

COMP 322: Fundamentals of Parallel Programming

Lecture 29: Linearizability

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Linearizability: Correctness of Concurrent Objects

- A *concurrent object* is an *object* that can correctly handle *methods* invoked *concurrently* by different tasks or threads
 - e.g., `AtomicInteger`, `ConcurrentHashMap`, `ConcurrentLinkedQueue`, ...
- For the discussion of linearizability, we will assume that the body of each method in a concurrent object is itself sequential
 - Assume that methods do not create threads or async tasks

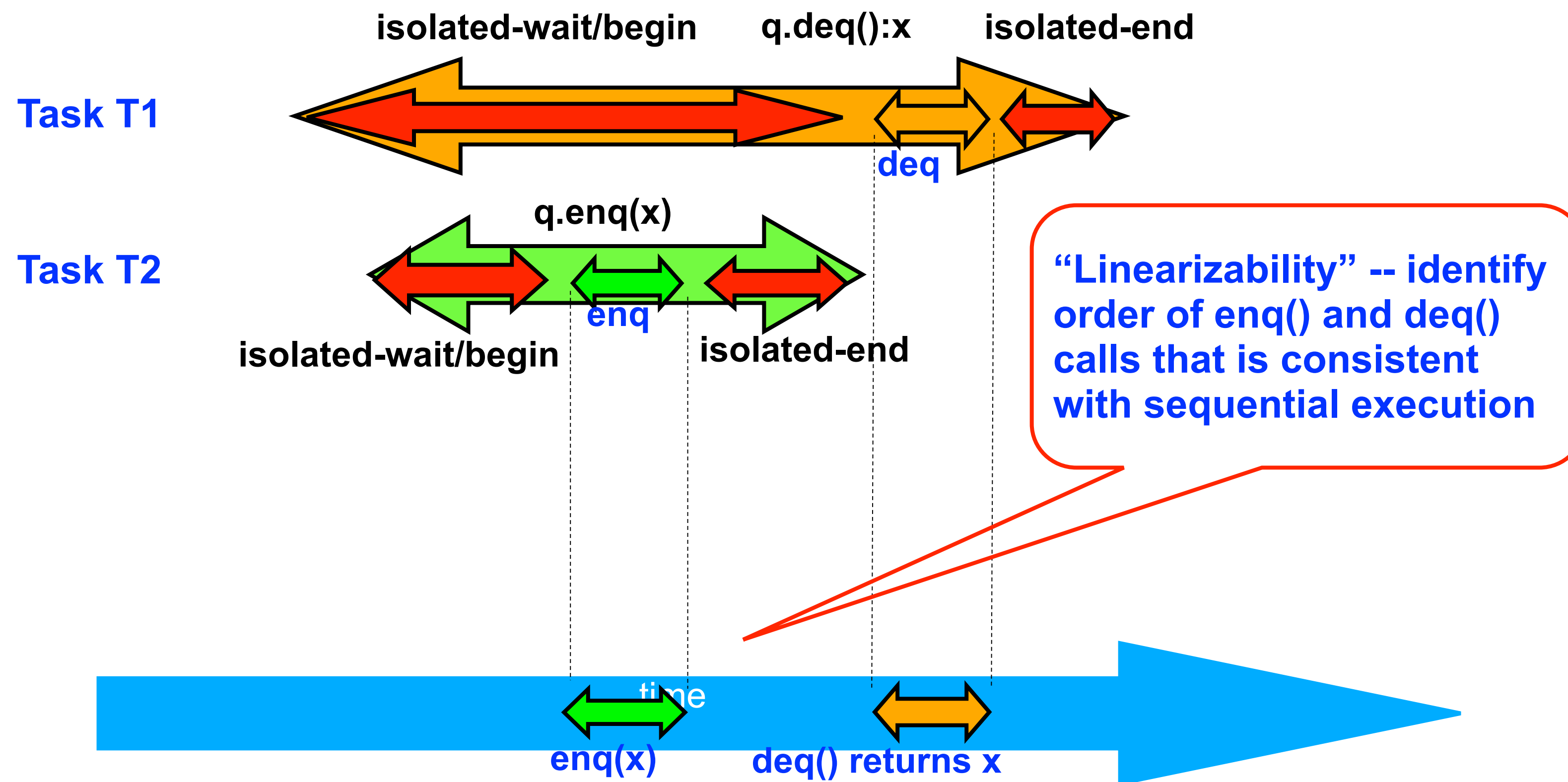


Linearizability: Correctness of Concurrent Objects

- Consider a simple FIFO (First In, First Out) queue as a canonical example of a concurrent object
 - Method `q.enq(o)` inserts object `o` at the tail of the queue
 - Assume that there is unbounded space available for all `enq()` operations to succeed
 - Method `q.deq()` removes and returns the item at the head of the queue.
 - Throws `EmptyException` if the queue is empty.
- Without seeing the implementation of the FIFO queue, we can tell if an execution of calls to `enq()` and `deq()` is correct or not, in a sequential program
- *How can we tell if the execution is correct for a parallel program?*



Linearization: Identifying a sequential order of concurrent method calls



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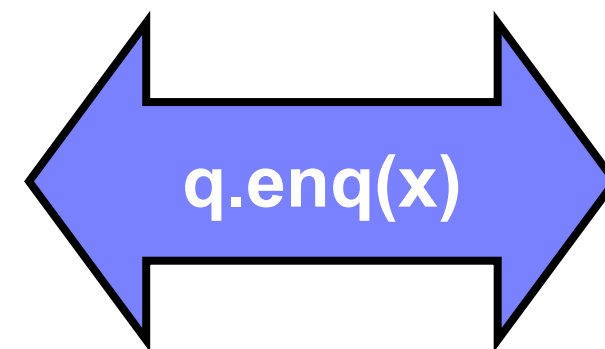
Informal Definition of Linearizability

- Assume that each method call takes effect “instantaneously” at some point in time between its invocation and return.
- An *execution (schedule)* is *linearizable* if we can choose *one set of* instantaneous points that is consistent with a sequential execution in which methods are executed at those points
 - It’s okay if some other set of instantaneous points is not linearizable
- A *concurrent object* is *linearizable* if all its executions are linearizable
 - Linearizability is a “black box” test based on the object’s behavior, not its internals



Example 1

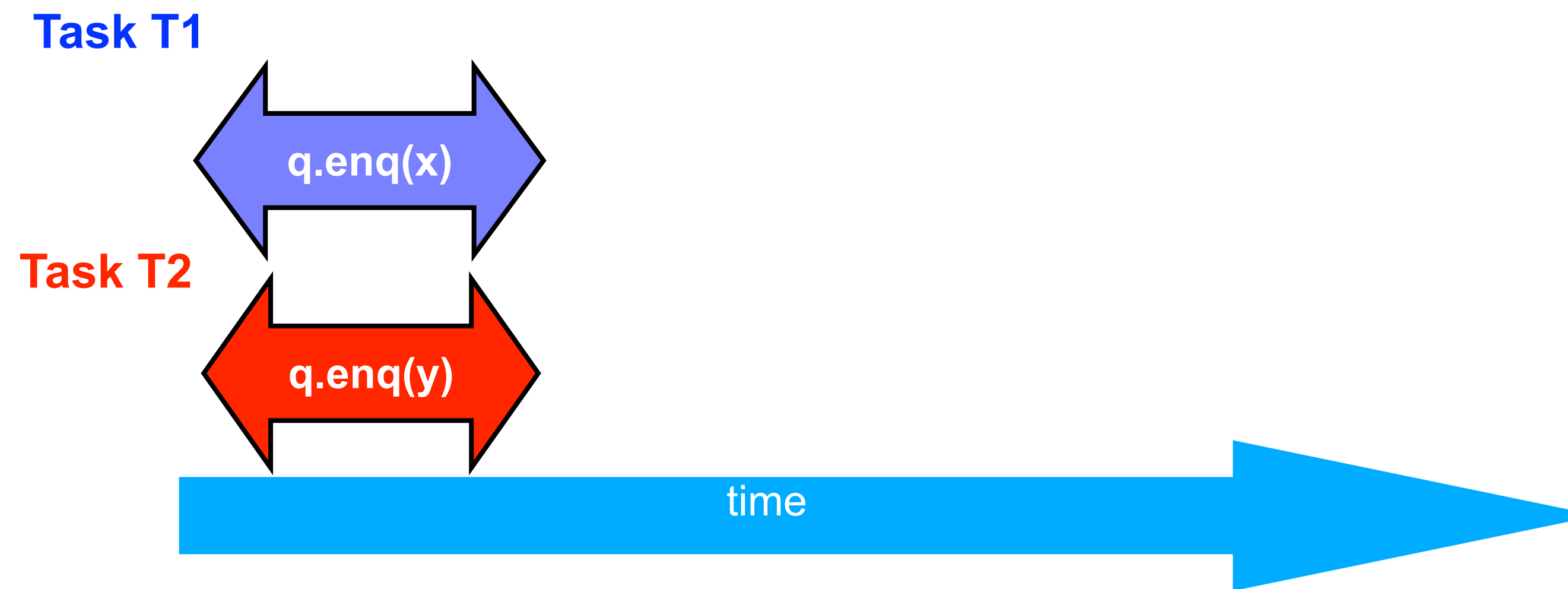
Task T1



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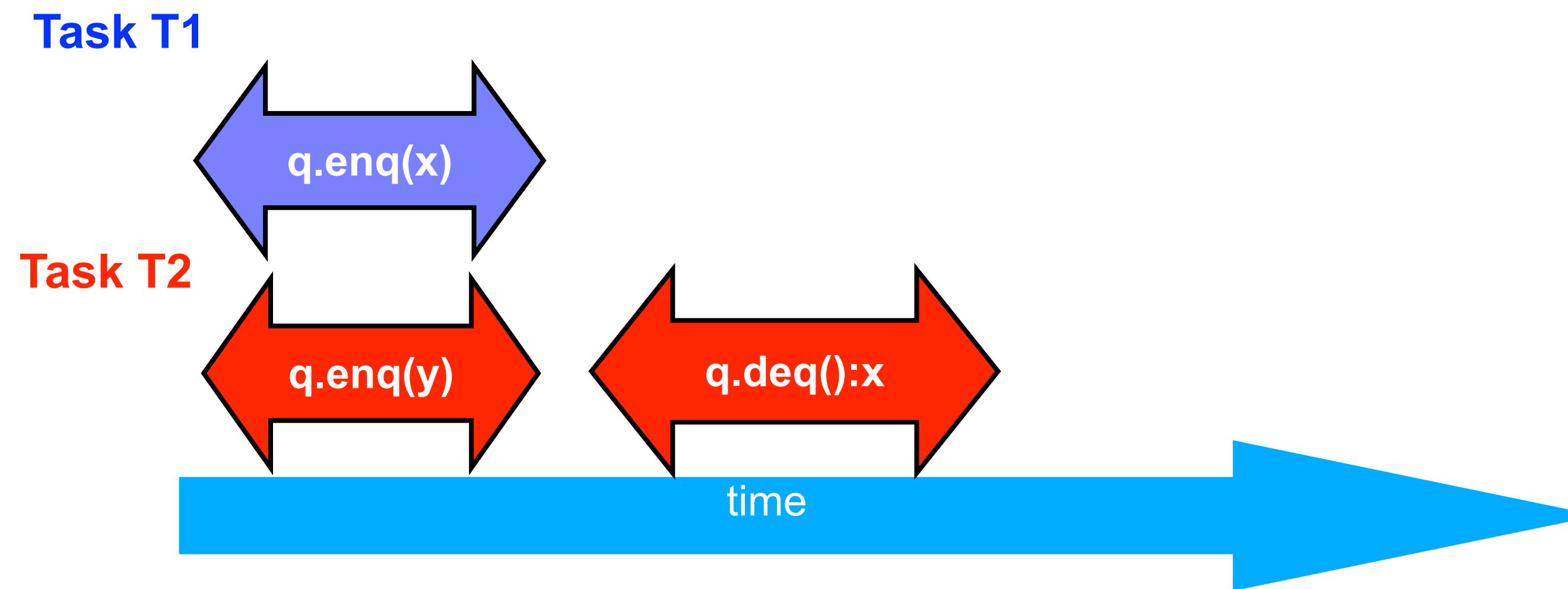
Example 1 cont.



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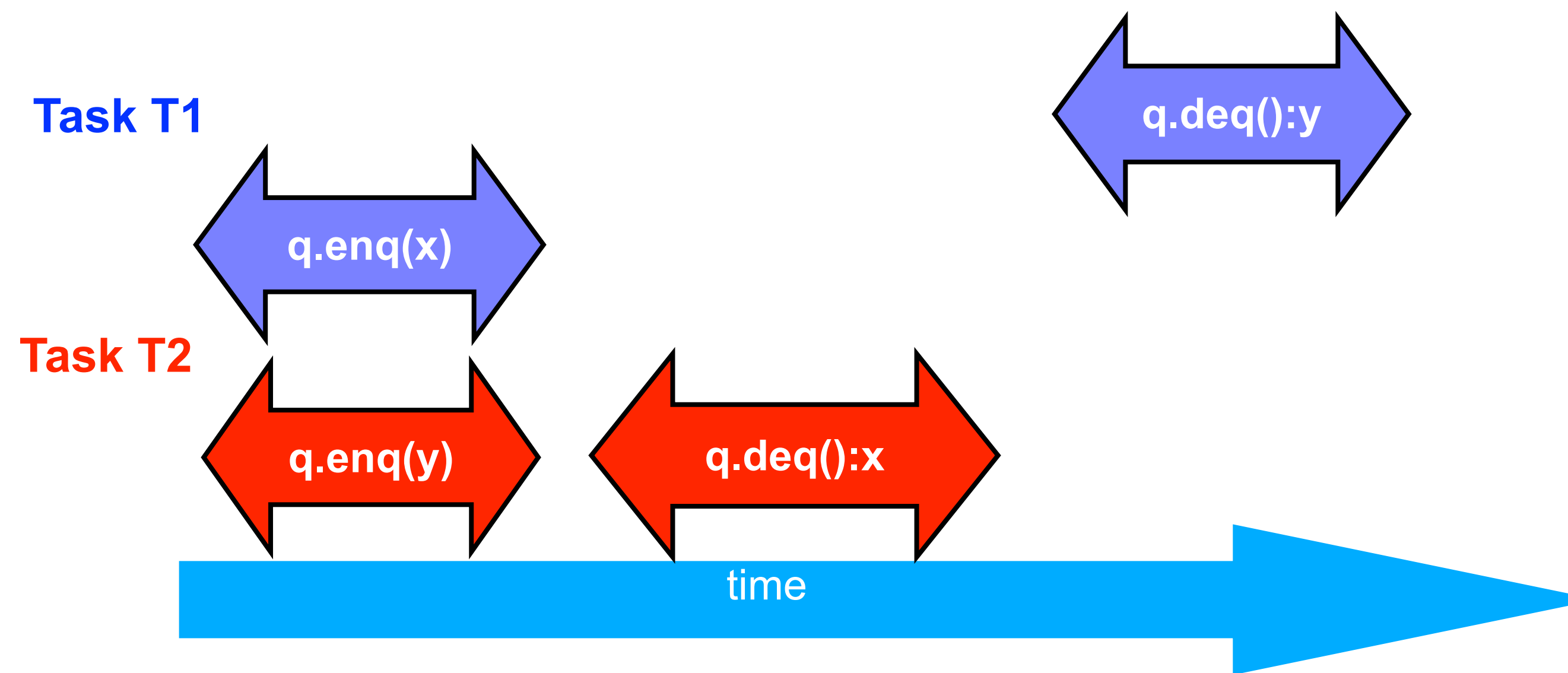
Example 1 cont.



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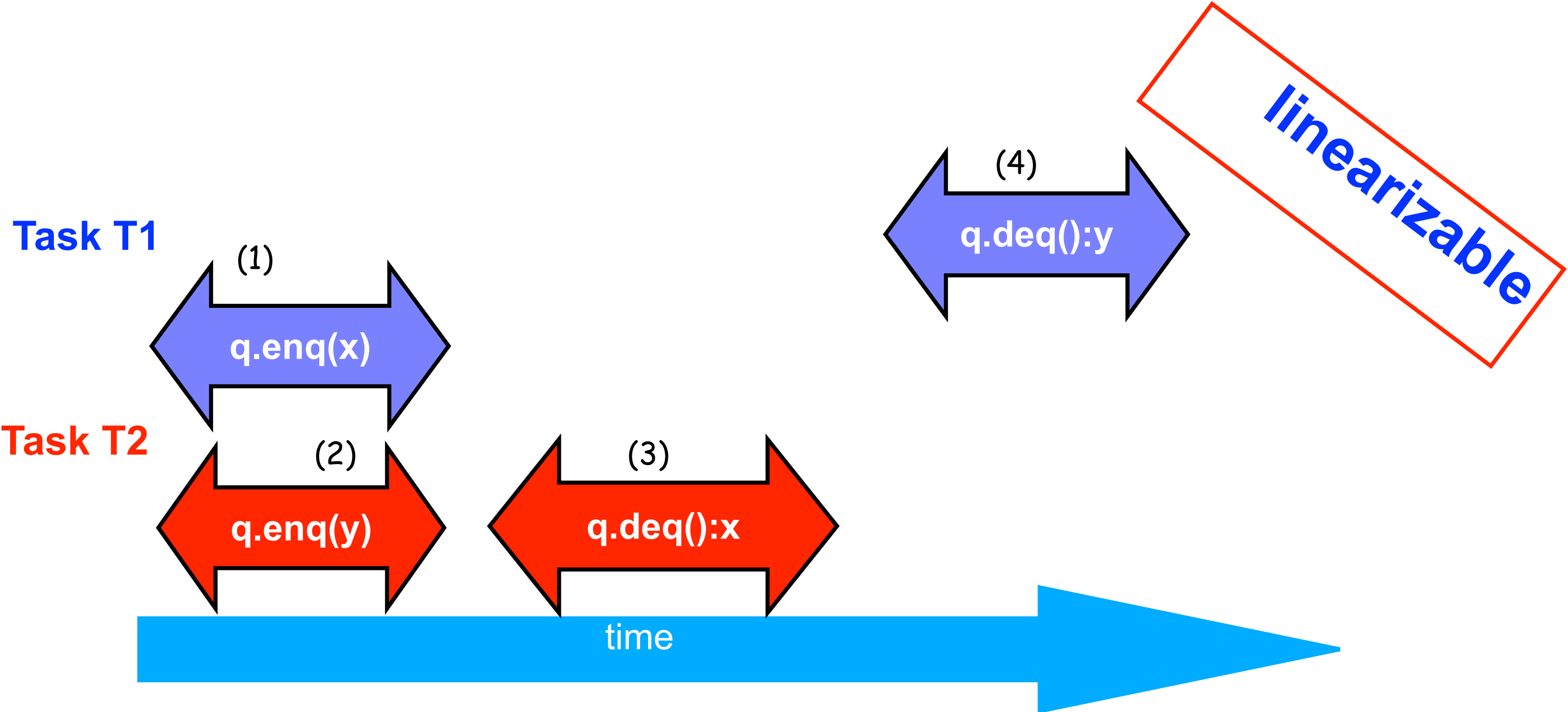
Example 1 cont.



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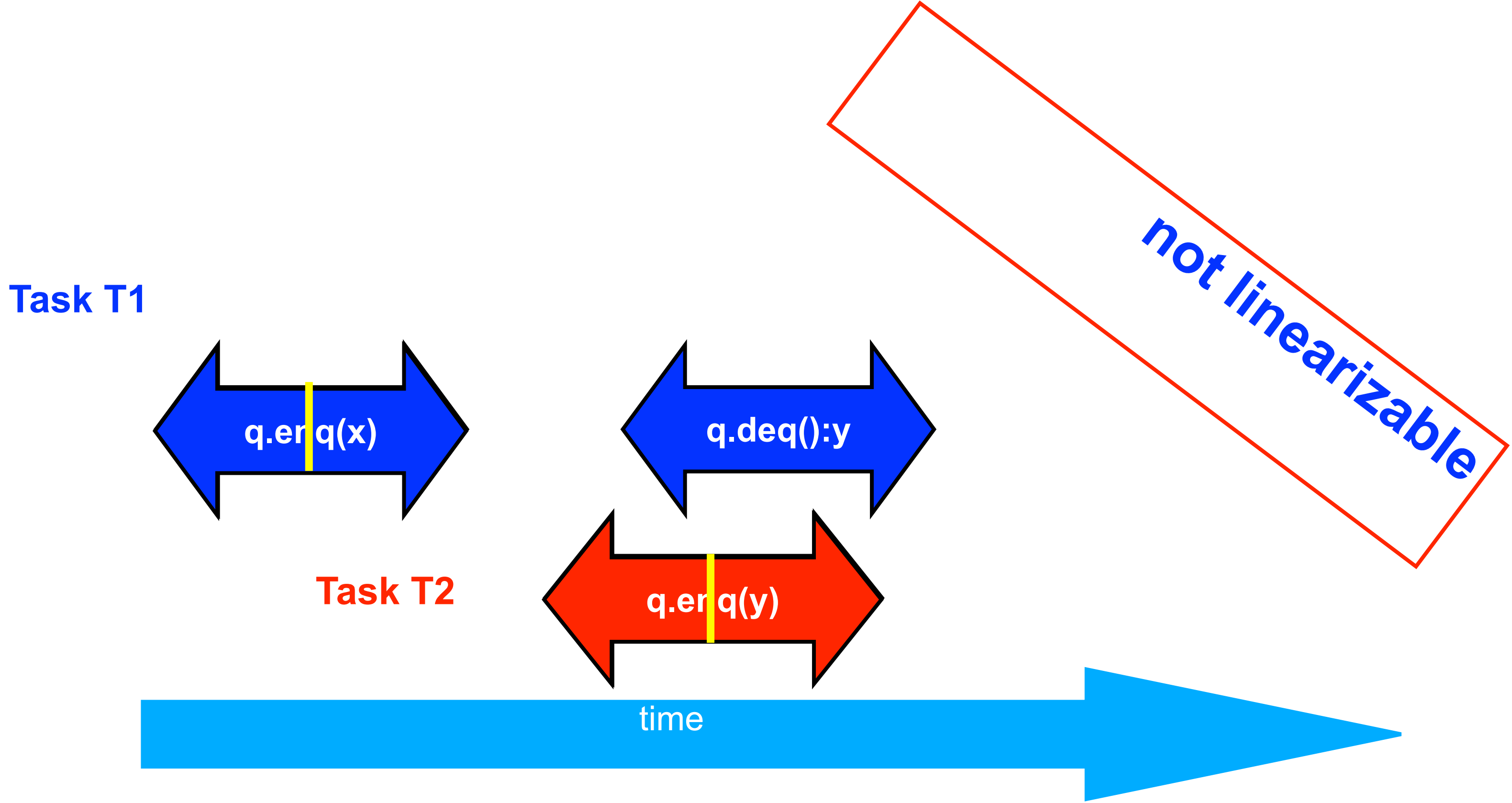
Example 1: is this execution linearizable?



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Example 2: is this execution linearizable?

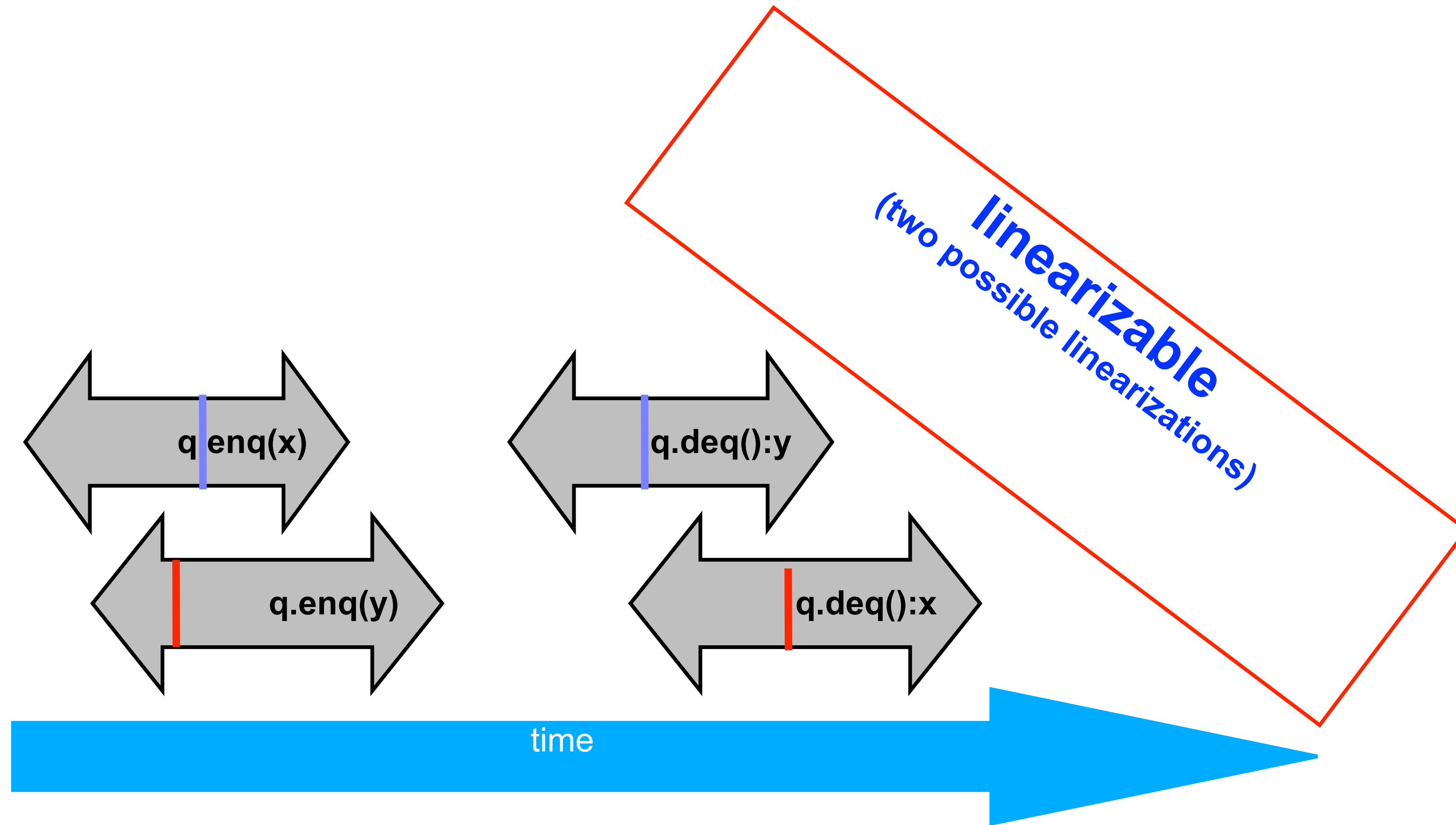


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Example 3

Is this execution linearizable? How many possible linearizations does it have?



Example 4: execution of isolated implementation of FIFO queue q

Is this a linearizable execution?

Time	Task A	Task B
0	Invoke $q.enq(x)$	
1	Work on $q.enq(x)$	
2	Work on $q.enq(x)$	
3	Return from $q.enq(x)$	
4		Invoke $q.enq(y)$
5		Work on $q.enq(y)$
6		Work on $q.enq(y)$
7		Return from $q.enq(y)$
8		Invoke $q.deq()$
9		Return x from $q.deq()$

Yes! Can be linearized as “ $q.enq(x) ; q.enq(y) ; q.deq():x$ ”



Linearizability of Concurrent Objects (Summary)

Concurrent object

- A concurrent object is an object that can correctly handle methods invoked in parallel by different tasks or threads
 - Examples: Concurrent Queue, AtomicInteger

Linearizability

- Assume that each method call takes effect “instantaneously” at some distinct point in time between its invocation and return.
- An execution is linearizable if we can choose instantaneous points that are consistent with a sequential execution in which methods are executed at those points
- An object is linearizable if all its possible executions are linearizable

