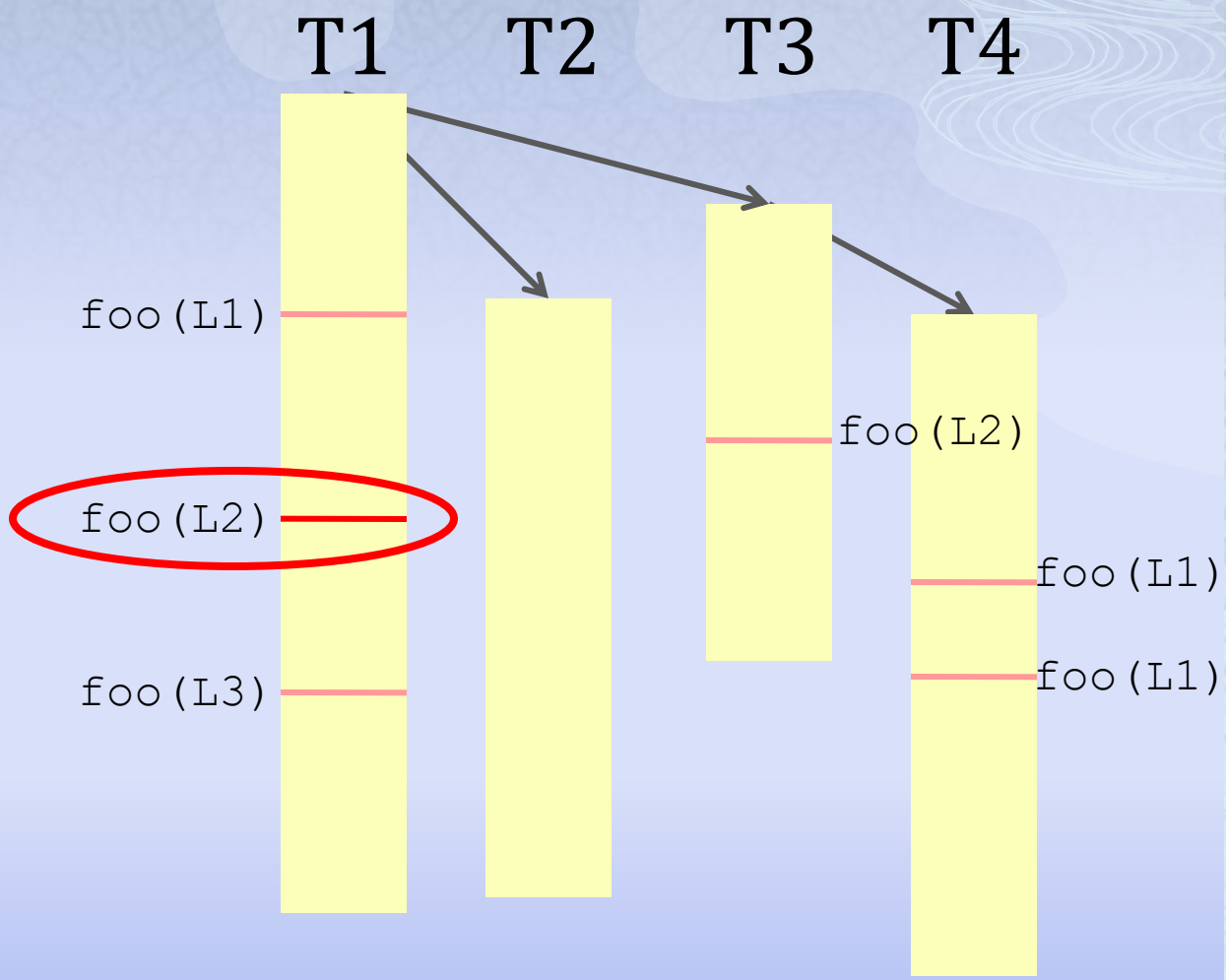
- Controlling scheduler makes testing effective
  - Focus on “potentially buggy schedules”
  - Reproduce bugs with high probability
- Need the right preemption points
  - Directed preemption uncovered many bugs
- Why not let the programmer choose the preemption points?
  - “Breakpoints” for concurrent programs
  - Language for describing schedules

Schedule Exploration Language

- Facility to specify thread schedules
  - User specifies “breakpoints”
    - Preempt a thread at a user specified state
  - User specifies ordering constraints on events
    - Control schedule to meet constraints
- Testing for logical (semantic) bugs
- Schedules are given as input to program
  - Either generated automatically (directed)
  - or programmer specified
  - Inputs to unit tests but on schedules

Example Usage

```
 foo(L) {
1: lock(L)
2: f()
3: unlock(L)
4: ...
5: lock(L)
6: g()
7: unlock(L)
 }
```



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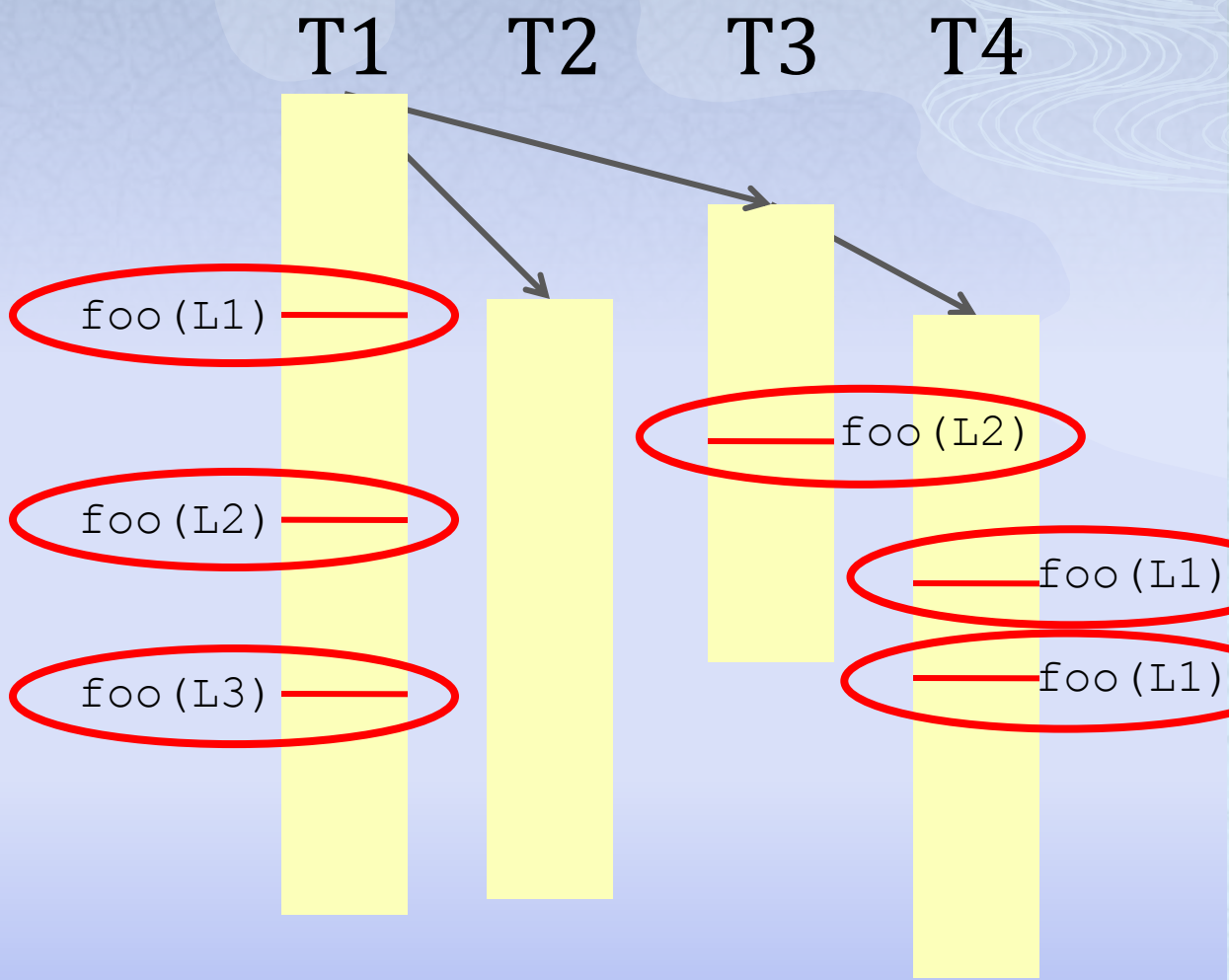

break 5

Example Usage

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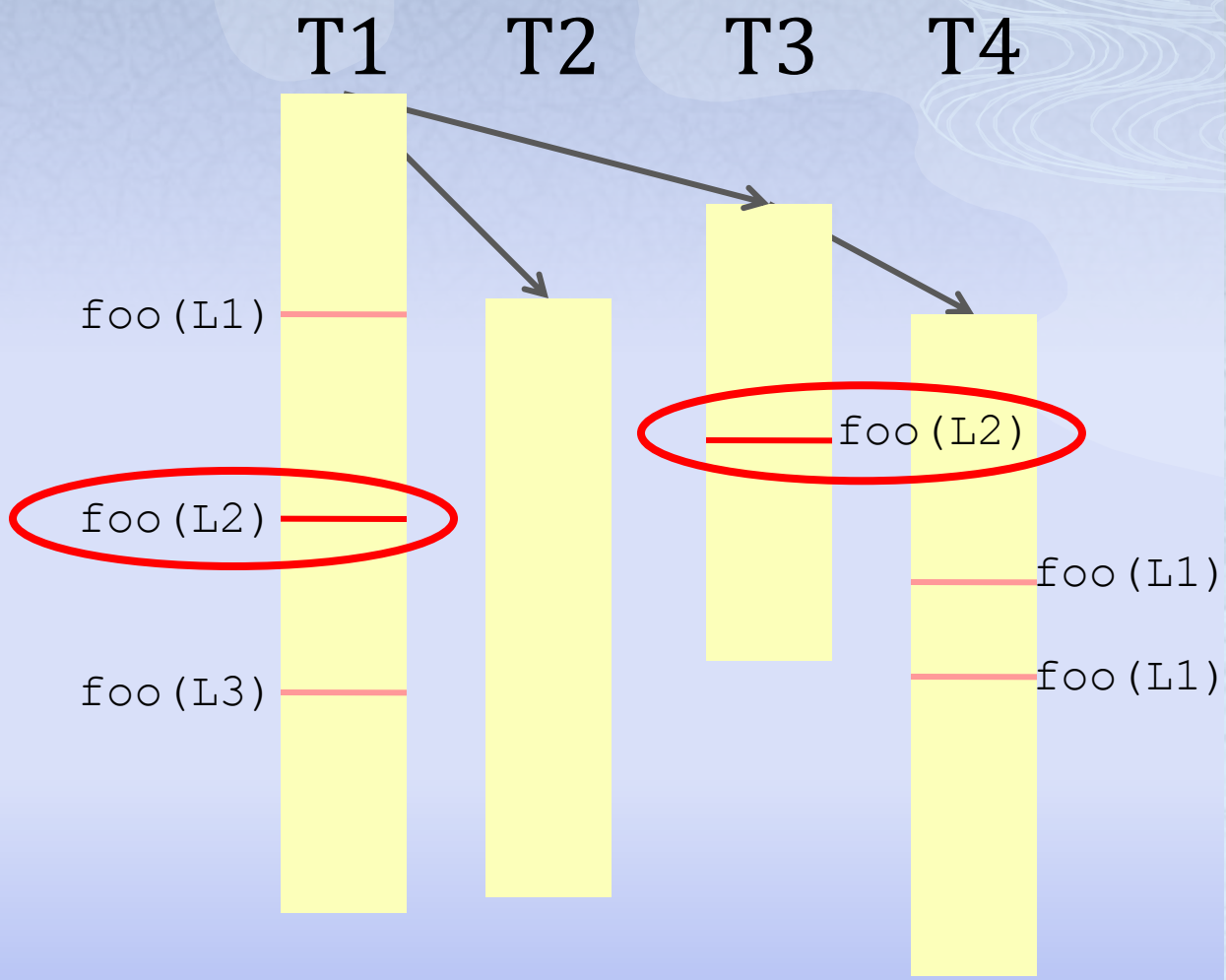

break `lock(L2)`

Example Usage

```
 foo(L) {
1: lock(L)
2: f()
3: unlock(L)
4: ...
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6: g()
7: unlock(L)
 }
```

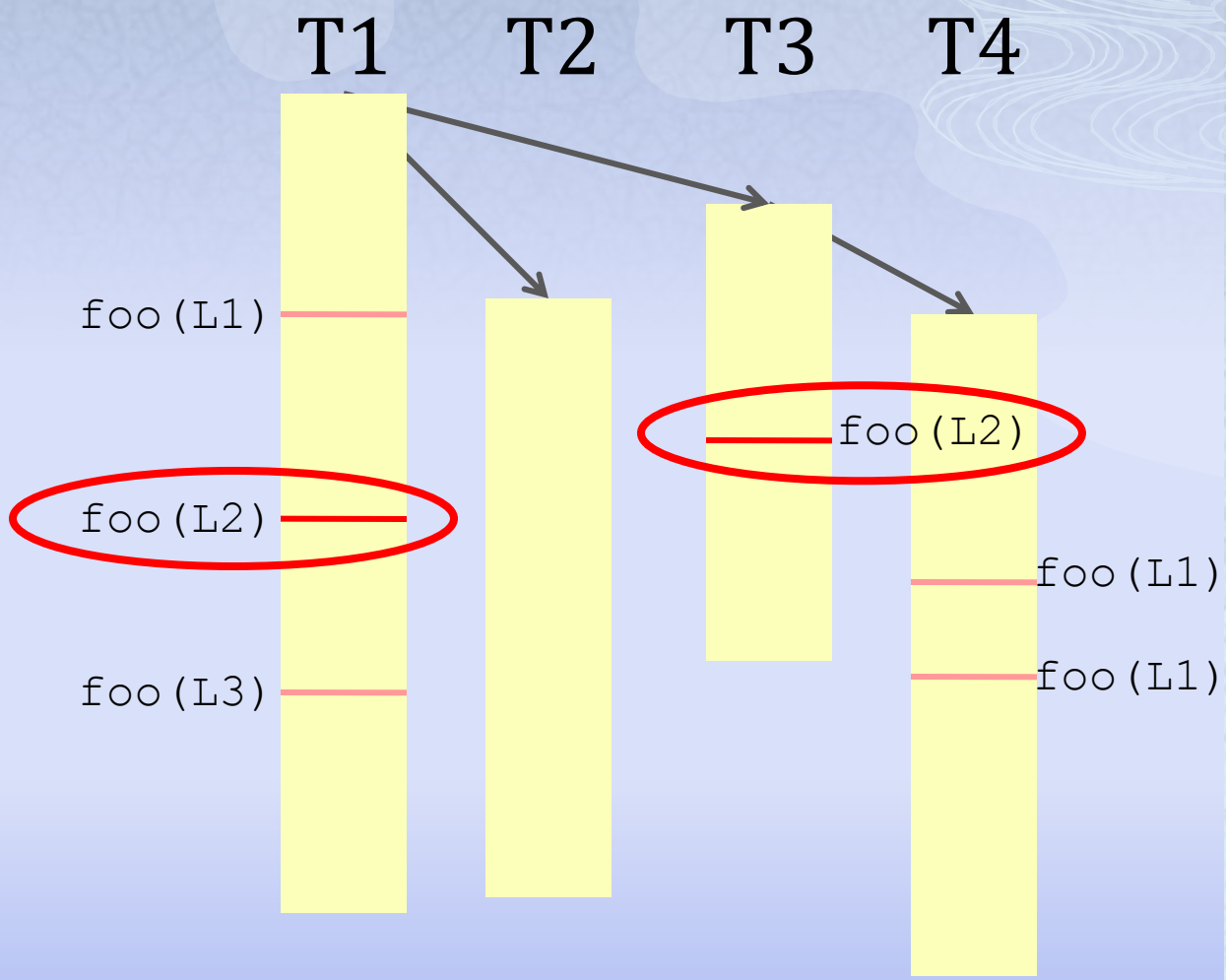

break `lock(L2),5`

Example Usage

```
 foo(L) {
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3: unlock(L)
4: ...
5: lock(L)
6: g()
7: unlock(L)
 }
```
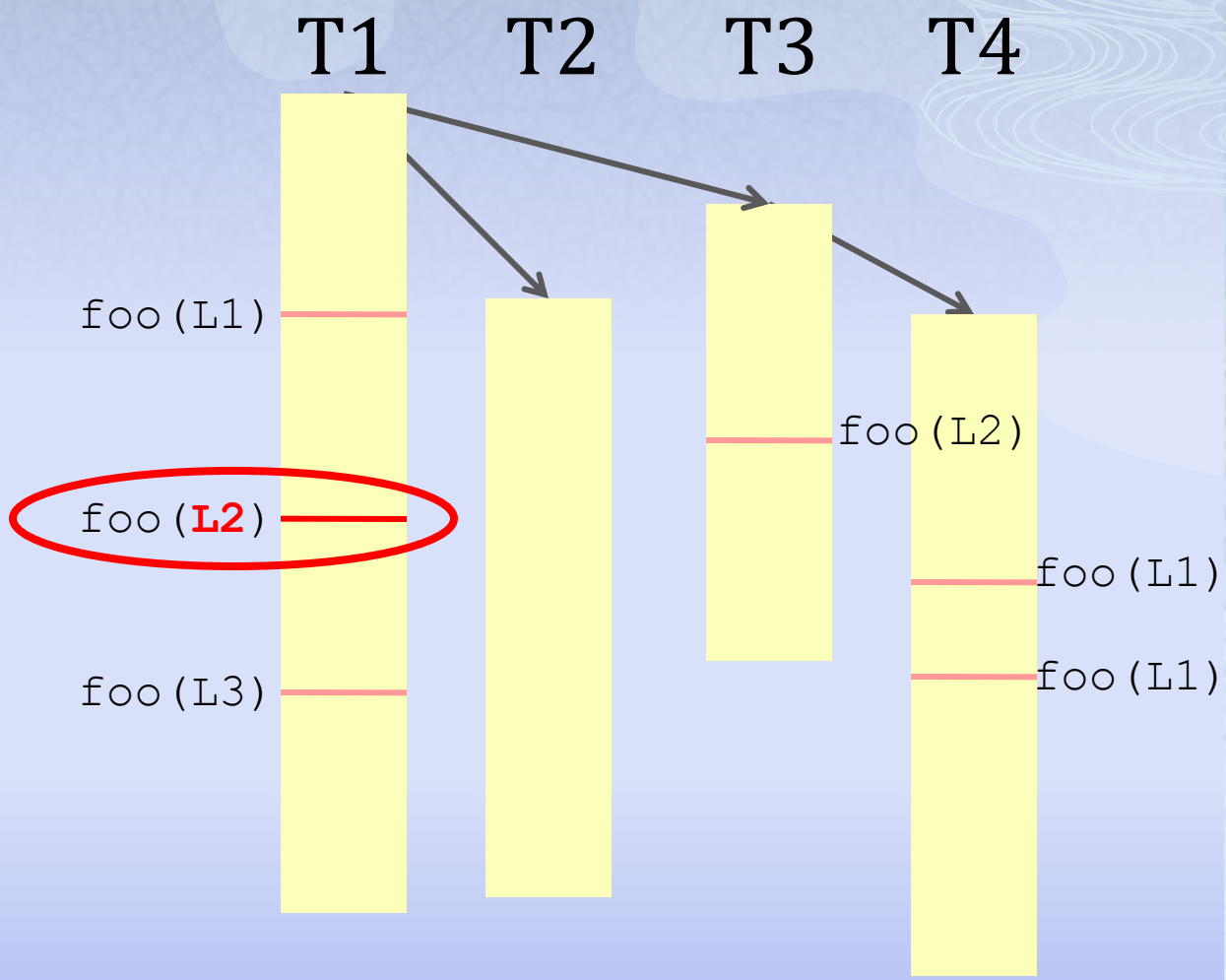



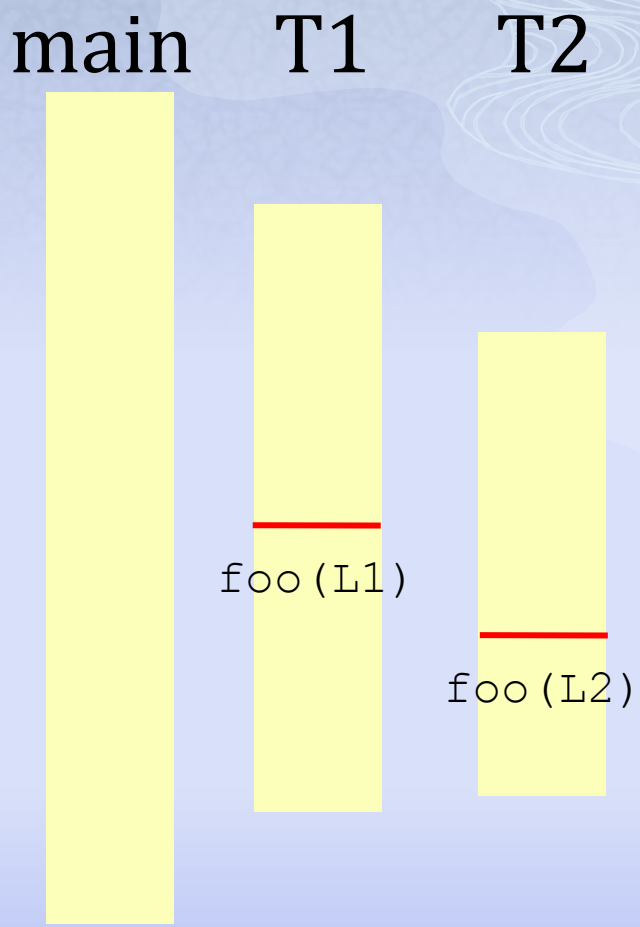
break `lock(L2), 5, T1`

Abstraction: Naming Runtime Objects

- Threads and locks are runtime objects
  - Address changes across runs
  - Need to identify consistently with only static information
- An abstraction based on object creation site
  - Line number (PC) of where object allocated

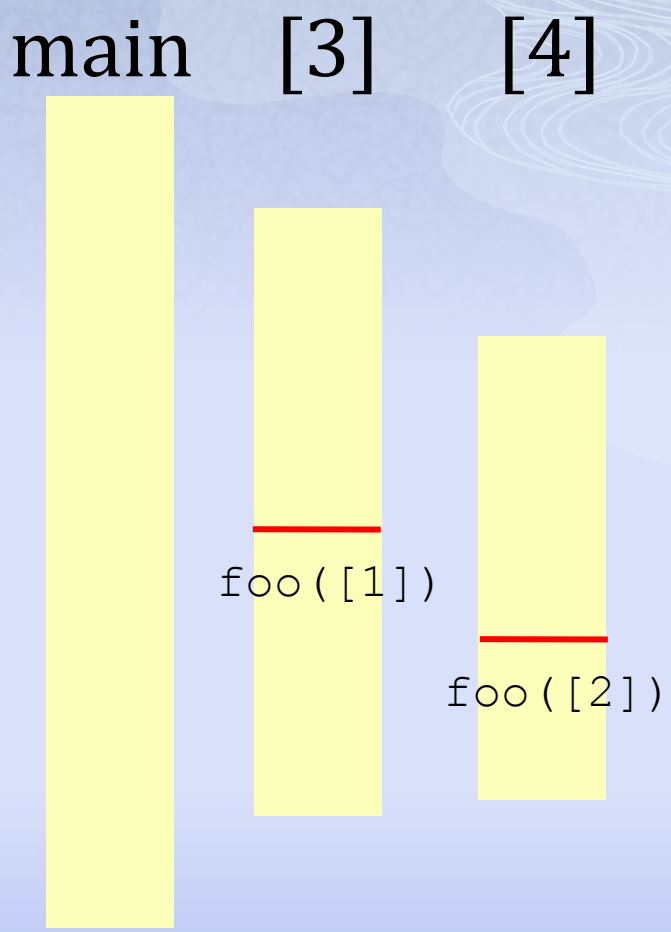
Abstraction Example

```
 main {
1: Lock L1 = new Lock();
2: Lock L2 = new Lock();
3: Thread T1 =
        new MyThread(L1);
4: Thread T2 =
        new MyThread(L2);
5: ...
 }
 MyThread(L) {
6: foo(L);
 }
```



Abstraction Example

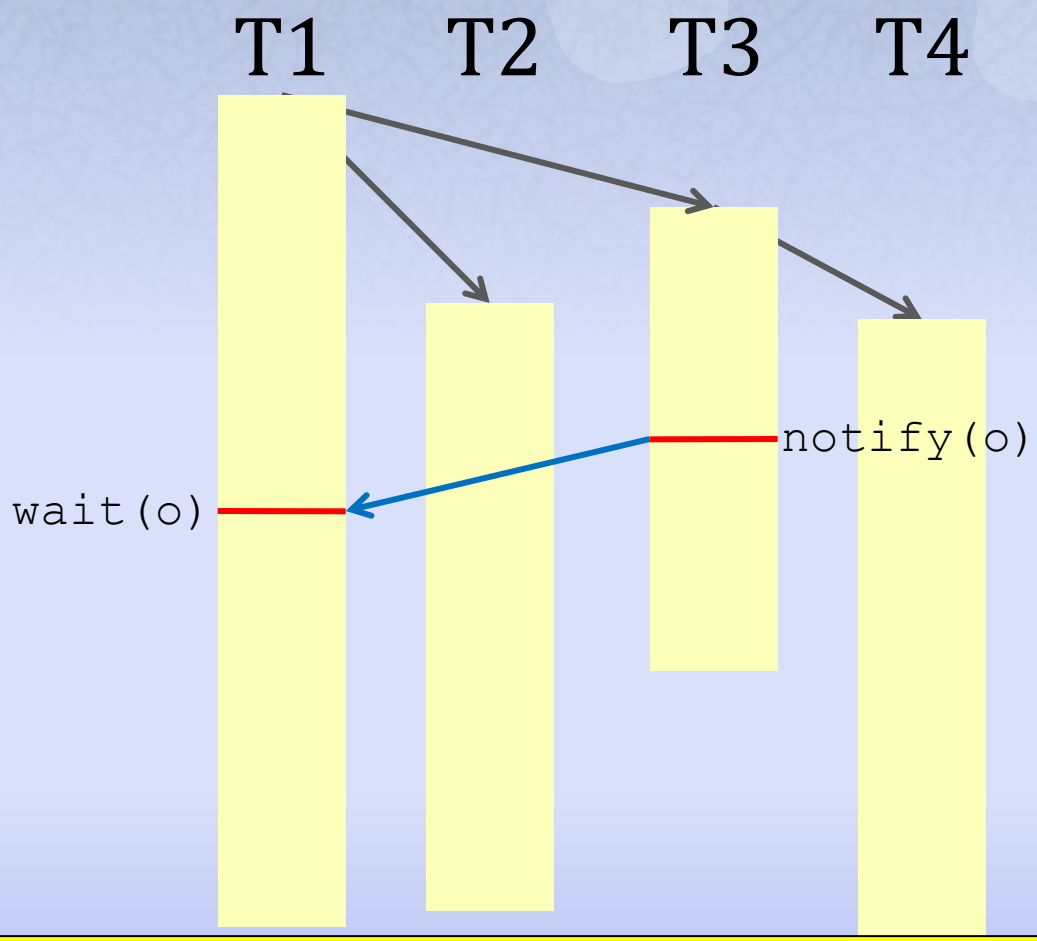
```
 main {
1: Lock L1 = new Lock();
2: Lock L2 = new Lock();
3: Thread T1 =
        new MyThread(L1);
4: Thread T2 =
        new MyThread(L2);
5: ...
 }
 MyThread(L) {
6: foo(L);
 }
```



Abstraction: Naming Runtime Objects

- Threads and locks are runtime objects
  - Address changes across runs
  - Need to name consistently and statically
- Abstraction based on object creation site
  - Line number (PC) of where object allocated
- Use and combine richer abstractions for increased separation
  - Objects created in loops
  - Objects created in different contexts

Another Example Usage



before (`notify(abs(o)),abs(T3)->`
`wait(abs(o)), abs(T1)`)

Conclusion

- Practical and efficient testing of concurrent programs
- Find and reproduce bugs to lessen burden of manual inspection
- “Input language” for user specified schedules

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