Efficient Large-scale Trace Checking using MapReduce

Srđan Krstić

with

Marcello M. Bersani, Domenico Bianculli, Carlo Ghezzi and Pierluigi San Pietro

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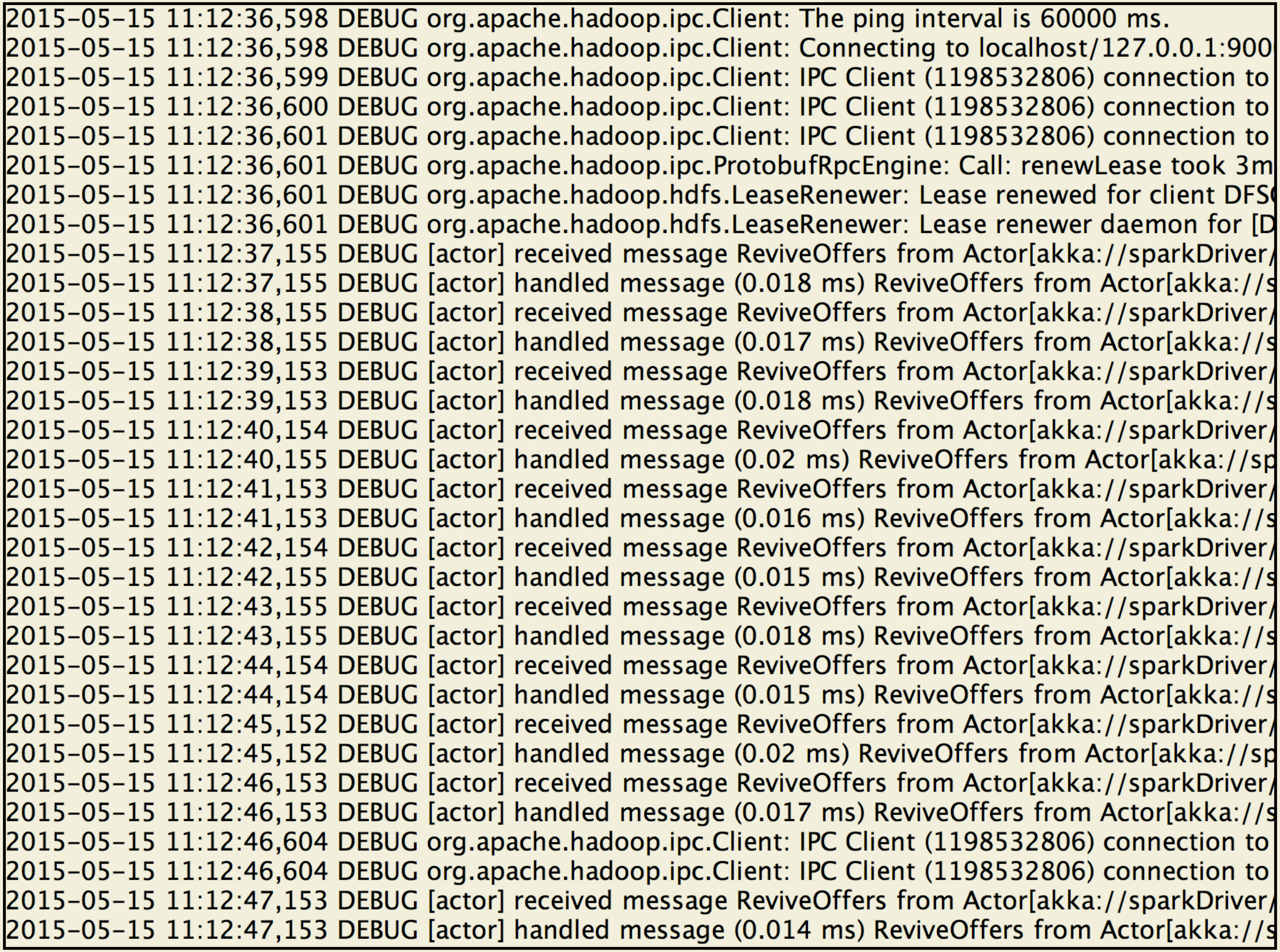

```
2015-05-15 11:12:36,598 DEBUG org.apache.hadoop.ipc.Client: The ping interval is 60000 ms.
2015-05-15 11:12:36,598 DEBUG org.apache.hadoop.ipc.Client: Connecting to localhost/127.0.0.1:900
2015-05-15 11:12:36,599 DEBUG org.apache.hadoop.ipc.Client: IPC Client (1198532806) connection to
2015-05-15 11:12:36,600 DEBUG org.apache.hadoop.ipc.Client: IPC Client (1198532806) connection to
2015-05-15 11:12:36,601 DEBUG org.apache.hadoop.ipc.Client: IPC Client (1198532806) connection to
2015-05-15 11:12:36,601 DEBUG org.apache.hadoop.ipc.ProtobufRpcEngine: Call: renewLease took 3m
2015-05-15 11:12:36,601 DEBUG org.apache.hadoop.hdfs.LeaseRenewer: Lease renewed for client DFS
2015-05-15 11:12:36,601 DEBUG org.apache.hadoop.hdfs.LeaseRenewer: Lease renewer daemon for [D
2015-05-15 11:12:37,155 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:37,155 DEBUG [actor] handled message (0.018 ms) ReviveOffers from Actor[akka://s
2015-05-15 11:12:38,155 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:38,155 DEBUG [actor] handled message (0.017 ms) ReviveOffers from Actor[akka://s
2015-05-15 11:12:39,153 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:39,153 DEBUG [actor] handled message (0.018 ms) ReviveOffers from Actor[akka://s
2015-05-15 11:12:40,154 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:40,155 DEBUG [actor] handled message (0.02 ms) ReviveOffers from Actor[akka://sp
2015-05-15 11:12:41,153 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:41,153 DEBUG [actor] handled message (0.016 ms) ReviveOffers from Actor[akka://s
2015-05-15 11:12:42,154 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:42,155 DEBUG [actor] handled message (0.015 ms) ReviveOffers from Actor[akka://s
2015-05-15 11:12:43,155 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:43,155 DEBUG [actor] handled message (0.018 ms) ReviveOffers from Actor[akka://s
2015-05-15 11:12:44,154 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:44,154 DEBUG [actor] handled message (0.015 ms) ReviveOffers from Actor[akka://s
2015-05-15 11:12:45,152 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:45,152 DEBUG [actor] handled message (0.02 ms) ReviveOffers from Actor[akka://sp
2015-05-15 11:12:46,153 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:46,153 DEBUG [actor] handled message (0.017 ms) ReviveOffers from Actor[akka://s
2015-05-15 11:12:46,604 DEBUG org.apache.hadoop.ipc.Client: IPC Client (1198532806) connection to
2015-05-15 11:12:46,604 DEBUG org.apache.hadoop.ipc.Client: IPC Client (1198532806) connection to
2015-05-15 11:12:47,153 DEBUG [actor] received message ReviveOffers from Actor[akka://sparkDriver/
2015-05-15 11:12:47,153 DEBUG [actor] handled message (0.014 ms) ReviveOffers from Actor[akka://s
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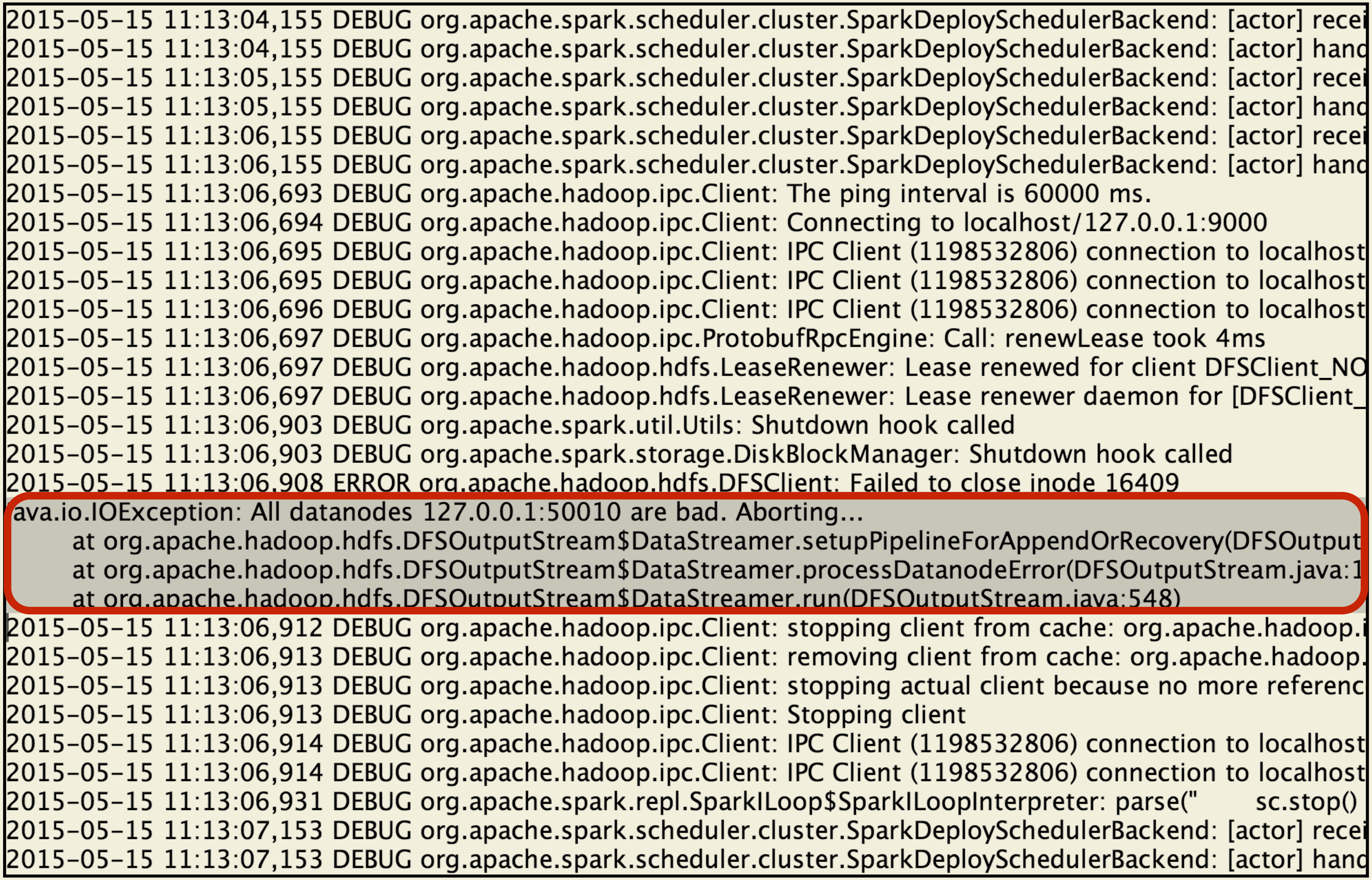

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2015-05-15 11:13:04,155 DEBUG org.apache.spark.scheduler.cluster.SparkDeploySchedulerBackend: [actor] recei
2015-05-15 11:13:04,155 DEBUG org.apache.spark.scheduler.cluster.SparkDeploySchedulerBackend: [actor] hand
2015-05-15 11:13:05,155 DEBUG org.apache.spark.scheduler.cluster.SparkDeploySchedulerBackend: [actor] recei
2015-05-15 11:13:05,155 DEBUG org.apache.spark.scheduler.cluster.SparkDeploySchedulerBackend: [actor] hand
2015-05-15 11:13:06,155 DEBUG org.apache.spark.scheduler.cluster.SparkDeploySchedulerBackend: [actor] recei
2015-05-15 11:13:06,155 DEBUG org.apache.spark.scheduler.cluster.SparkDeploySchedulerBackend: [actor] hand
2015-05-15 11:13:06,693 DEBUG org.apache.hadoop.ipc.Client: The ping interval is 60000 ms.
2015-05-15 11:13:06,694 DEBUG org.apache.hadoop.ipc.Client: Connecting to localhost/127.0.0.1:9000
2015-05-15 11:13:06,695 DEBUG org.apache.hadoop.ipc.Client: IPC Client (1198532806) connection to localhost
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2015-05-15 11:13:06,697 DEBUG org.apache.hadoop.ipc.ProtobufRpcEngine: Call: renewLease took 4ms
2015-05-15 11:13:06,697 DEBUG org.apache.hadoop.hdfs.LeaseRenewer: Lease renewed for client DFSClient_NO
2015-05-15 11:13:06,697 DEBUG org.apache.hadoop.hdfs.LeaseRenewer: Lease renewer daemon for [DFSClient_
2015-05-15 11:13:06,903 DEBUG org.apache.spark.util.Utils: Shutdown hook called
2015-05-15 11:13:06,903 DEBUG org.apache.spark.storage.DiskBlockManager: Shutdown hook called
2015-05-15 11:13:06,908 ERROR org.apache.hadoop.hdfs.DFSClient: Failed to close inode 16409
ava.io.IOException: All datanodes 127.0.0.1:50010 are bad. Aborting...
        at org.apache.hadoop.hdfs.DFSOutputStream$DataStreamer.setupPipelineForAppendOrRecovery(DFSOutput
        at org.apache.hadoop.hdfs.DFSOutputStream$DataStreamer.processDatanodeError(DFSOutputStream.java:1
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2015-05-15 11:13:06,912 DEBUG org.apache.hadoop.ipc.Client: stopping client from cache: org.apache.hadoop.i
2015-05-15 11:13:06,913 DEBUG org.apache.hadoop.ipc.Client: removing client from cache: org.apache.hadoop.
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2015-05-15 11:13:06,931 DEBUG org.apache.spark.repl.SparkILoop$SparkILoopInterpreter: parse("       sc.stop()
2015-05-15 11:13:07,153 DEBUG org.apache.spark.scheduler.cluster.SparkDeploySchedulerBackend: [actor] recei
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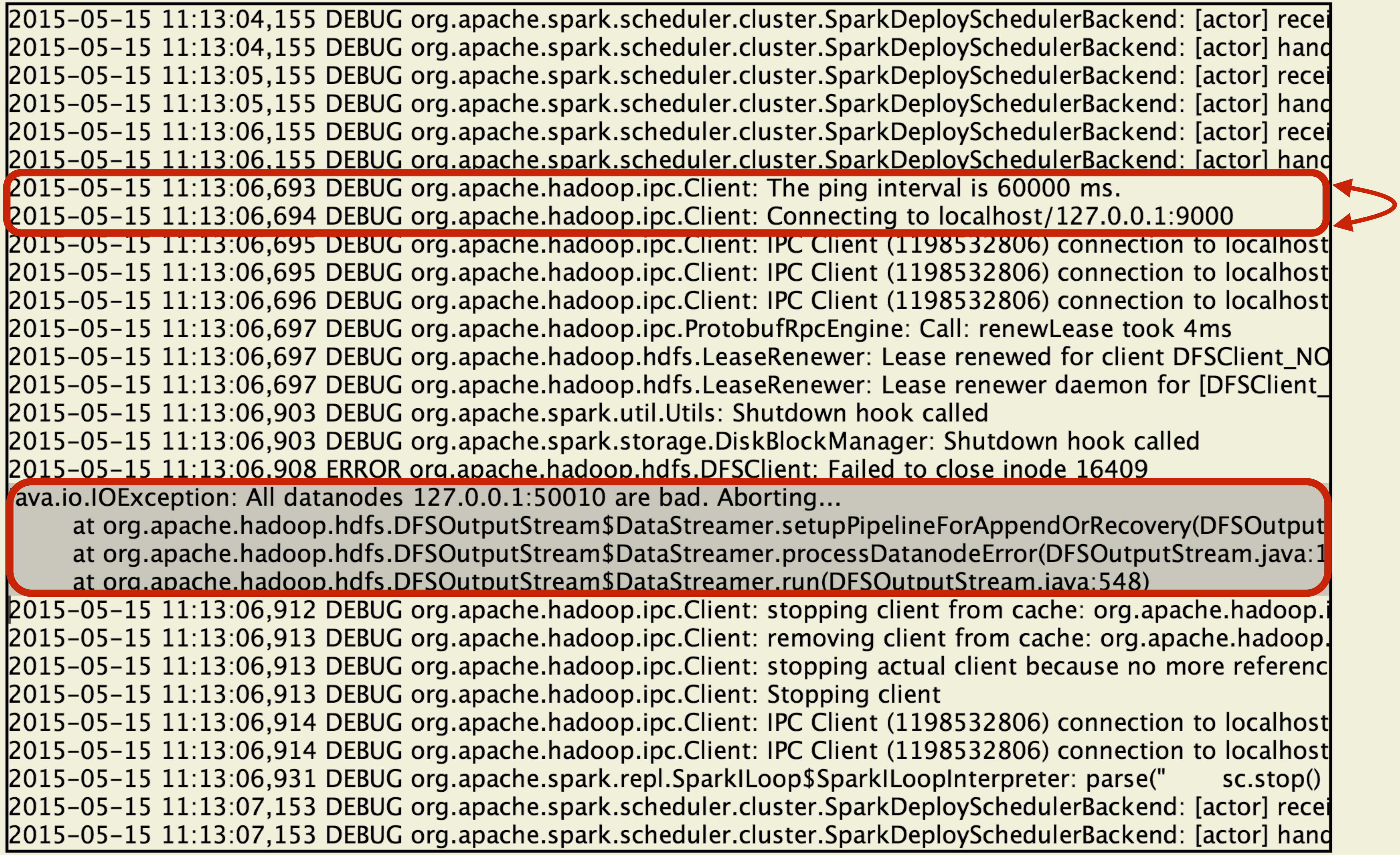

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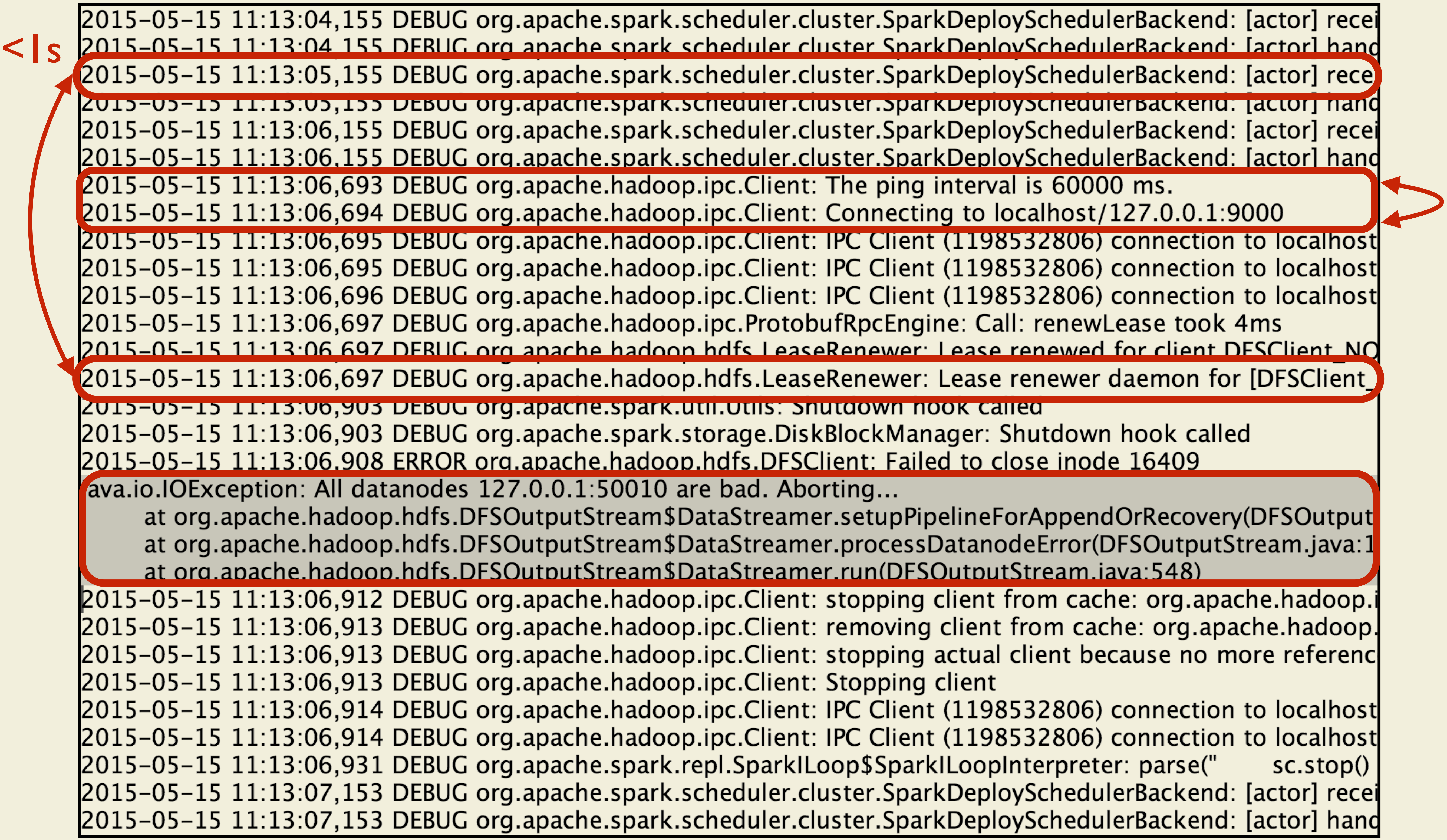

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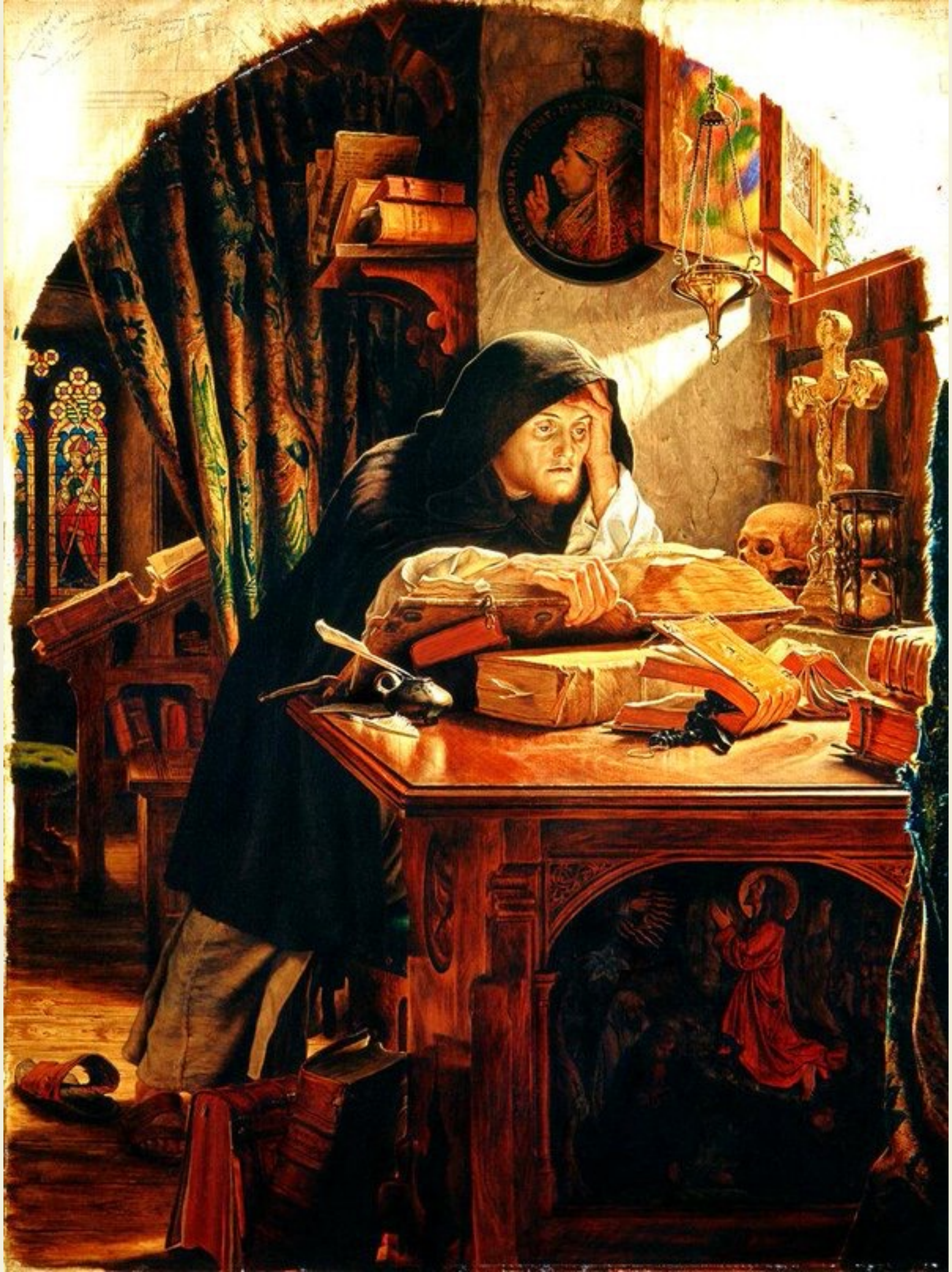


“Developer looking at production logs after a regression with downtime”

Sir Joseph Noel Paton, Oil on Canvas, 1861

Trace Checking

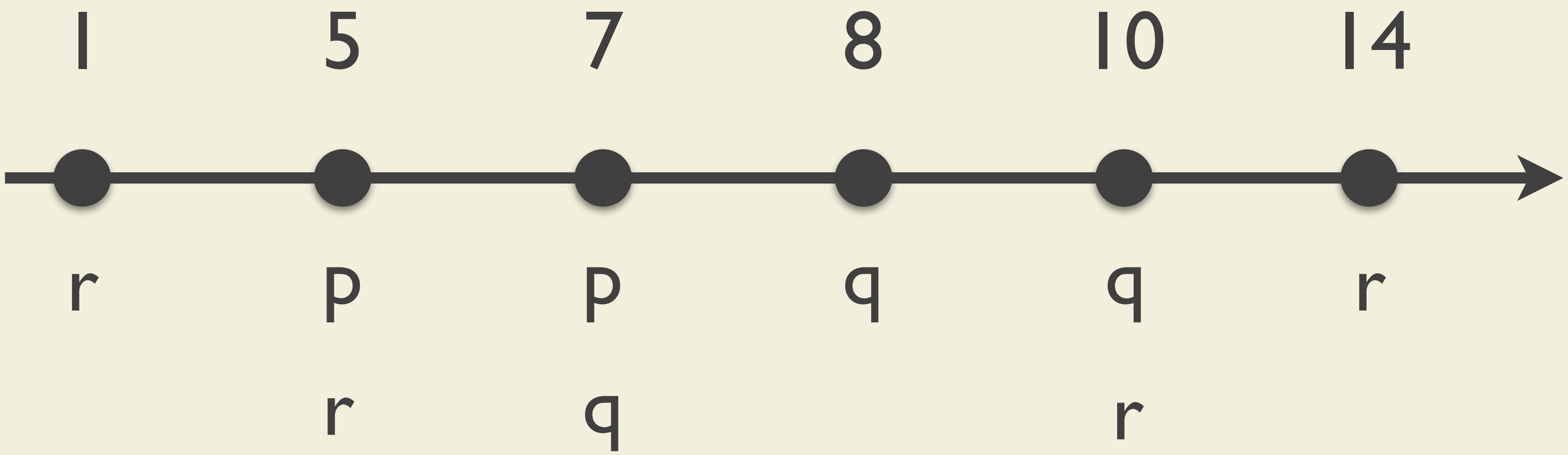
“Automatic procedure for evaluating a formal specification over a trace of recorded events produced by a system”

How do we specify properties to check?

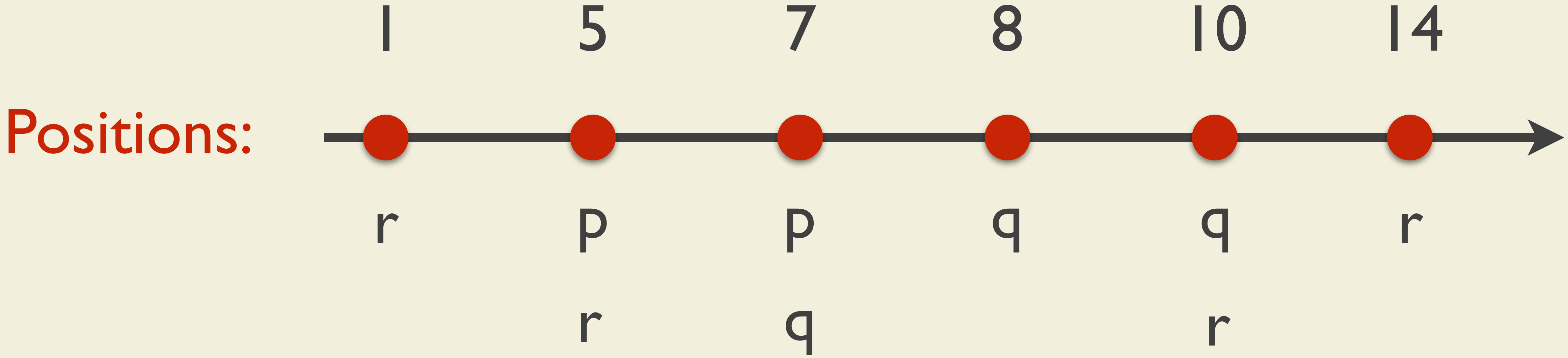
Metric Temporal Logic

$$\phi ::= p \mid \neg\phi \mid \phi \vee \phi \mid \phi \mathsf{U}_{\mathsf{I}} \phi$$

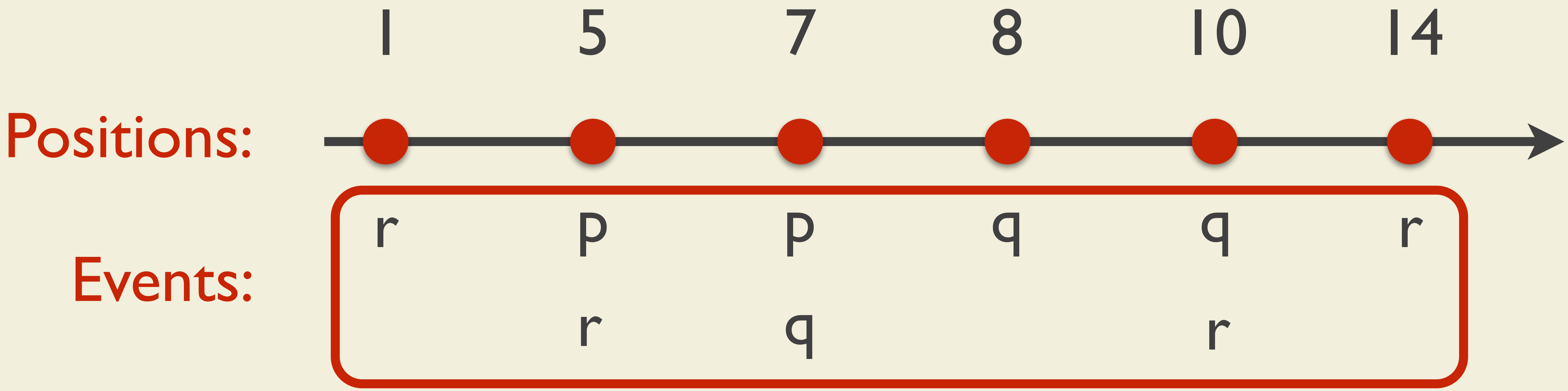
Model: Timed Word



Model: Timed Word

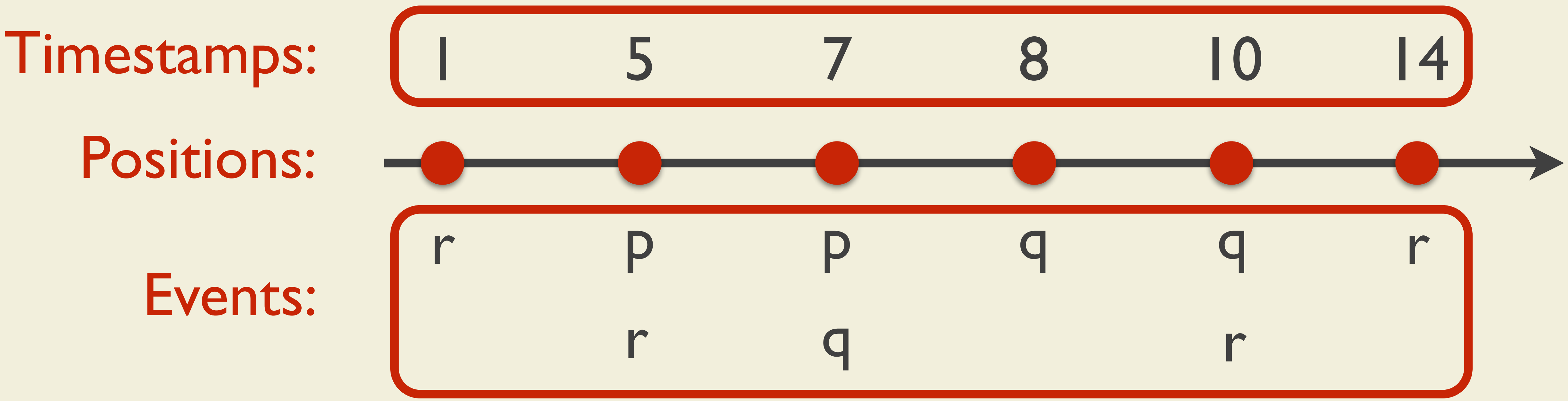


Model: Timed Word



	1	5	7	8	10	14
Positions:	●	●	●	●	●	●
Events:	r	p r	p q	q	q r	r

Model: Timed Word



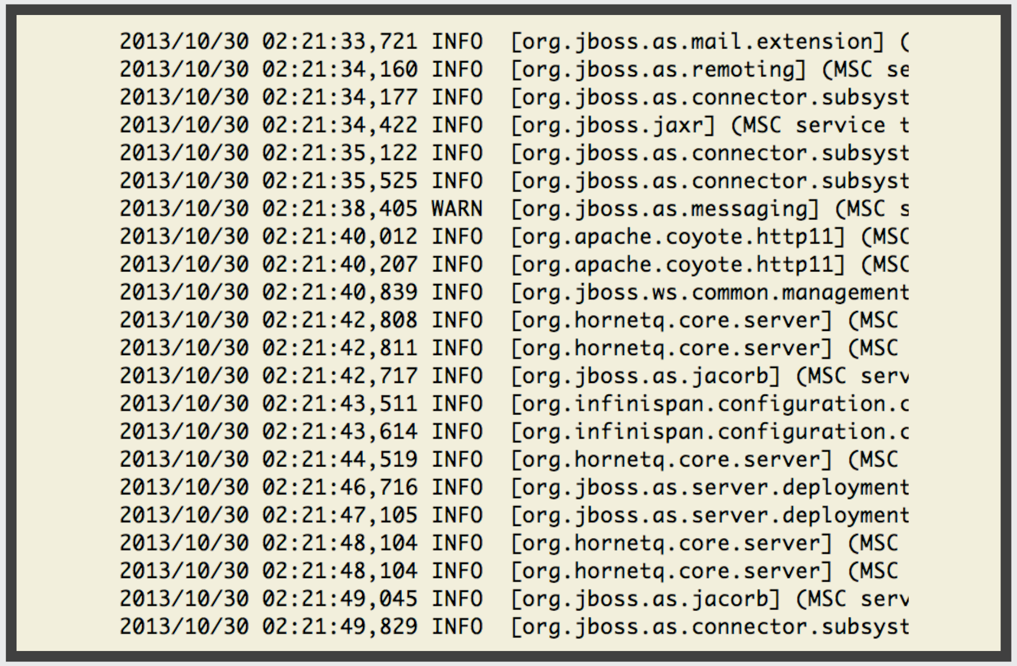
Timestamps:	1	5	7	8	10	14
Positions:	●	●	●	●	●	●
Events:	r	p r	p q	q	q r	r

MTL Semantics

$$\mathsf{F}_I(\phi)$$

"Formula ϕ holds eventually in the future within a time window I"

MTL Trace Checking: Challenges



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2013/10/30 02:21:33,721 INFO  [org.jboss.as.mail.extension] (
2013/10/30 02:21:34,160 INFO  [org.jboss.as.remoting] (MSC se
2013/10/30 02:21:34,177 INFO  [org.jboss.as.connector.subsyst
2013/10/30 02:21:34,422 INFO  [org.jboss.jaxr] (MSC service t
2013/10/30 02:21:35,122 INFO  [org.jboss.as.connector.subsyst
2013/10/30 02:21:35,525 INFO  [org.jboss.as.connector.subsyst
2013/10/30 02:21:38,405 WARN  [org.jboss.as.messaging] (MSC s
2013/10/30 02:21:40,012 INFO  [org.apache.coyote.http11] (MSC
2013/10/30 02:21:40,207 INFO  [org.apache.coyote.http11] (MSC
2013/10/30 02:21:40,839 INFO  [org.jboss.ws.common.management
2013/10/30 02:21:42,808 INFO  [org.hornetq.core.server] (MSC
2013/10/30 02:21:42,811 INFO  [org.hornetq.core.server] (MSC
2013/10/30 02:21:42,717 INFO  [org.jboss.as.jacorb] (MSC serv
2013/10/30 02:21:43,511 INFO  [org.infinispan.configuration.c
2013/10/30 02:21:43,614 INFO  [org.infinispan.configuration.c
2013/10/30 02:21:44,519 INFO  [org.hornetq.core.server] (MSC
2013/10/30 02:21:46,716 INFO  [org.jboss.as.server.deployment
2013/10/30 02:21:47,105 INFO  [org.jboss.as.server.deployment
2013/10/30 02:21:48,104 INFO  [org.hornetq.core.server] (MSC
2013/10/30 02:21:48,104 INFO  [org.hornetq.core.server] (MSC
2013/10/30 02:21:49,045 INFO  [org.jboss.as.jacorb] (MSC serv
2013/10/30 02:21:49,829 INFO  [org.jboss.as.connector.subsyst
```
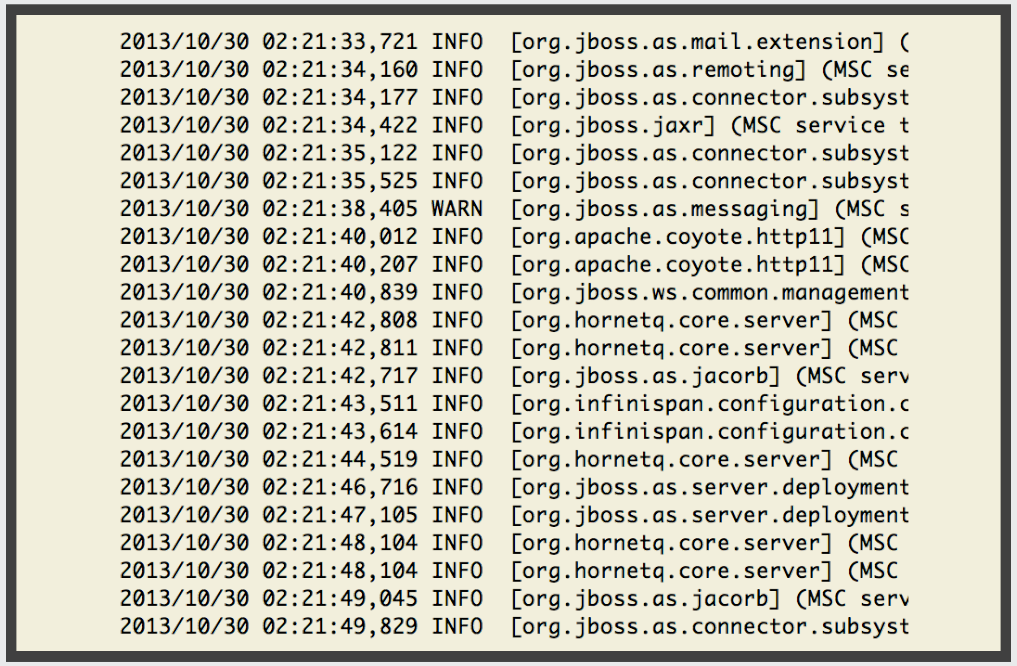

Scalability with respect to the size of the trace

$$\neg\ \mathsf{F}_{(0,3333]}(\phi) \wedge \mathsf{G}_{(0,5000]}(\psi) \rightarrow \mathsf{F}\ \phi \mathsf{U}_{(0,105000]}(\varphi)$$

Scalability with respect to the size of the timing intervals in the formula

MTL Trace Checking: Challenges



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Scalability with respect to the size of the trace

Wikipedia Page Traffic Statistics Dataset

Contains 7 months of hourly page view statistics for all articles in Wikipedia

Size: 320 GB
Created On: June 9, 2009

DARPA Scalable Network Monitoring (SNM) Program Traffic

Contains 9 days of captured network traffic

Size: 7083.4 TB
Created On: November 12, 2009

Scalability with respect to the size of the trace

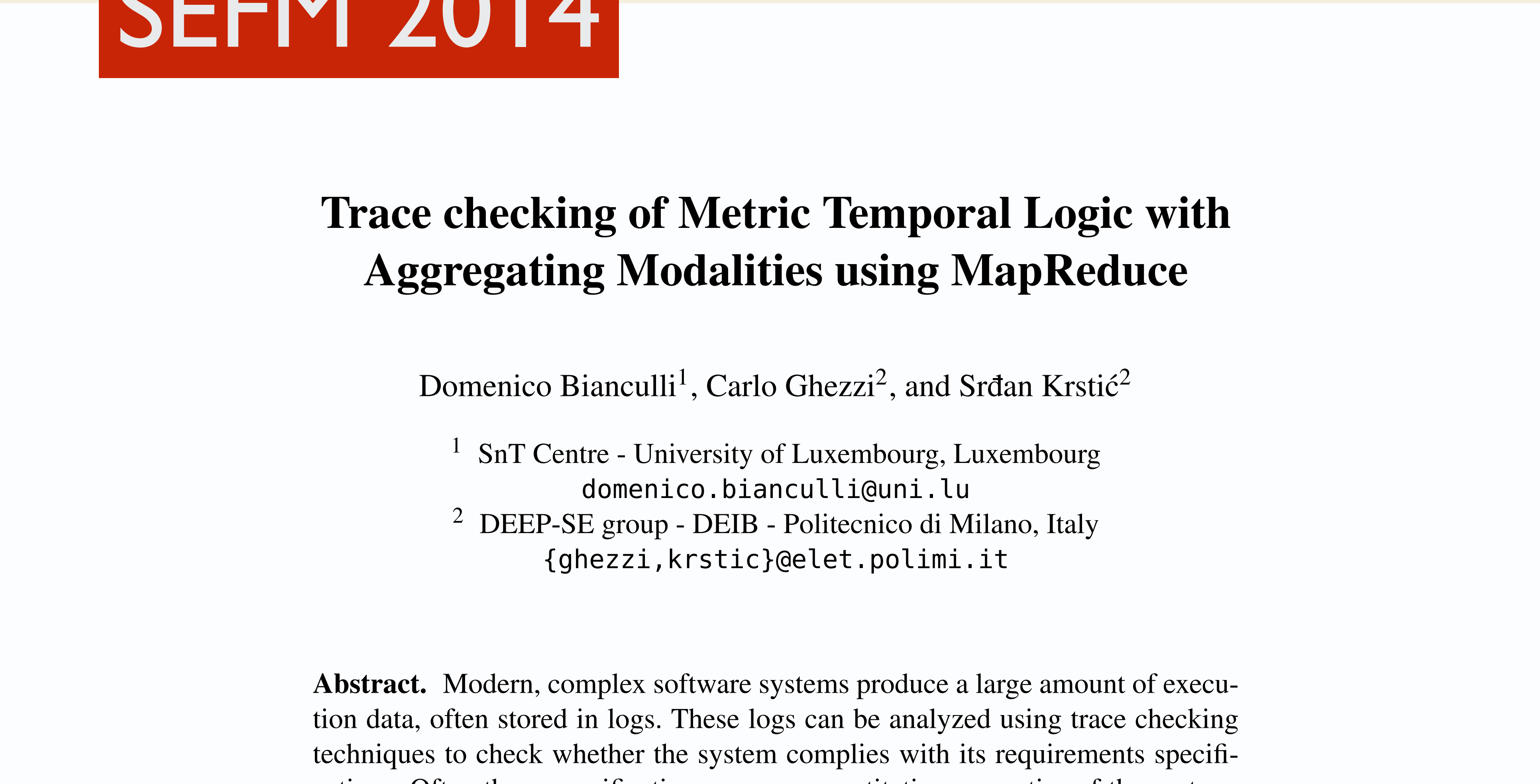
Scalability with respect to the size of the trace

Solution: Distributed Trace Checking

Scalability with respect to the size of the trace

Solution: Distributed Trace Checking

SEFM 2014



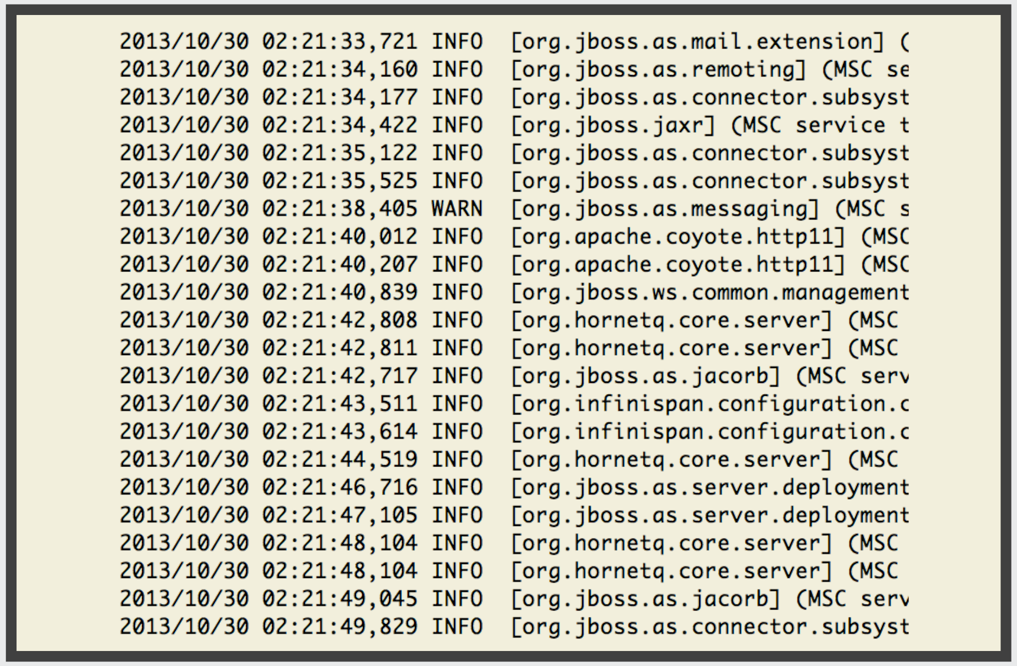
Trace checking of Metric Temporal Logic with Aggregating Modalities using MapReduce

Domenico Bianculli[1], Carlo Ghezzi[2], and Srđan Krstić[2]

[1] SnT Centre - University of Luxembourg, Luxembourg
domenico.bianculli@uni.lu
[2] DEEP-SE group - DEIB - Politecnico di Milano, Italy
{ghezzi,krstic}@elet.polimi.it

Abstract. Modern, complex software systems produce a large amount of execution data, often stored in logs. These logs can be analyzed using trace checking techniques to check whether the system complies with its requirements specifi-

MTL Trace Checking: Challenges



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2013/10/30 02:21:35,122 INFO  [org.jboss.as.connector.subsyst
2013/10/30 02:21:35,525 INFO  [org.jboss.as.connector.subsyst
2013/10/30 02:21:38,405 WARN  [org.jboss.as.messaging] (MSC s
2013/10/30 02:21:40,012 INFO  [org.apache.coyote.http11] (MSC
2013/10/30 02:21:40,207 INFO  [org.apache.coyote.http11] (MSC
2013/10/30 02:21:40,839 INFO  [org.jboss.ws.common.management
2013/10/30 02:21:42,808 INFO  [org.hornetq.core.server] (MSC
2013/10/30 02:21:42,811 INFO  [org.hornetq.core.server] (MSC
2013/10/30 02:21:42,717 INFO  [org.jboss.as.jacorb] (MSC serv
2013/10/30 02:21:43,511 INFO  [org.infinispan.configuration.c
2013/10/30 02:21:43,614 INFO  [org.infinispan.configuration.c
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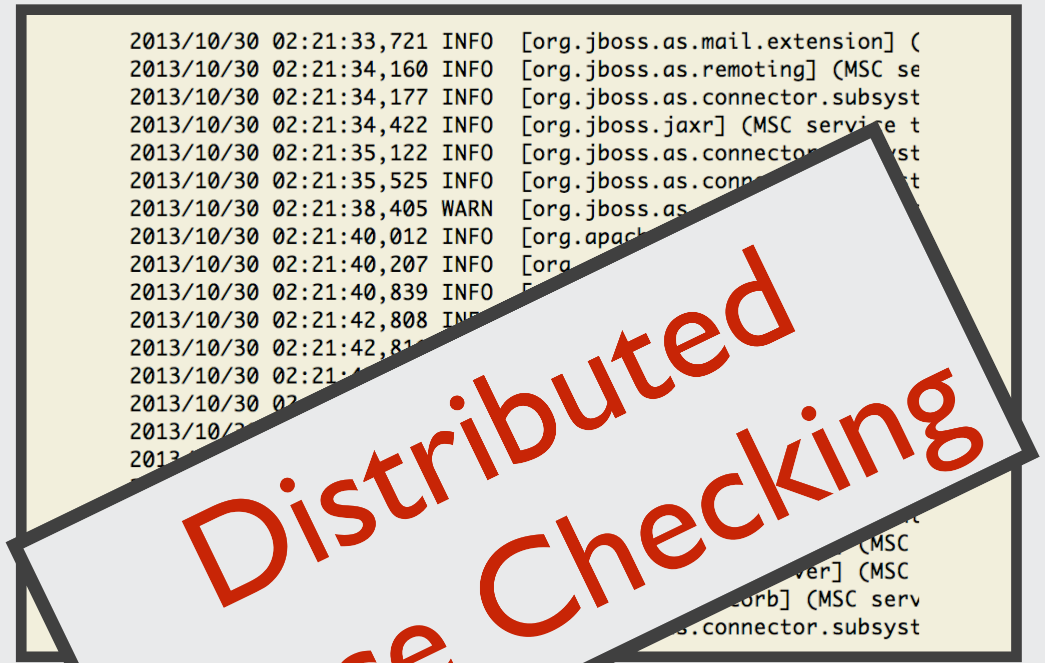
2013/10/30 02:21:49,045 INFO  [org.jboss.as.jacorb] (MSC serv
2013/10/30 02:21:49,829 INFO  [org.jboss.as.connector.subsyst
```

Scalability with respect to the **size of the trace**

$$
\neg\ \mathsf{F}_{(0,3333]}(\phi) \wedge \\
\mathsf{G}_{(0,5000]}(\psi) \rightarrow \mathsf{F} \\
\phi \mathsf{U}_{(0,105000]}(\varphi)
$$

Scalability with respect to **the size of the timing intervals in the formula**

MTL Trace Checking: Challenges



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2013/10/30 02:21:33,721 INFO  [org.jboss.as.mail.extension] (
2013/10/30 02:21:34,160 INFO  [org.jboss.as.remoting] (MSC se
2013/10/30 02:21:34,177 INFO  [org.jboss.as.connector.subsyst
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2013/10/30 02:21:35,122 INFO  [org.jboss.as.connecto      yst
2013/10/30 02:21:35,525 INFO  [org.jboss.as.conn           t
2013/10/30 02:21:38,405 WARN  [org.jboss.as
2013/10/30 02:21:40,012 INFO  [org.apac
2013/10/30 02:21:40,207 INFO  [org
2013/10/30 02:21:40,839 INFO
2013/10/30 02:21:42,808 IN
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2013/10/30 0
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2013
                                              (MSC
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                                  s.connector.subsyst
```

Distributed Trace Checking

Scalability with respect to the size of the trace

$$\neg\, F_{(0,3333]}(\phi) \wedge G_{(0,5000]}(\psi) \rightarrow F\, \phi U_{(0,105000]}(\varphi)$$

Scalability with respect to the size of the timing intervals in the formula

MTL Trace Checking: Challenges

$$\begin{gathered}\neg\ \mathsf{F}_{(0,3333]}(\phi) \wedge \\ \mathsf{G}_{(0,5000]}(\psi) \rightarrow \mathsf{F} \\ \phi\mathsf{U}_{(0,105000]}(\varphi)\end{gathered}$$

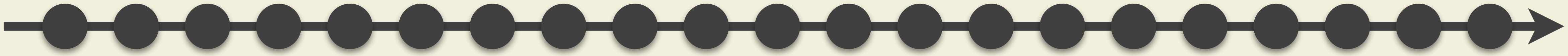
Scalability with respect to the size of the timing intervals in the formula

Health Insurance Portability and Accountability Act of 1996

"Retain the documentation [...] for **6 years** from the date of its creation or the date when it last was in effect, whichever is later"

Trace Checking Temporal operators

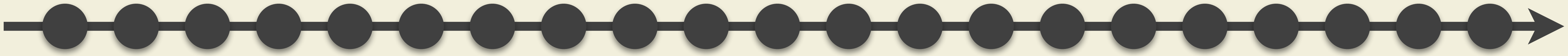
$\mathsf{F}_I(\phi)$



Trace Checking Temporal operators

Metric Eventually operator

$\mathsf{F}_I(\phi)$

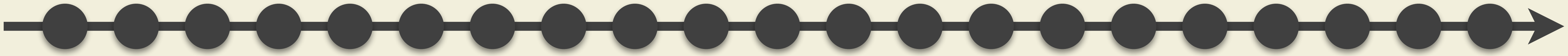


Trace Checking Temporal operators

Metric Eventually operator

Reverse scanning

$\mathsf{F}_I(\phi)$



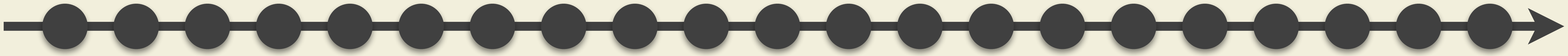
Trace Checking Temporal operators

Metric Eventually operator

Reverse scanning

Incremental verdict

$F_I(\phi)$



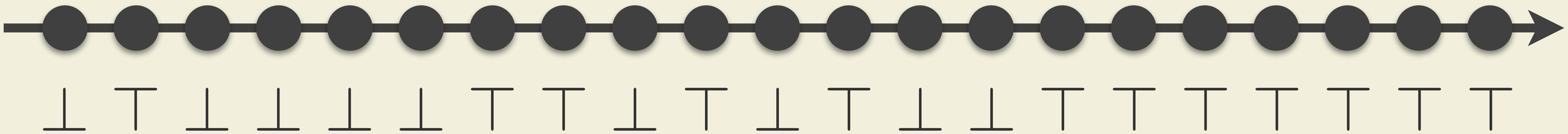
Trace Checking Temporal operators

Metric Eventually operator

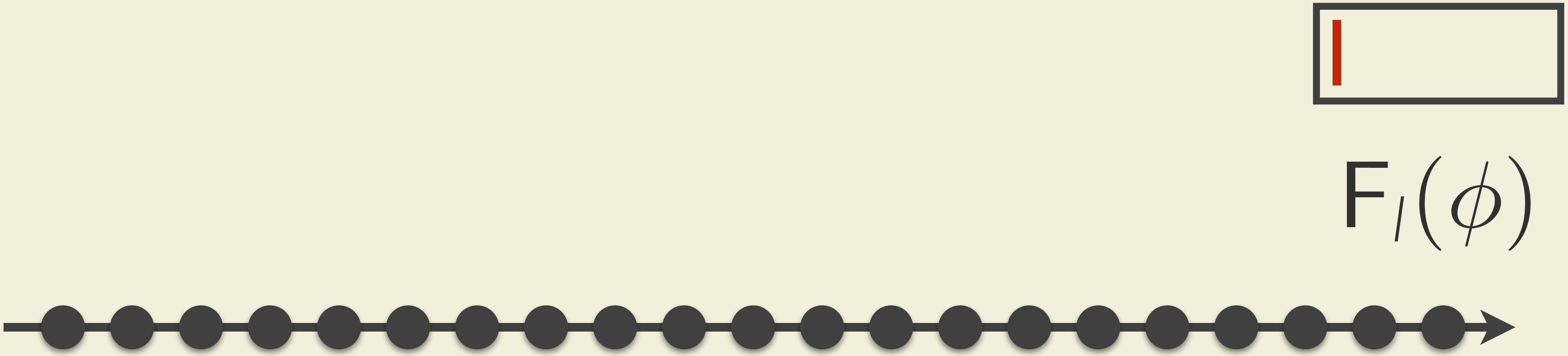
Reverse scanning

Incremental verdict

$$\mathsf{F}_I(\phi)$$



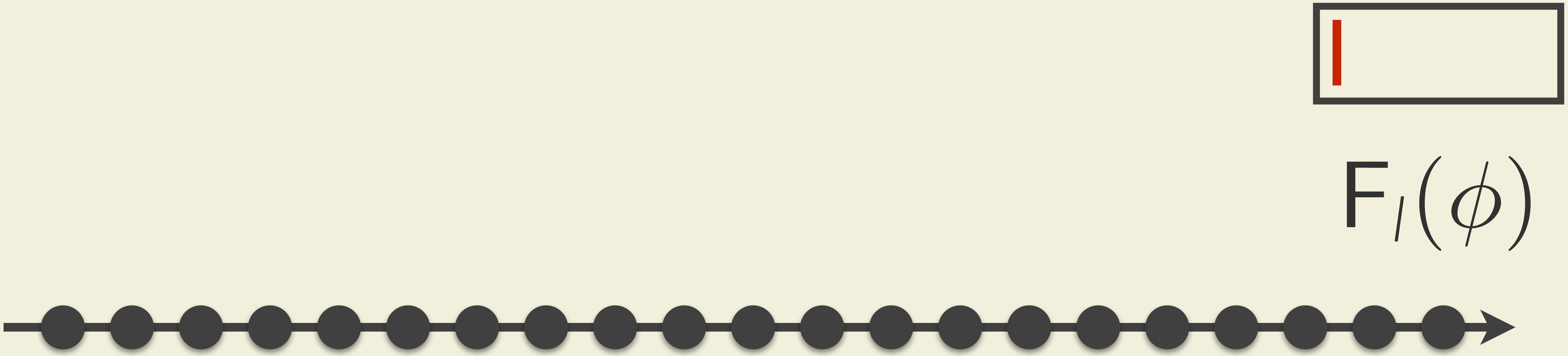
Trace Checking Temporal operators



$F_I(\phi)$

Trace Checking Temporal operators

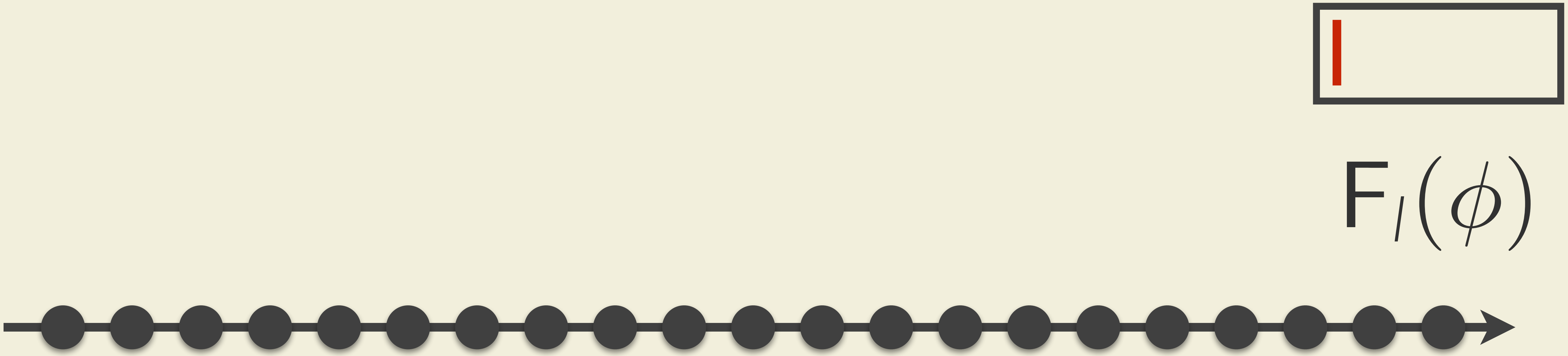
Queue-like data structure



Trace Checking Temporal operators

Queue-like data structure

Size of the temporal interval



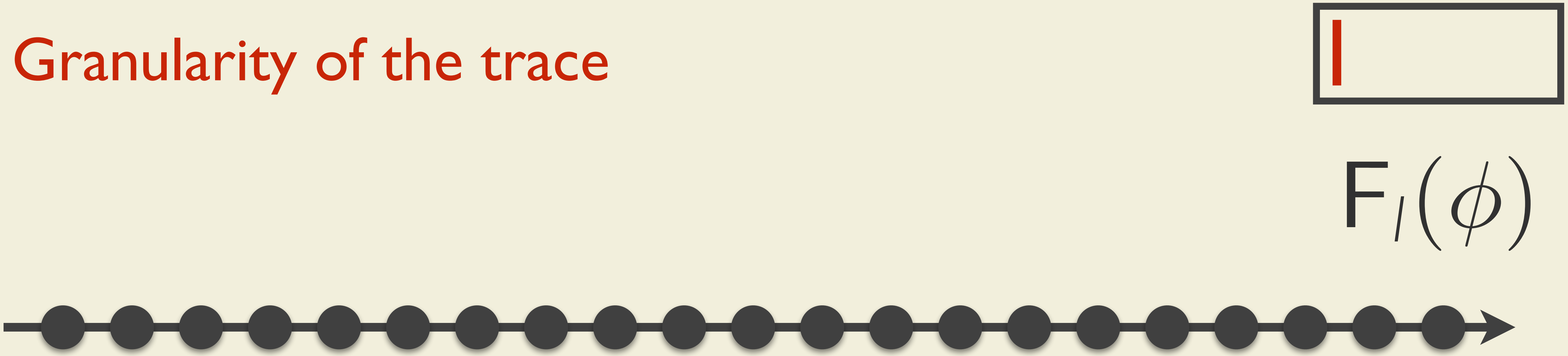
$F_I(\phi)$

Trace Checking Temporal operators

Queue-like data structure

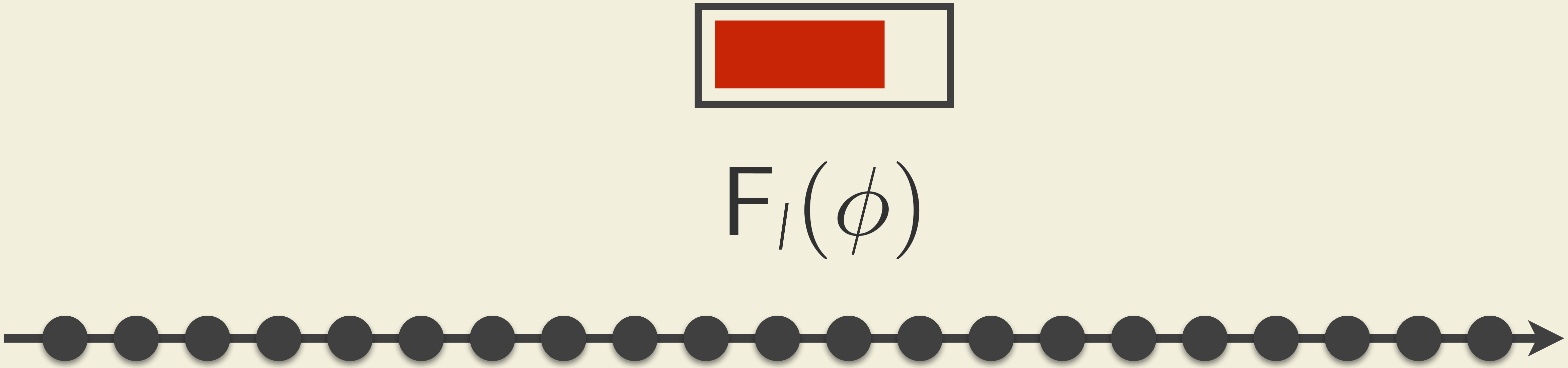
Size of the temporal interval

Granularity of the trace



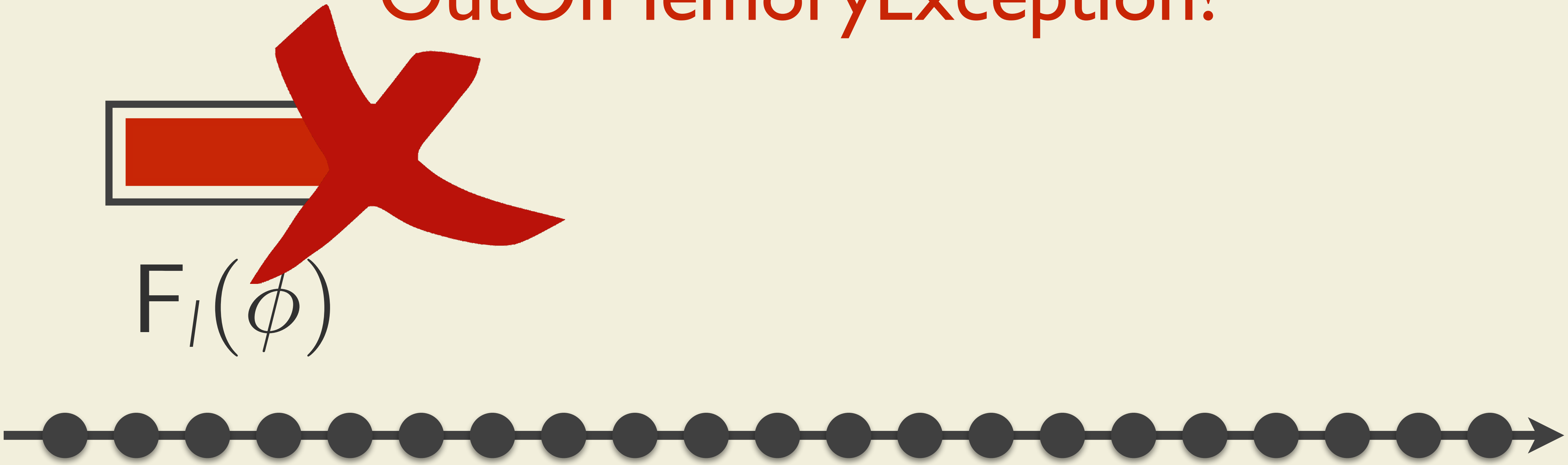
$\mathsf{F}_I(\phi)$

Trace Checking Temporal operators



$\mathsf{F}_I(\phi)$

Trace Checking Temporal operators



OutOfMemoryException!

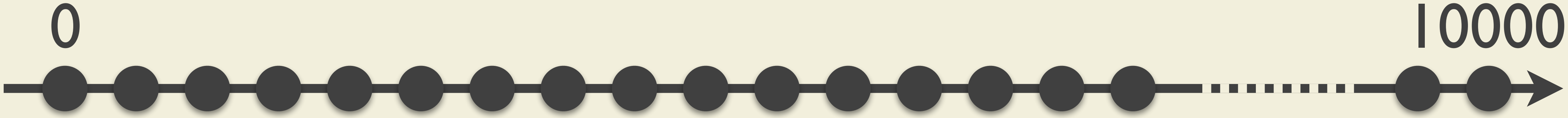
$F_l(\phi)$

Scalability with respect to the size of the temporal intervals

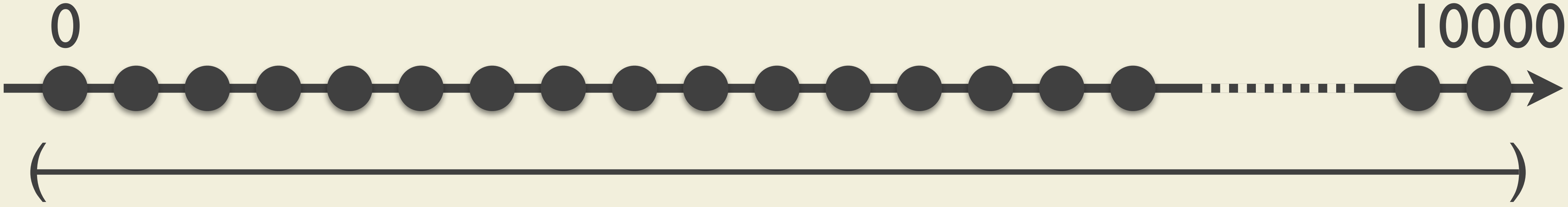
Scalability with respect to the size of the temporal intervals

Solution: Decomposing formulae with large intervals

Decomposition of temporal formulae

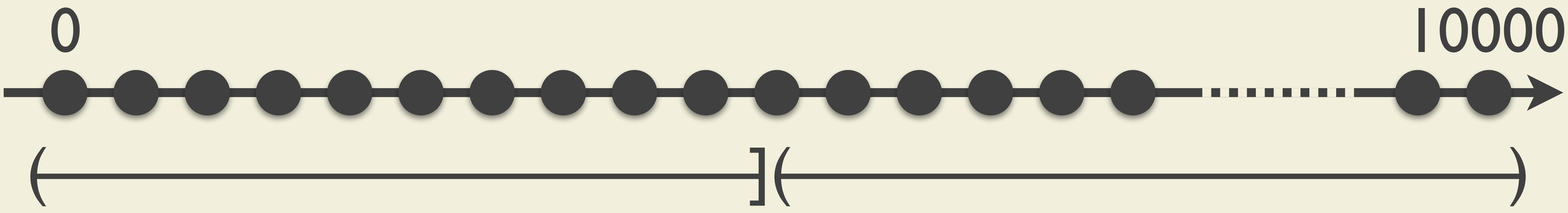


Decomposition of temporal formulae



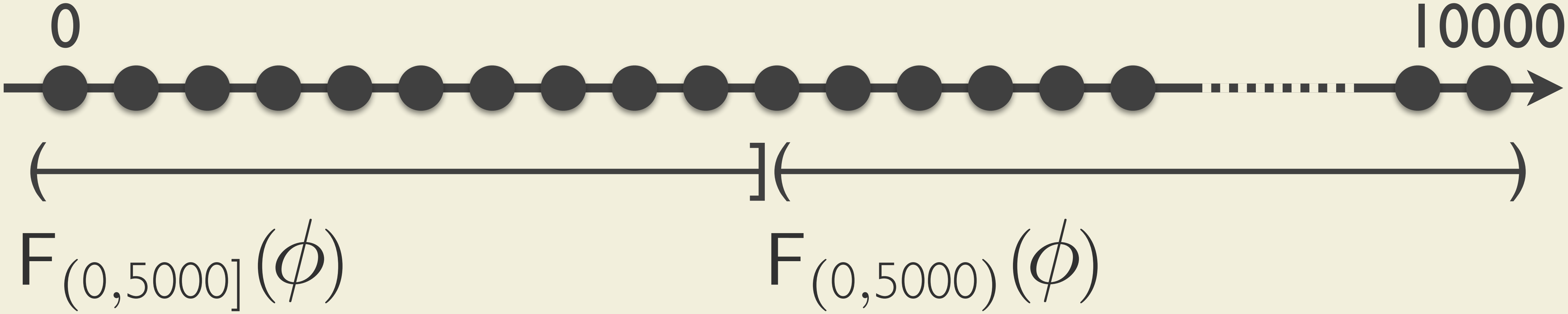
$F_{(0,10000]}(\phi)$

Decomposition of temporal formulae



$F_{(0,5000]}(\phi)$ $F_{(0,5000)}(\phi)$

Decomposition of temporal formulae



$$\mathsf{F}_{(0,10000)}(\phi) \equiv \mathsf{F}_{(0,5000]}(\phi) \vee \mathsf{F}_{=5000}(\mathsf{F}_{(0,5000)}(\phi))$$

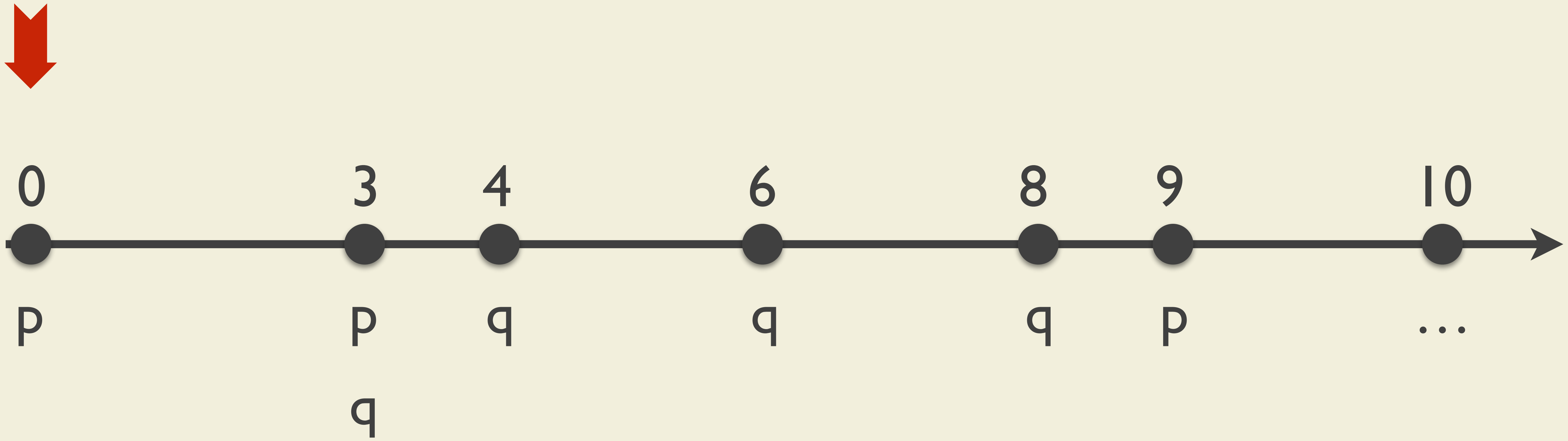
Decomposition of temporal formulae

$$F_{(0,10000)}(\phi) \equiv F_{(0,5000]}(\phi) \vee F_{=5000}(F_{(0,5000)}(\phi))$$

Equivalent?

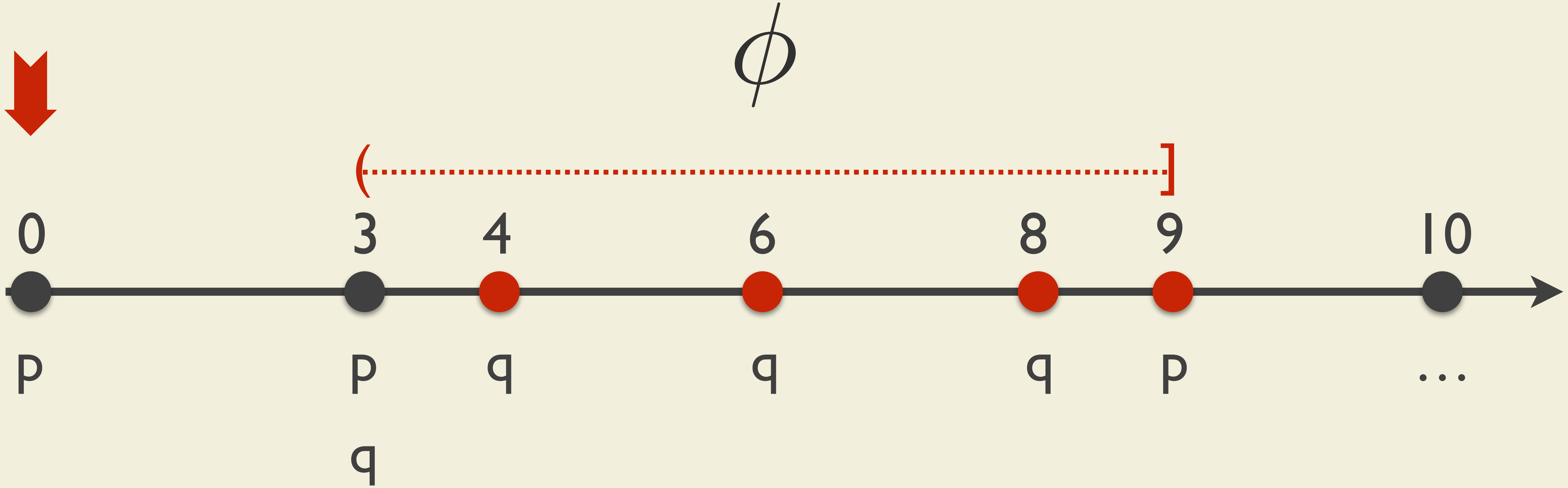
Point-based MTL Semantics

$$F_{(3,9]}(\phi)$$



Point-based MTL Semantics

$F_{(3,9]}(\phi)$



Point-based MTL Semantics

$$(\sigma, \tau, i) \models \mathsf{F}_I \phi \Leftrightarrow \exists i'.(i' \geq i \;\wedge \tau_{i'} - \tau_i \in I \wedge (\sigma, \tau, i') \models \phi)$$

Point-based semantics relies on
the explicit existence of a position for every formula

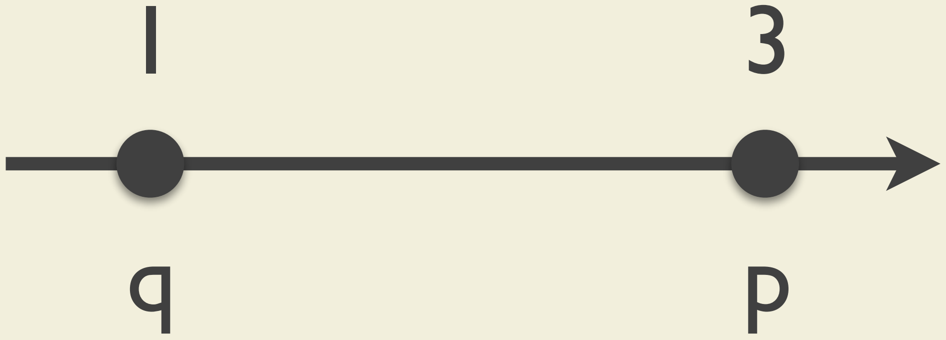
Point-based MTL Semantics

$$(\sigma, \tau, i) \models \mathsf{F}_I \phi \Leftrightarrow \boxed{\exists i'}.(i' \geq i \ \wedge \tau_{i'} - \tau_i \in I \wedge (\sigma, \tau, i') \models \phi)$$

Point-based semantics relies on
the explicit existence of a position for every formula

Point-based MTL Semantics

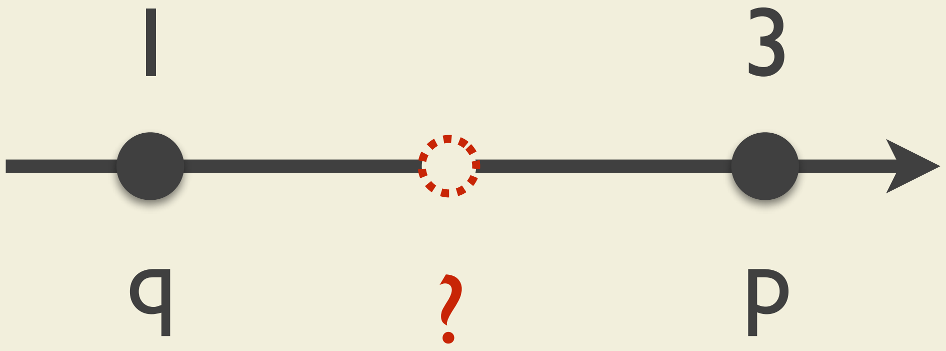
$\mathsf{F}_{=2}(p)$ $\mathsf{F}_{=1}\mathsf{F}_{=1}(p)$



Point-based MTL Semantics

$\mathsf{F}_{=2}(p)$ ✓

$\mathsf{F}_{=1}\mathsf{F}_{=1}(p)$ ✗

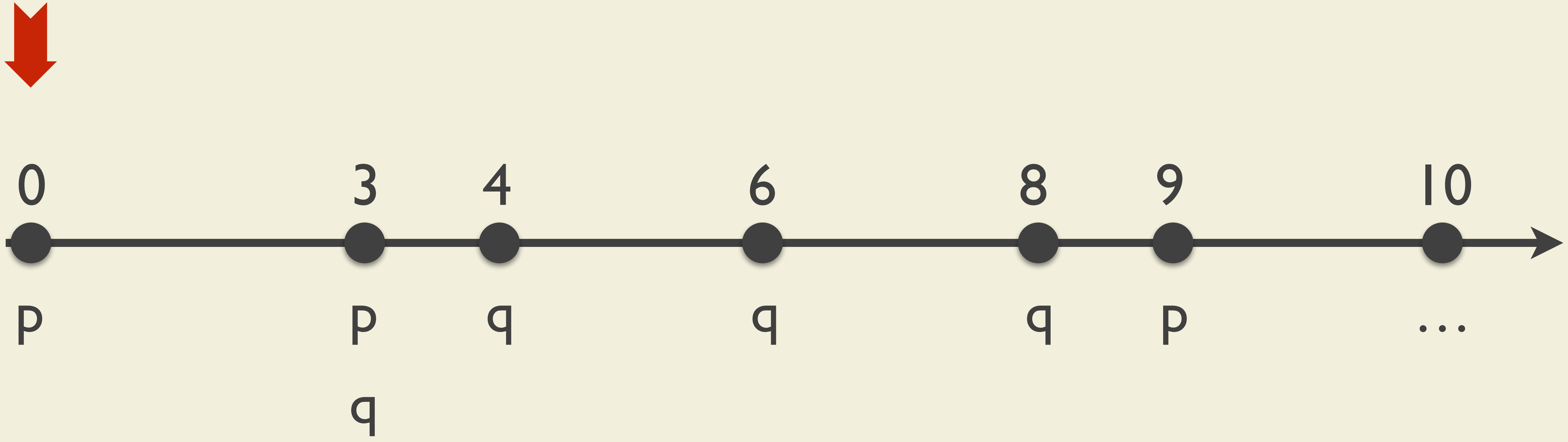


Our Proposal

Lazy MTL Semantics

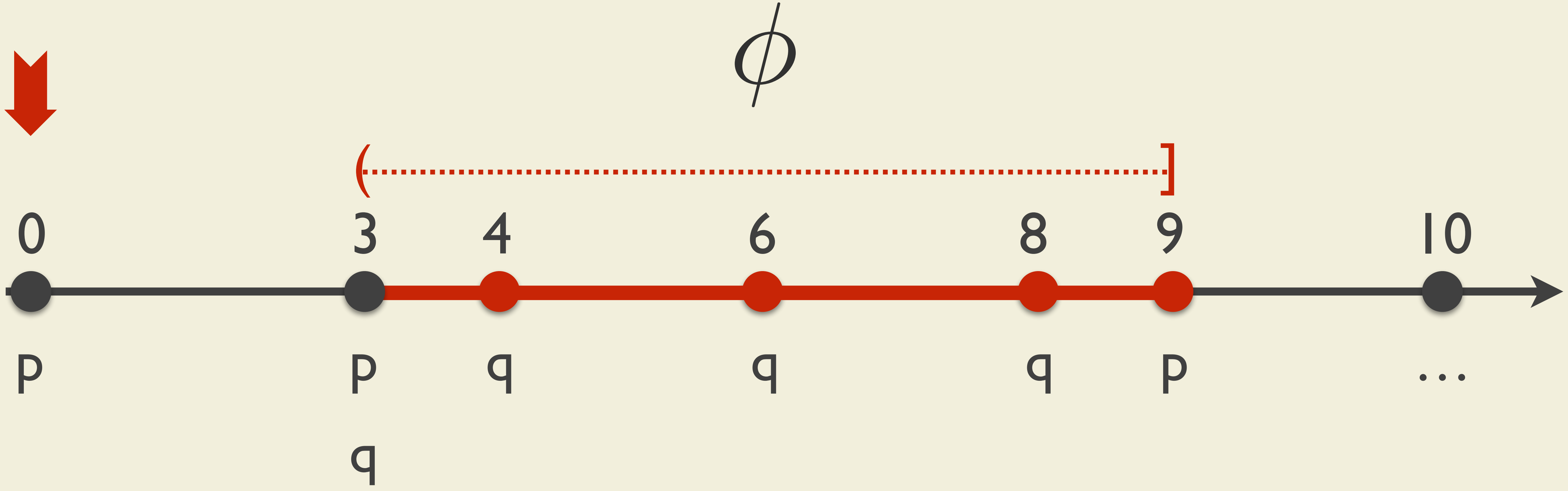
Lazy MTL Semantics

$$F_{(3,9]}(\phi)$$



Lazy MTL Semantics

$F_{(3,9]}(\phi)$



Lazy MTL Semantics

$$(\sigma, \tau, t) \models_L \mathsf{F}_I\phi \Leftrightarrow \exists t'.(t' \geq t \ \wedge t' - t \in I \wedge (\sigma, \tau, t') \models_L \phi)$$

Lazy semantics does not require the explicit existence of a position for temporal operators

Lazy MTL Semantics

$$(\sigma, \tau, t) \models_L \mathsf{F}_I \phi \Leftrightarrow \exists t'.(t' \geq t \; \wedge t' - t \in I \wedge (\sigma, \tau, t') \models_L \phi)$$

Lazy semantics does not require the explicit existence of a position for temporal operators

Lazy MTL Semantics

$$(\sigma, \tau, t) \models_L \mathsf{F}_I \phi \Leftrightarrow \exists t'.(t' \geq t \; \wedge t' - t \in I \wedge (\sigma, \tau, t') \models_L \phi)$$

Lazy semantics does not require the explicit existence of a position for temporal operators

(however, atomic propositions still require the explicit existence of a position)

Properties of Lazy MTL Semantics

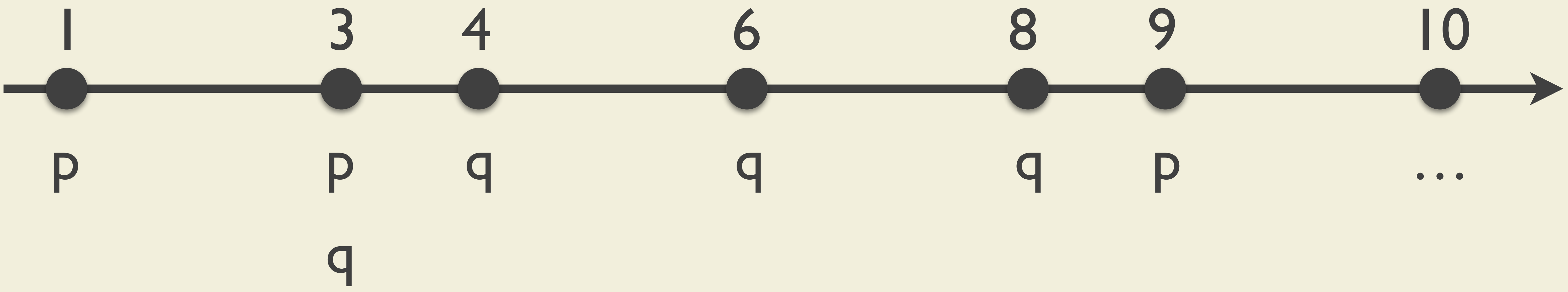
Properties of Lazy MTL Semantics

Nested intervals can be combined

Overlapping intervals can be combined

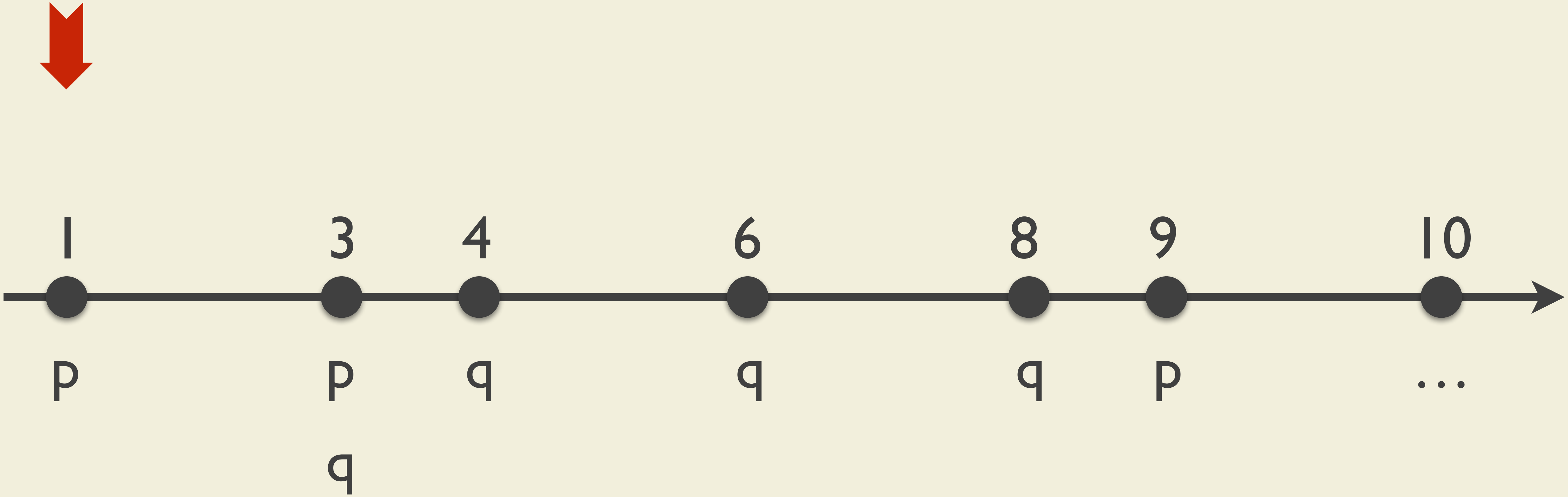
Strictly more expressive than point-based semantics

Combining the nested intervals



Combining the nested intervals

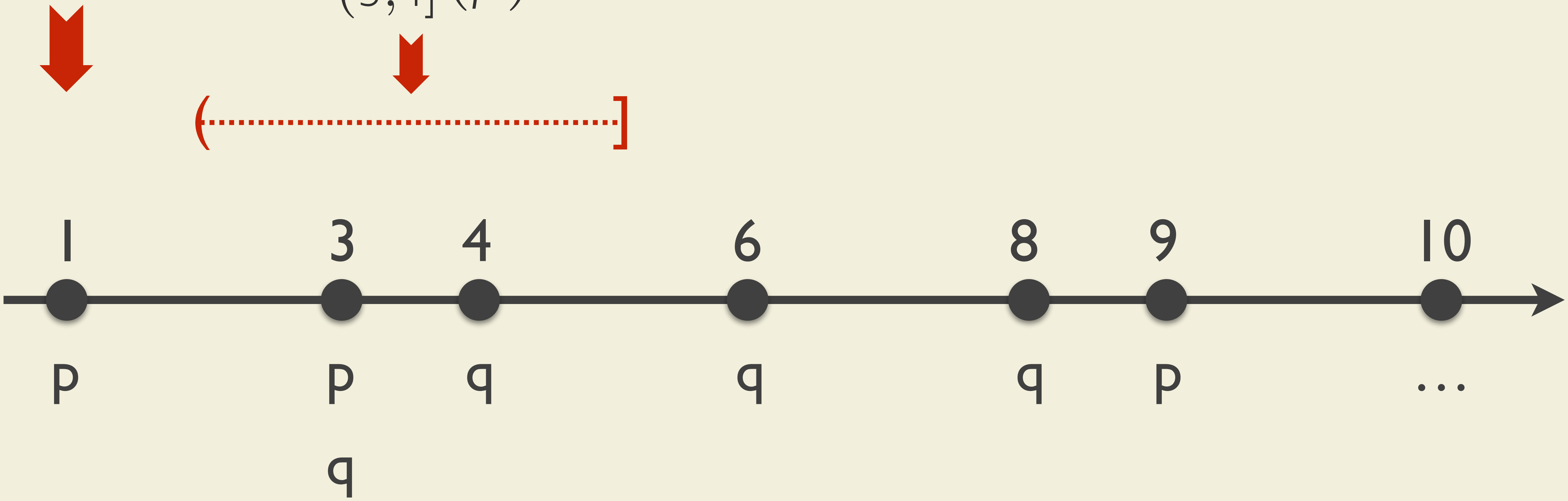
$\mathsf{F}_{(2,5]}\mathsf{F}_{(3,4]}(p)$



Combining the nested intervals

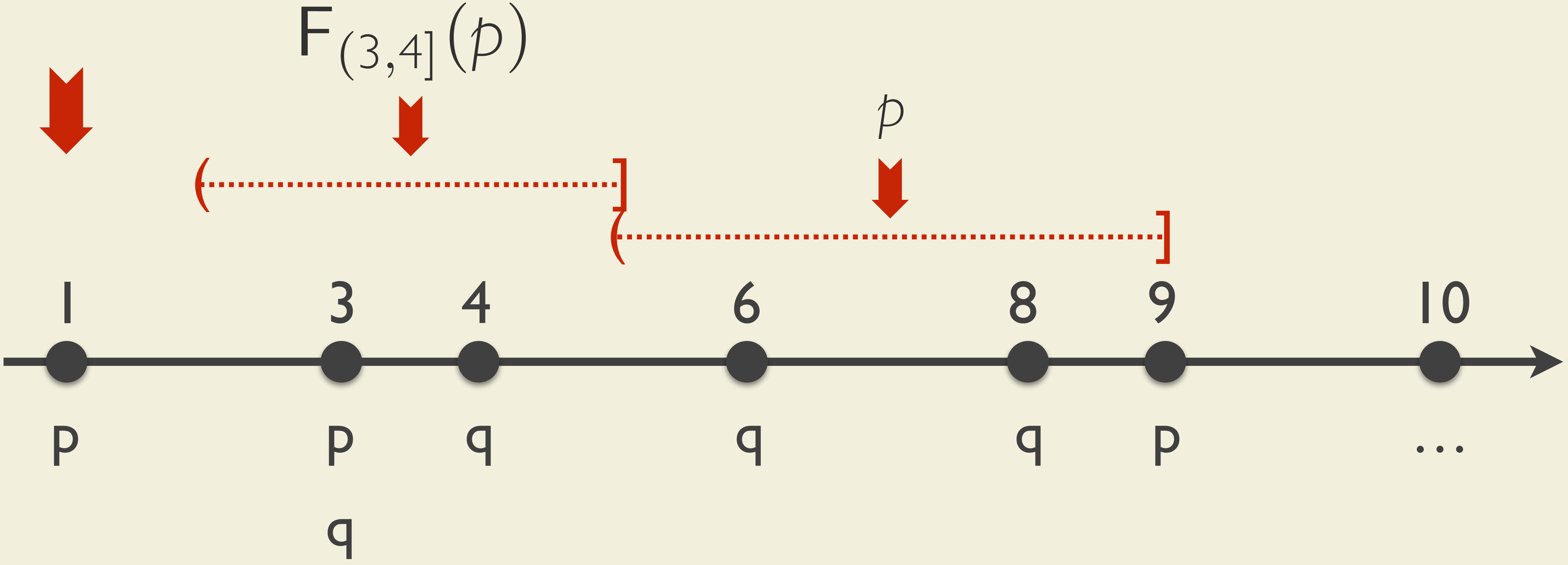
$F_{(2,5]} F_{(3,4]}(p)$

$F_{(3,4]}(p)$

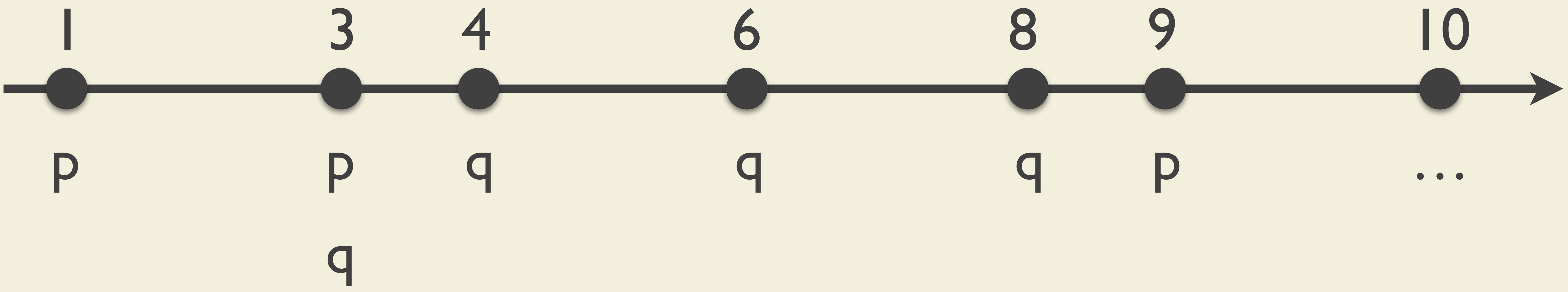


Combining the **nested** intervals

$$F_{(2,5]}F_{(3,4]}(p) \equiv F_{(5,9]}(p)$$

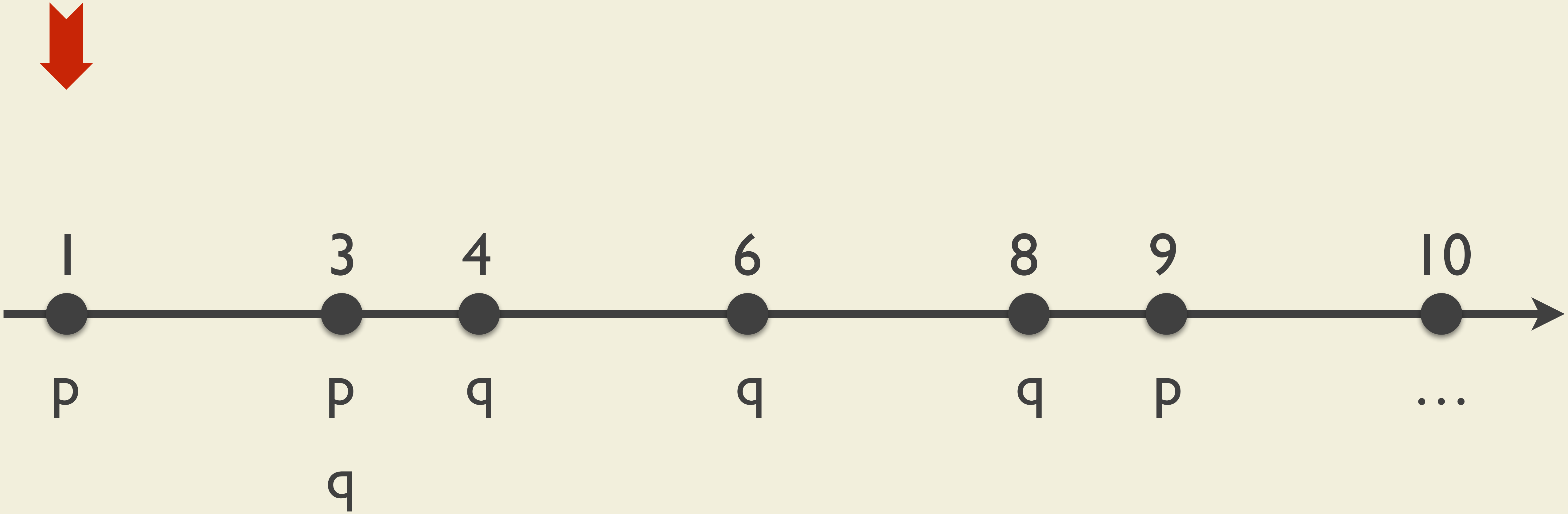


Combining overlapping intervals



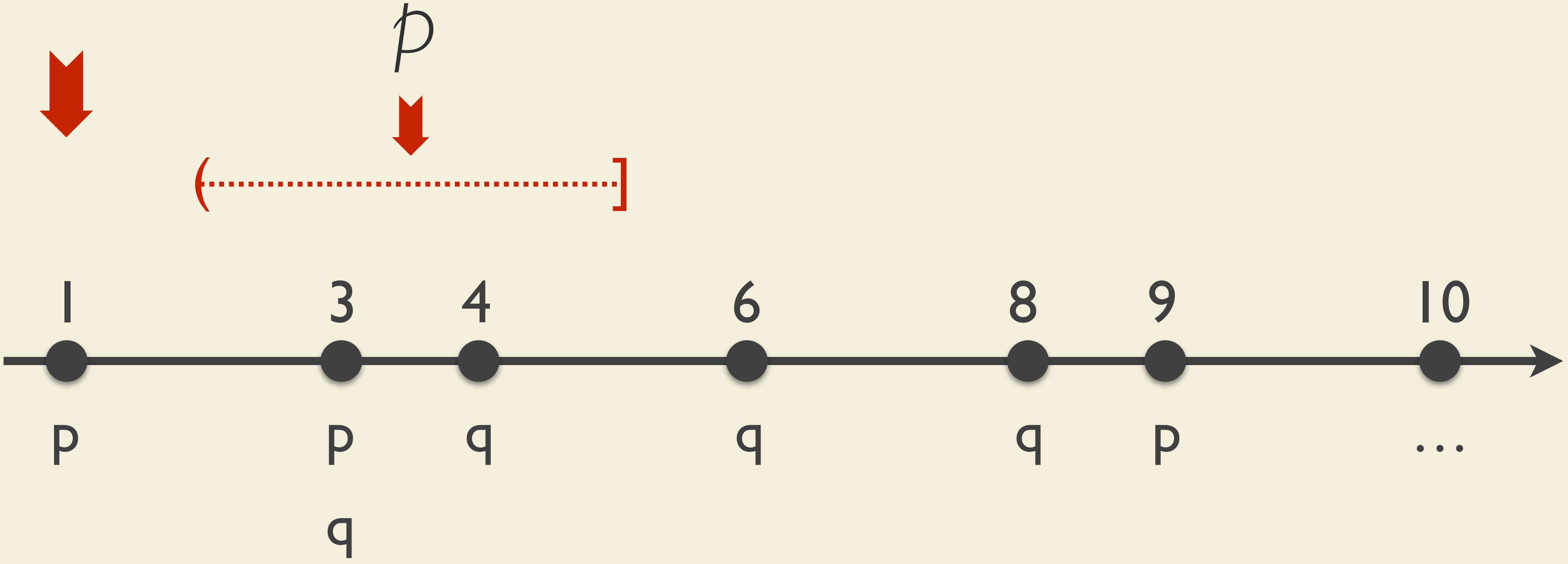
Combining overlapping intervals

$$F_{(2,5]}(p) \vee F_{(4,8]}(p)$$



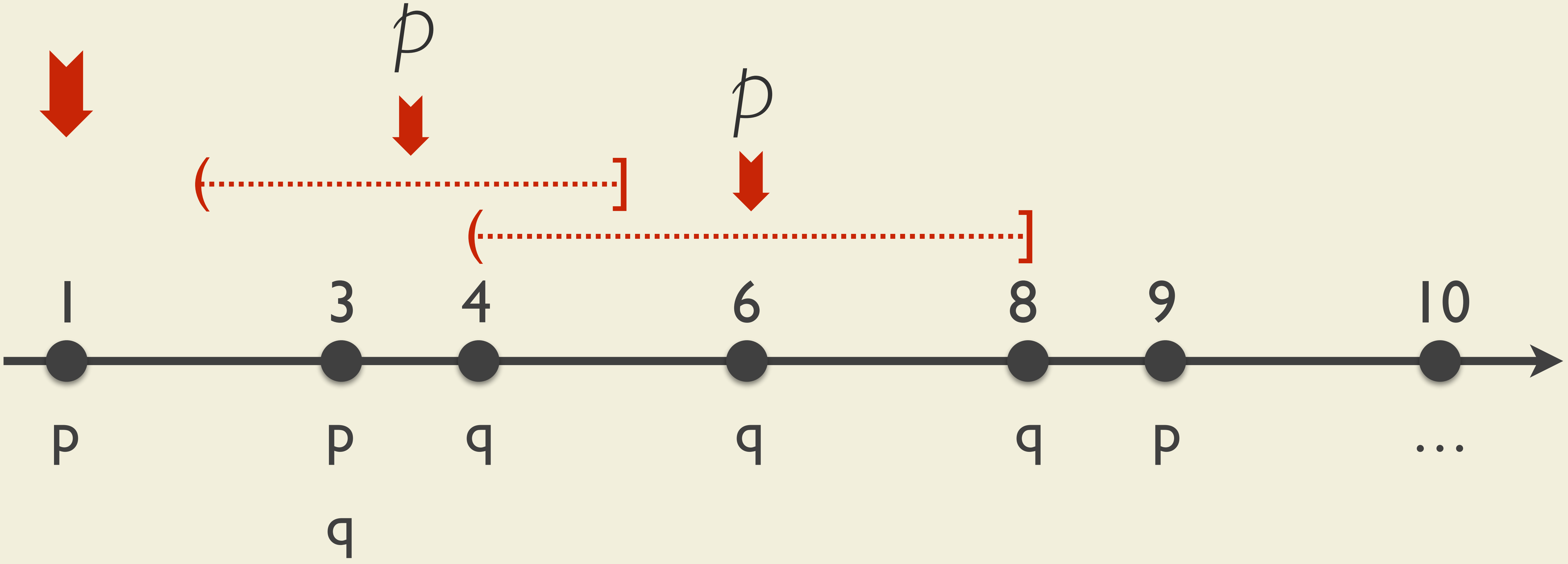
Combining overlapping intervals

$$F_{(2,5]}(p) \lor F_{(4,8]}(p)$$



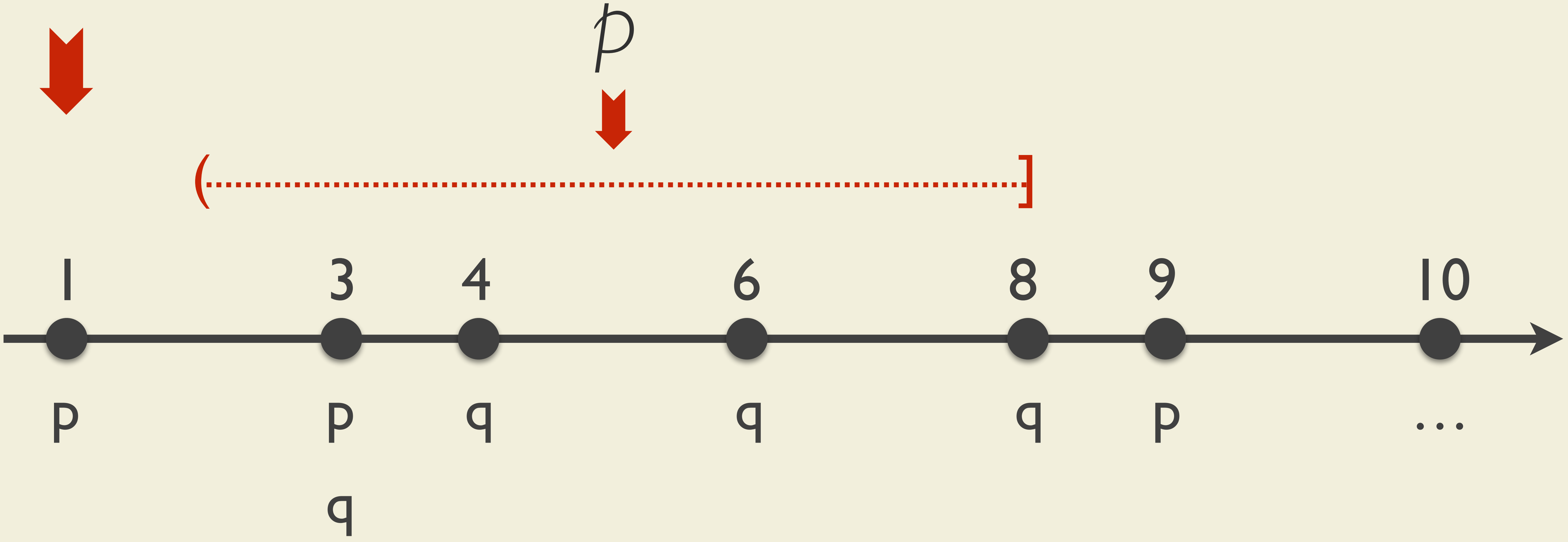
Combining overlapping intervals

$F_{(2,5]}(p) \vee F_{(4,8]}(p)$



Combining overlapping intervals

$$F_{(2,5]}(p) \vee F_{(4,8]}(p) \equiv F_{(2,8]}(p)$$



Decomposition of temporal formulae

$$\mathsf{F}_{(0,10000)}(\phi) \equiv \mathsf{F}_{(0,5000]}(\phi) \vee \mathsf{F}_{=5000}(\mathsf{F}_{(0,5000)}(\phi))$$

Decomposition of temporal formulae

$$\mathsf{F}_{(0,10000)}(\phi) \equiv \mathsf{F}_{(0,5000]}(\phi) \vee \overbrace{\mathsf{F}_{=5000}(\mathsf{F}_{(0,5000)}(\phi))}^{\text{Nested intervals}}$$

Decomposition of temporal formulae

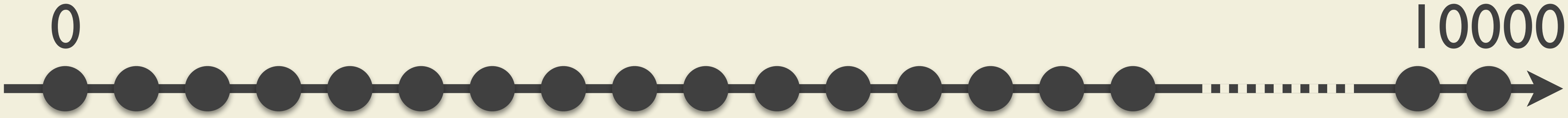
$$\mathsf{F}_{(0,10000)}(\phi) \equiv \underbrace{\mathsf{F}_{(0,5000]}(\phi) \vee \overbrace{\mathsf{F}_{=5000}(\mathsf{F}_{(0,5000)}(\phi))}^{\text{Nested intervals}}}_{\text{Overlapping intervals}}$$

Decomposition of temporal formulae

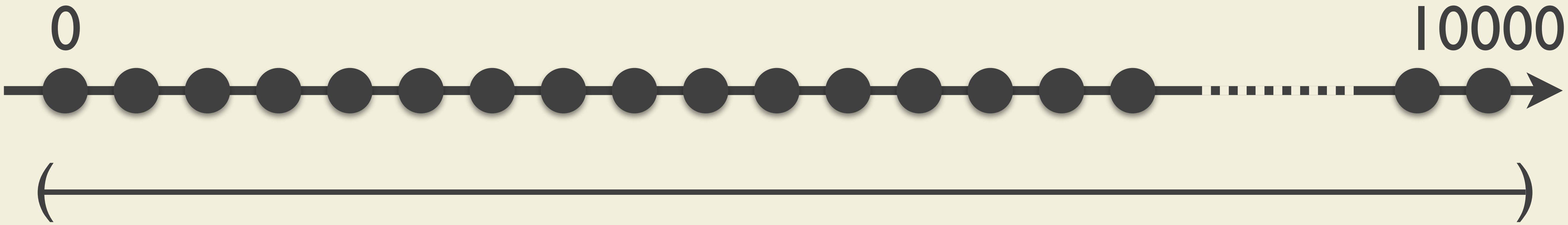
$$\mathsf{F}_{(0,10000)}(\phi) \equiv \underbrace{\mathsf{F}_{(0,5000]}(\phi) \vee \overbrace{\mathsf{F}_{=5000}(\mathsf{F}_{(0,5000)}(\phi))}^{\text{Nested intervals}}}_{\text{Overlapping intervals}}$$

✓

Parametric Decomposition



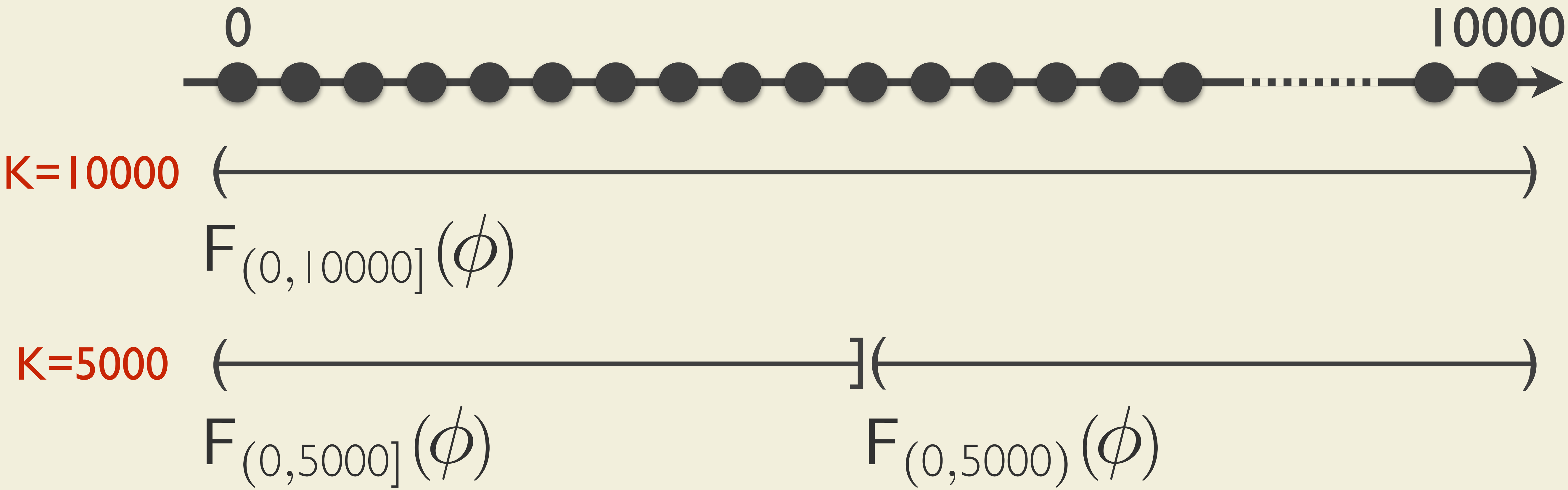
Parametric Decomposition



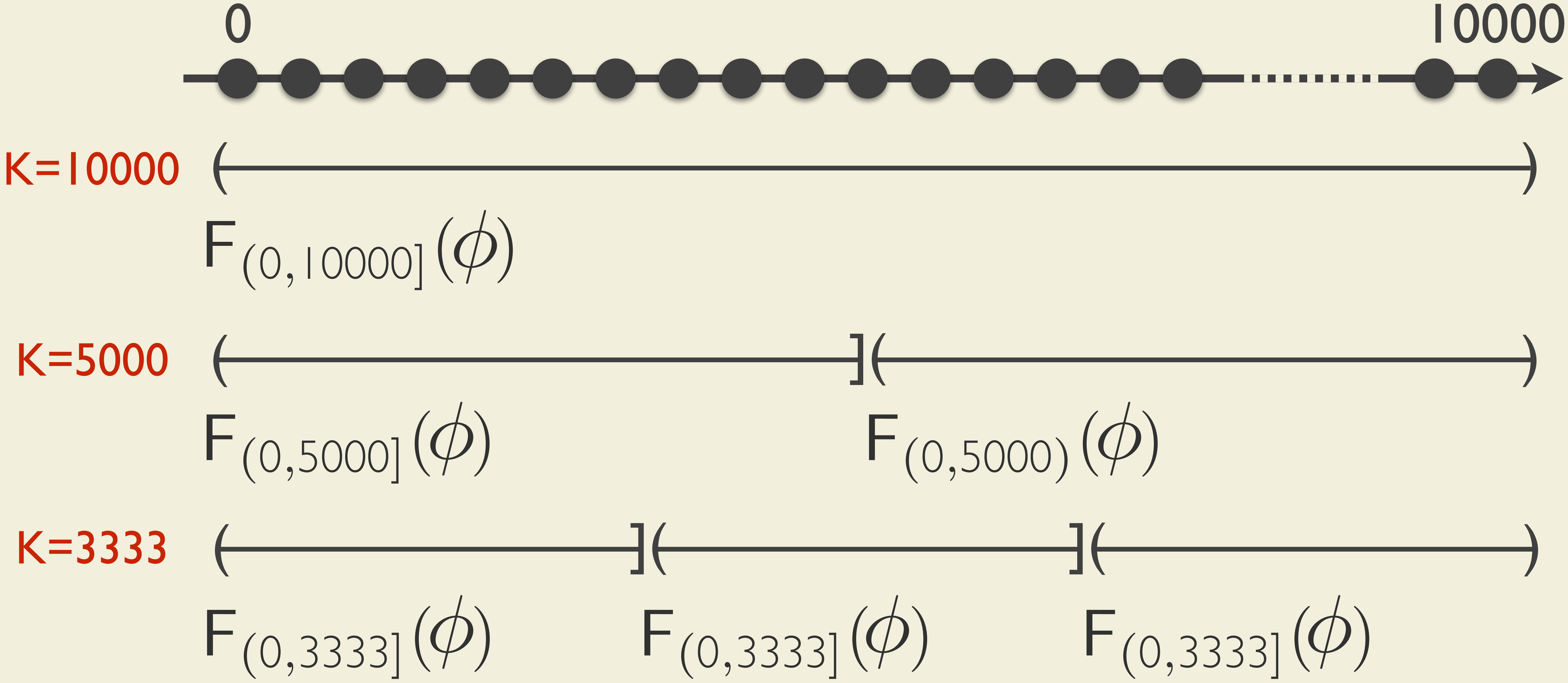
K=10000

$$F_{(0,10000]}(\phi)$$

Parametric Decomposition



Parametric Decomposition



K=10000

$F_{(0,10000]}(\phi)$

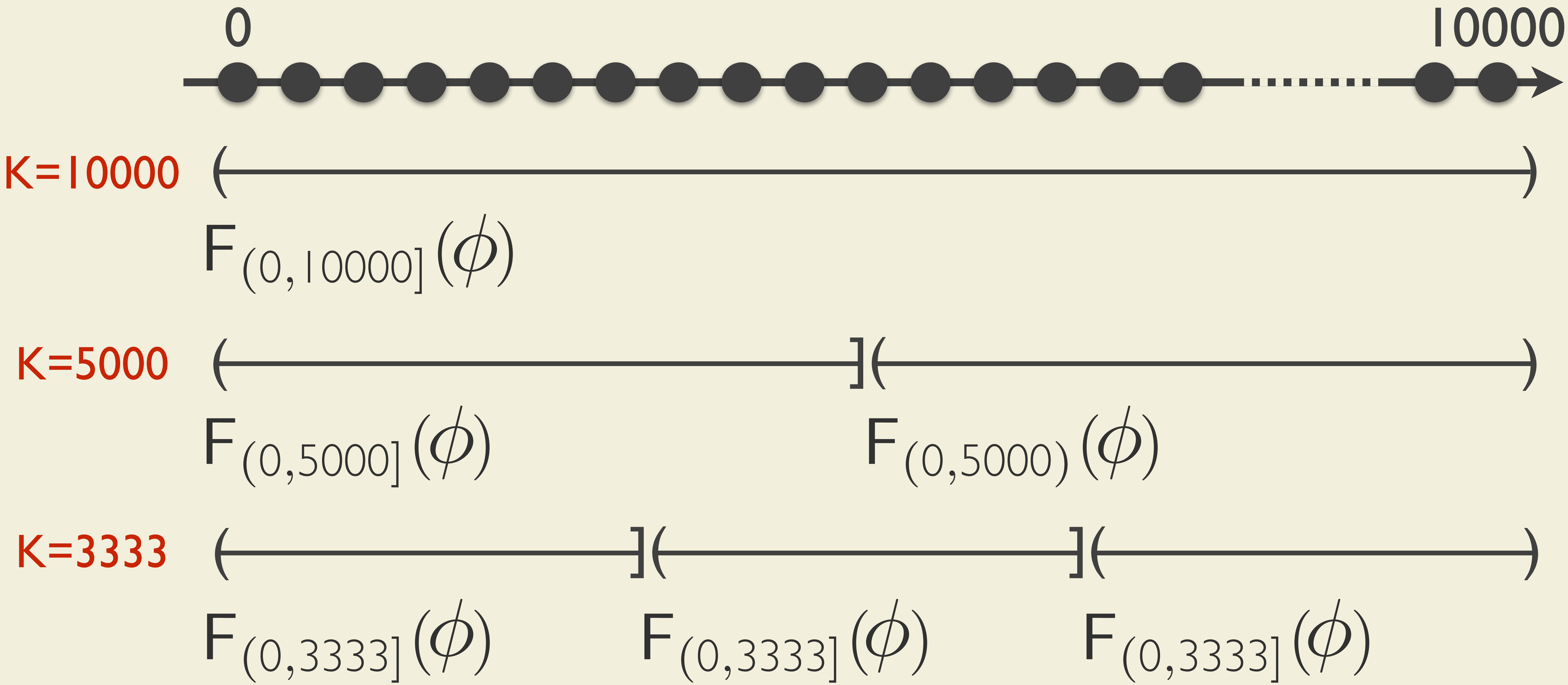
K=5000

$F_{(0,5000]}(\phi)$ $F_{(0,5000)}(\phi)$

K=3333

$F_{(0,3333]}(\phi)$ $F_{(0,3333]}(\phi)$ $F_{(0,3333]}(\phi)$

Parametric Decomposition



0

10000

K=10000

$F_{(0,10000]}(\phi)$

K=5000

$F_{(0,5000]}(\phi)$ $F_{(0,5000)}(\phi)$

K=3333

$F_{(0,3333]}(\phi)$ $F_{(0,3333]}(\phi)$ $F_{(0,3333]}(\phi)$

… or using any parameter K

How to pick an appropriate parameter K?

How to pick an appropriate parameter K?

Rule of thumb: largest K supported by the infrastructure

Trace Checking using MapReduce and Lazy Semantics

1. Infer the value of K

2. Analyze the input formula Φ

3. If all intervals are bounded by K, apply the point-based semantics

4. Otherwise, decompose the formula according to K and then apply the lazy semantics

Evaluation Highlights

- RQ1: Scalability with respect to the size of the time interval

- RQ2: Time/memory tradeoff with respect to the decomposition parameter K

- RQ3: Size and the height of the decomposed formula

Evaluation Highlights

- RQ1: Scalability with respect to the size of the time interval

Memory scalability obtained

- RQ2: Time/memory tradeoff with respect to the decomposition parameter K

- RQ3: Size and the height of the decomposed formula

Evaluation Highlights

- RQ1: Scalability with respect to the size of the time interval

Memory scalability obtained

- RQ2: Time/memory tradeoff with respect to the decomposition parameter K

Smaller K: less memory, more time

- RQ3: Size and the height of the decomposed formula

Evaluation Highlights

- RQ1: Scalability with respect to the size of the time interval

Memory scalability obtained

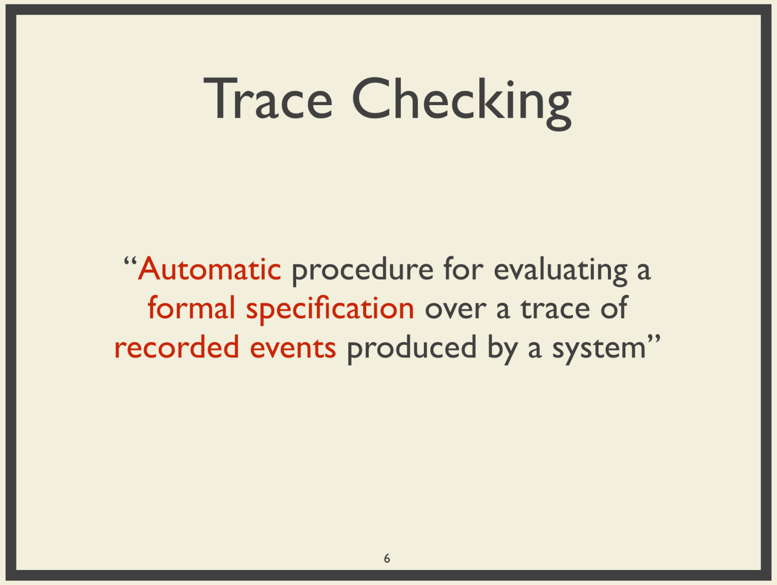
- RQ2: Time/memory tradeoff with respect to the decomposition parameter K

Smaller K: less memory, more time

- RQ3: Size and the height of the decomposed formula

Smaller K: larger formula

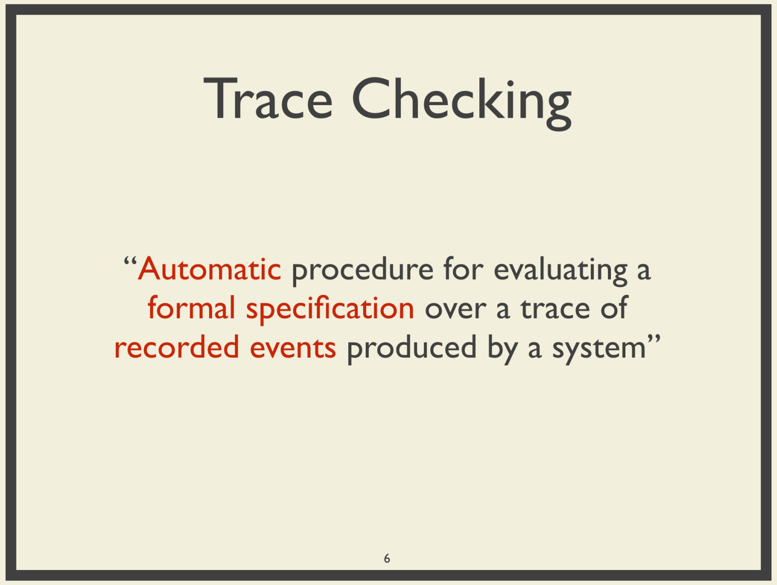
Summary



Trace Checking

"Automatic procedure for evaluating a formal specification over a trace of recorded events produced by a system"

6



Trace Checking

"Automatic procedure for evaluating a formal specification over a trace of recorded events produced by a system"

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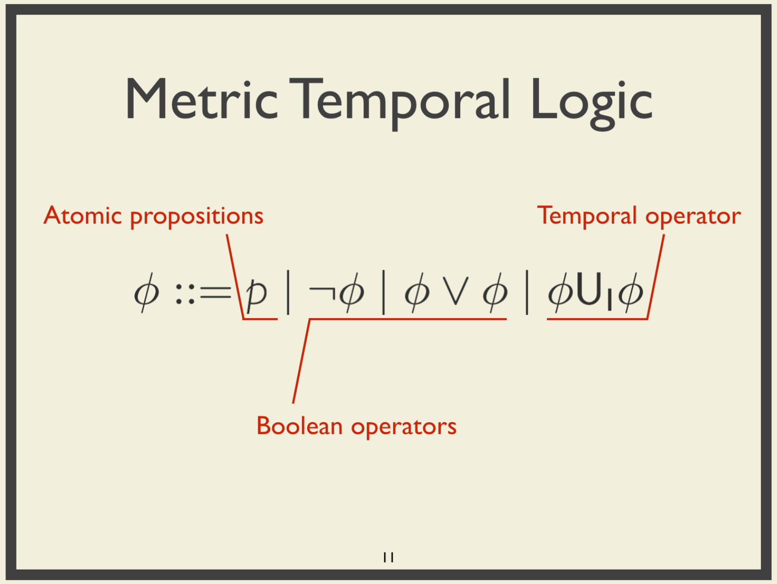
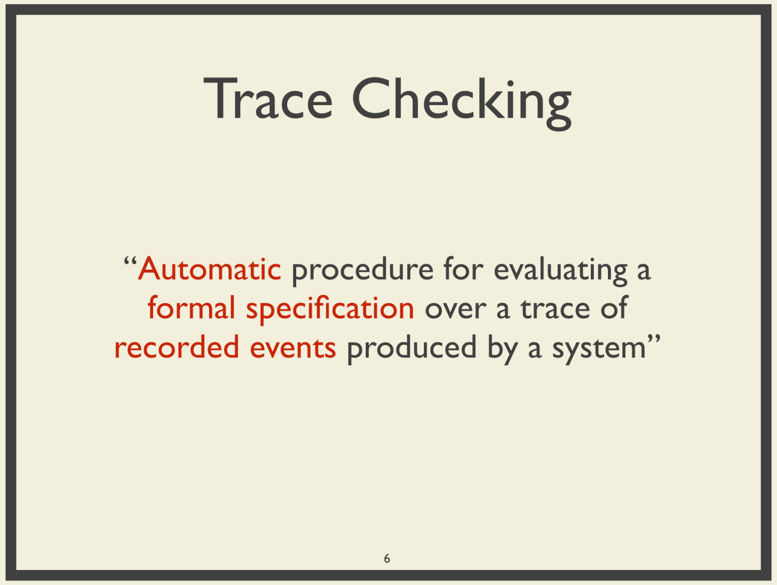


Metric Temporal Logic

$$\phi ::= \overbrace{p}^{\text{Atomic propositions}} \mid \underbrace{\neg\phi \mid \phi \vee \phi}_{\text{Boolean operators}} \mid \overbrace{\phi \mathsf{U}_I \phi}^{\text{Temporal operator}}$$

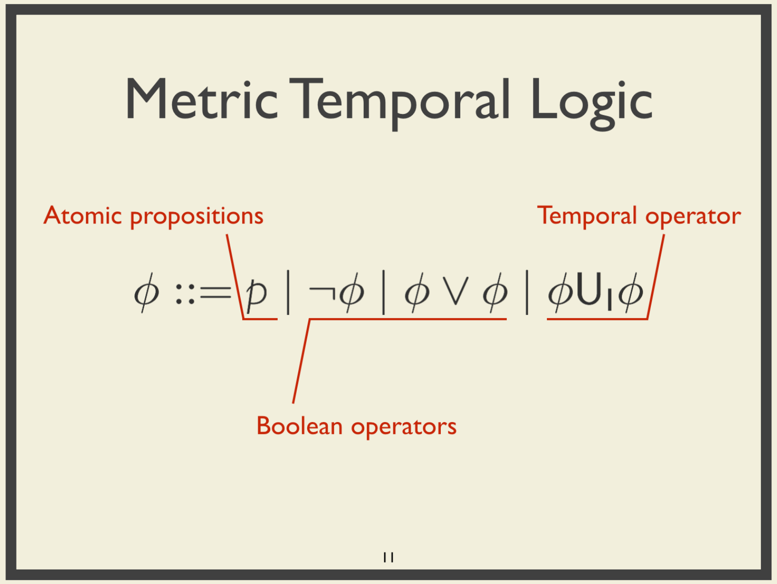
11



Trace Checking

"Automatic procedure for evaluating a formal specification over a trace of recorded events produced by a system"

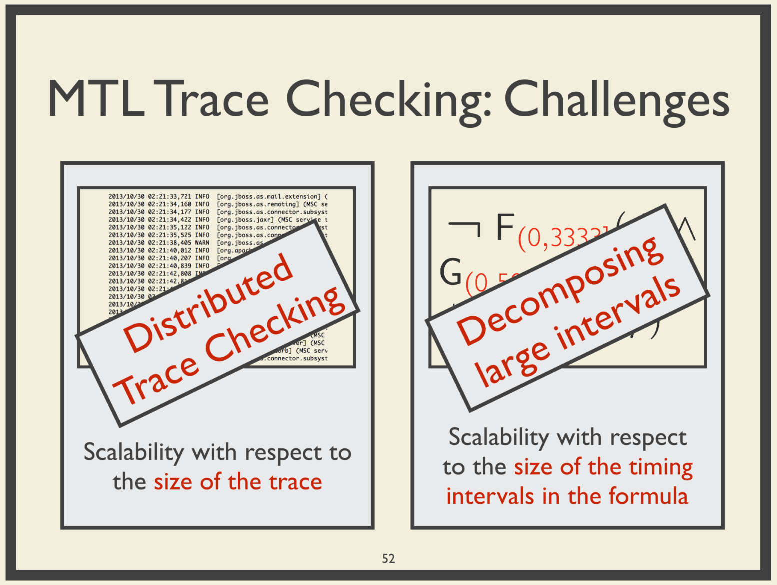
6



Metric Temporal Logic

$$\phi ::= \overbrace{p}^{\text{Atomic propositions}} \mid \underbrace{\neg\phi \mid \phi \vee \phi}_{\text{Boolean operators}} \mid \overbrace{\phi \mathsf{U}_I \phi}^{\text{Temporal operator}}$$

11

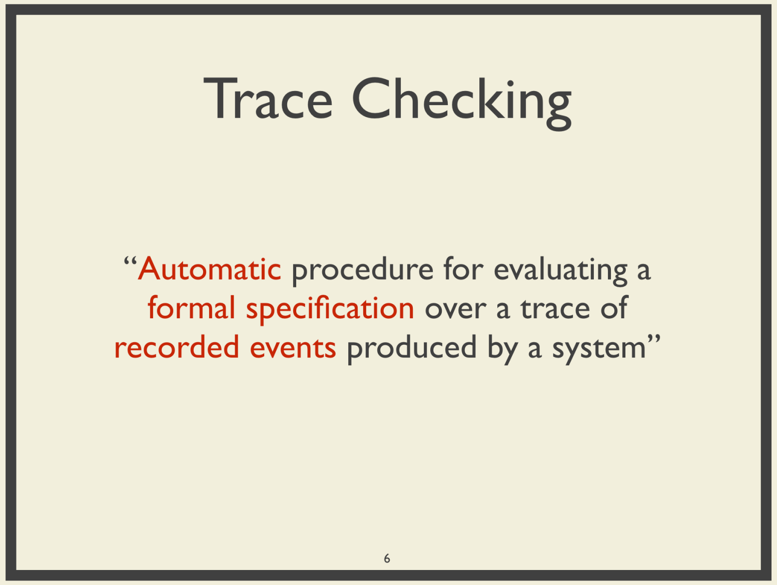


MTL Trace Checking: Challenges

Scalability with respect to the size of the trace

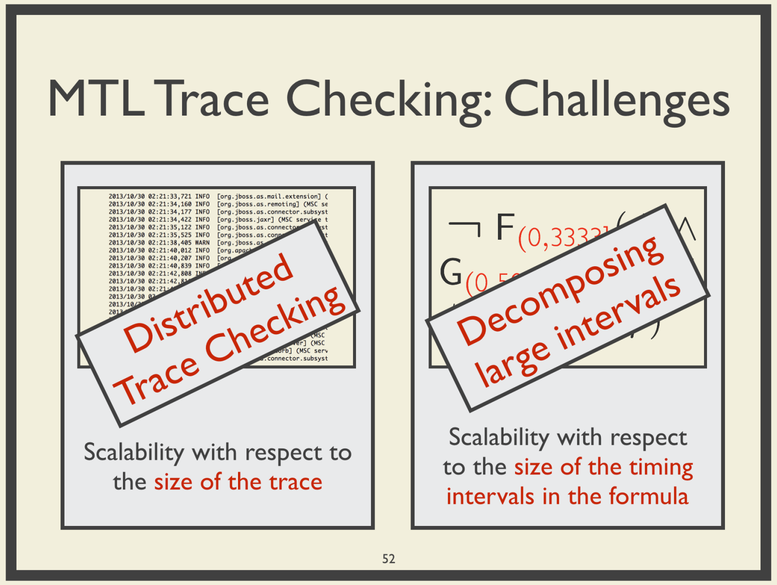
Scalability with respect to the size of the timing intervals in the formula

52



Trace Checking

"Automatic procedure for evaluating a formal specification over a trace of recorded events produced by a system"



MTL Trace Checking: Challenges

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2013/10/30 02:21:33,721 INFO  [org.jboss.as.mail.extension] (
2013/10/30 02:21:34,160 INFO  [org.jboss.as.remoting] (MSC se
2013/10/30 02:21:34,177 INFO  [org.jboss.as.connector.subsyst
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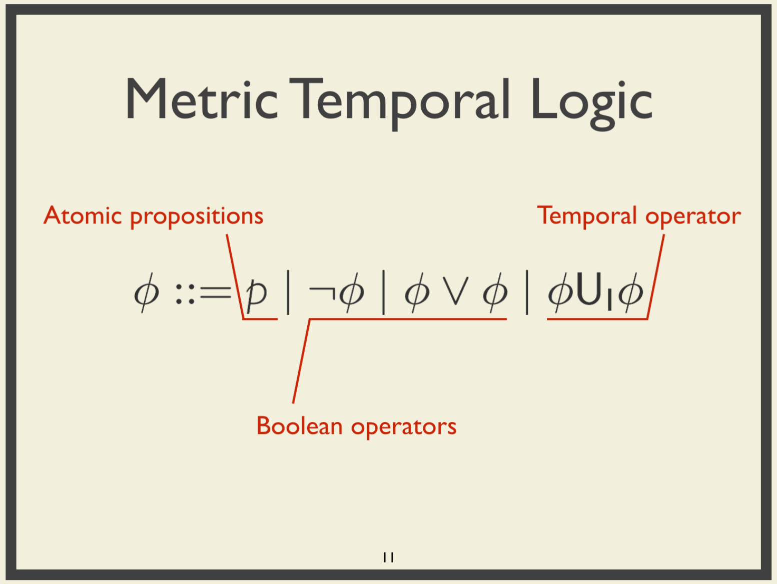
Distributed Trace Checking

Scalability with respect to the size of the trace

$\neg\ \mathsf{F}_{(0,3333]}$ … $\mathsf{G}_{(0,5}$ …

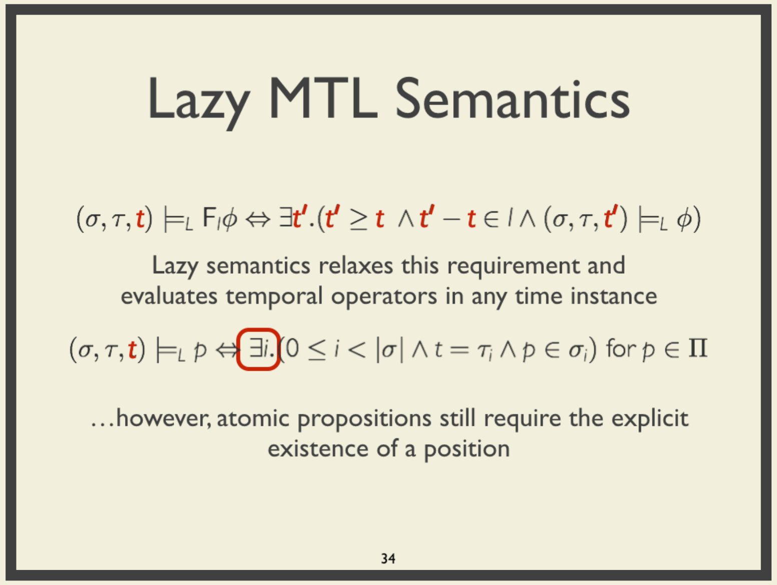
Decomposing large intervals

Scalability with respect to the size of the timing intervals in the formula



Metric Temporal Logic

$$\phi ::= \underbrace{p}_{\text{Atomic propositions}} \mid \underbrace{\neg\phi \mid \phi \vee \phi}_{\text{Boolean operators}} \mid \underbrace{\phi \mathsf{U}_I \phi}_{\text{Temporal operator}}$$



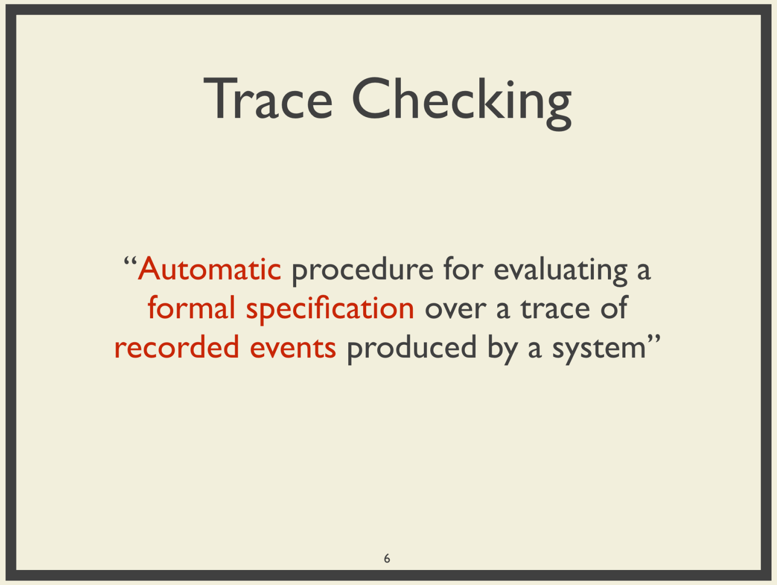
Lazy MTL Semantics

$$(\sigma,\tau,t) \models_L \mathsf{F}_I\phi \Leftrightarrow \exists t'.(t' \geq t \ \wedge t' - t \in I \wedge (\sigma,\tau,t') \models_L \phi)$$

Lazy semantics relaxes this requirement and evaluates temporal operators in any time instance

$$(\sigma,\tau,t) \models_L p \Leftrightarrow \boxed{\exists i.}(0 \leq i < |\sigma| \wedge t = \tau_i \wedge p \in \sigma_i) \text{ for } p \in \Pi$$

…however, atomic propositions still require the explicit existence of a position



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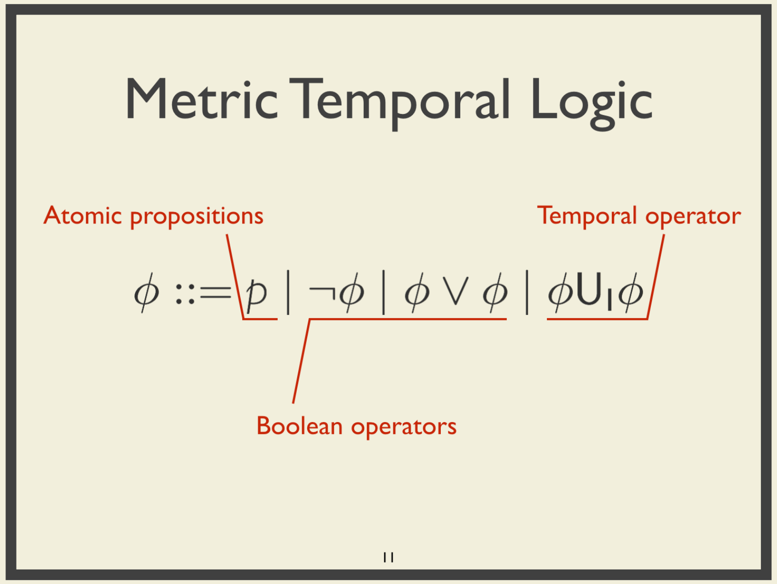

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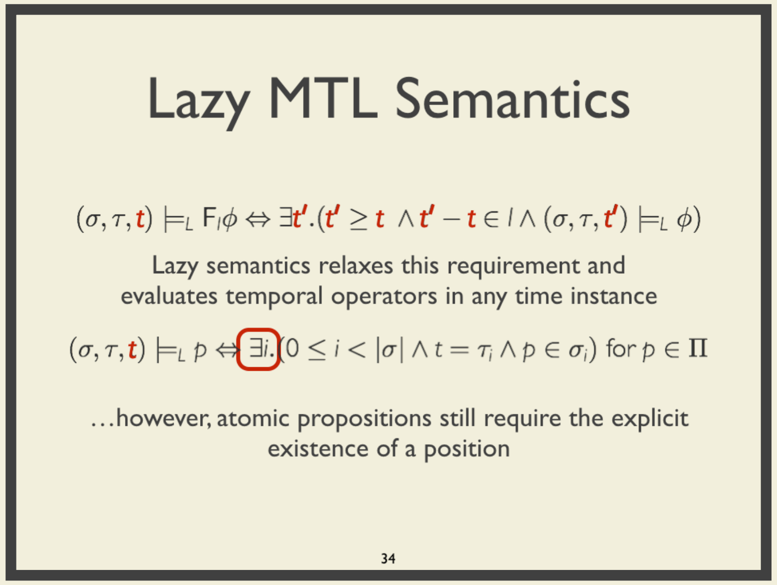

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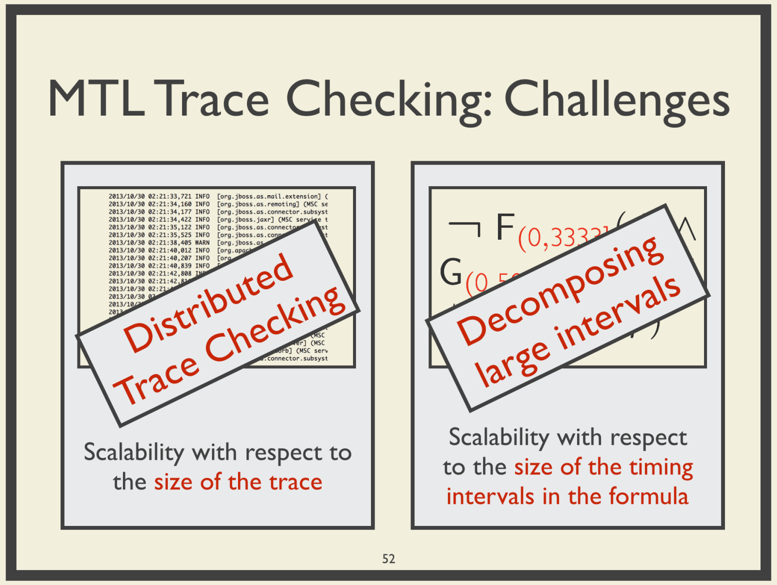

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2013/10/30 02:21:42,808 IN
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2013/10/30 0
2013/10/
2013
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Distributed Trace Checking

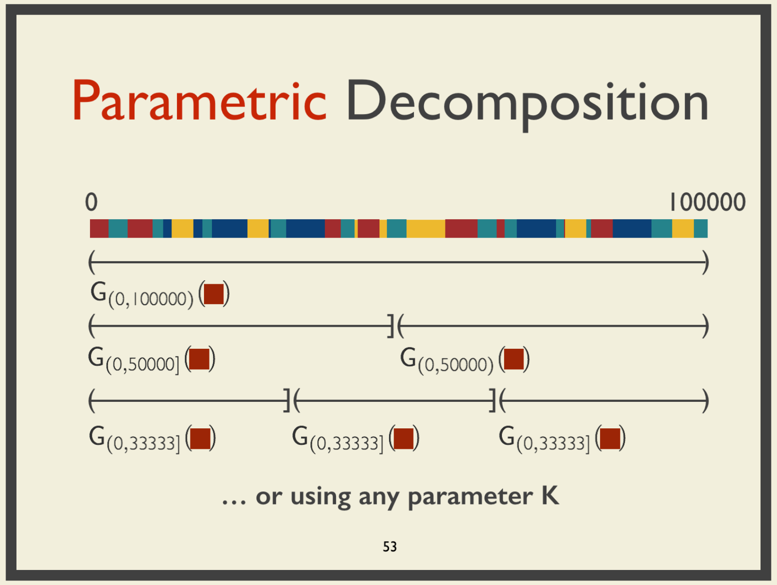
Scalability with respect to the size of the trace

$\neg\ \mathsf{F}_{(0,3333}$ … $\wedge$

$\mathsf{G}_{(0,5}$

Decomposing large intervals

Scalability with respect to the size of the timing intervals in the formula



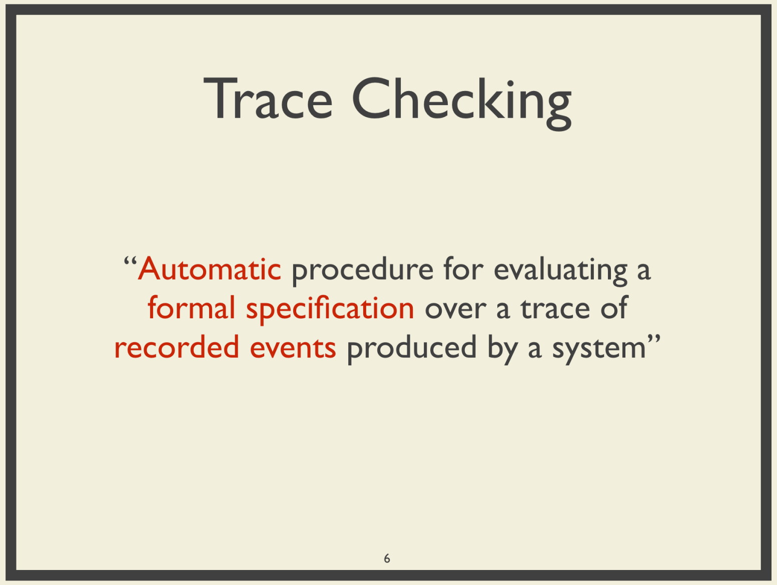
Parametric Decomposition

$\mathsf{G}_{(0,100000)}(\blacksquare)$

$\mathsf{G}_{(0,50000]}(\blacksquare)$ $\mathsf{G}_{(0,50000)}(\blacksquare)$

$\mathsf{G}_{(0,33333]}(\blacksquare)$ $\mathsf{G}_{(0,33333]}(\blacksquare)$ $\mathsf{G}_{(0,33333]}(\blacksquare)$

… or using any parameter K



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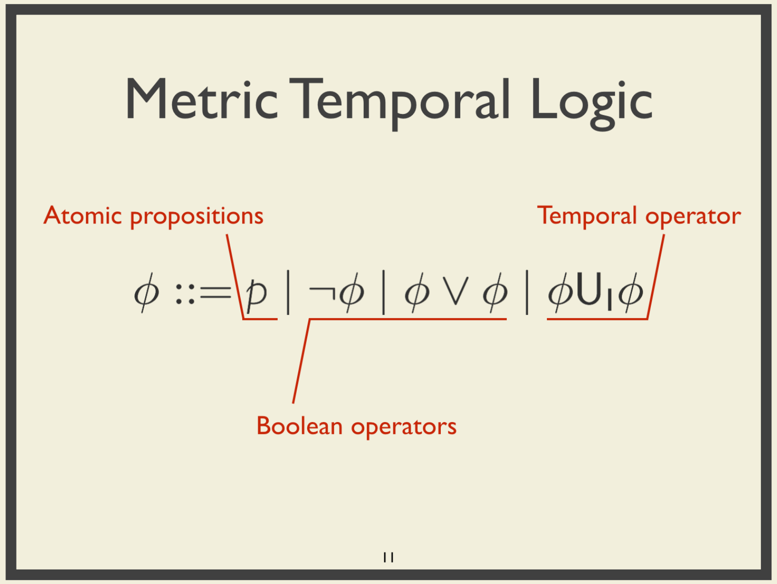

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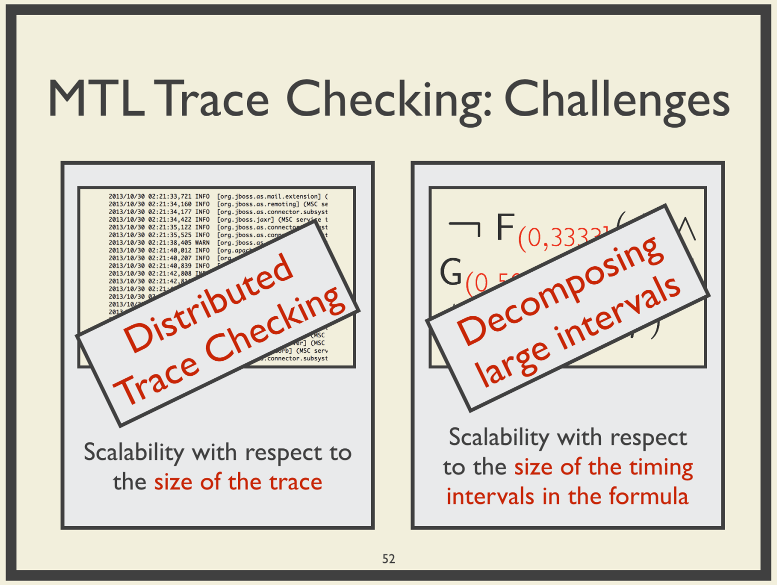
Atomic propositions

Temporal operator

Boolean operators

11



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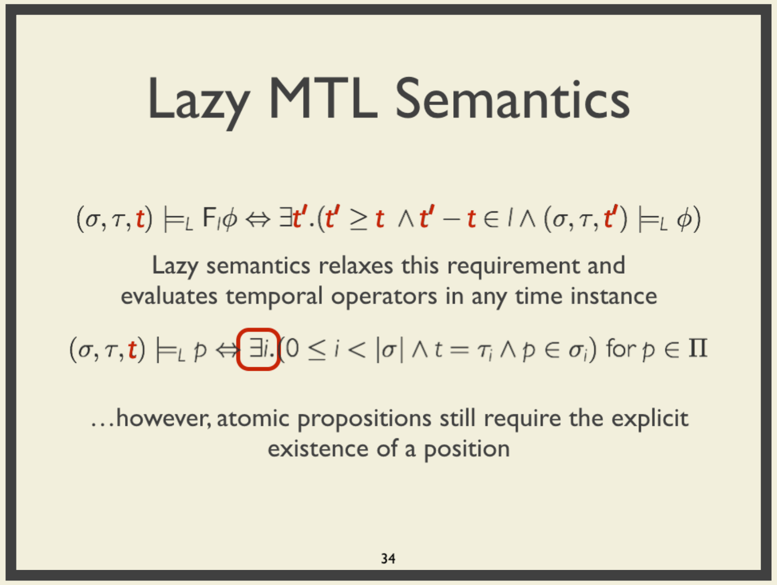

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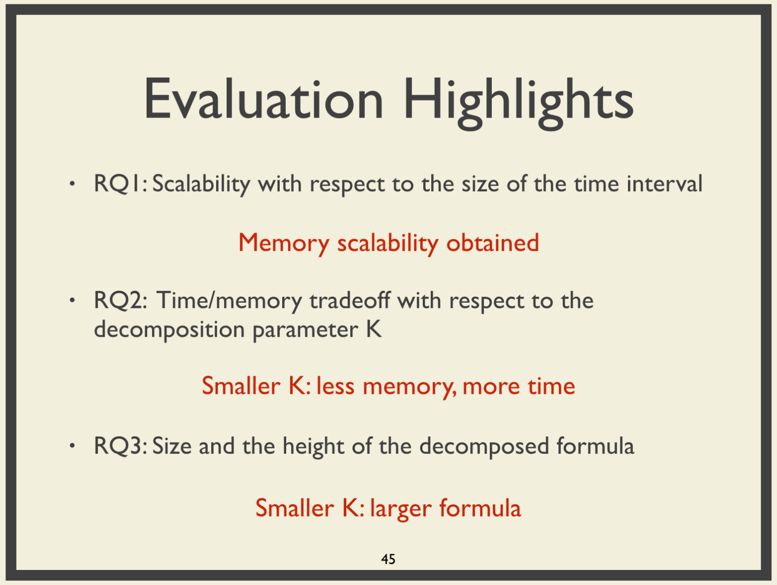


Evaluation Highlights

- RQ1: Scalability with respect to the size of the time interval

Memory scalability obtained

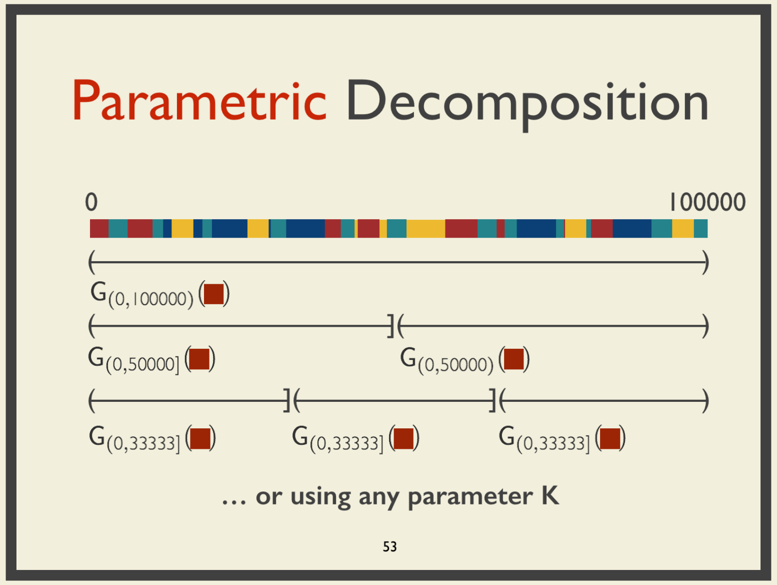
- RQ2: Time/memory tradeoff with respect to the decomposition parameter K

Smaller K: less memory, more time

- RQ3: Size and the height of the decomposed formula

Smaller K: larger formula

45



Parametric Decomposition

… or using any parameter K

53

Efficient Large-scale Trace Checking using MapReduce

Srđan Krstić

with

Marcello M. Bersani, Domenico Bianculli, Carlo Ghezzi and Pierluigi San Pietro

POLITECNICO MILANO

uni.lu UNIVERSITÉ DU LUXEMBOURG

Future Research Directions

- Lazy semantics vs signal-based semantics
- Automatic and heterogeneous decomposition
- Decomposition of other operators