Introduction to Discrete-Event Simulation Using SimPy

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Outline

What is Simulation and Why do we need it?

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  - problems that can be analyzed by pencil and paper

Categories of Simulation

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    - called Monte-Carlo Simulation [2]
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  - Dynamic: represents systems as they change over time
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- Deterministic or stochastic
  - Deterministic: contains no random variable
  - Stochastic: has one or more random variables

What is Discrete-Event Simulation?

- Simulation of weather system is **continuous**.
- Simulation of queue in a post office is **discrete**.
  - Number of customers in any time is discrete.
  - Simulation for this kind of systems is called discrete-event simulation.
- Mostly, but not limited to, queueing systems
  - factory work flow
  - freeway traffic simulation
  - network traffic simulation

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Example to Illustrate World Views

- Simulating a post office with only one clerk
- Customers come in at random time
  and wait if the clerk is already serving
- Clerk serves each customer for a random period of time

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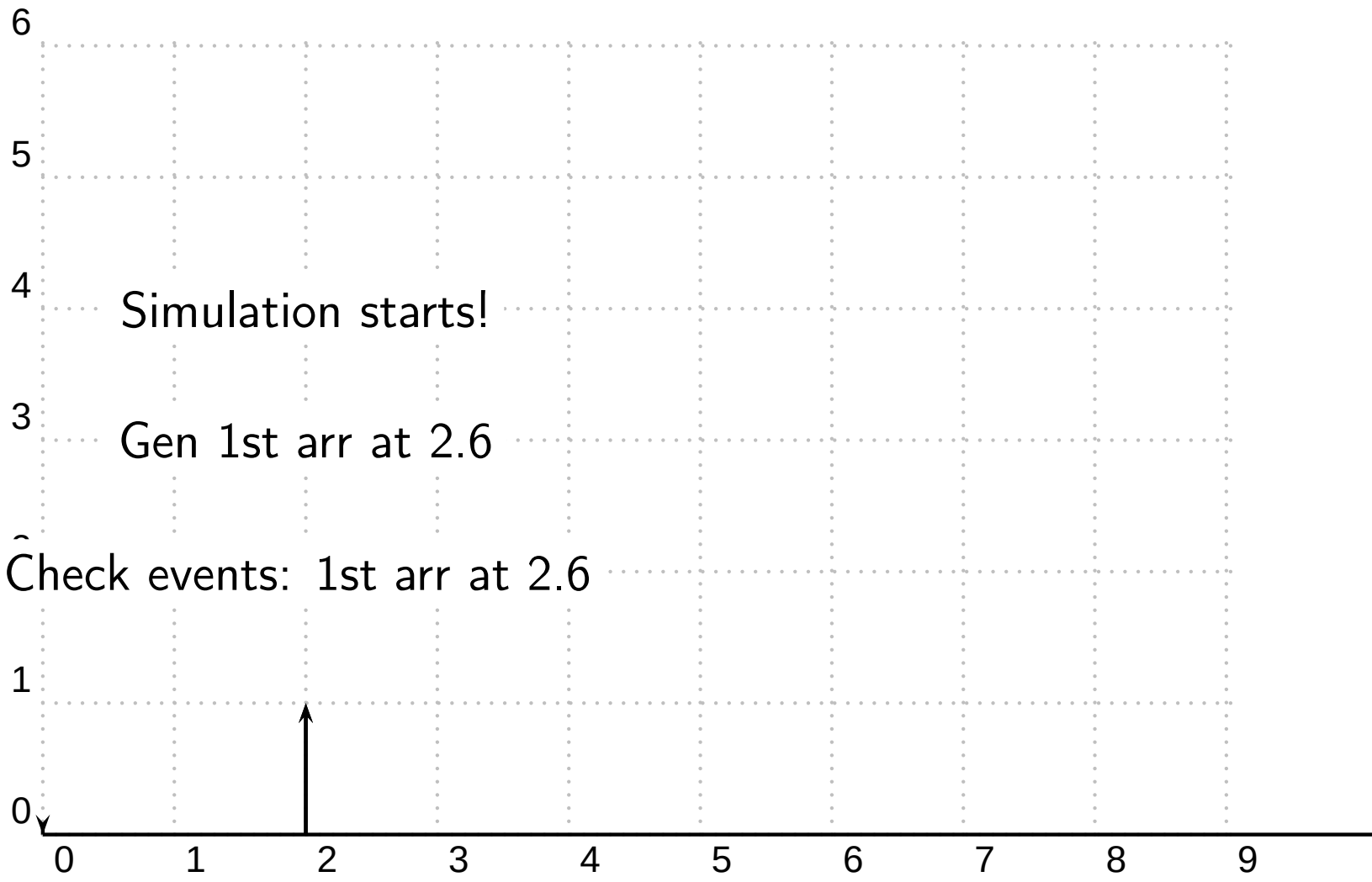

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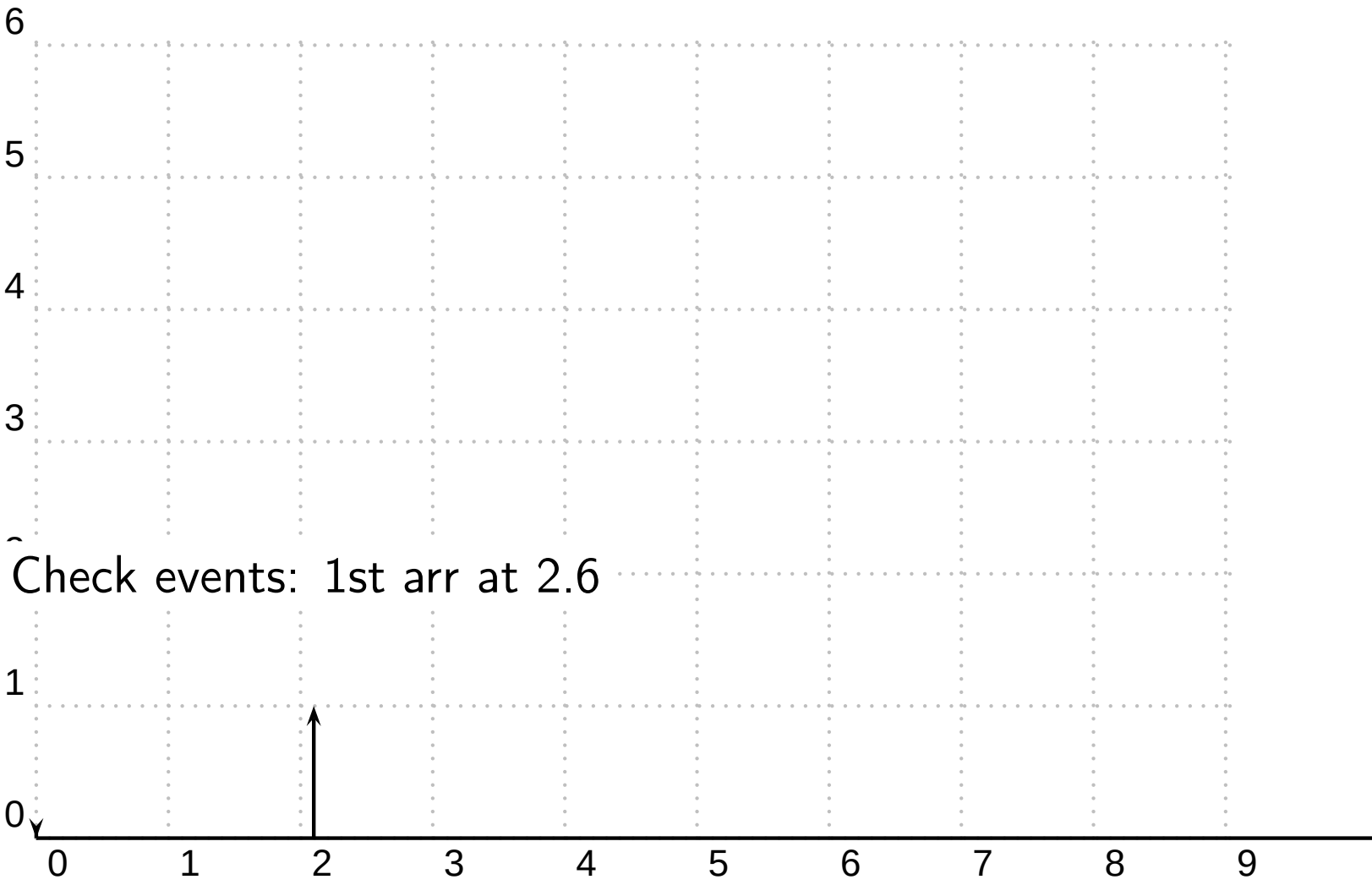

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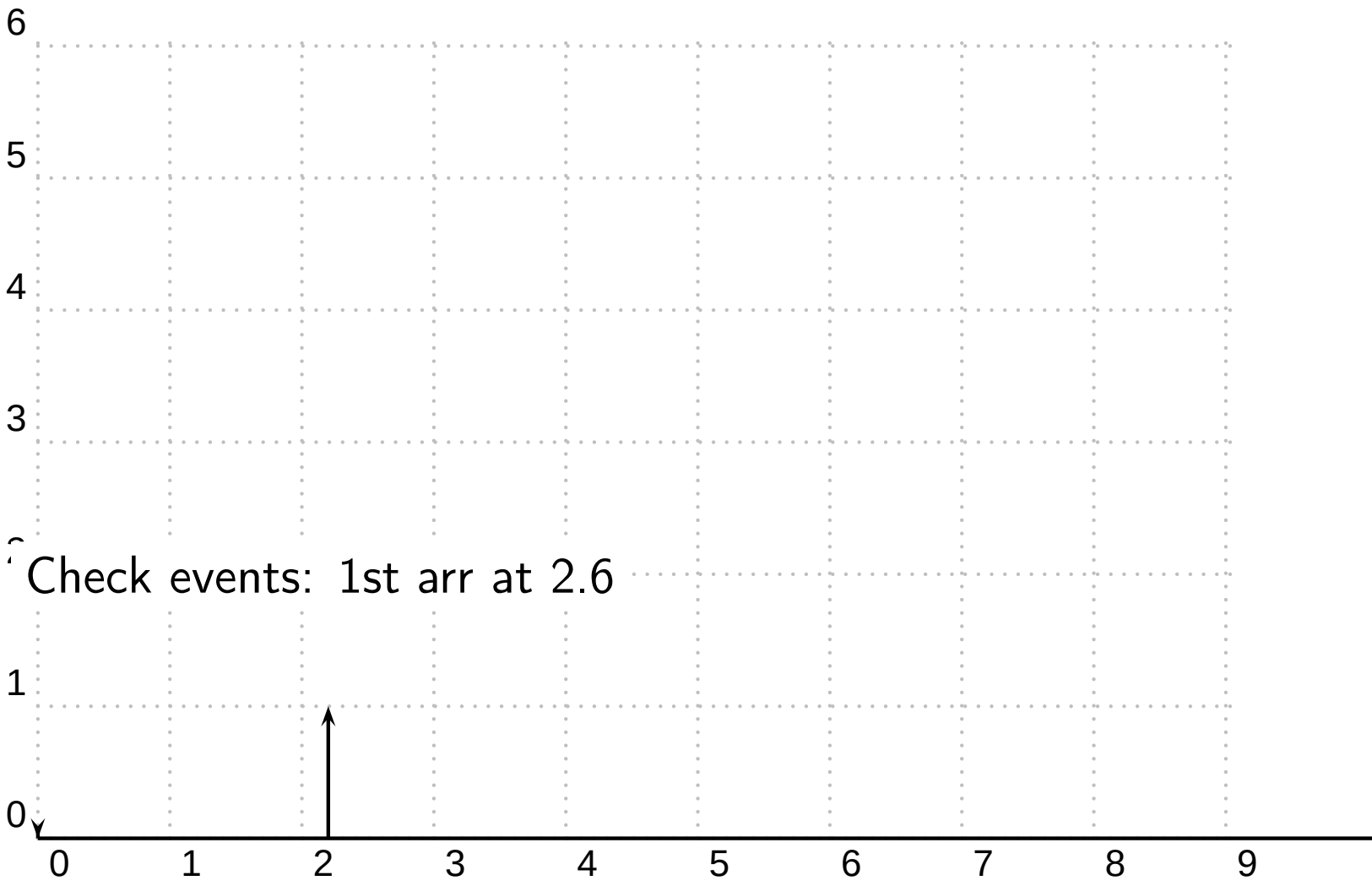

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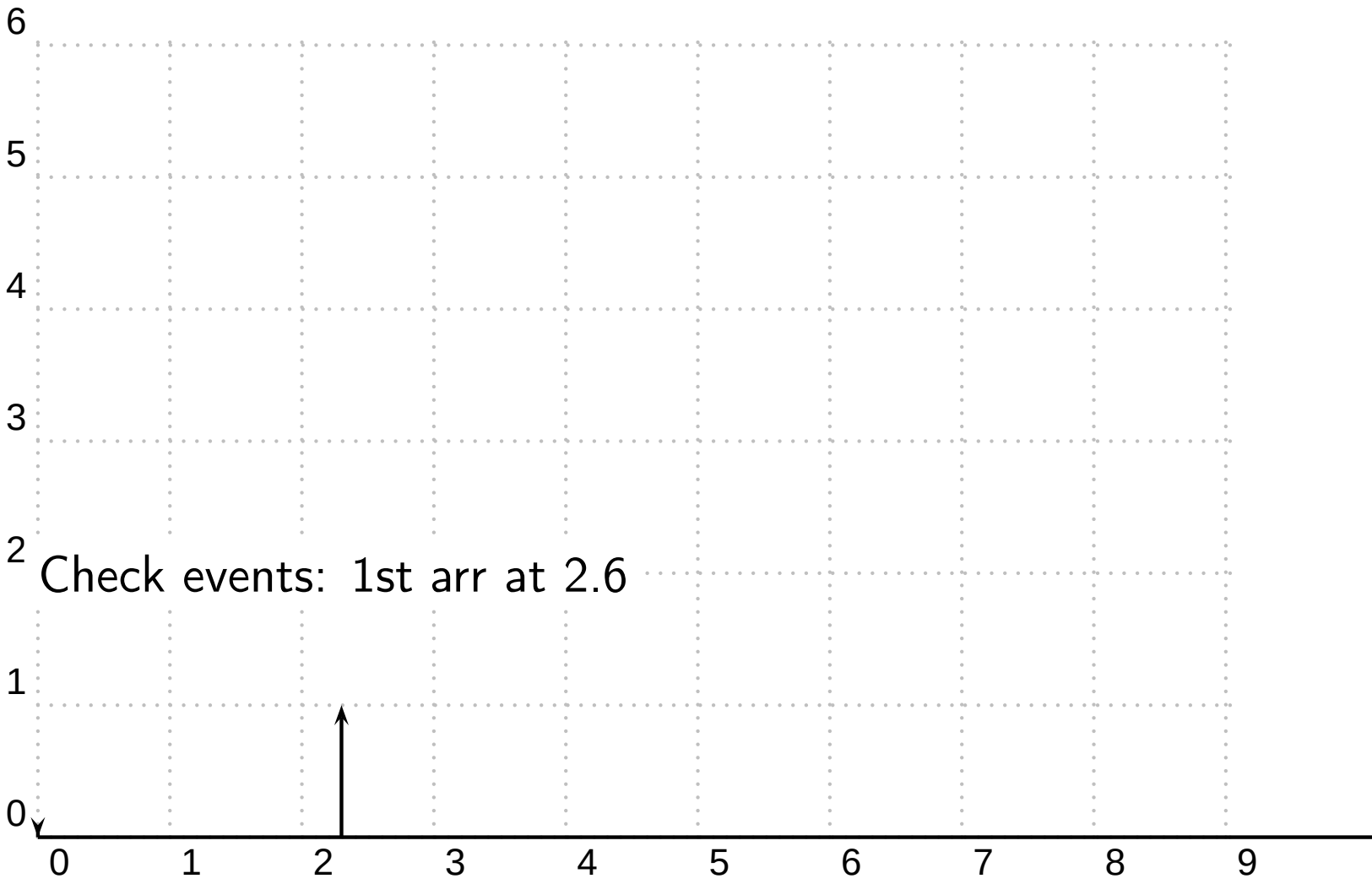

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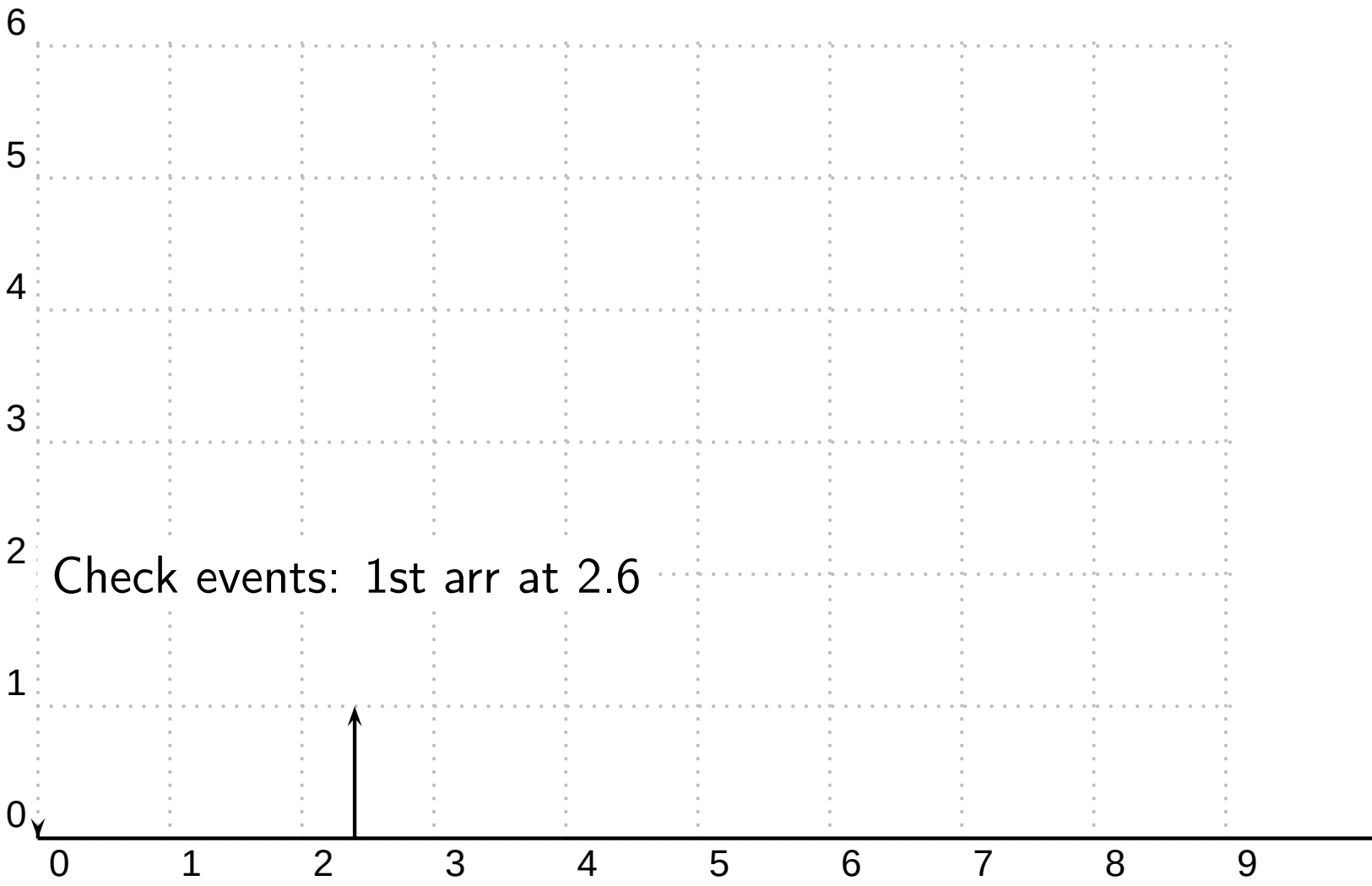

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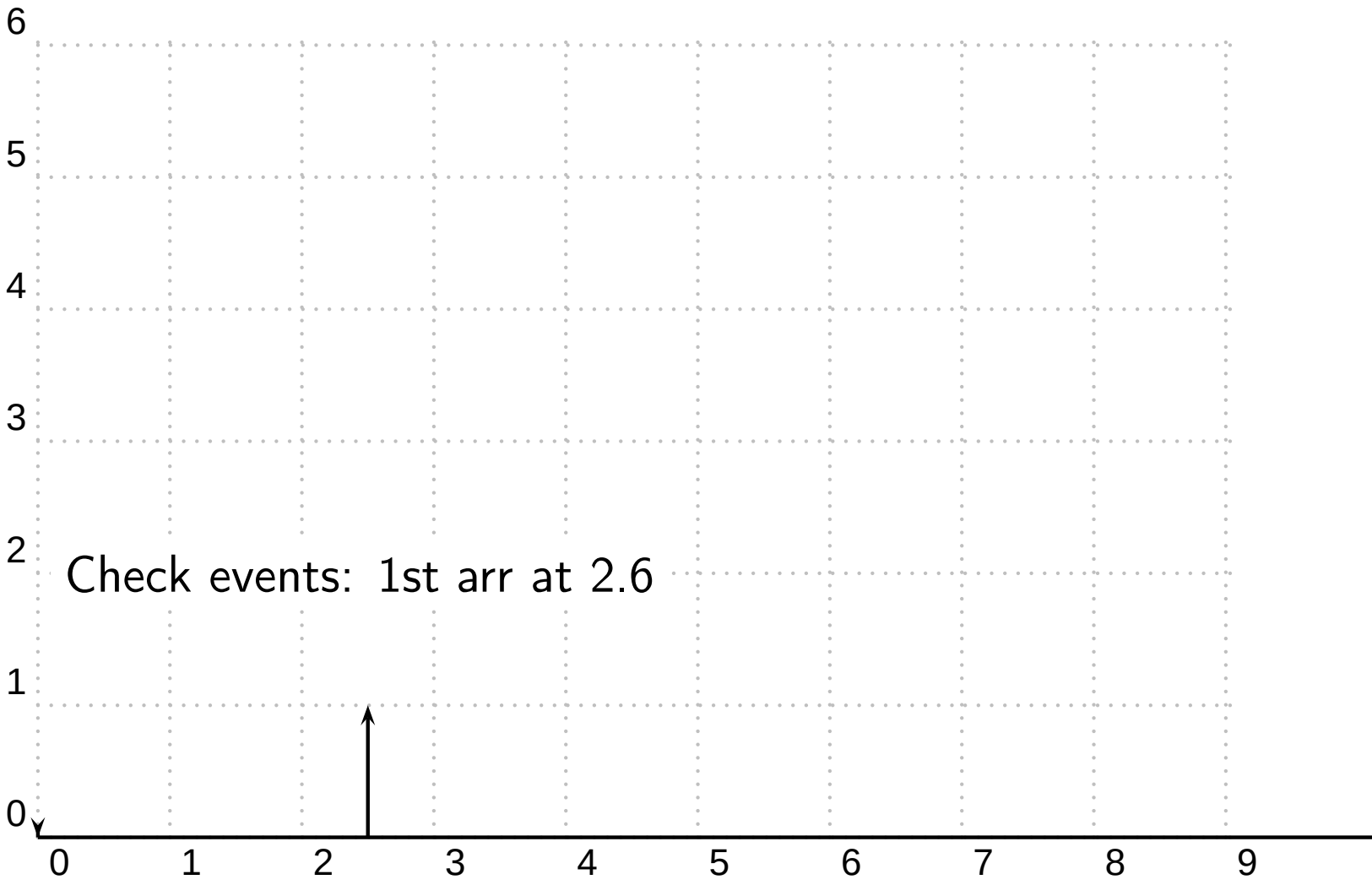

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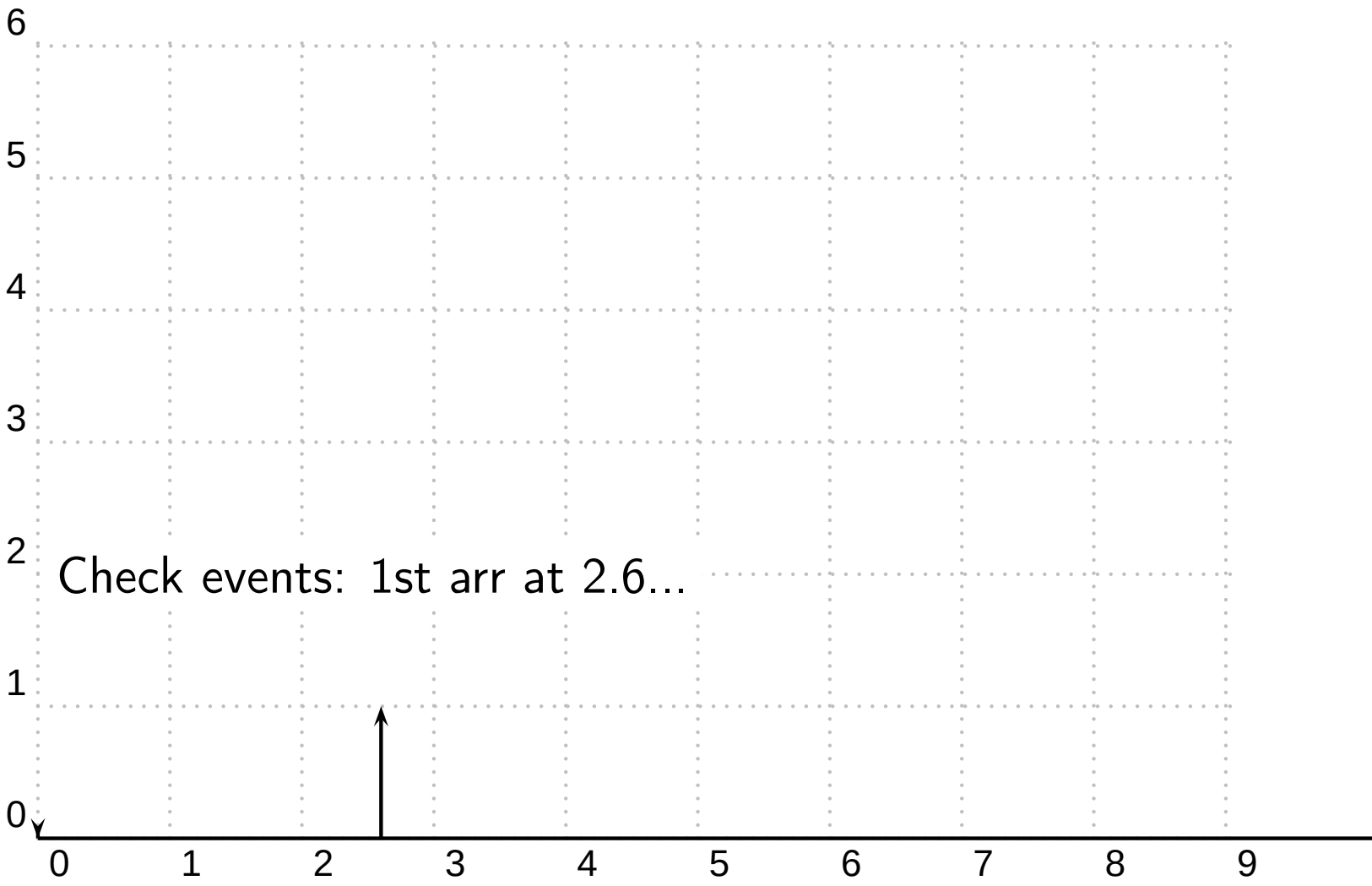

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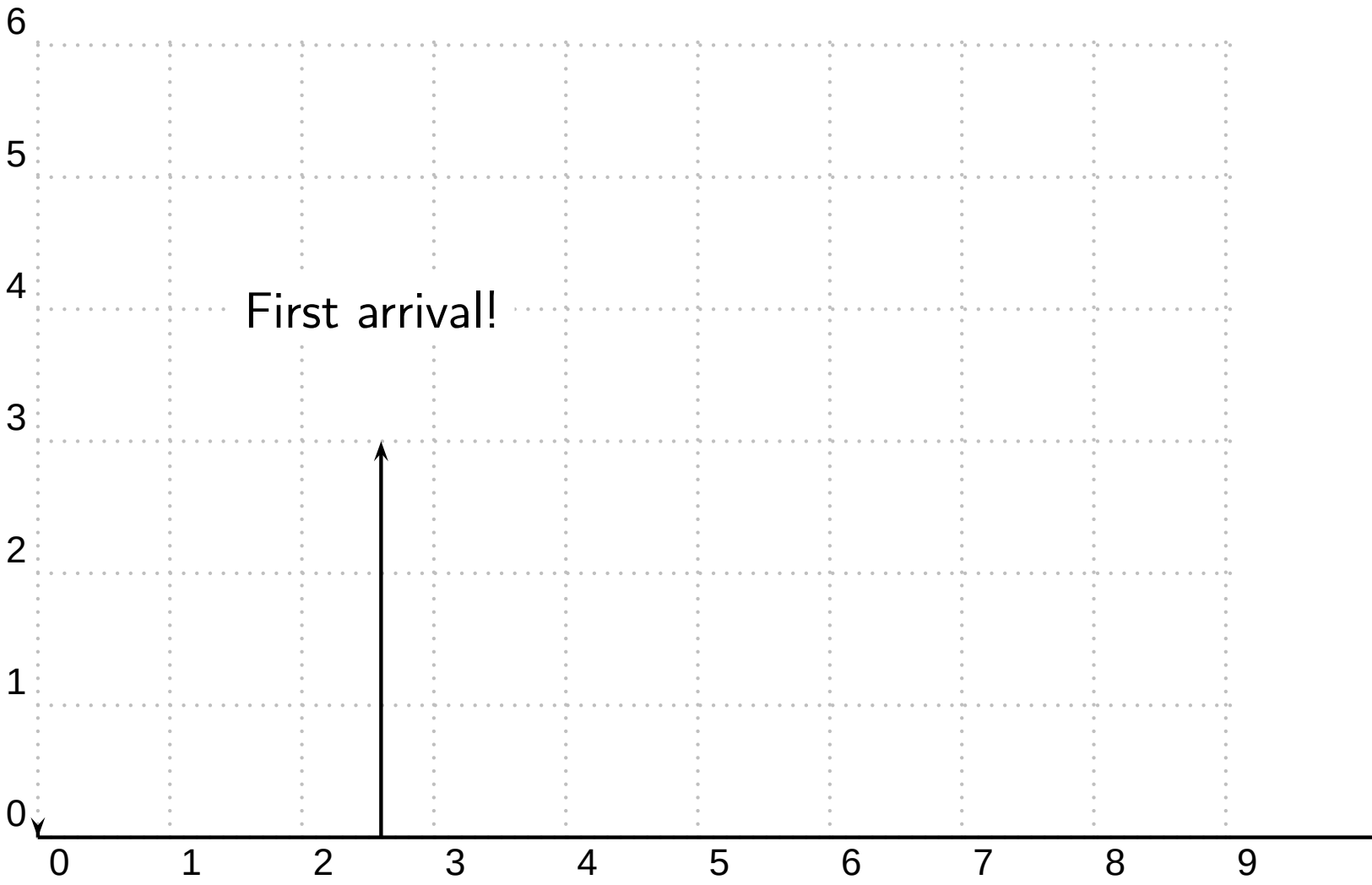

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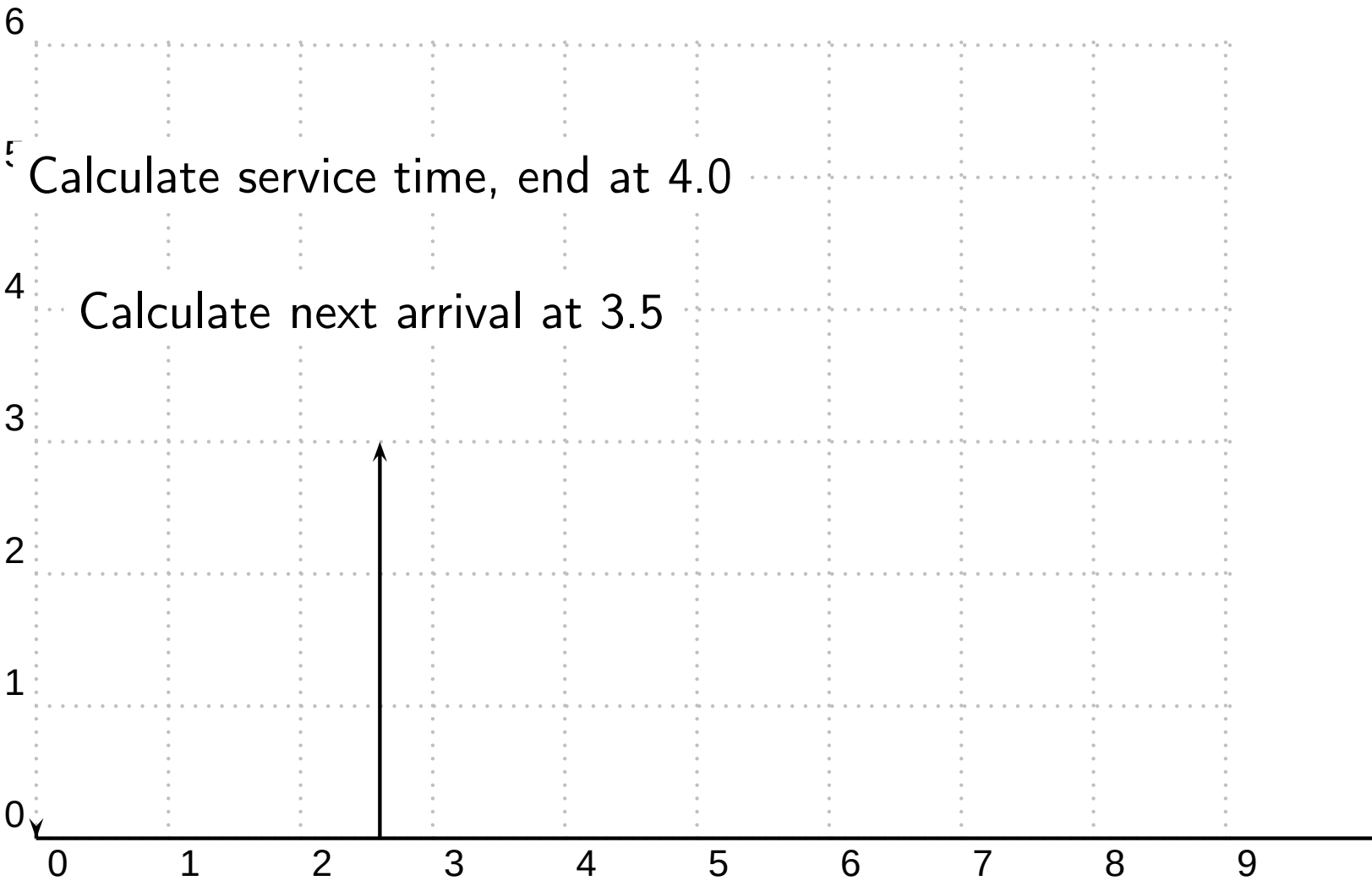

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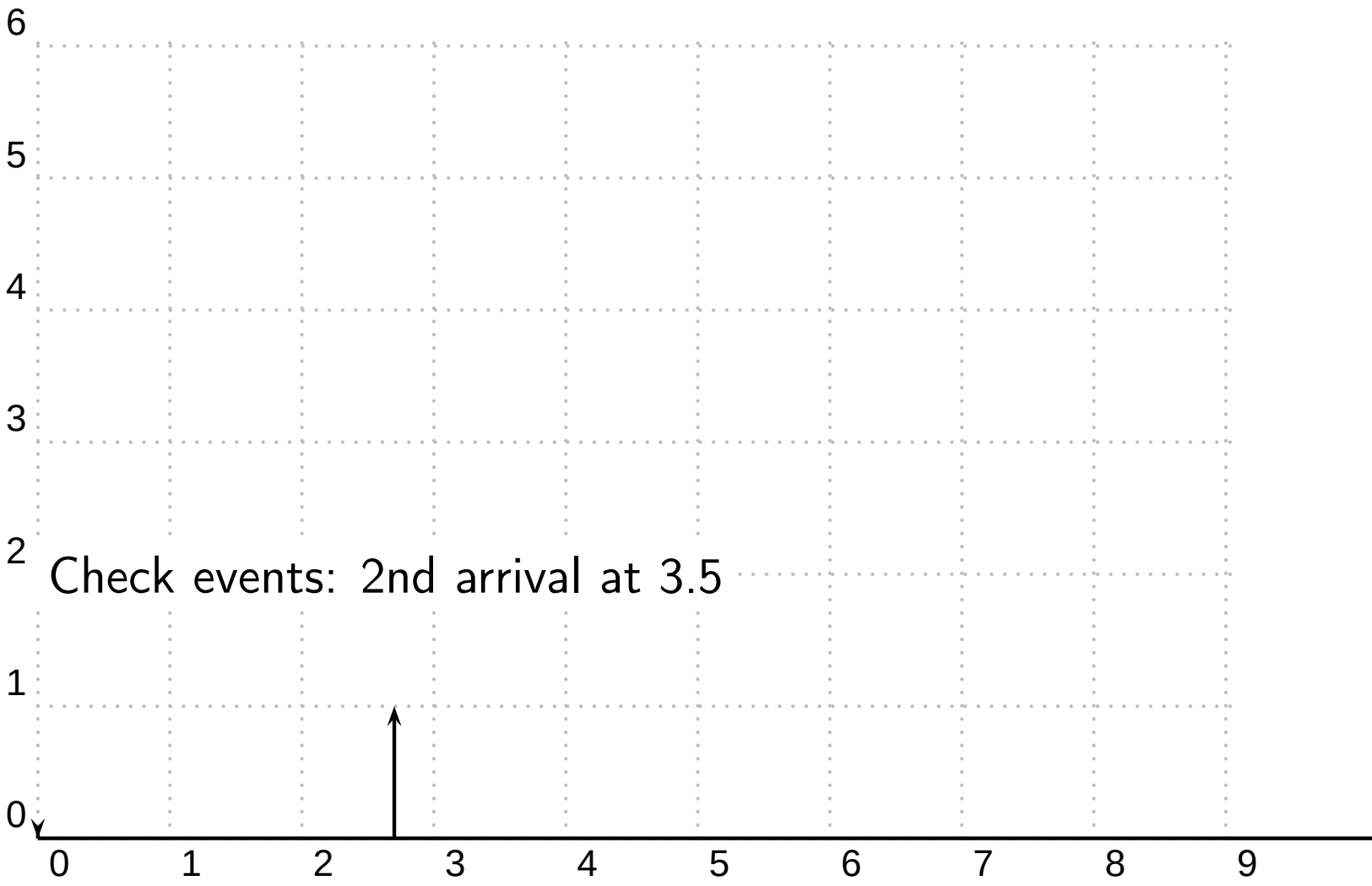

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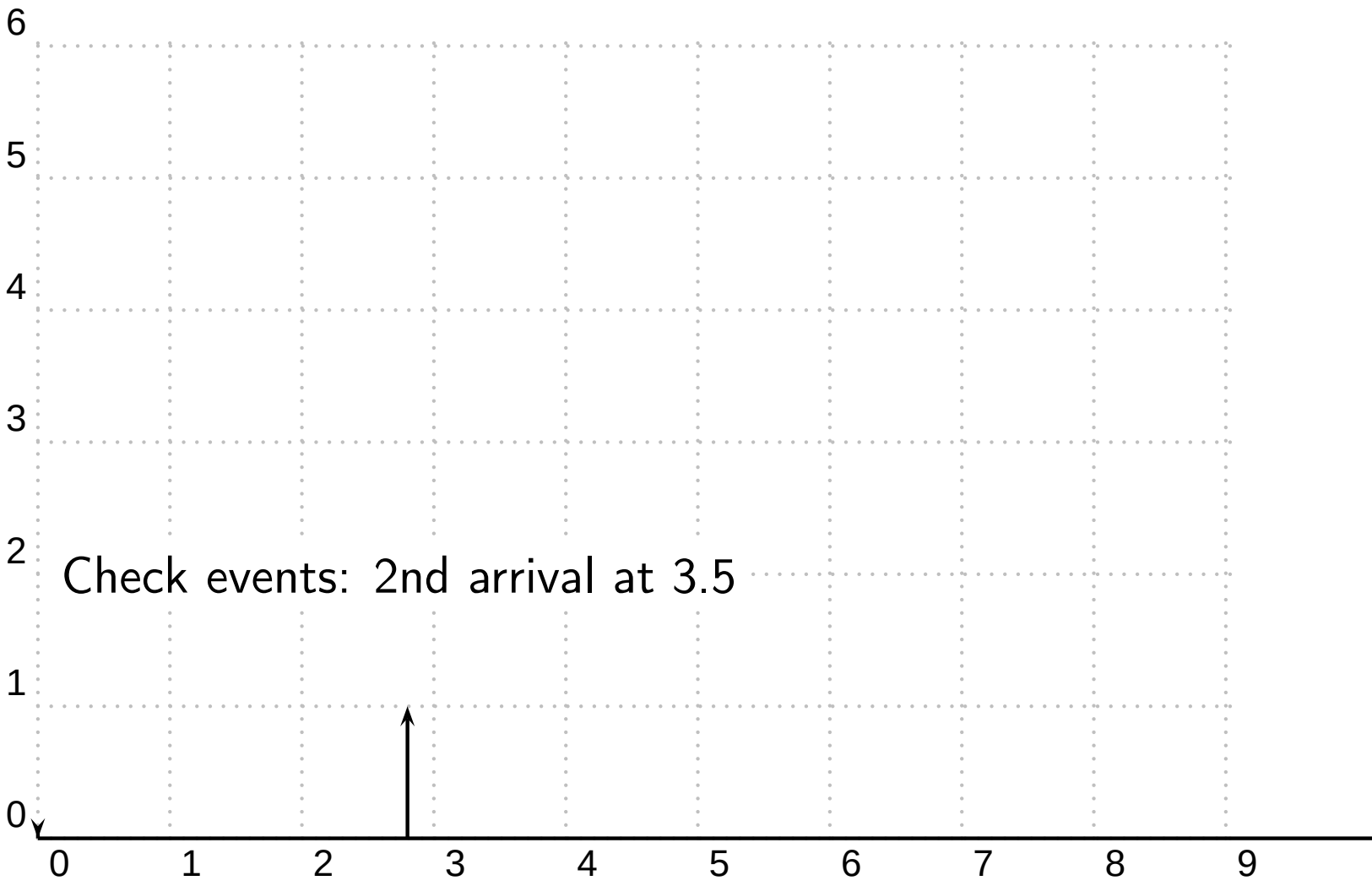

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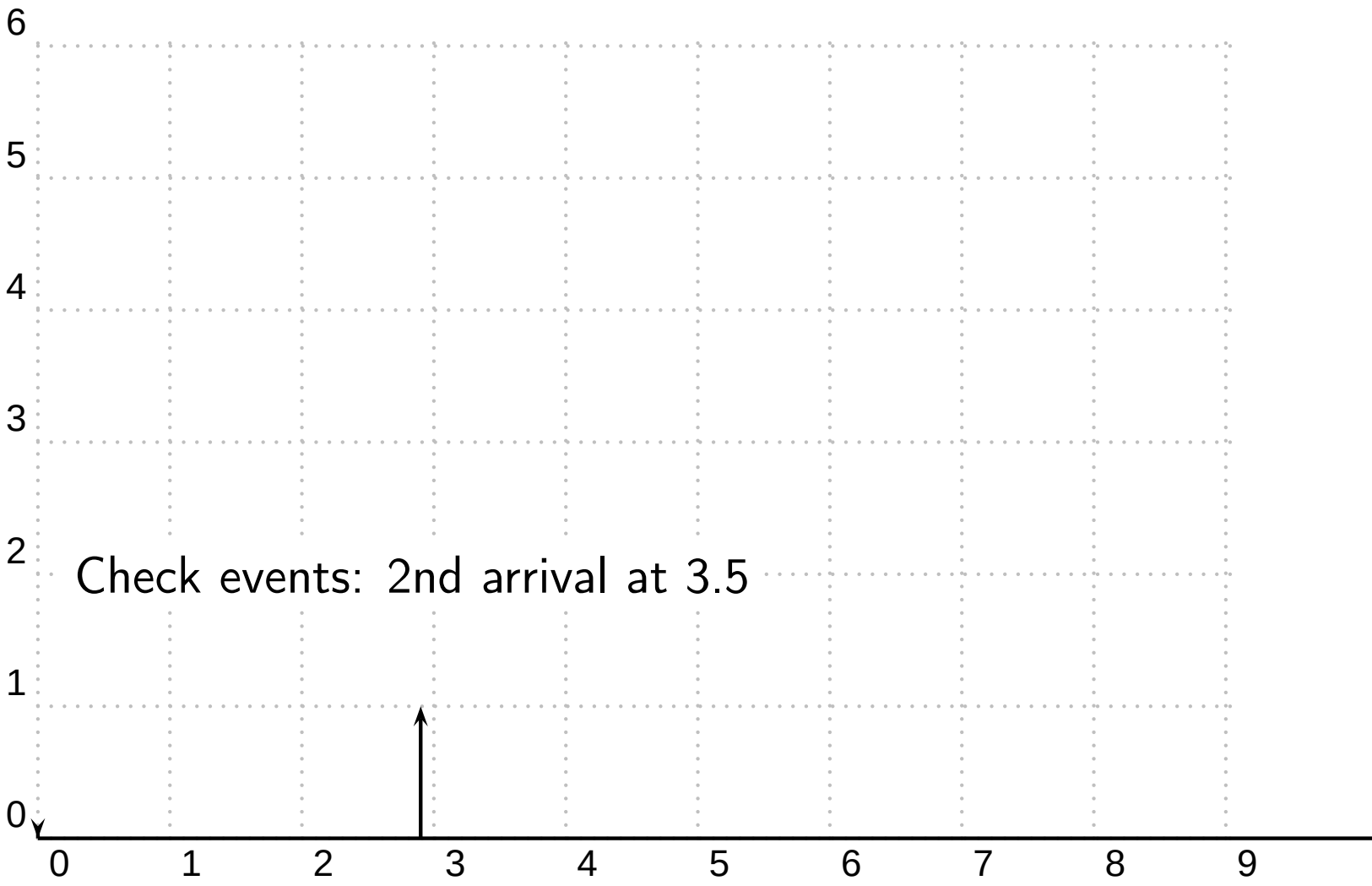

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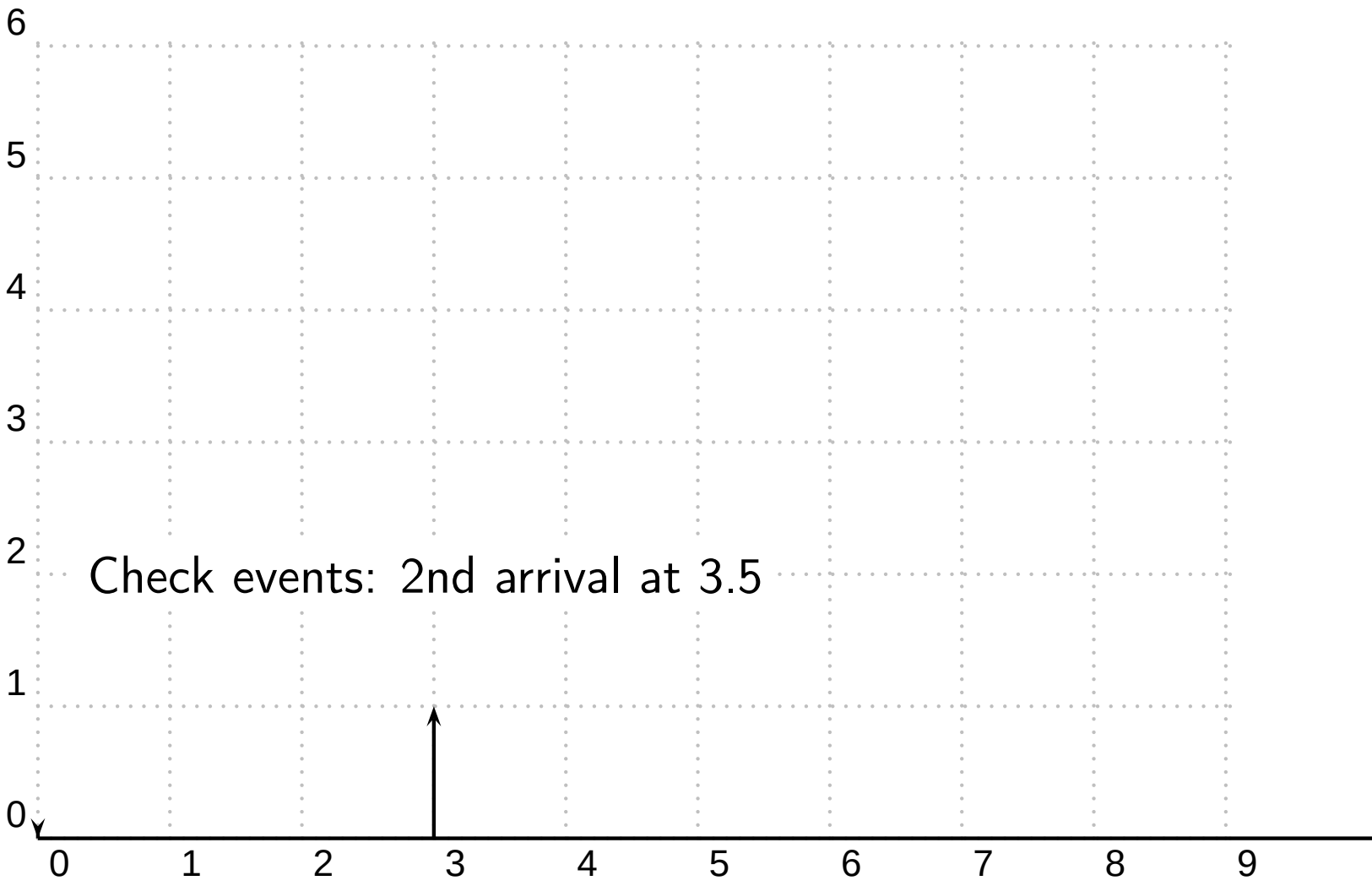

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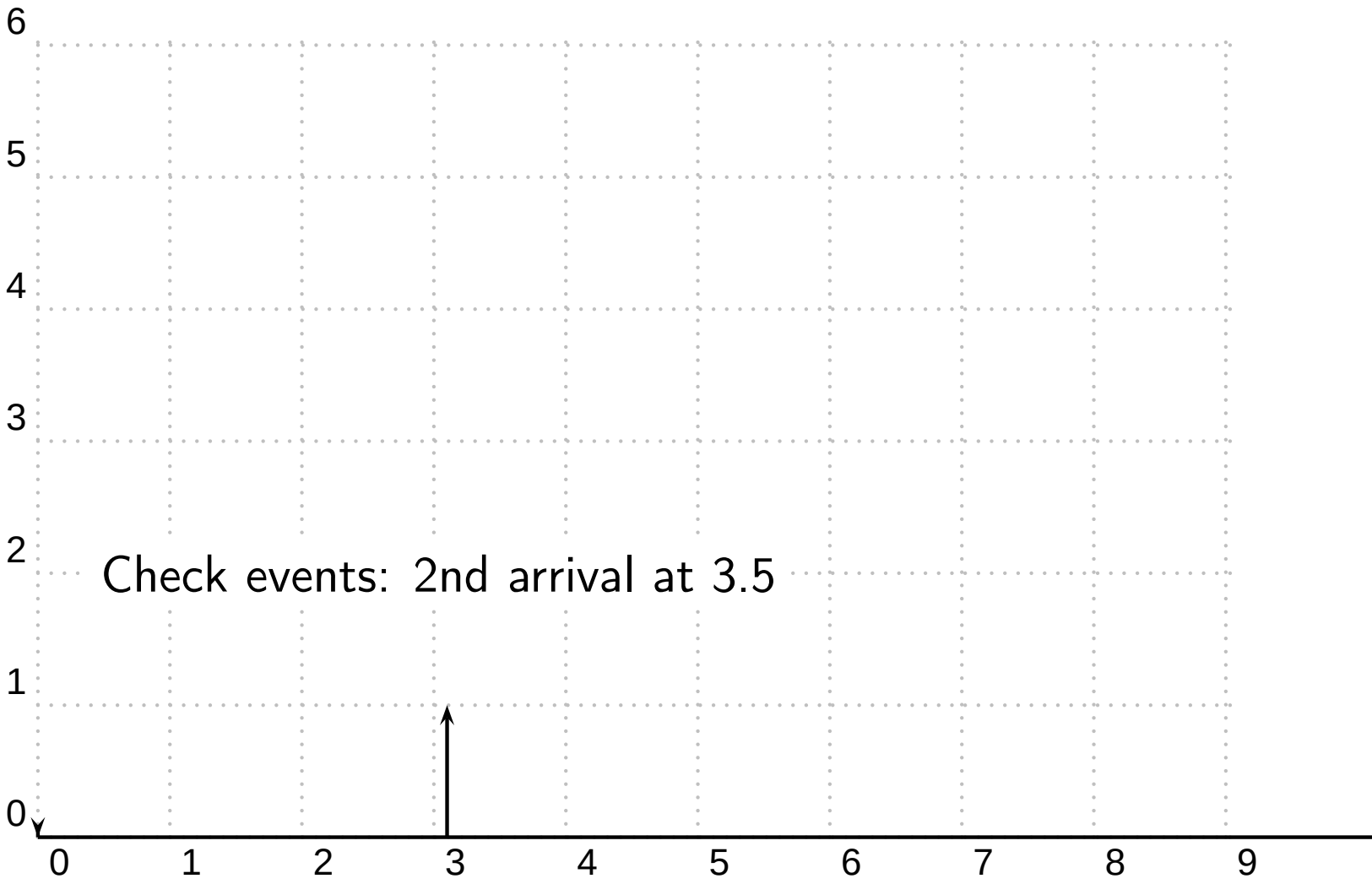

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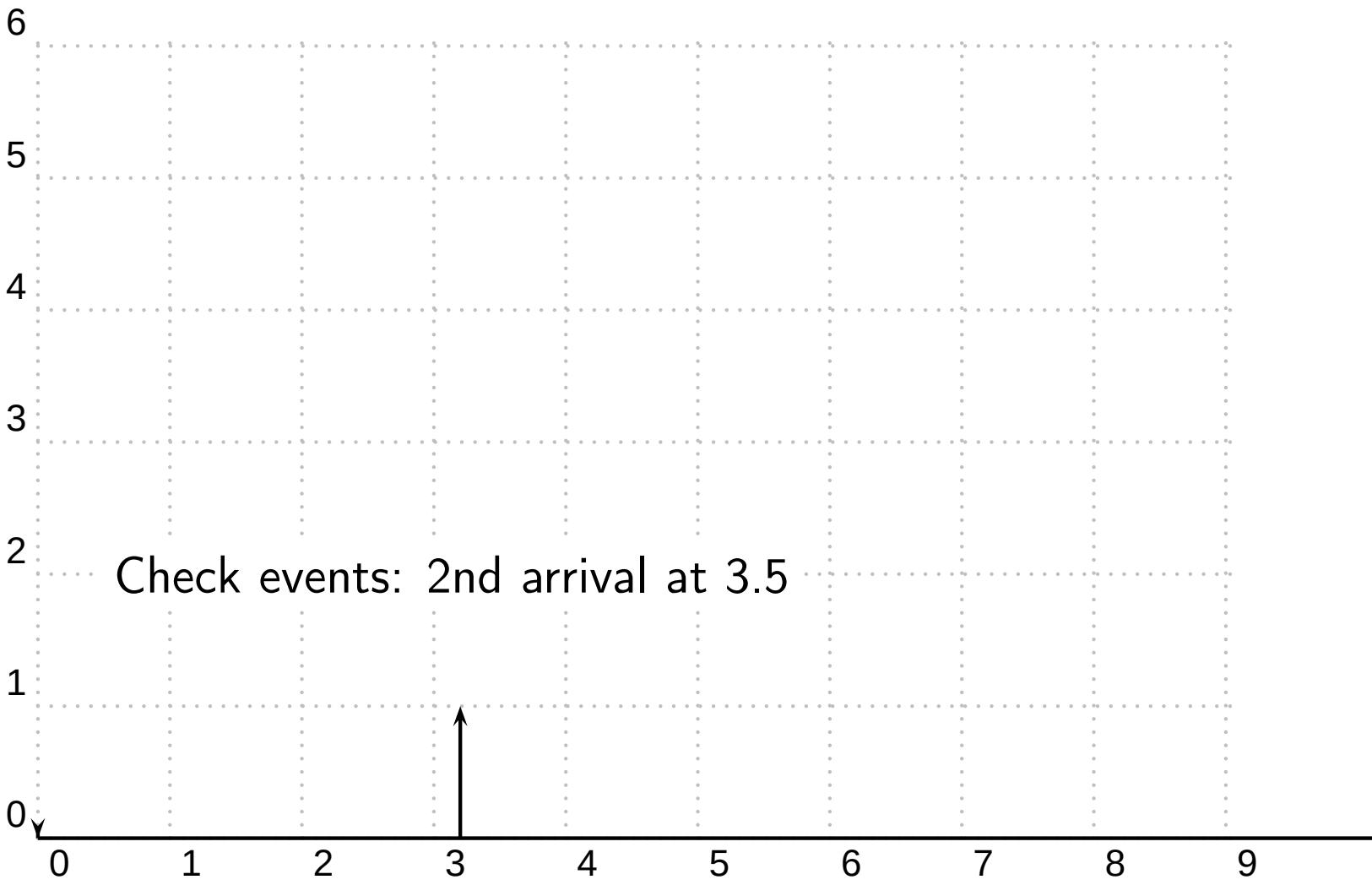

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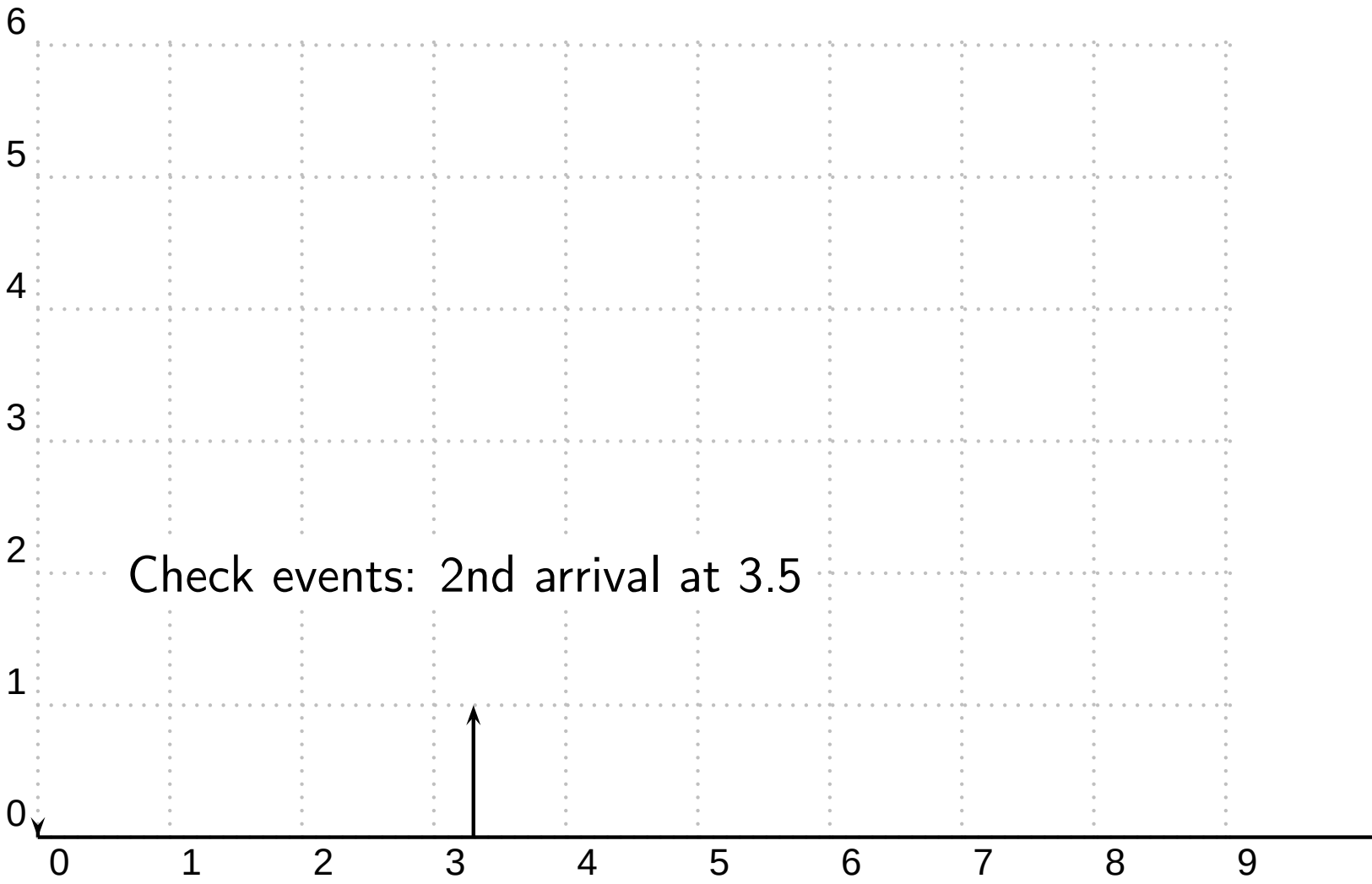

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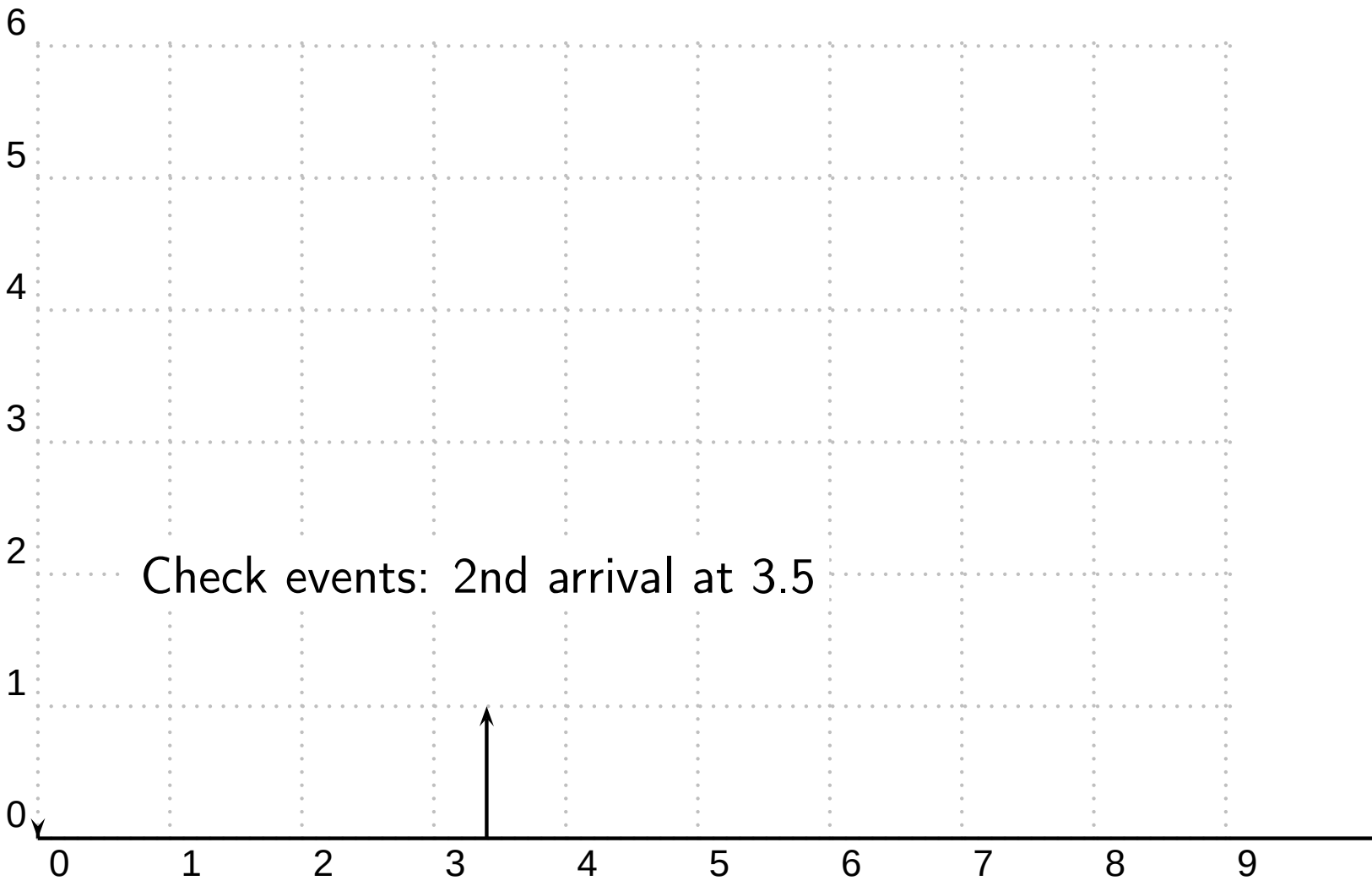

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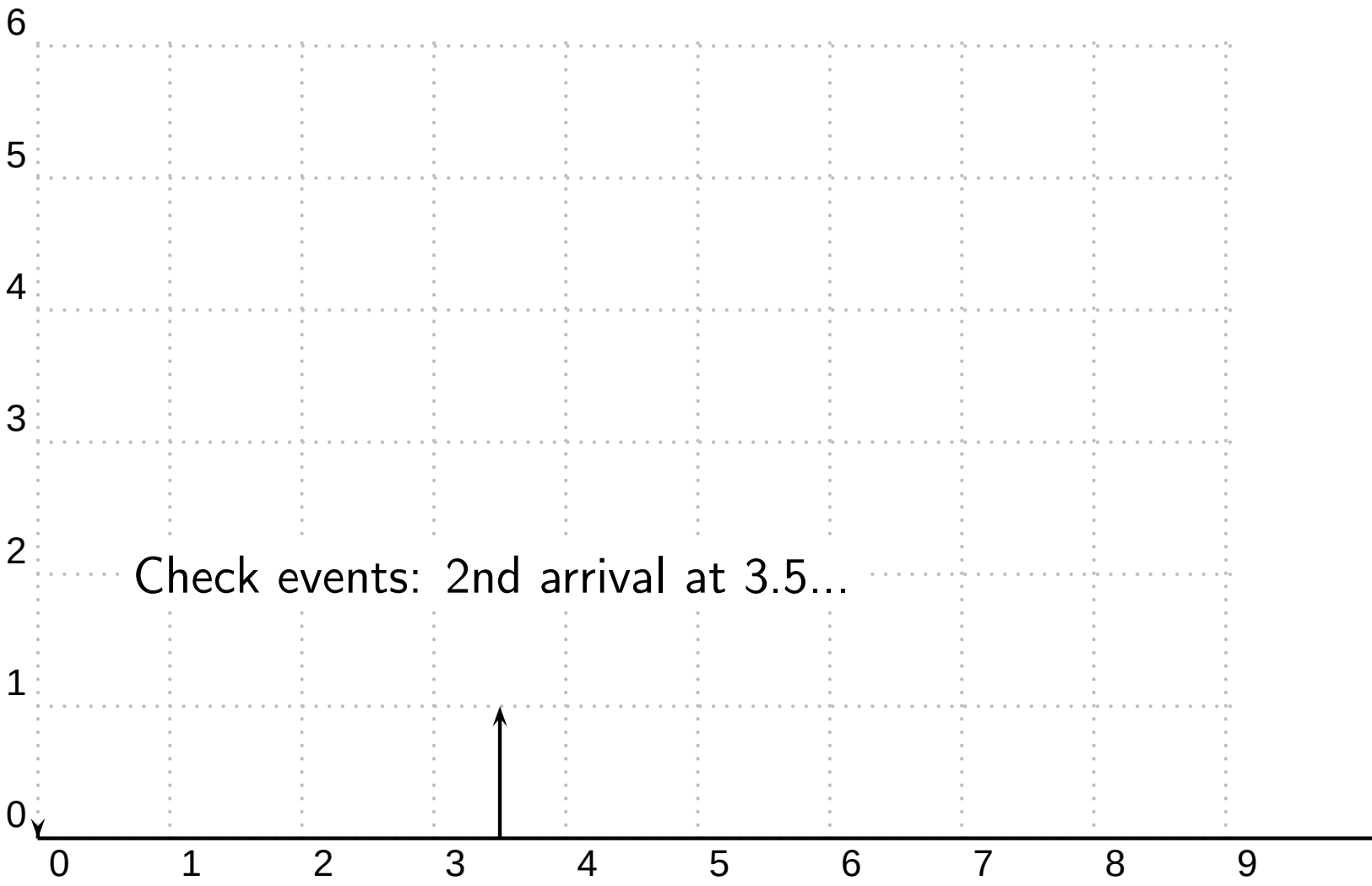

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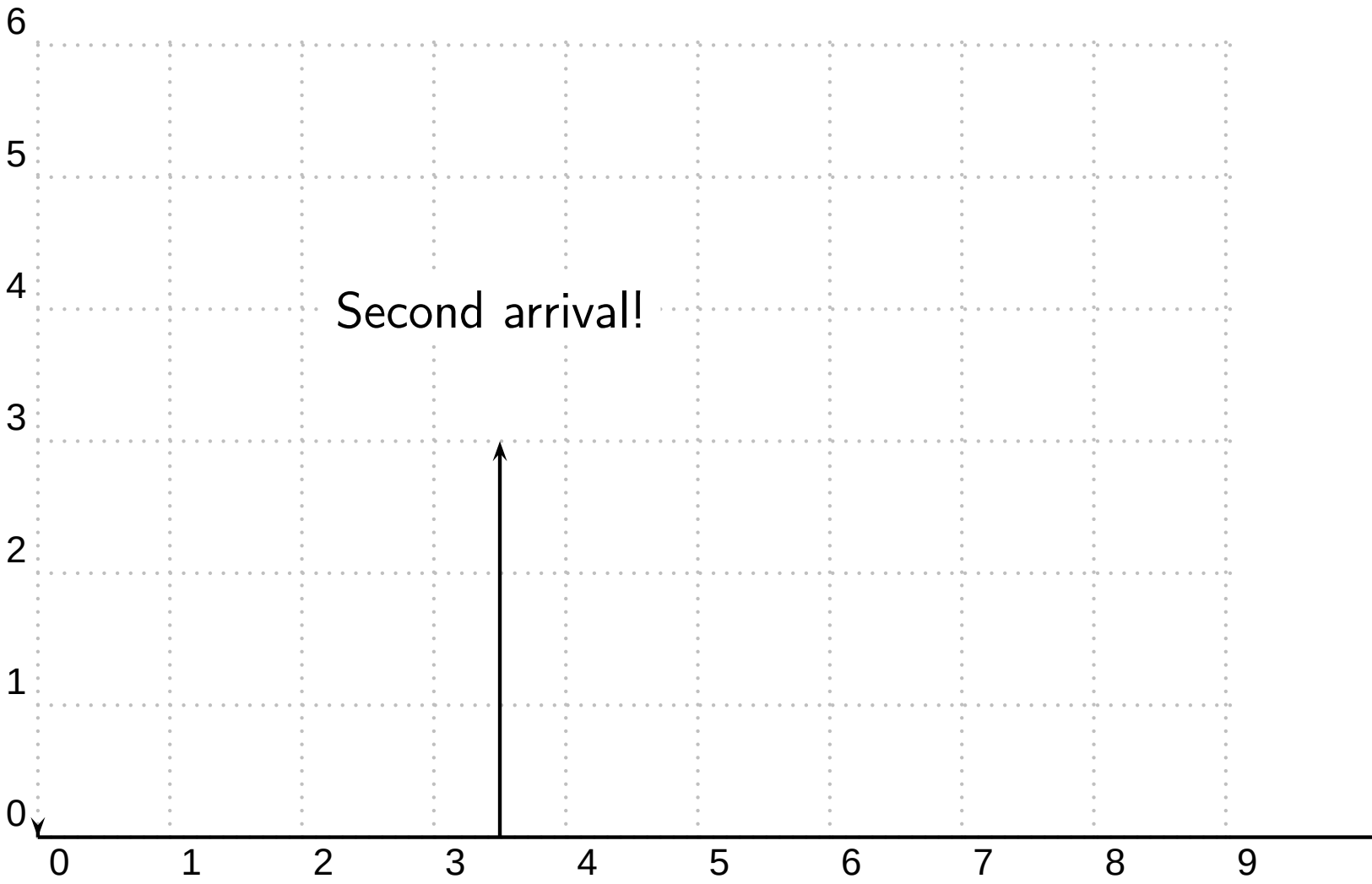

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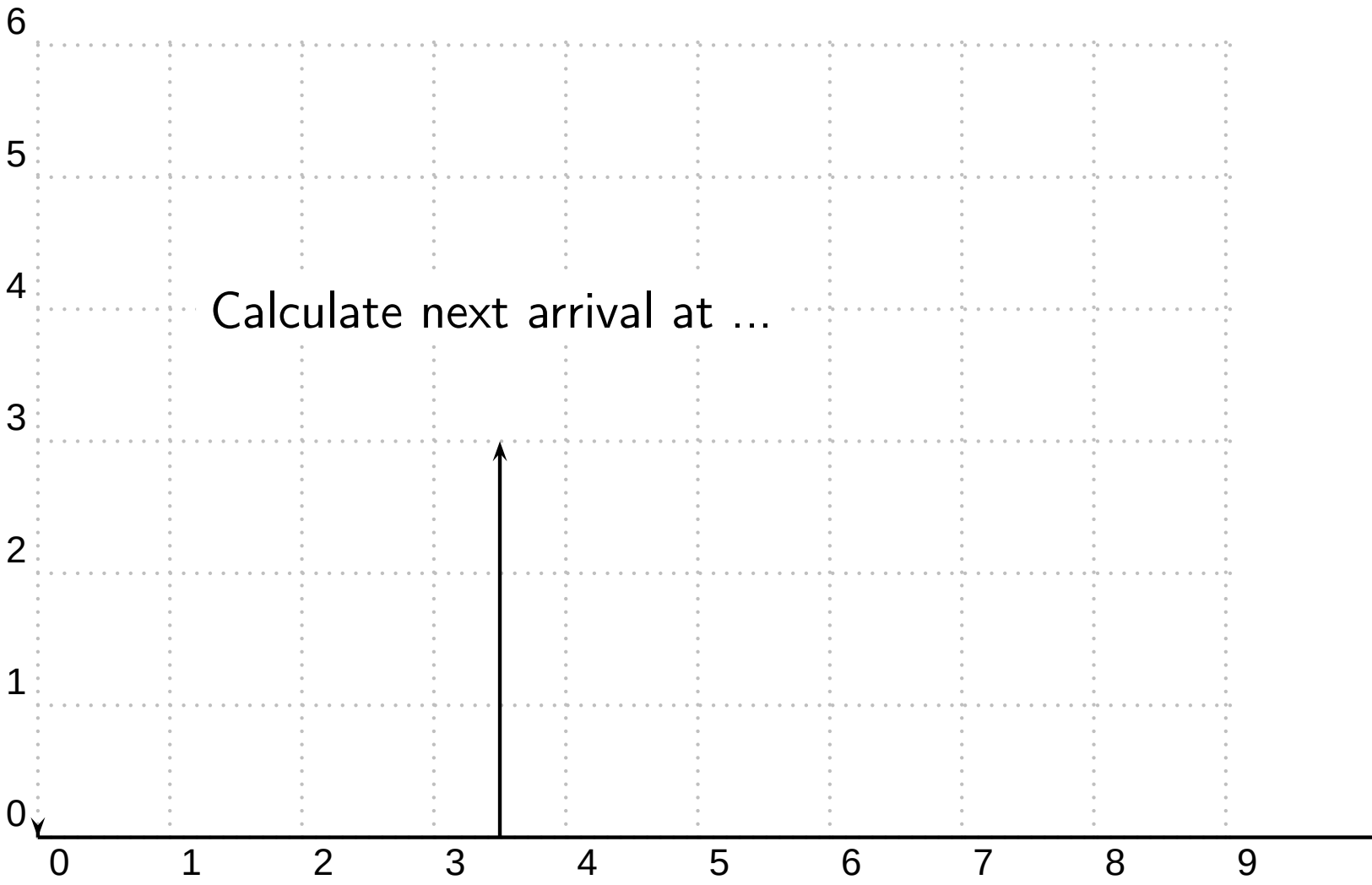

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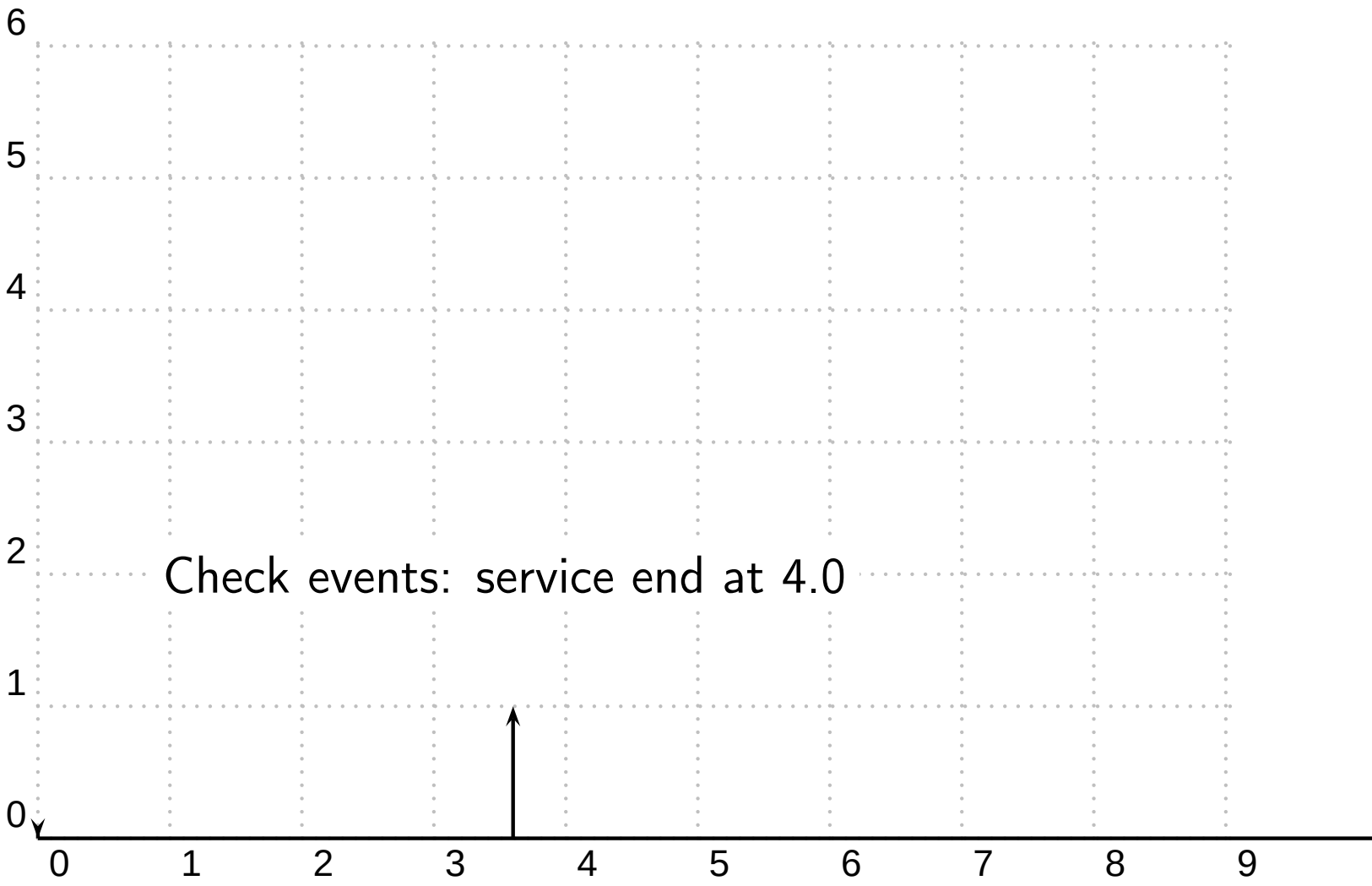

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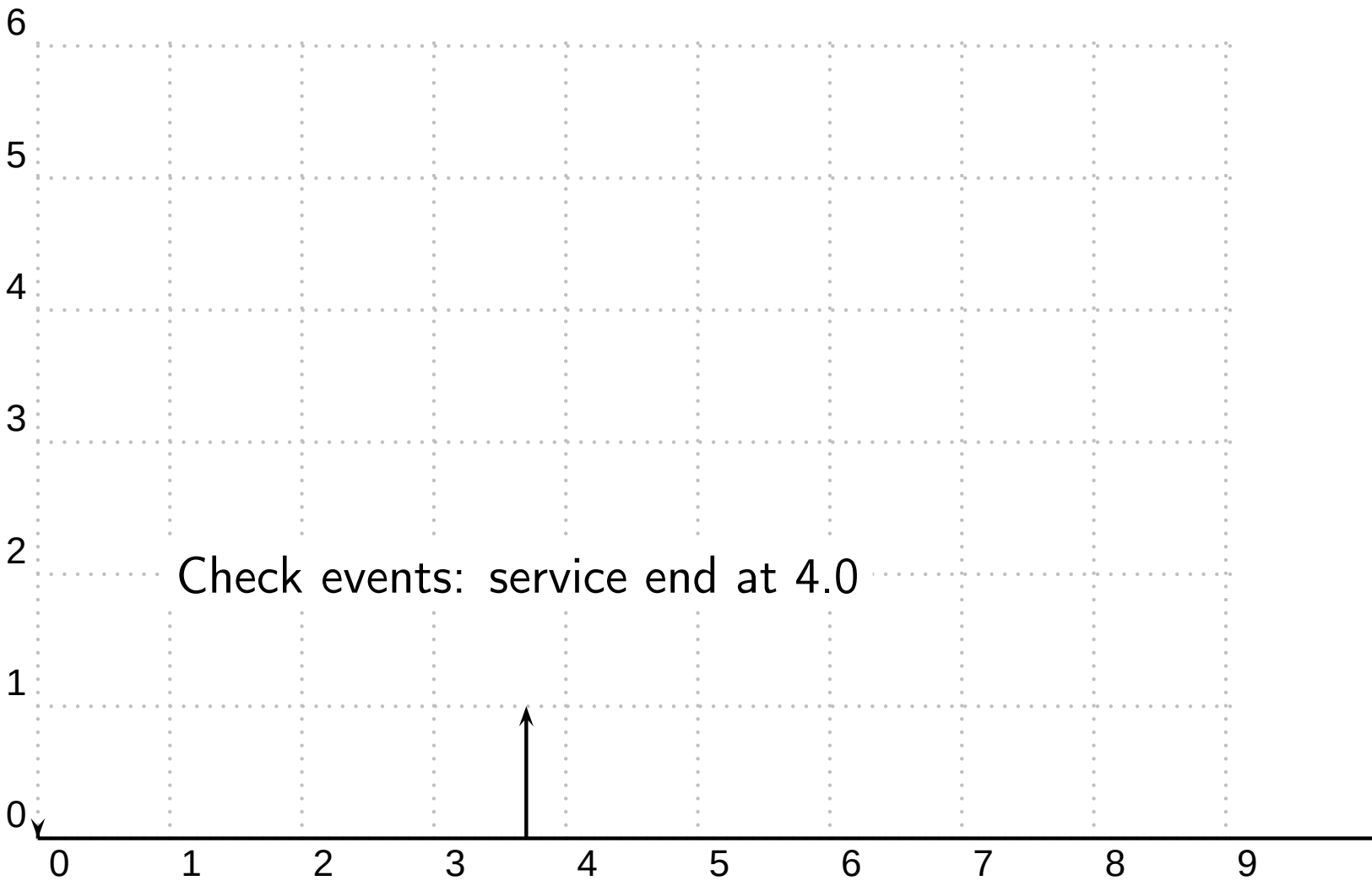

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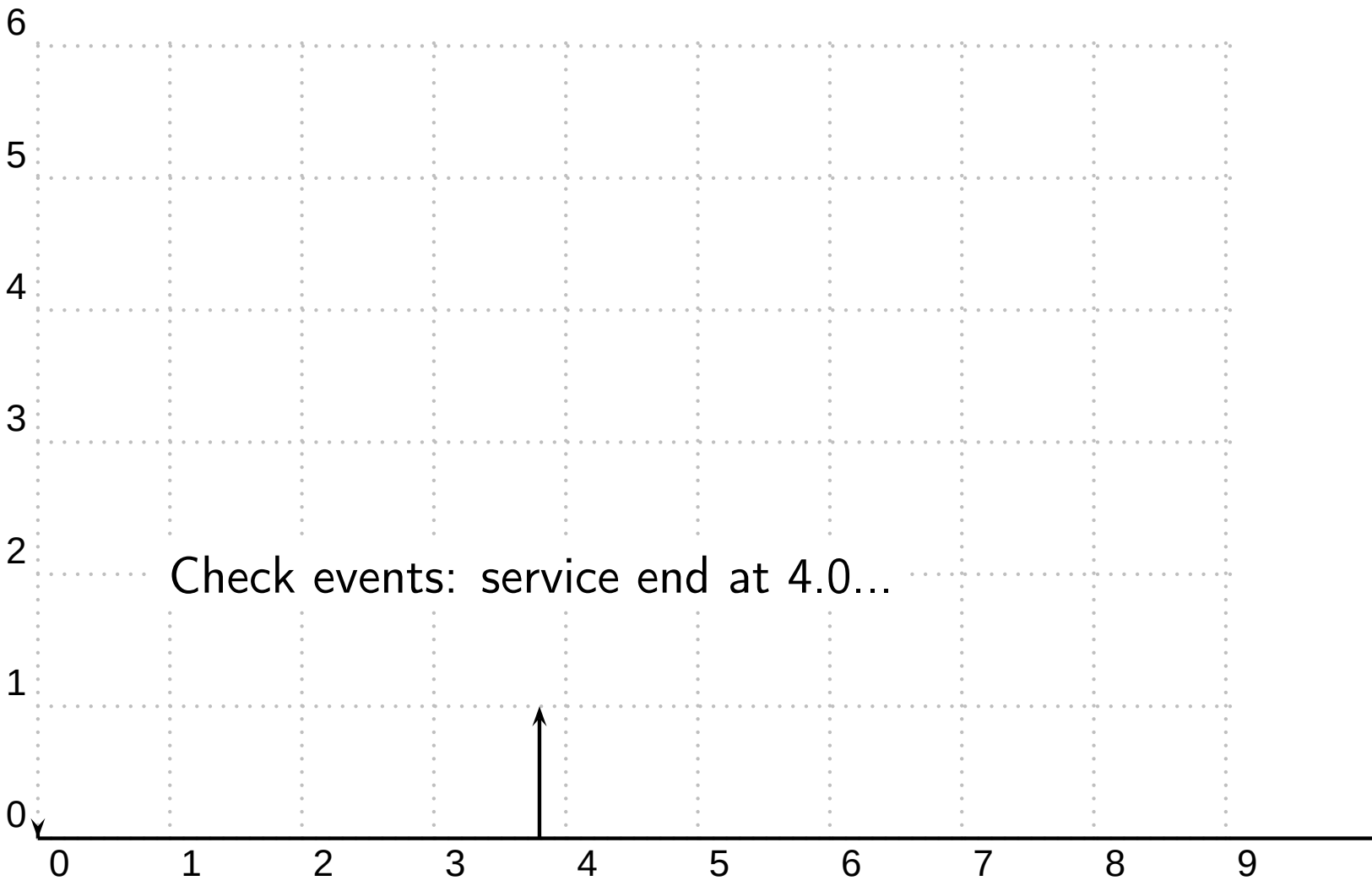

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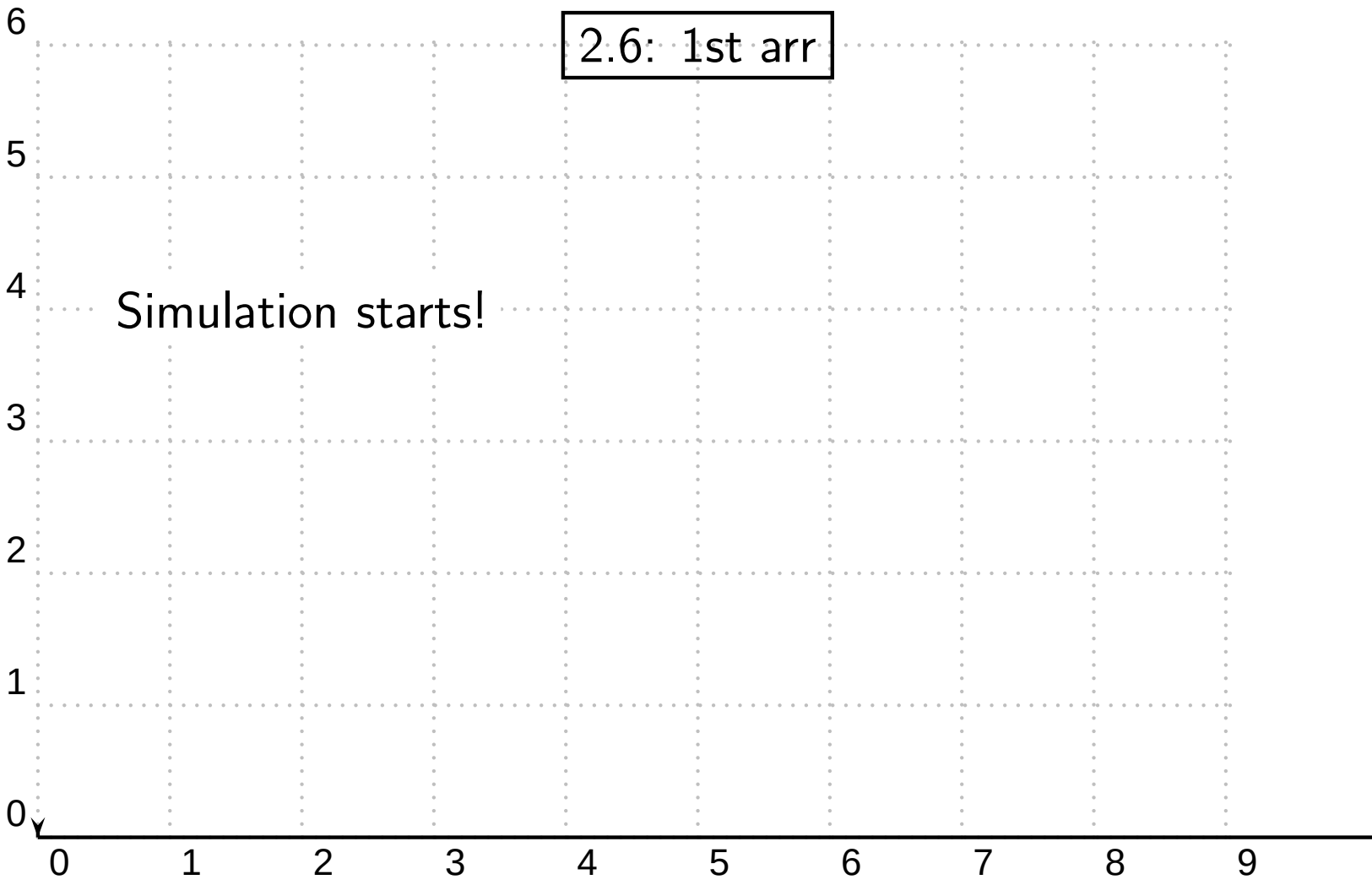

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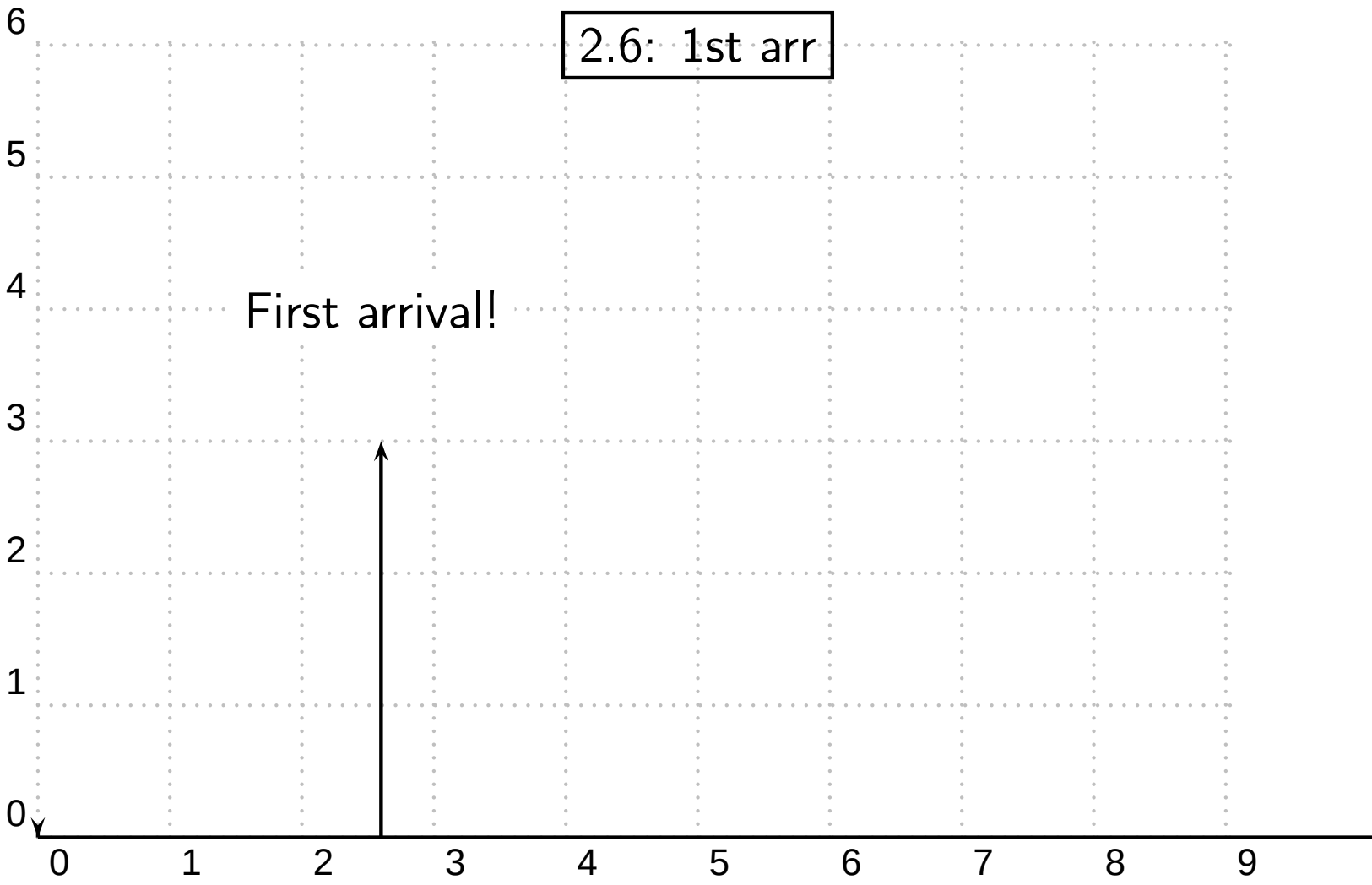

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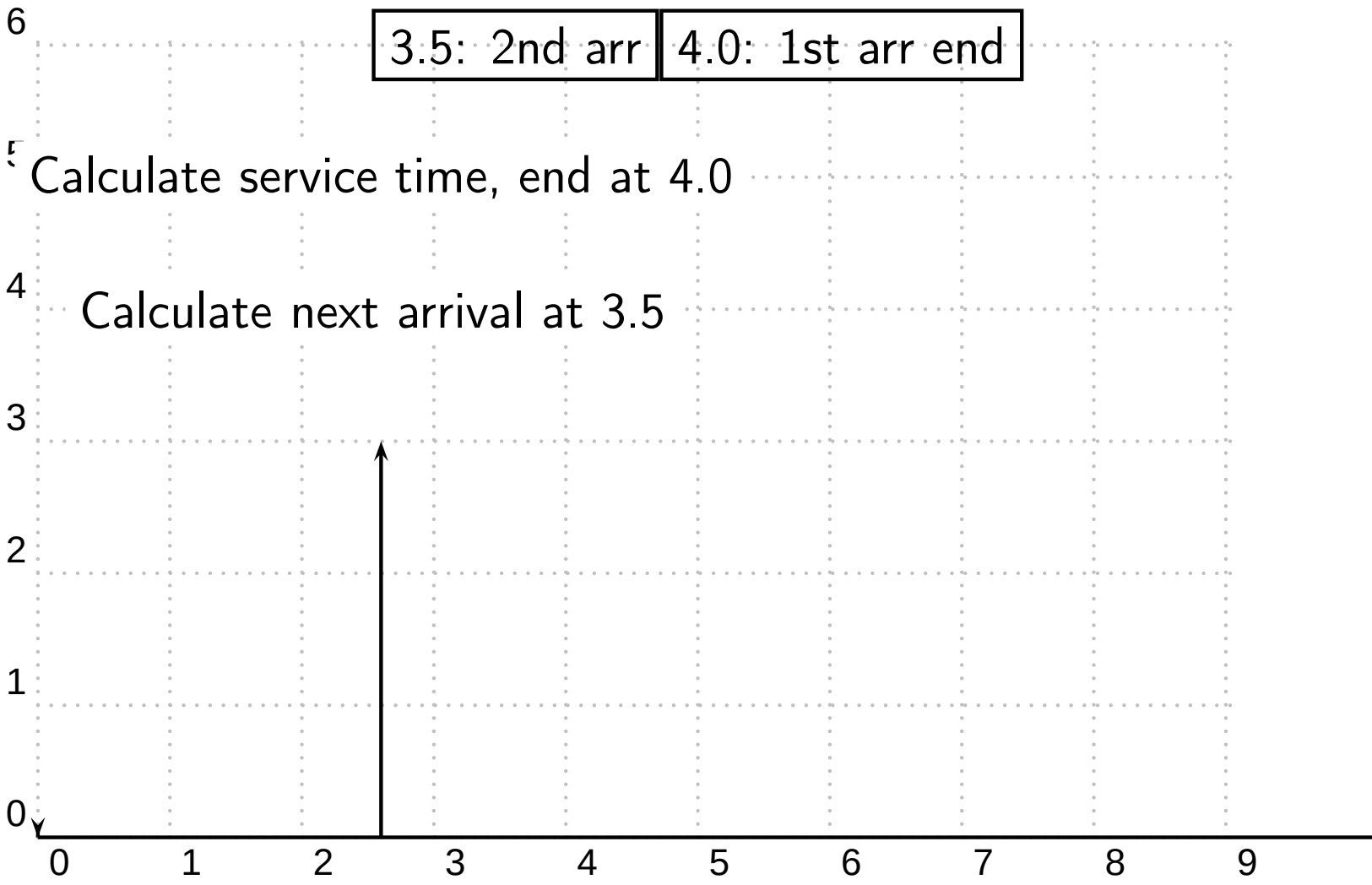

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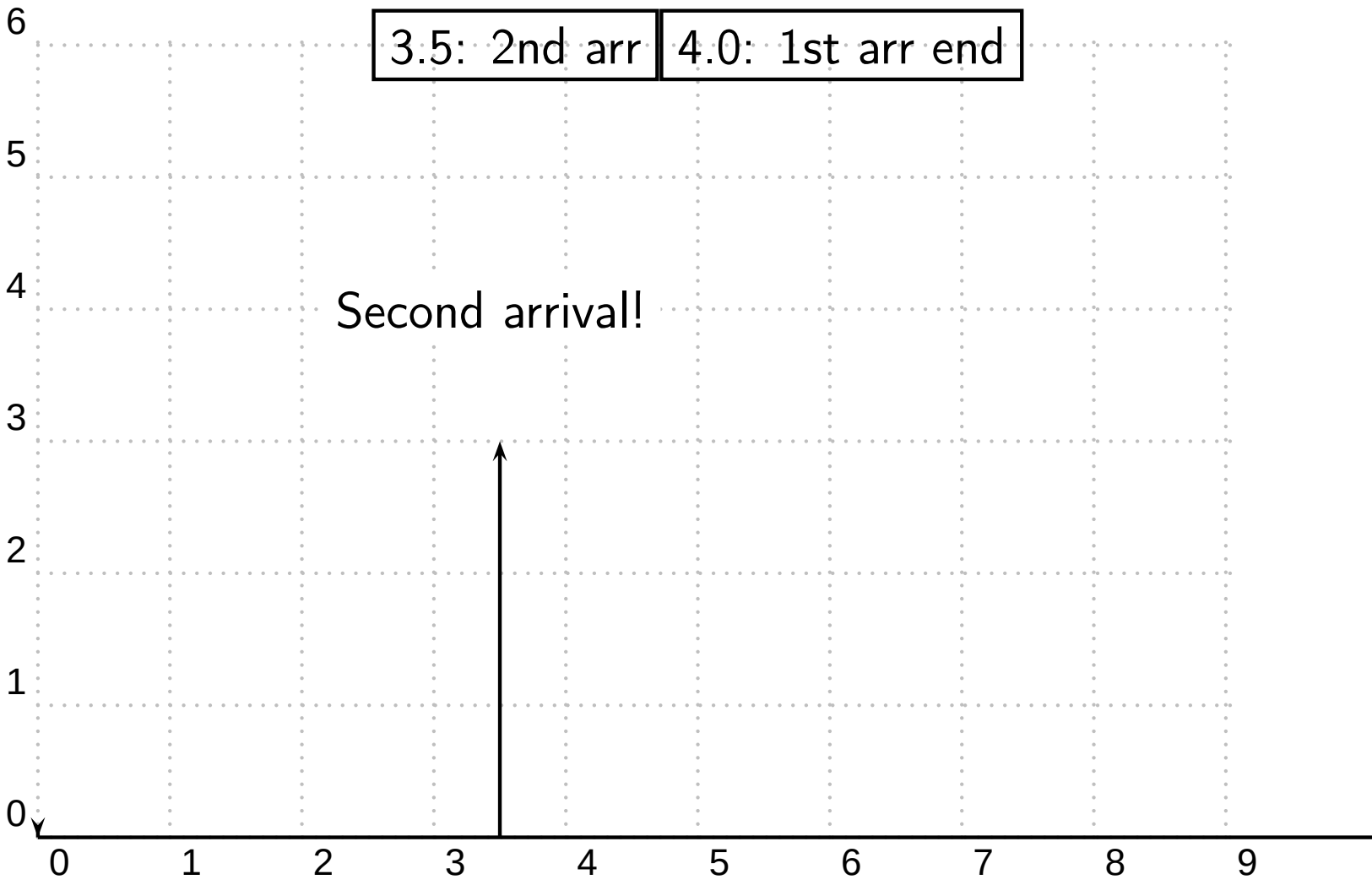

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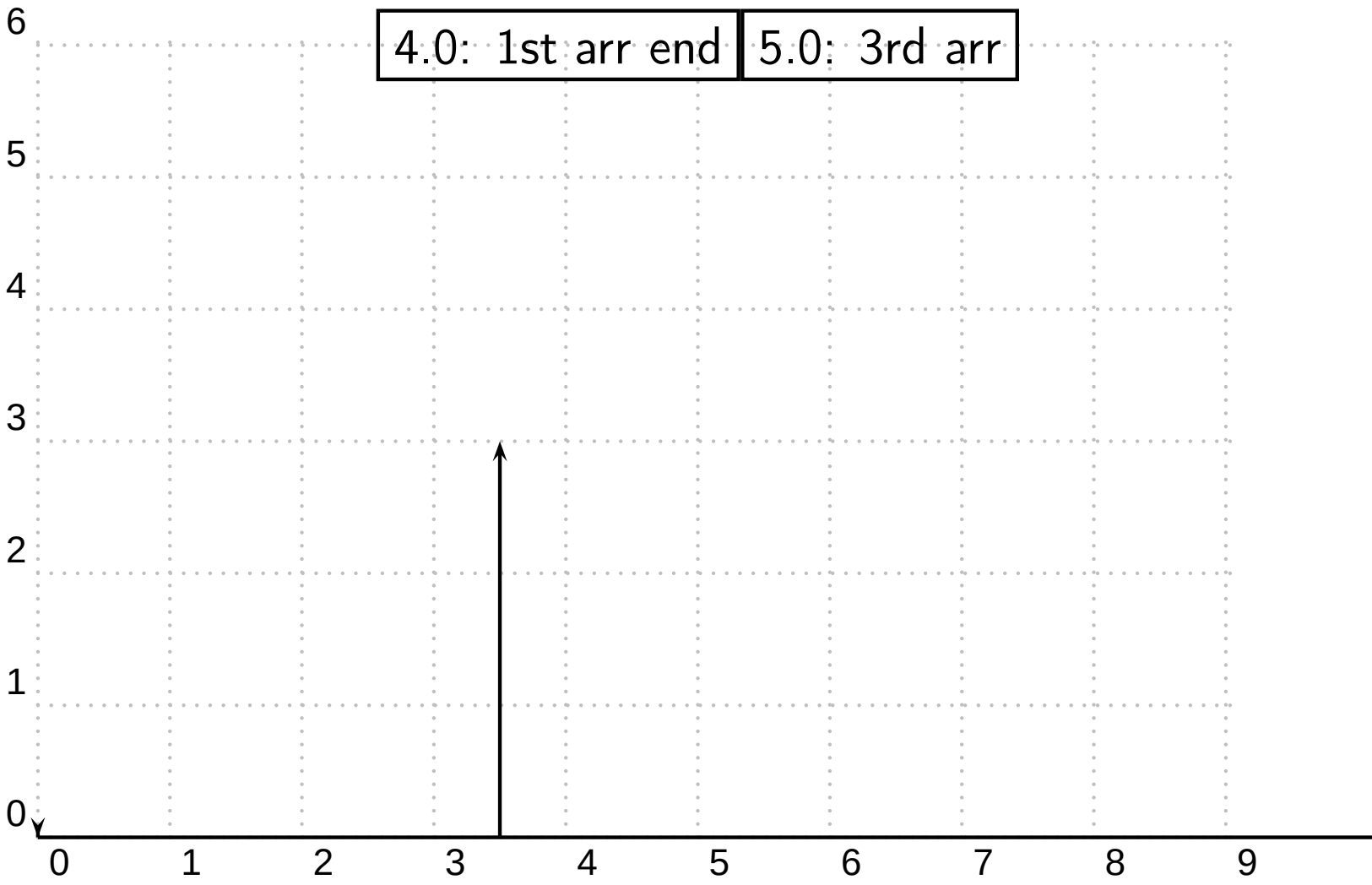

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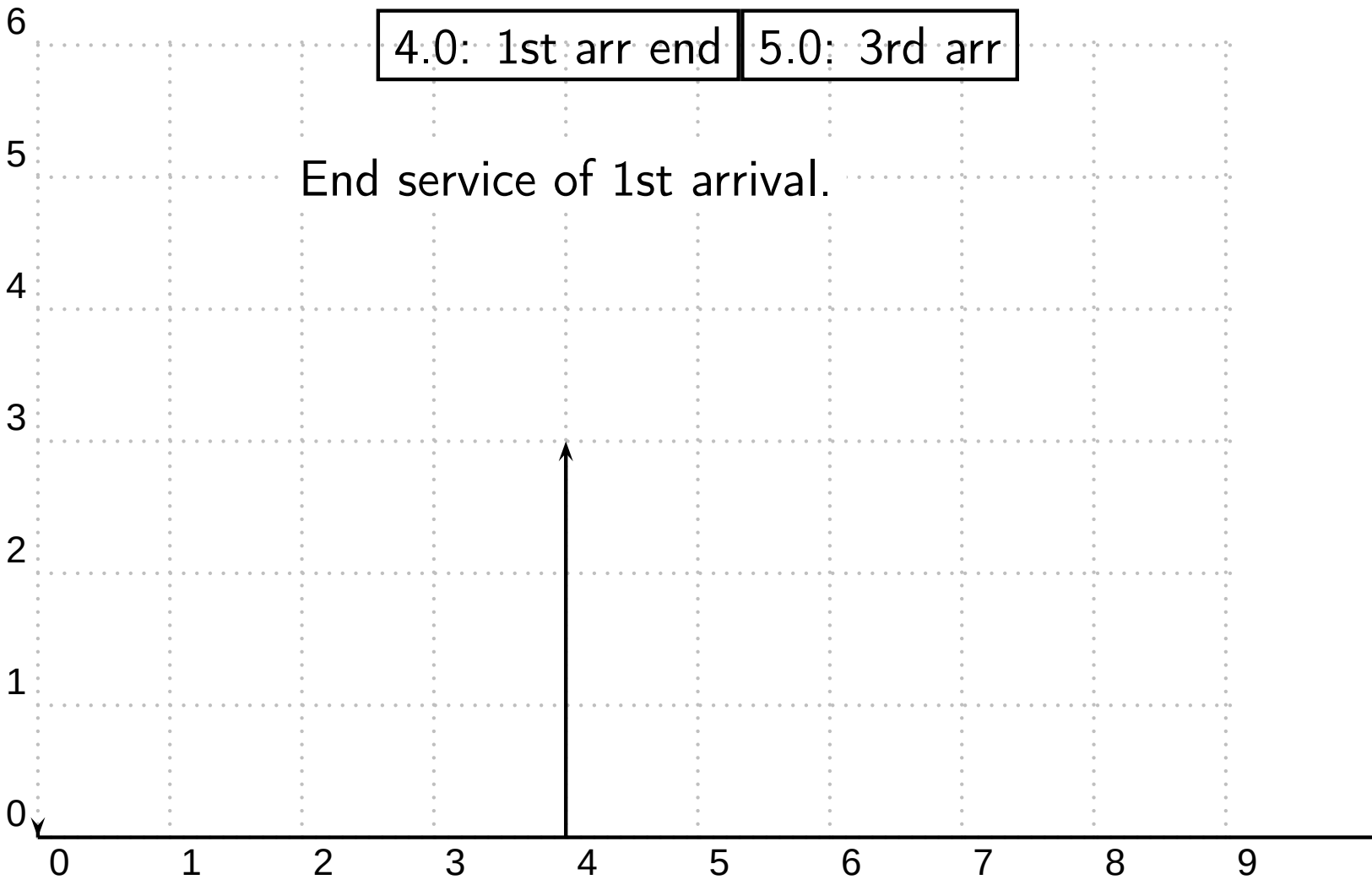

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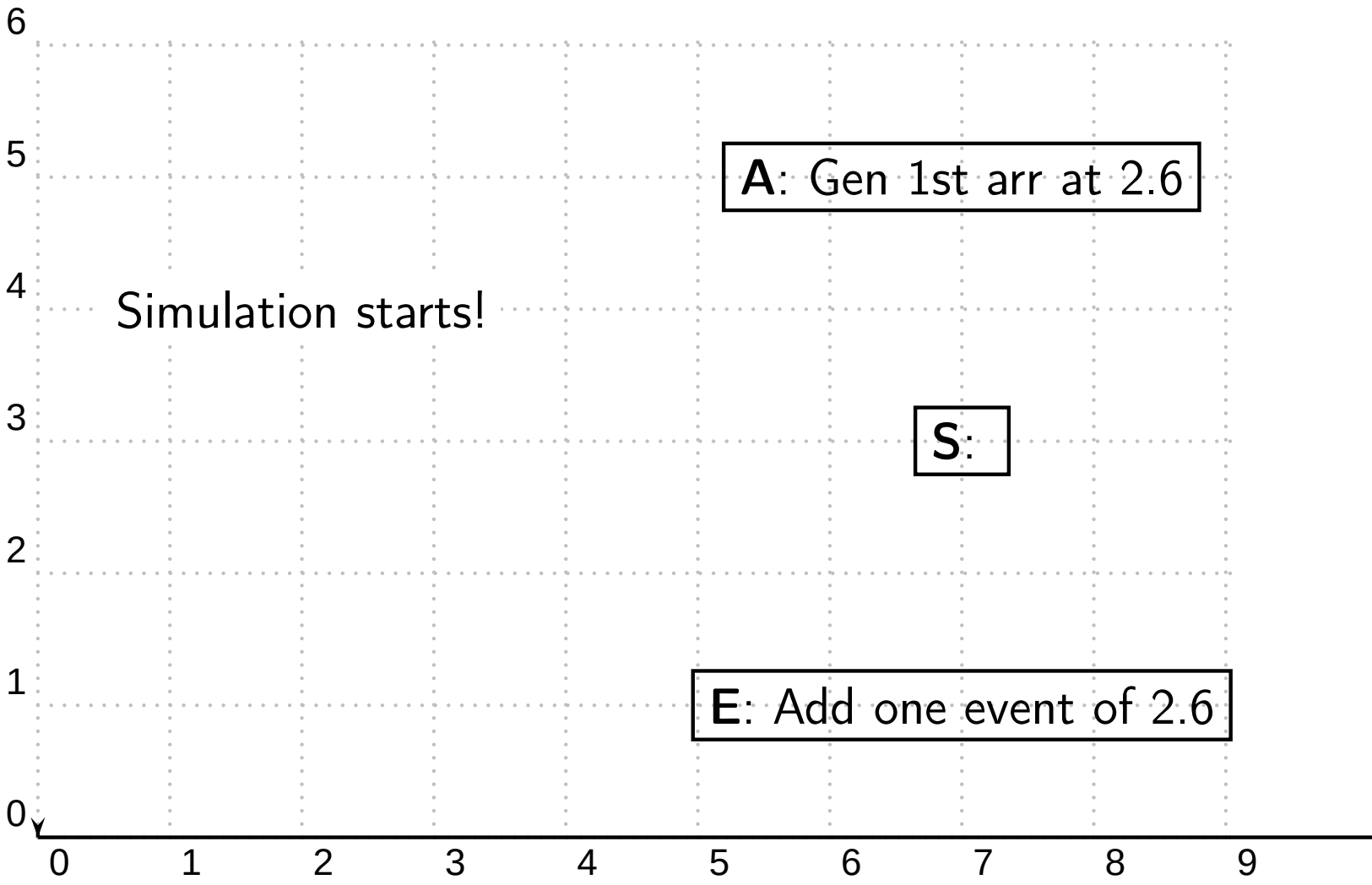
    - Arrival process for customers, or **A**
    - Clerk process, or **S**
    - Event manager, or **E**
  - easier to maintain in the end

Process-Oriented Discrete-Event Simulation



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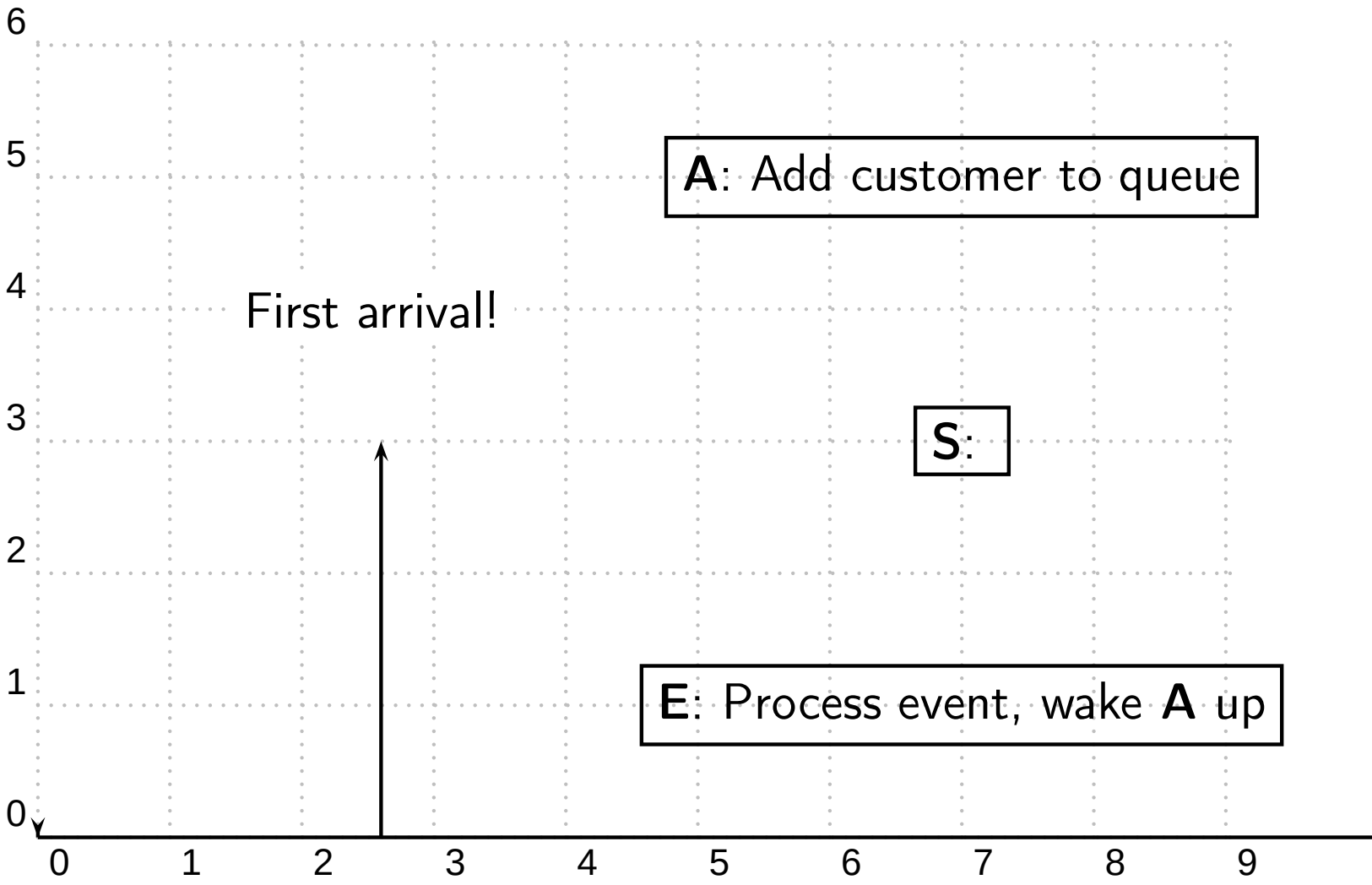

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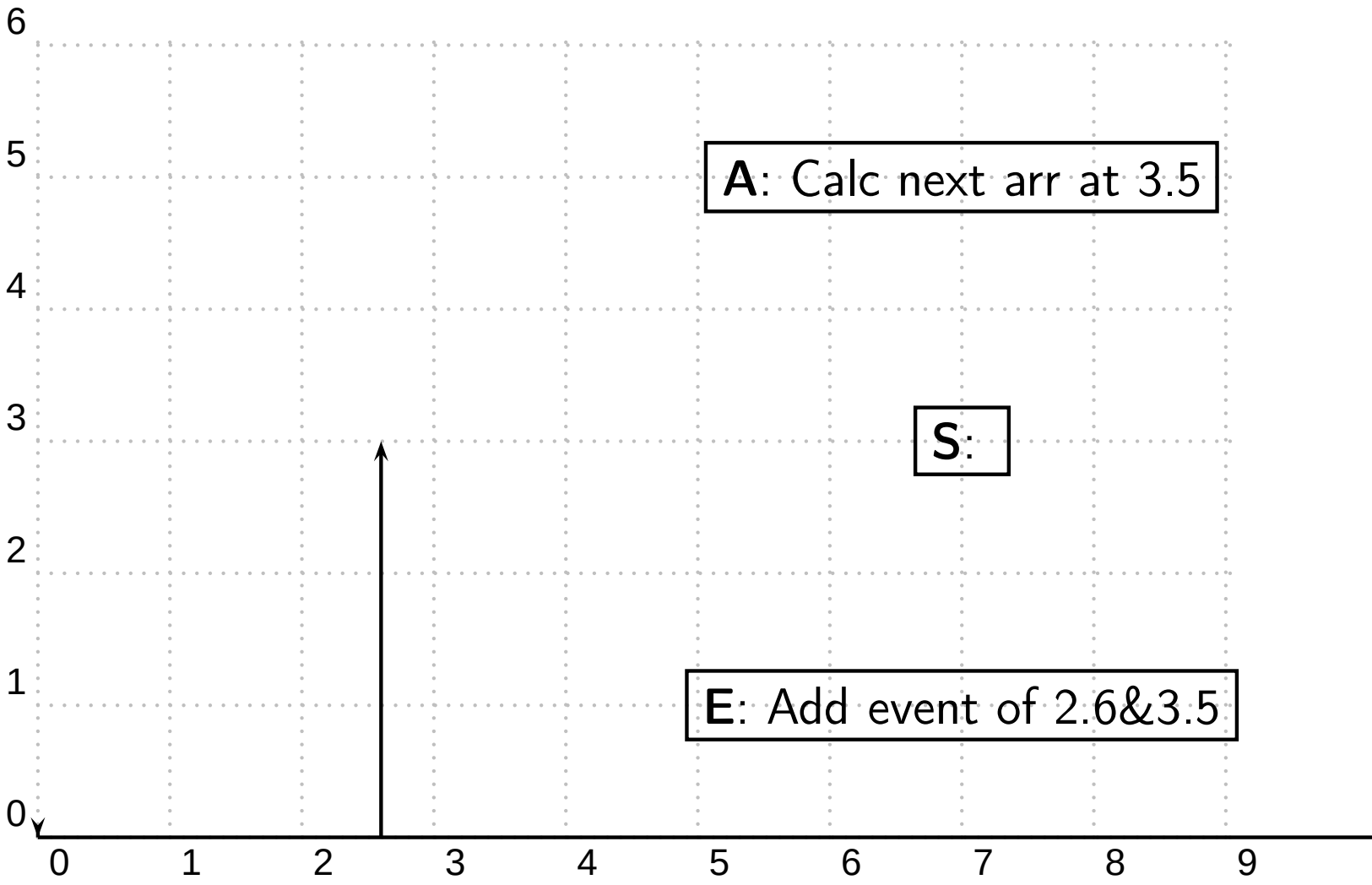

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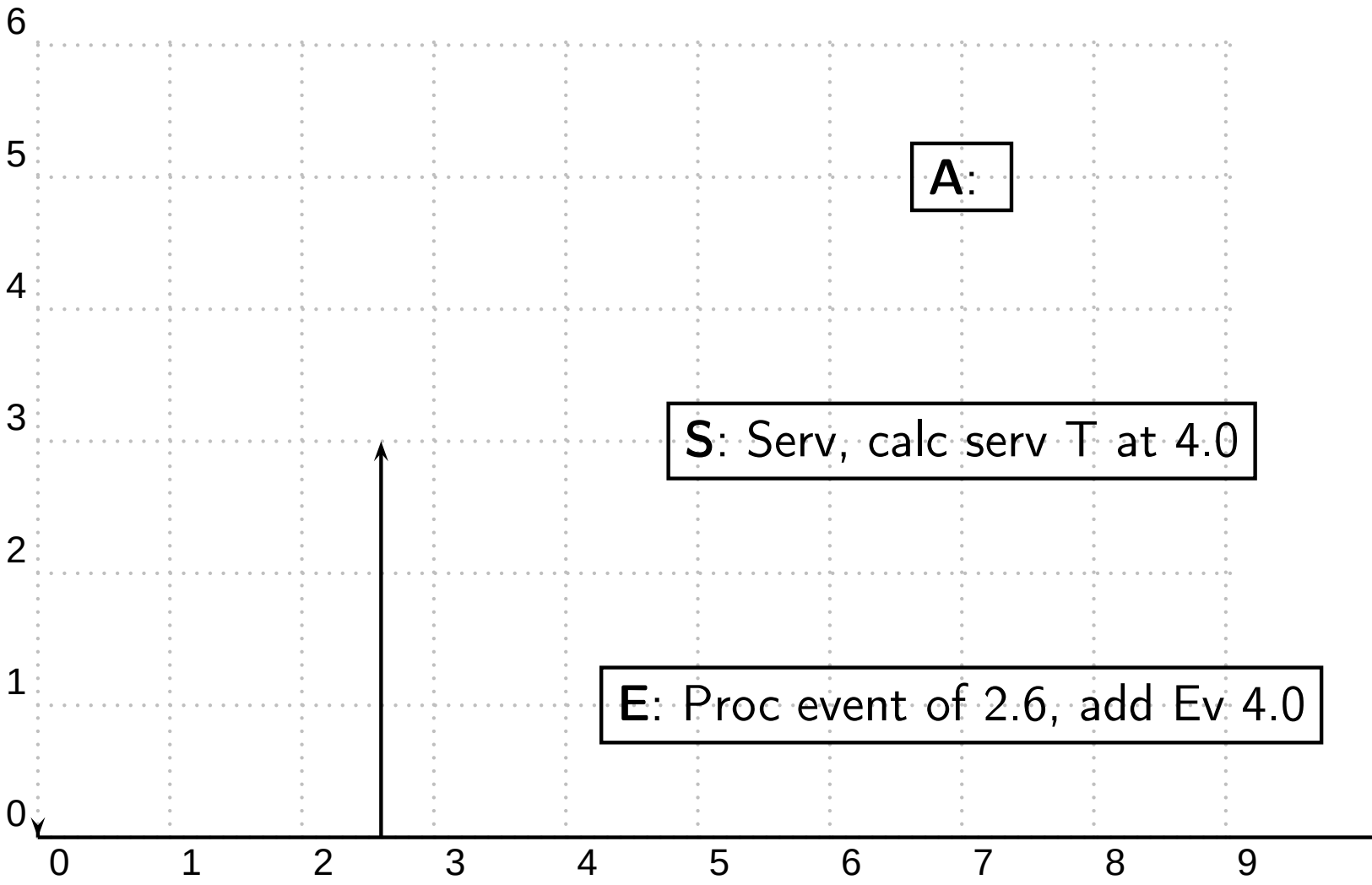

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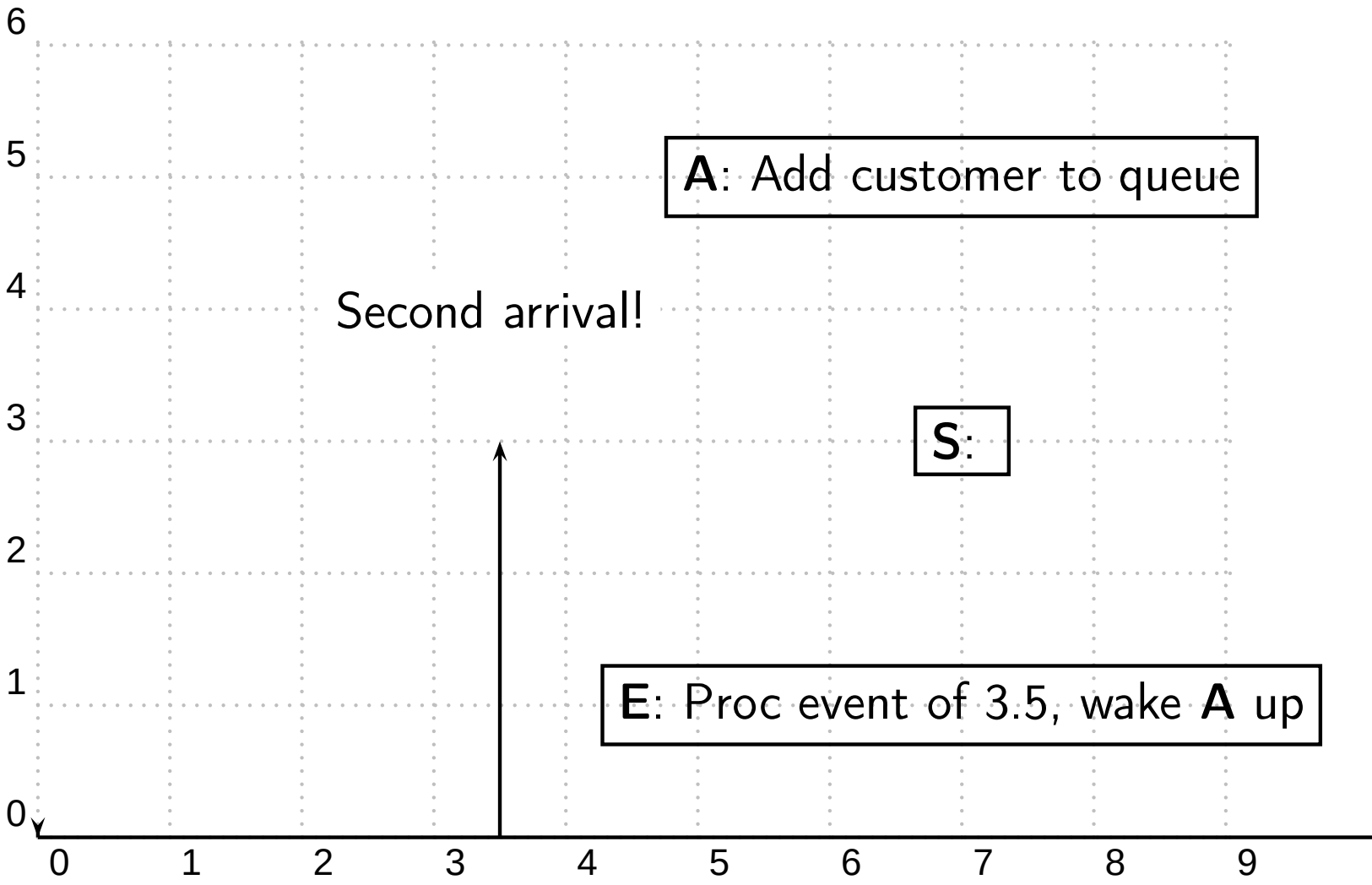

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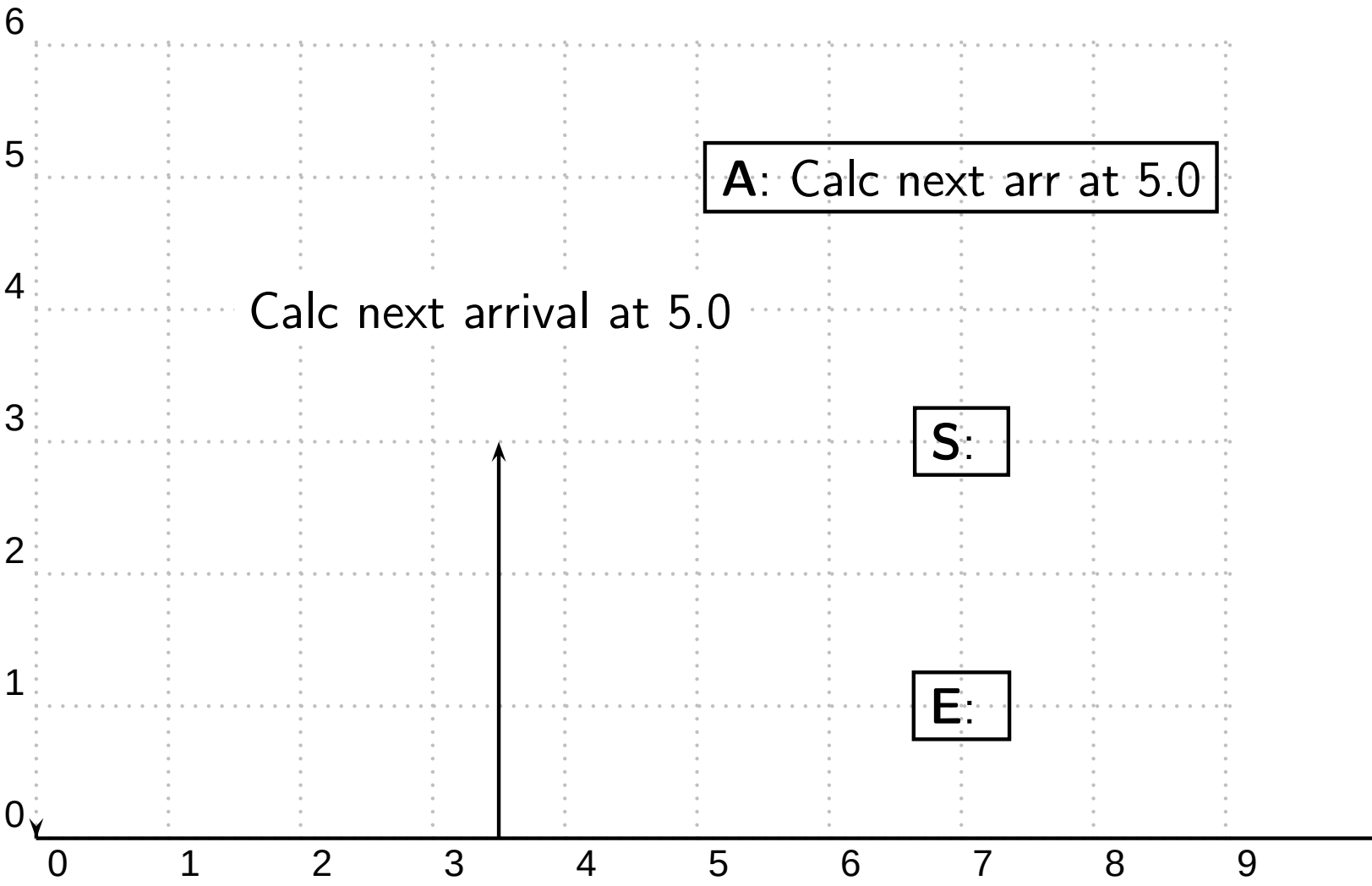

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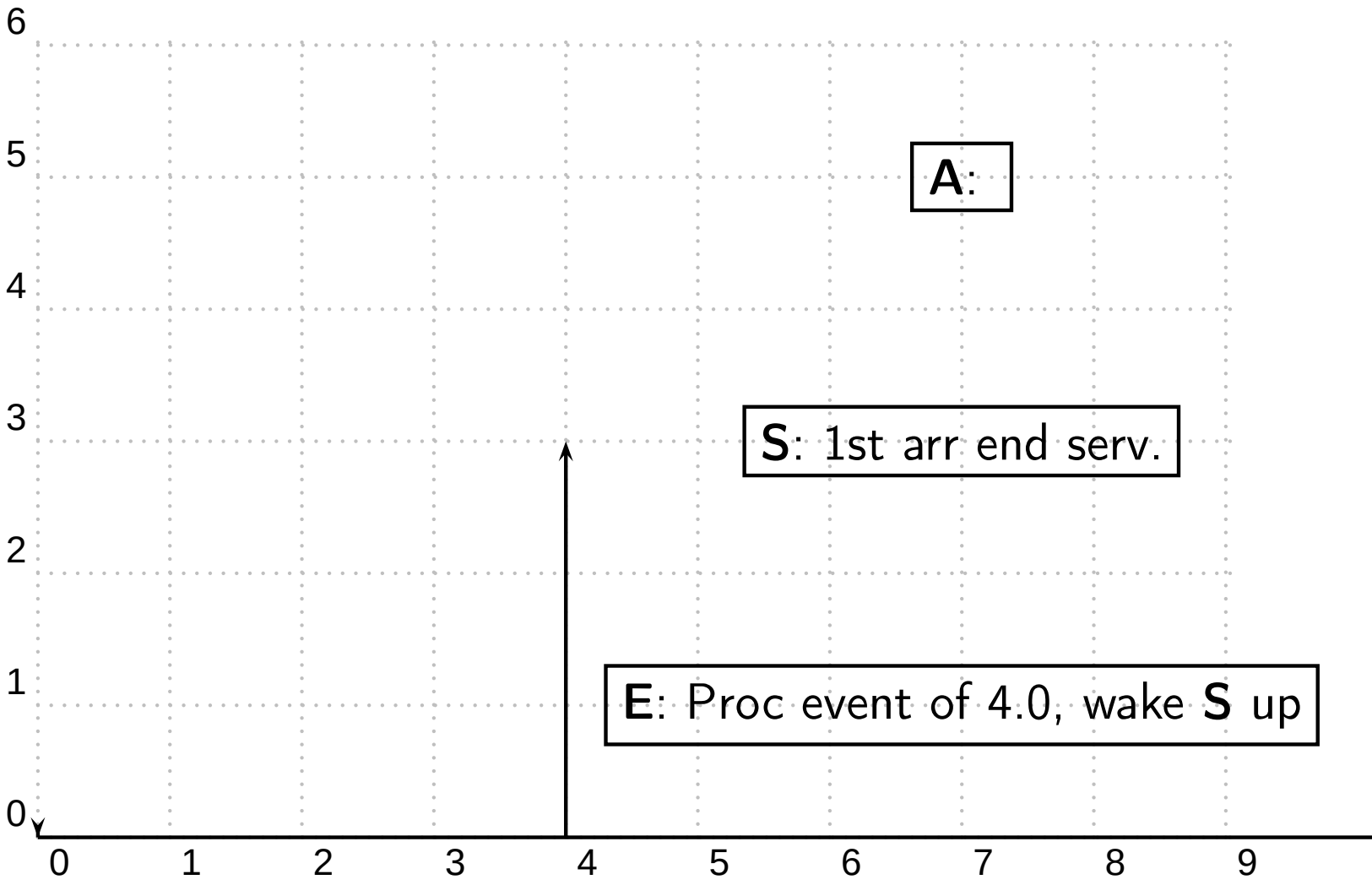

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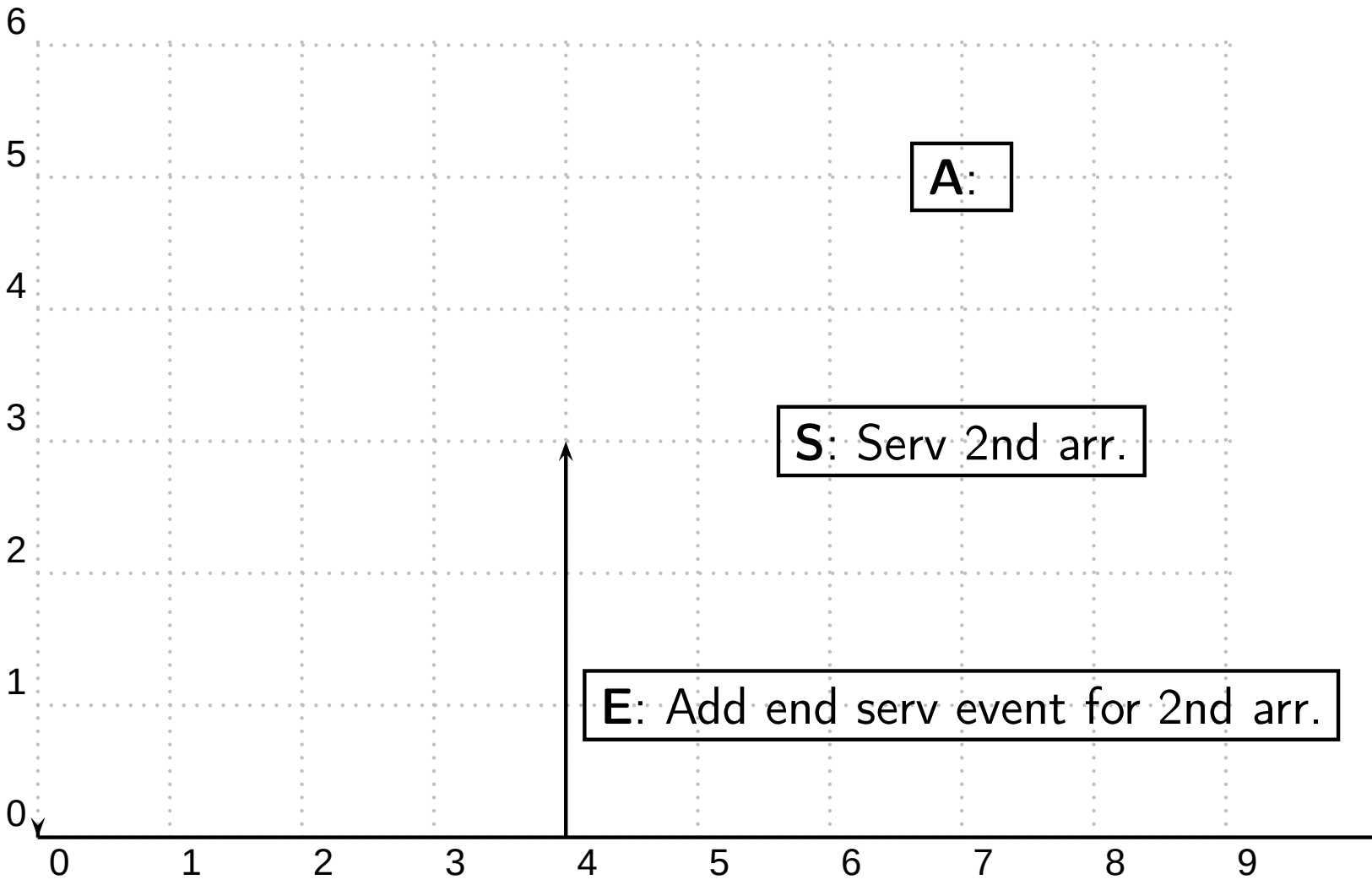

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- Use special purpose simulation packages
  - ns-3 for network simulation [4]

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  - Python is very easy to write and very beautiful!
- Process-oriented Discrete Event Simulation Language
  - easier to write model
  - provides event manager implementation
- Uses coroutine to suspend/resume process
  - will be refered to as **thread** in this presentation
  - guarantees order of execution
  - cannot run on parallel machine

SimPy Terminology: Classes

- Process
  - simulates an entity which evolves in time, e.g. a customer who needs to be served by a clerk
  - refered to as **thread** in [3]

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  - refered to as **thread** in [3]
- Resource
  - simulates something to be queued, e.g. the waiting list

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yield passivate	put current thread into suspension and wait until awakened by some other thread
reactivate()	awakes a previously-passivated thread
cancel()	cancels all the events associated with a previously-passivated thread

SimPy Example

- Scenario
  - A post office with only one clerk.
  - Customers arrival is poisson process,
    i.e. inter-arrival time is exponential distribution.
  - Service time is also poisson process.
- Process
  - Arrival
  - Clerk
- Queue is managed by ourselves.

Arrival Process


```
class ArrivalClass(Process):
    ArrivalRate = 1/1.0                    # reciprocal of mean arrival tim

    def __init__(self):
        Process.__init__(self)

    def Run(self):
        while 1:
            InterArrivalTime = G.Rnd.expovariate(ArrivalClass.ArrivalRat
            yield hold,self,InterArrivalTime
            C = Customer()
            ClerkClass.Queue.append(C) # a customer arrives
            G.NumCustomers += 1

            if ClerkClass.Idle != []:   # Is there any clerk idle?
                reactivate(ClerkClass.Idle[0]) # Yes, wake him/her up
```

Clerk Process


```
class ClerkClass(Process):
    ServiceRate = 1/1.2                    # reciprocal of mean service tim
    MaxQueueLength = 0
    Queue = []
    Idle = []
    Busy = []
    NumDone = 0
    def __init__(self):
        Process.__init__(self)
        ClerkClass.Idle.append(self)       # Initially idle
    def Run(self):
        while 1:
            yield passivate,self           # wait until awaken by customers
            ClerkClass.Idle.remove(self)
            ClerkClass.Busy.append(self) # going to be busy
            while ClerkClass.Queue != []:
                C = ClerkClass.Queue.pop() # call next customer in line
                if len(ClerkClass.Queue) > ClerkClass.MaxQueueLength:
                    ClerkClass.MaxQueueLength = len(ClerkClass.Queue)
                # Start service the customer
                ServiceTime = G.Rnd.expovariate(ClerkClass.ServiceRate)
                yield hold,self,ServiceTime
                C.endService()
                G.TotalWaitingTime += C.WaitingTime
                ClerkClass.NumDone += 1
                del C

            ClerkClass.Busy.remove(self)
            ClerkClass.Idle.append(self)
```

Live Demo

Important Simulation Parameters

Purpose List below parameters to prove that your work is repeatable.

RNG Random number generator method

- Linear Congruential Method
  - oldest and best well known
- Mersenne Twister
  - designed with simulation purpose in mind
  - used to implement random library in python after version 2.5

RNG Random number generator seed

Concluding Remarks

- Simulation is a powerful tool to study physical problems with cheaper cost.
- SimPy provides process-oriendted DES framework to write simlation easily and reasonably fast.

References

[1] JavaSIM and C++SIM. http://javasim.codehaus.org/.

[2] Jerry Banks, John S. Carson, Barry L. Nelson, and David M. Nicol. *Discrete-Event System Simulation (5th Edition)*. Prentice Hall, 2009.

[3] N Matloff. A discrete-event simulation course based on the simpy language. *Davis*, 2006.

[4] ns -3 Network Simulator. http://www.nsnam.org/.

[5] SimPy Simulation Package. http://simpy.sourceforge.net/.

Q & A