Synthesizing Racy Tests

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Introduction

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- Developers use multithreaded libraries as building blocks.
- Do the client applications need to acquire additional locks to avoid data races?
- If YES
  - what locks need to be acquired?
  - which method invocations require these acquisitions?

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Apply Dynamic Race Detection

Dynamic Race Detection

Dynamic Race Detection

Library

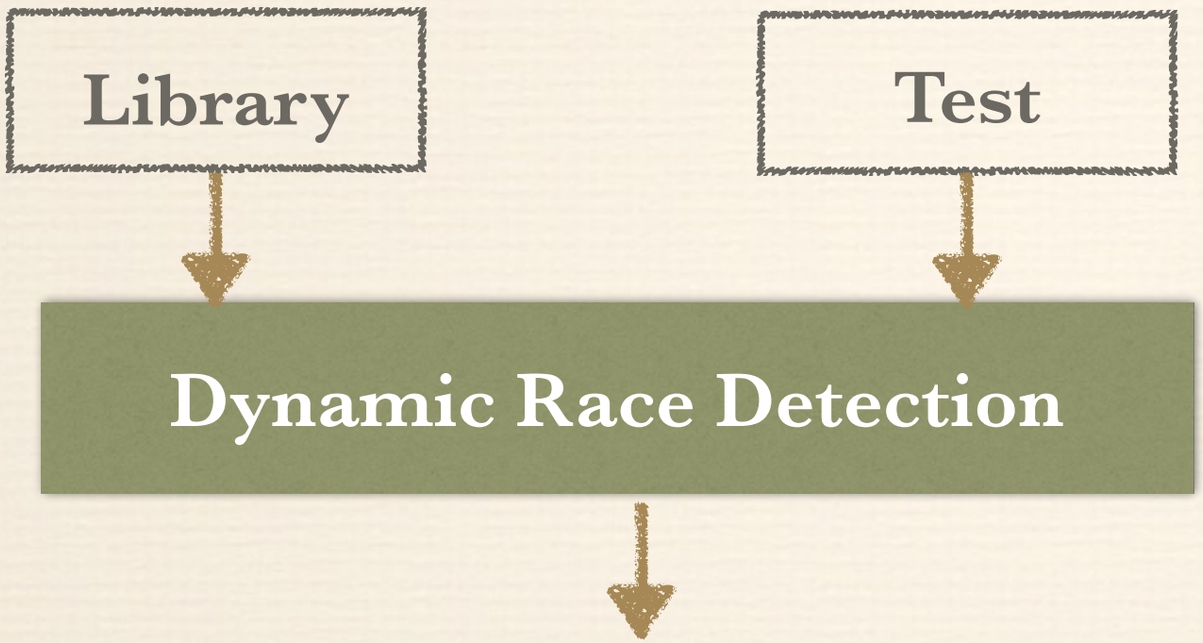
Dynamic Race Detection

Library

Test

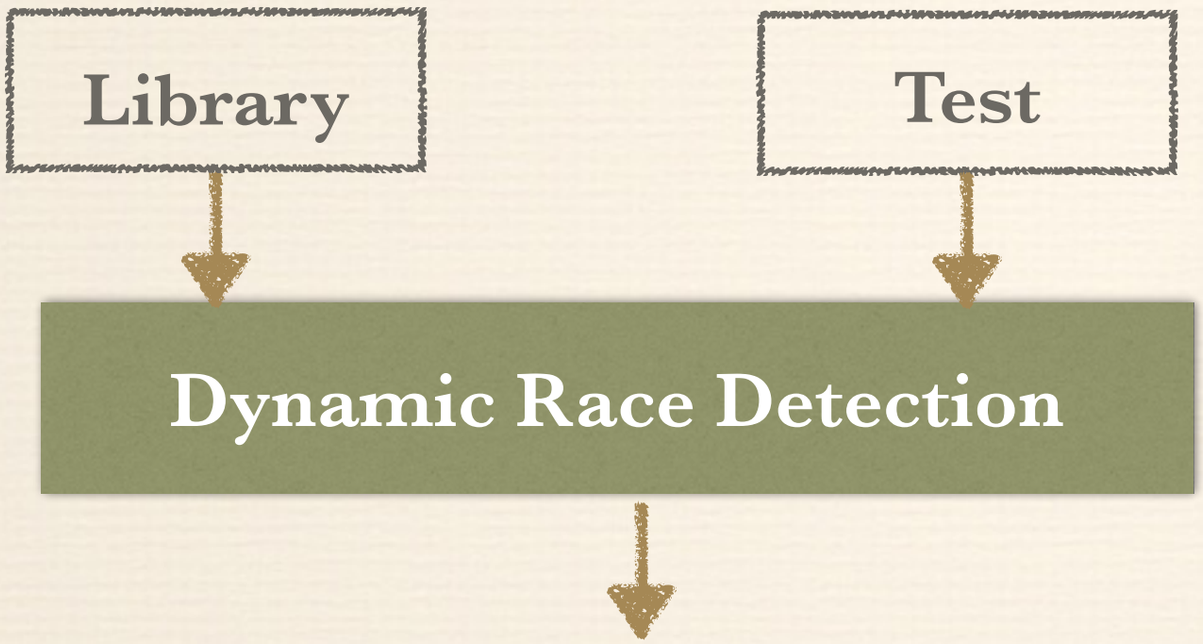
Dynamic Race Detection

Dynamic Race Detection



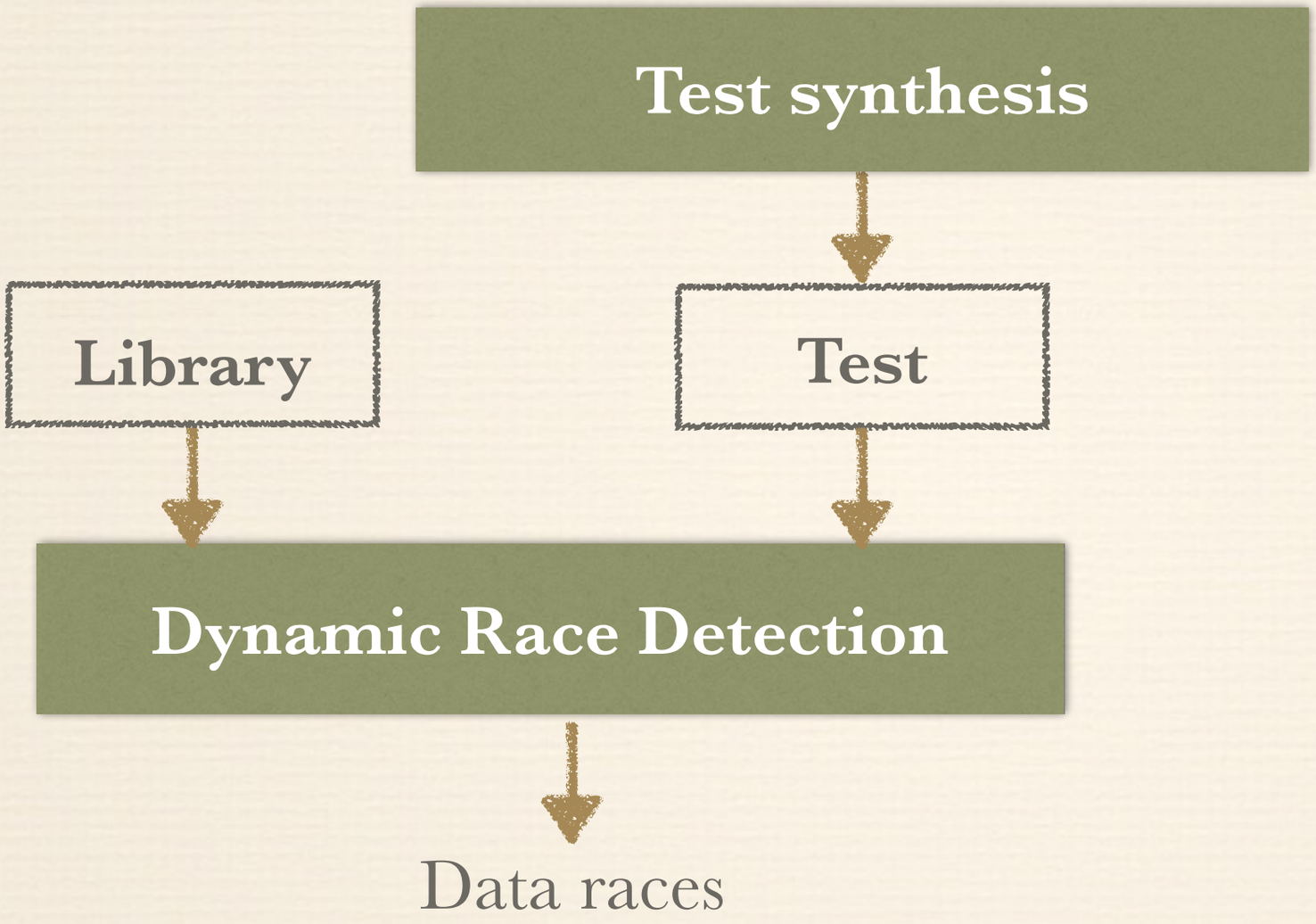
- **Eraser,** SOSP'97
- **DJIT+,** PPoPP'03
- **RaceFuzzer,** PLDI'08
- **FastTrack,** PLDI'09
- **Causally Precedes,** POPL'12

Dynamic Race Detection



- **Significant manual effort**
- **Higher false negatives**

Dynamic Race Detection



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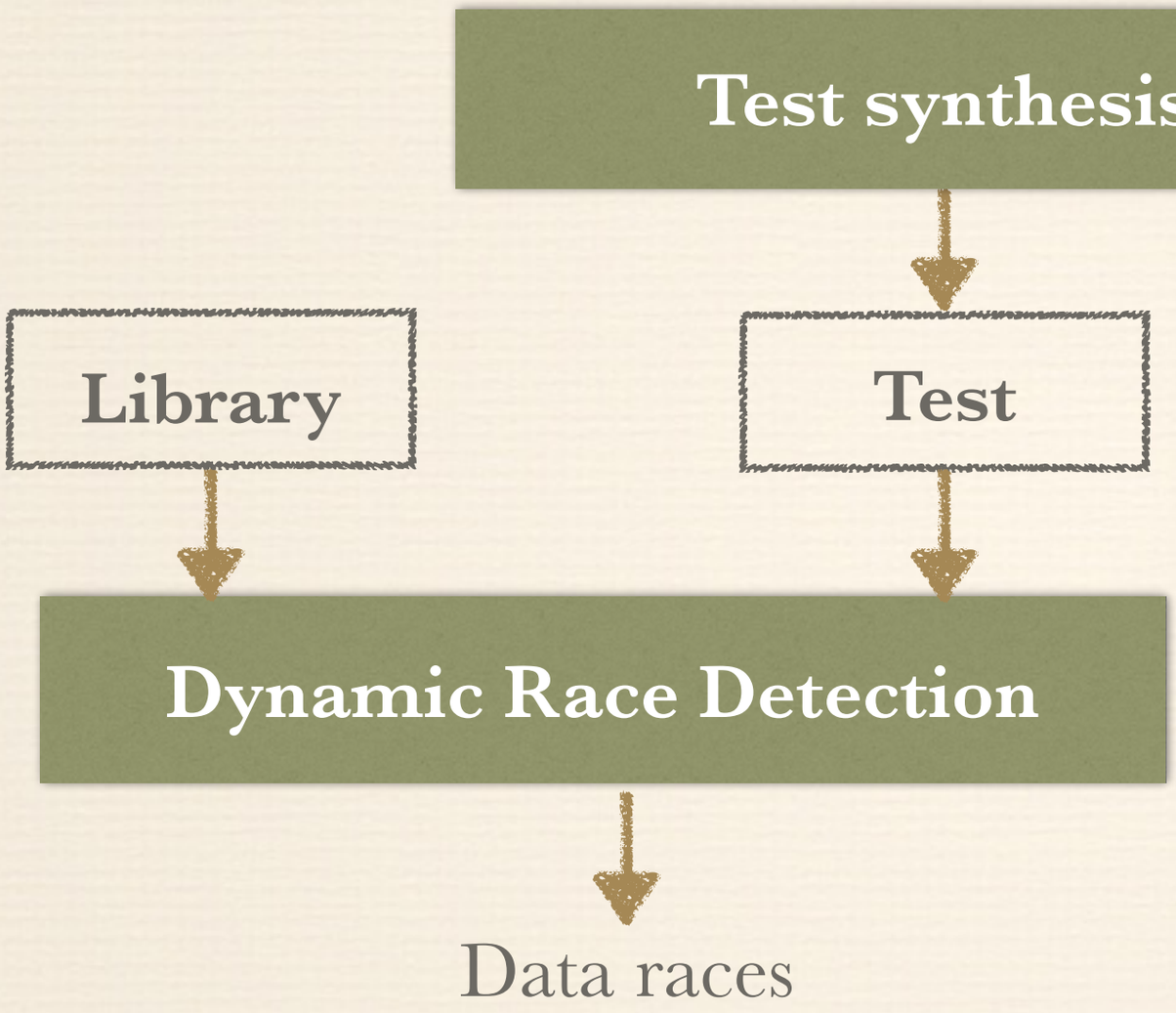

Goal of this work

Motivating example

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- hazelcast-3.3.2
  - in-memory data grid
  - manage high data ingest rates
  - 82 contributors, 68 releases, 12K commits

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- SynchronizedWriteBehindQueue class is declared thread-safe
  - clients need not acquire additional locks

Motivating example

- hazelcast-3.3.2
  - in-memory data grid
  - manage high data ingest rates
  - 82 contributors, 68 releases, 12K commits
- SynchronizedWriteBehindQueue class is declared thread-safe
  - clients need not acquire additional locks
- Class is **NOT** thread-safe
  - corner case leads to a race
  - requires a complex multi-threaded test

Motivating example

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t_1: a.removeFirst()

t_2: b.removeFirst()

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- Which methods need to be invoked concurrently?

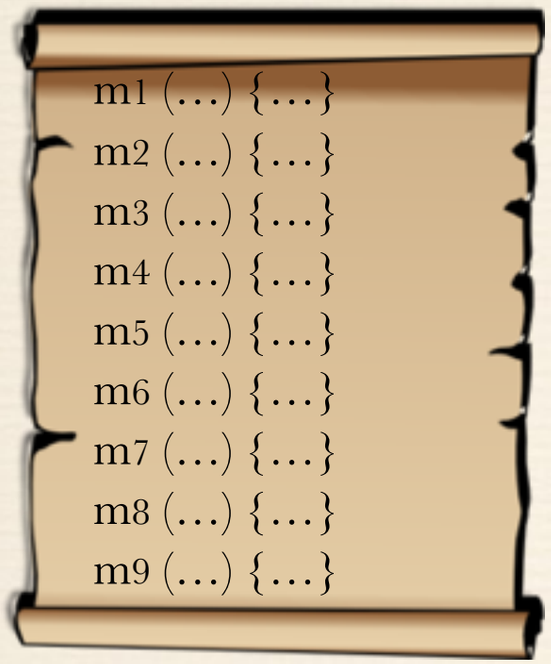
Motivating example

t_1: a.removeFirst()

t_2: b.removeFirst()

- Which methods need to be invoked concurrently?
- What parameters need to be passed to these methods?

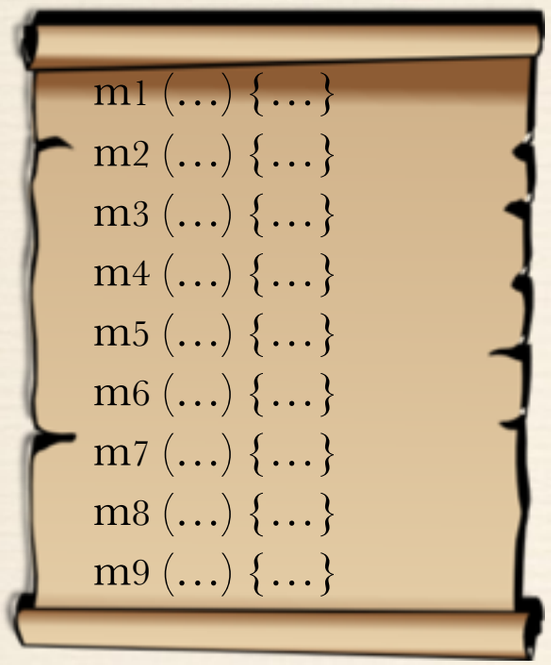
Random Test Generation



Library

Possible Parameters

Random Test Generation



Library

Possible Parameters

t_1: m1( )
t_2: m2( )

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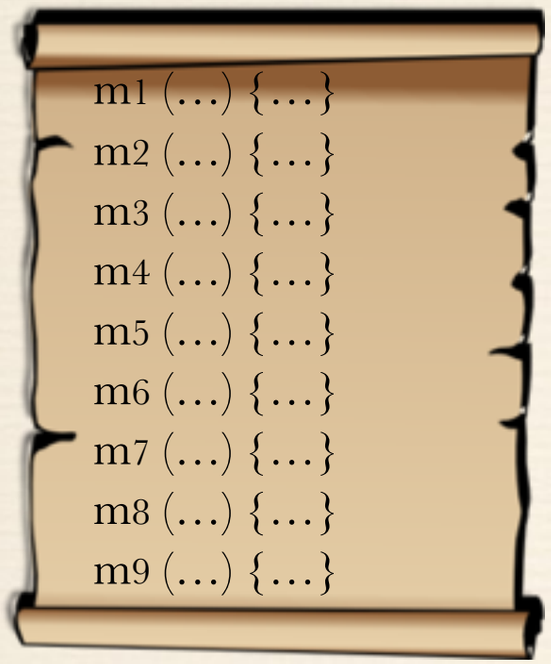

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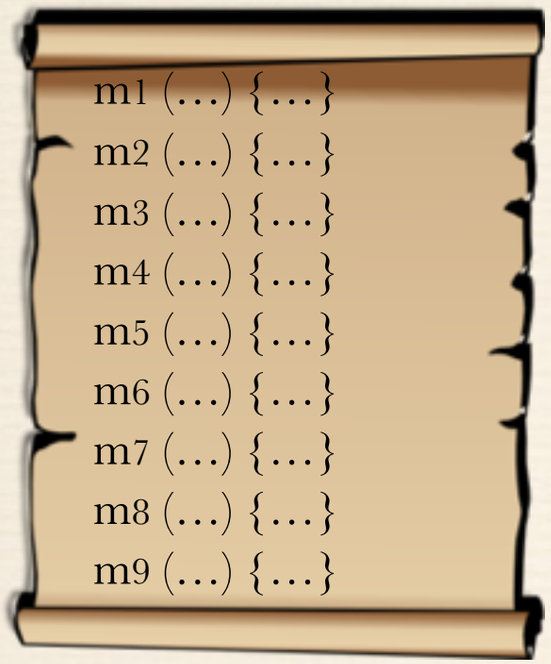

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t_1: m2(● ●)
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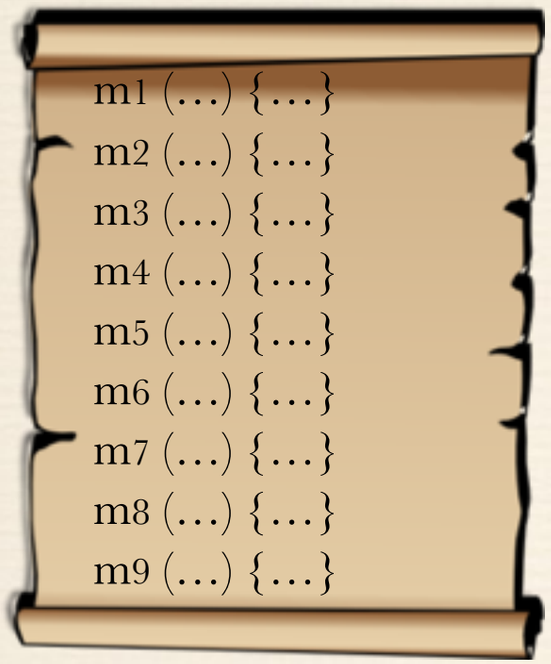

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Random Test Generation

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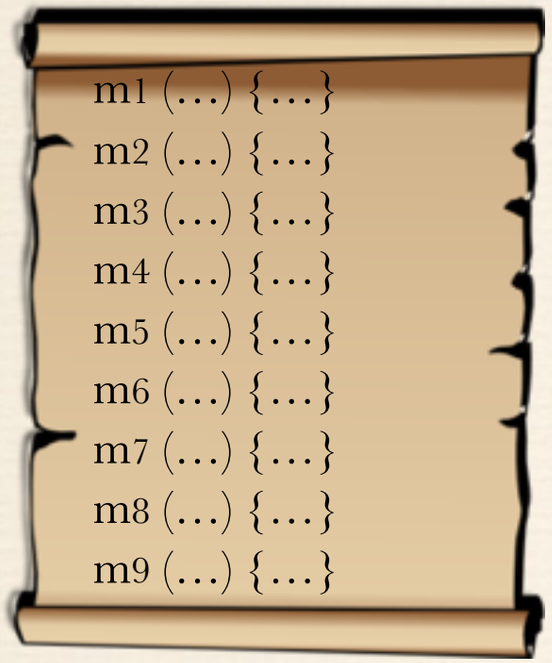

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Possible Parameters

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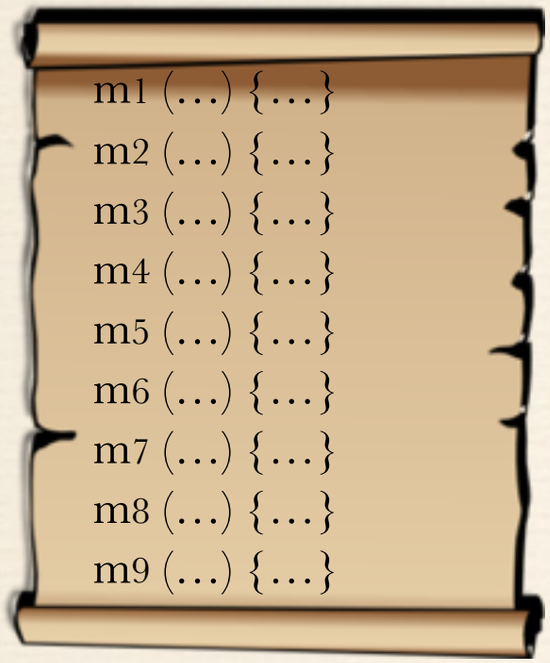
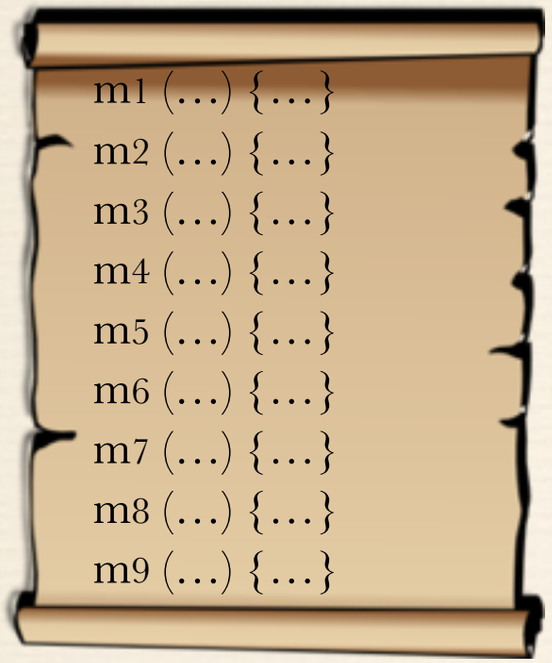


Library

Possible Parameters

m1( )

Targeted Test Synthesis

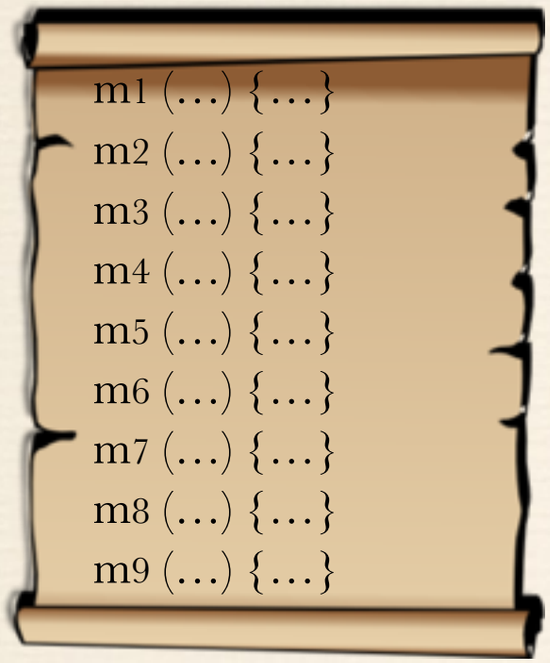


Library

Possible Parameters

m1( ) **m4**( )

Targeted Test Synthesis



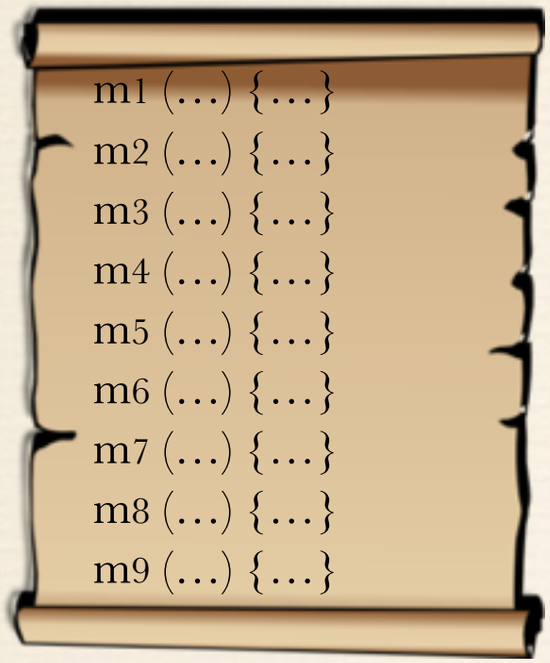
Library

Possible Parameters

m1(● ● ● **)**

m4(**)**

Targeted Test Synthesis



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Possible Parameters

m1()

m4()

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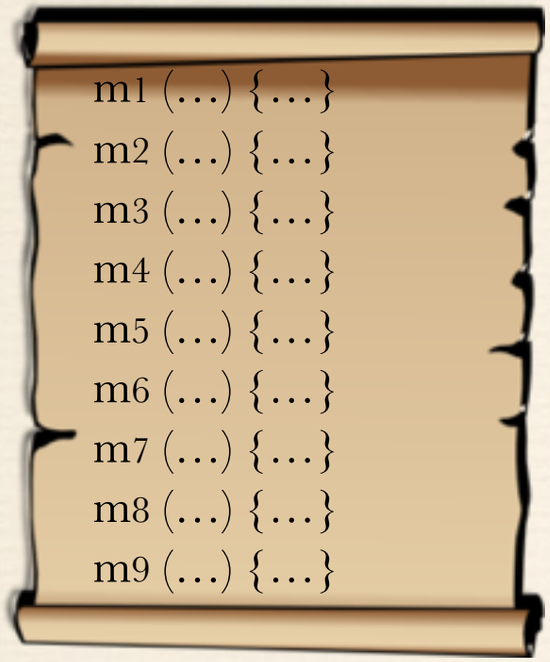


Library

Possible Parameters

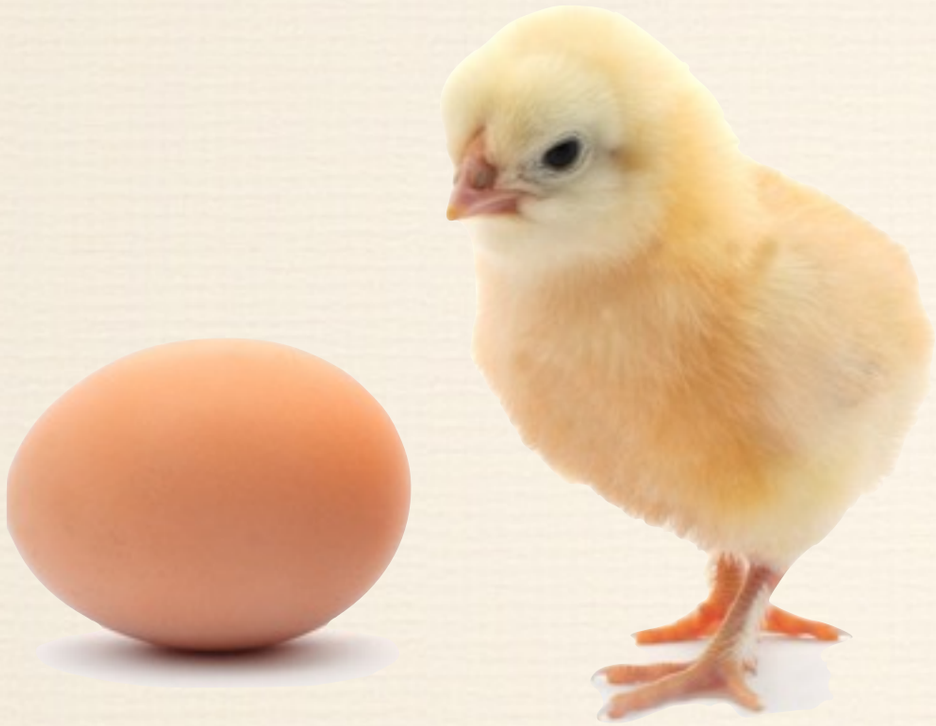
t_1

m1(● ● ●)

t_2

m4(● ●)

Conundrum



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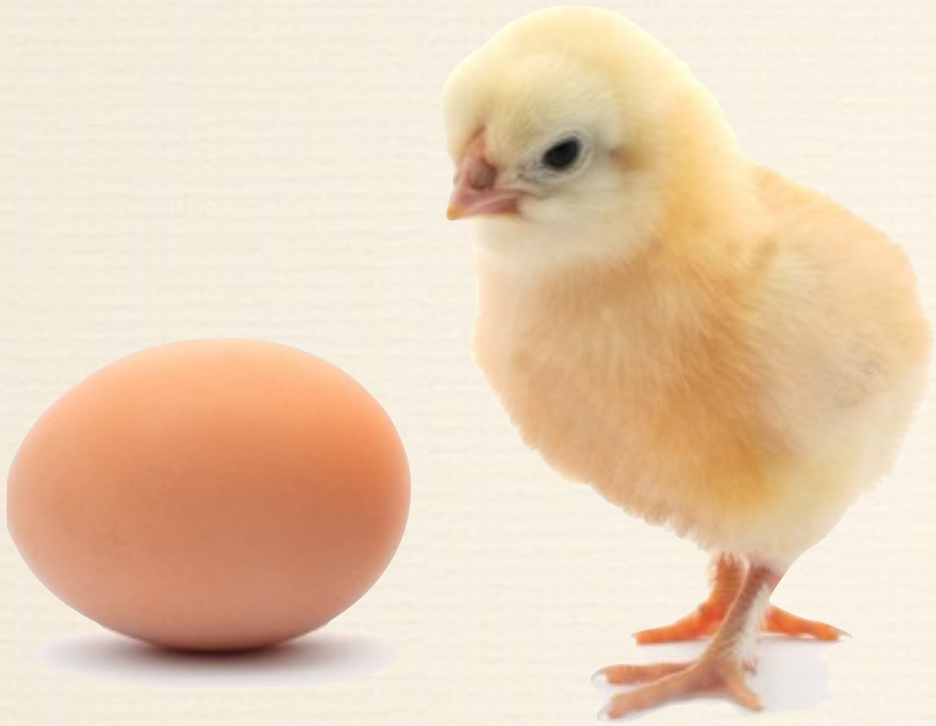

- Dynamic race detection requires effective tests

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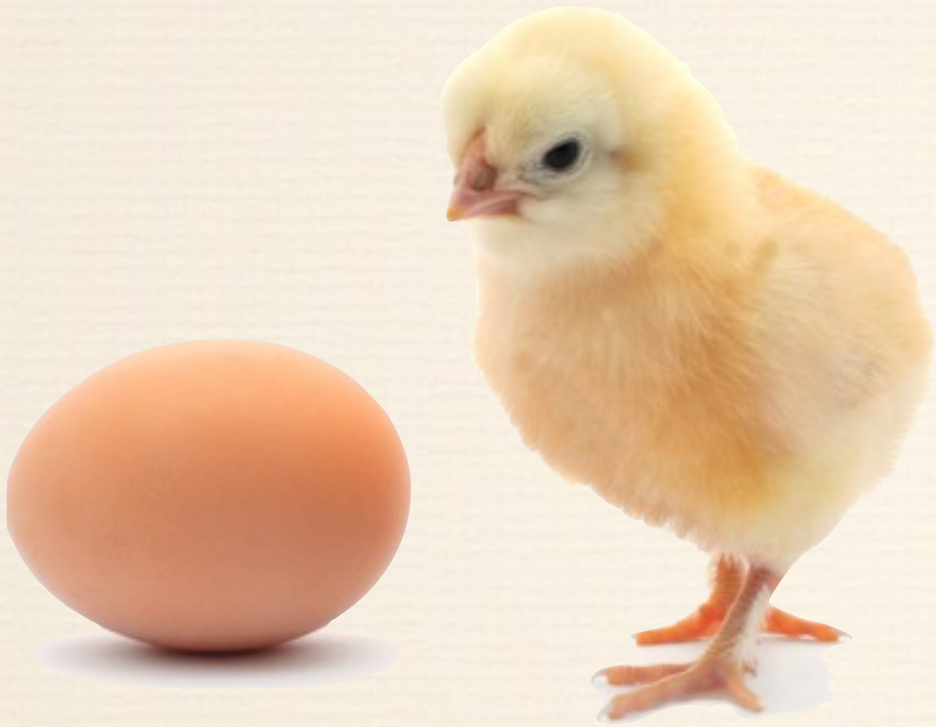

- Dynamic race detection requires effective tests
- Test synthesis requires some knowledge of races

Key Insight

Use data from sequential test execution to construct multithreaded tests

Overview

Overview

Library **Sequential Tests**

Overview

Library

Sequential Tests

Overview

Library **Sequential Tests**

Overview

Library

Sequential Tests

NARADA

Multithreaded Tests

Challenge 1: Identify access pairs

T_1	**write(●)**	**read(●)**	**…**	**write(●)**
T_2	**read(●)**	**write(●)**	**…**	**read(●)**
T_3	**write(●)**	**read(●)**	**…**	**write(●)**
		…		
T_{n-1}	**write(●)**	**read(●)**	**…**	**write(●)**
T_n	**read(●)**	**read(●)**	**…**	**read(●)**

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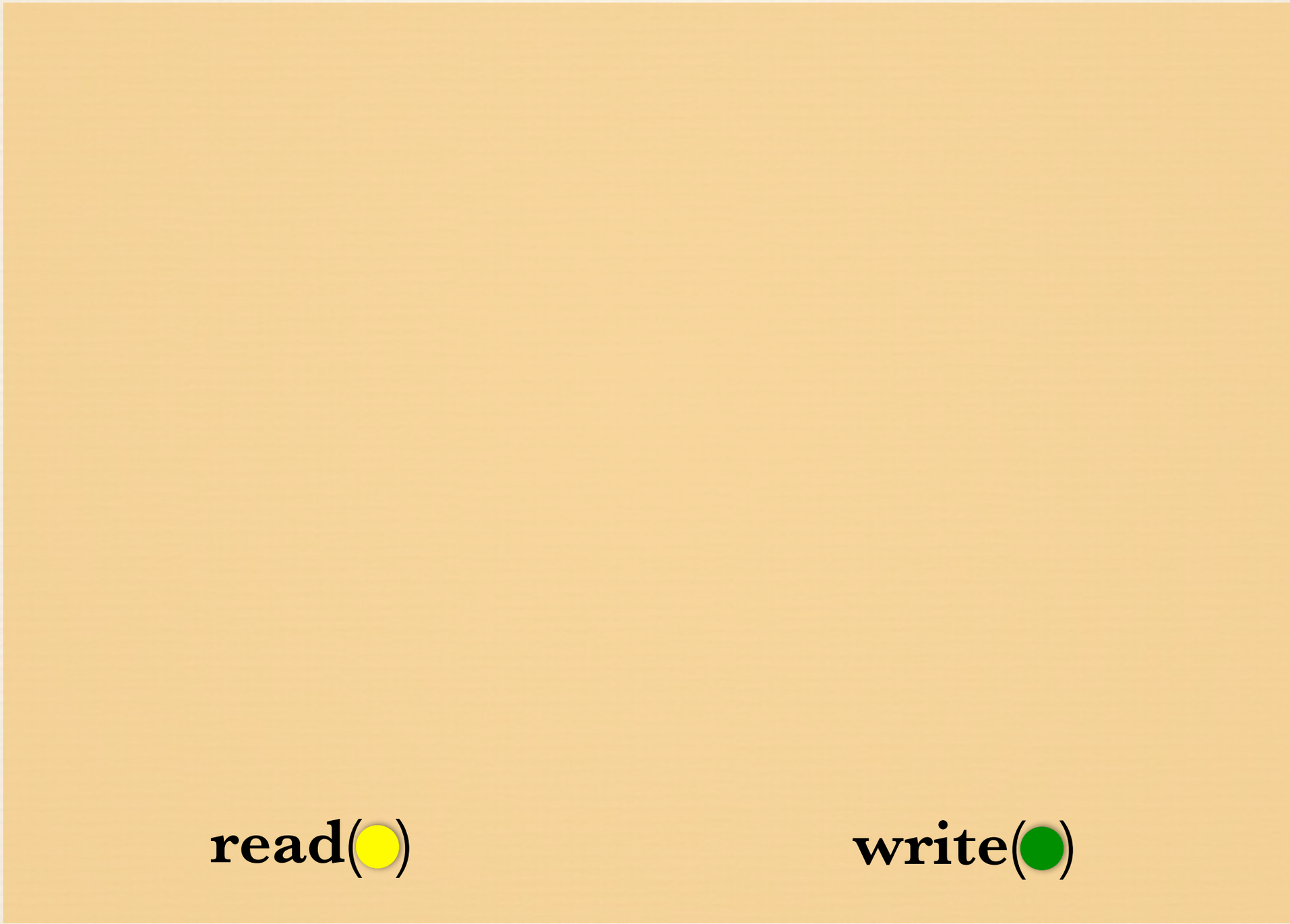

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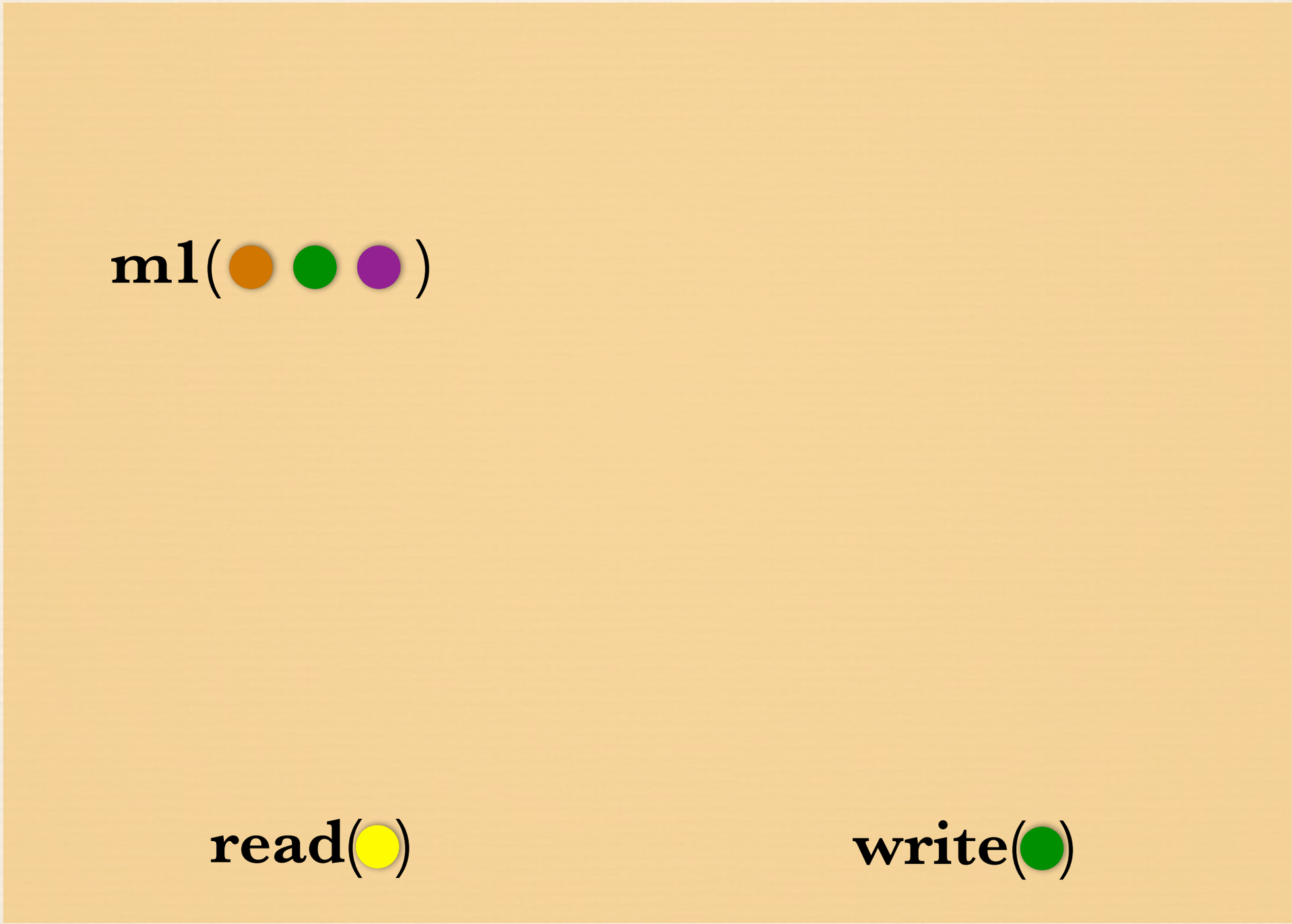

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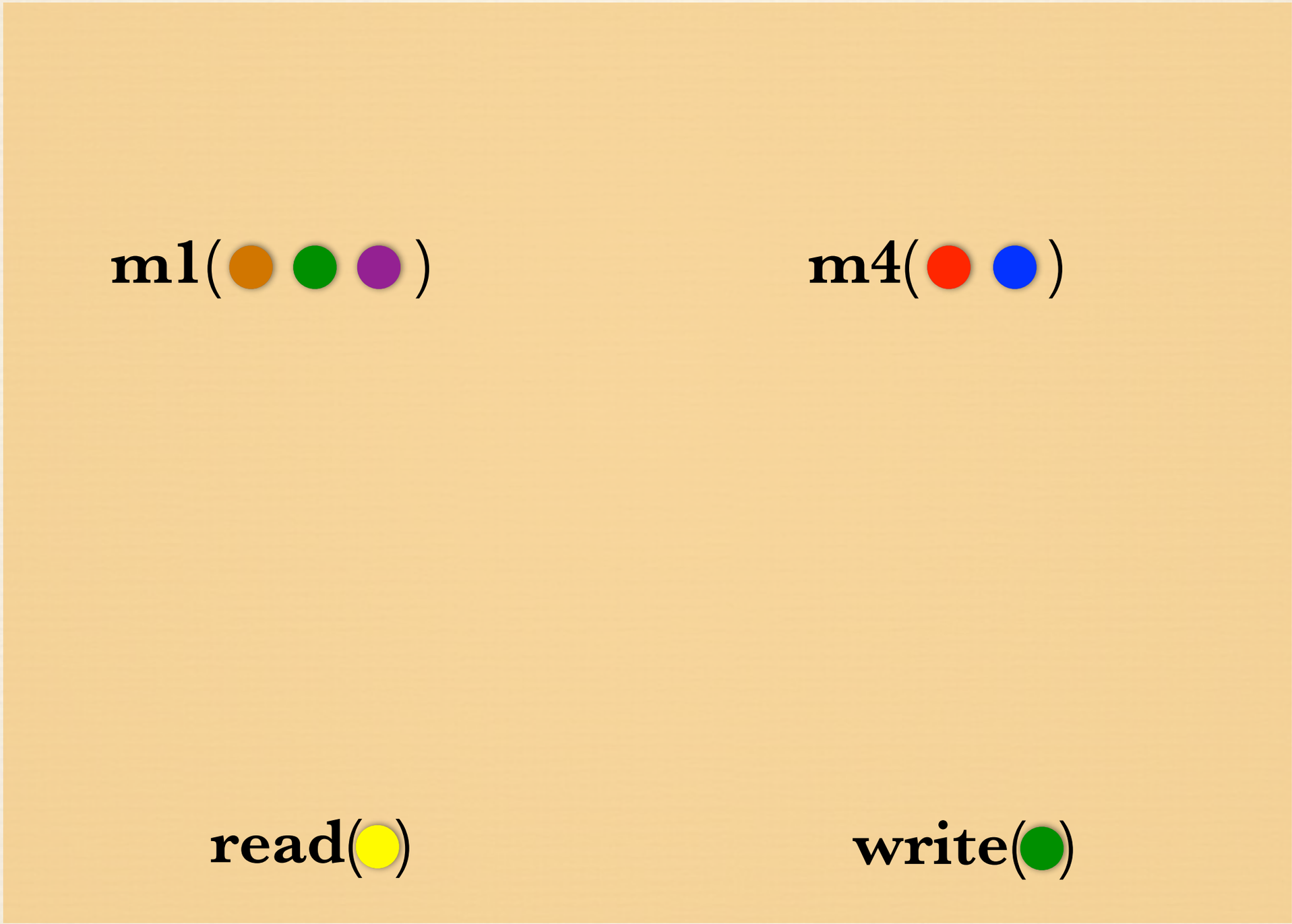

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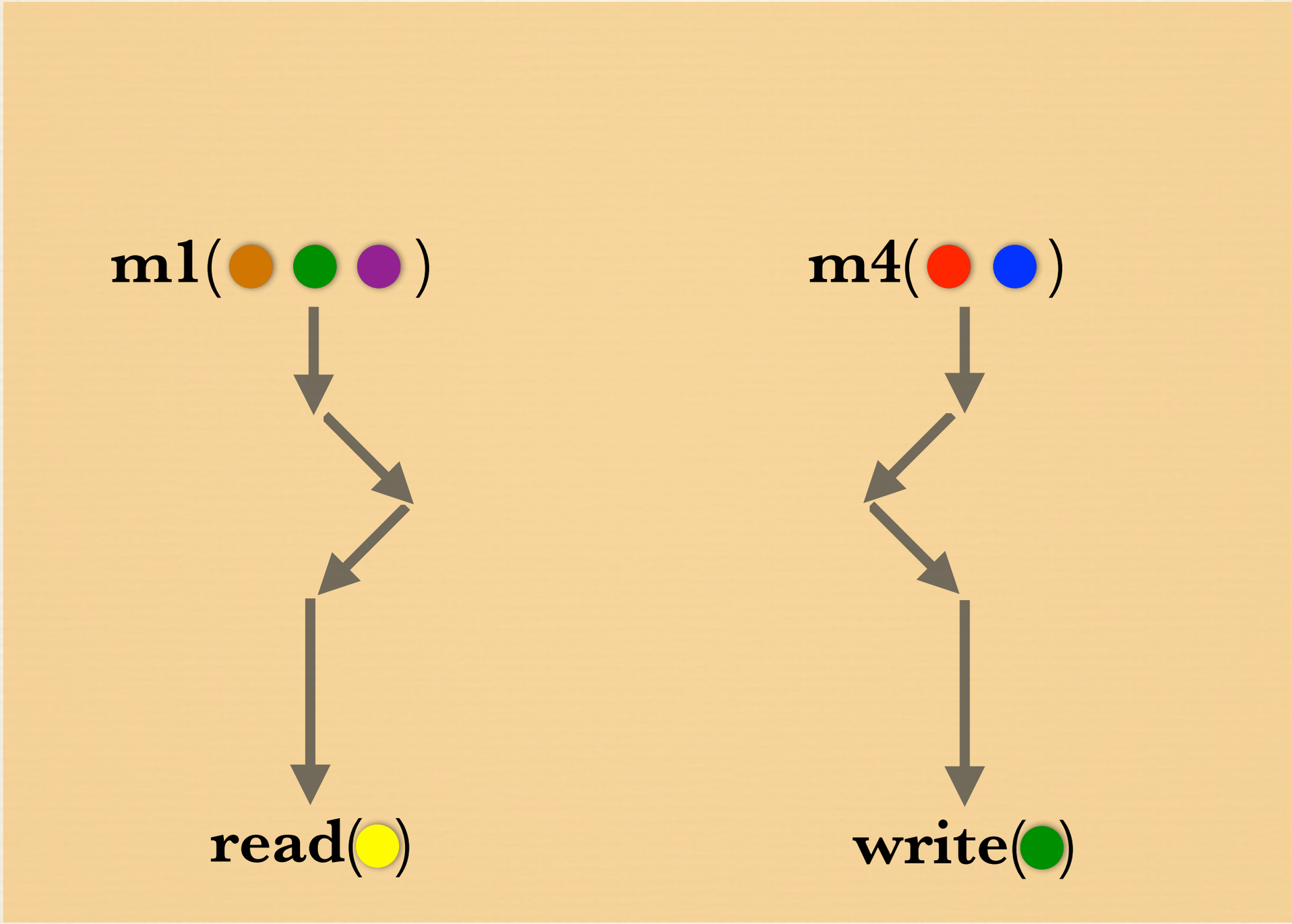
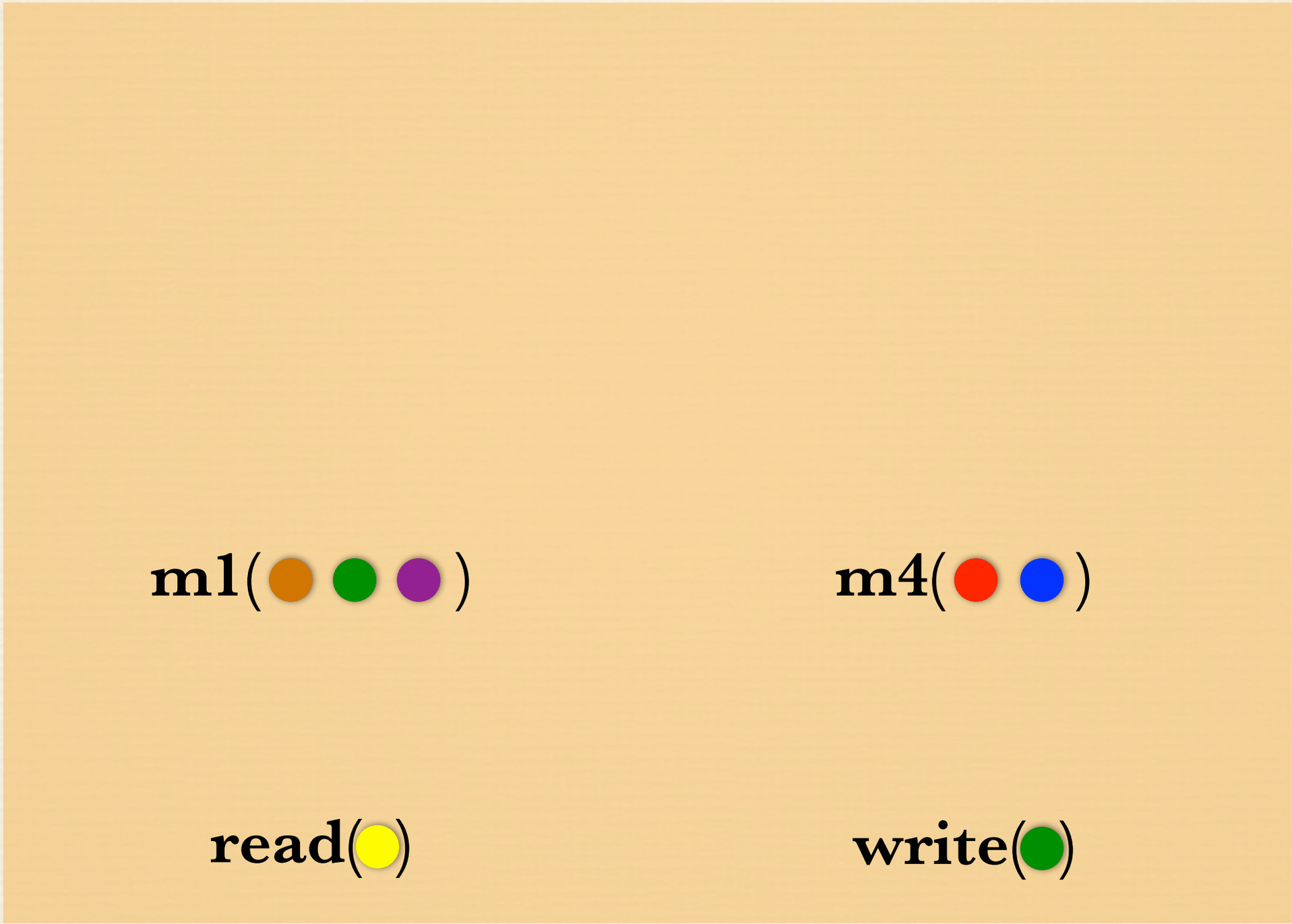


Challenge 3: Set the context



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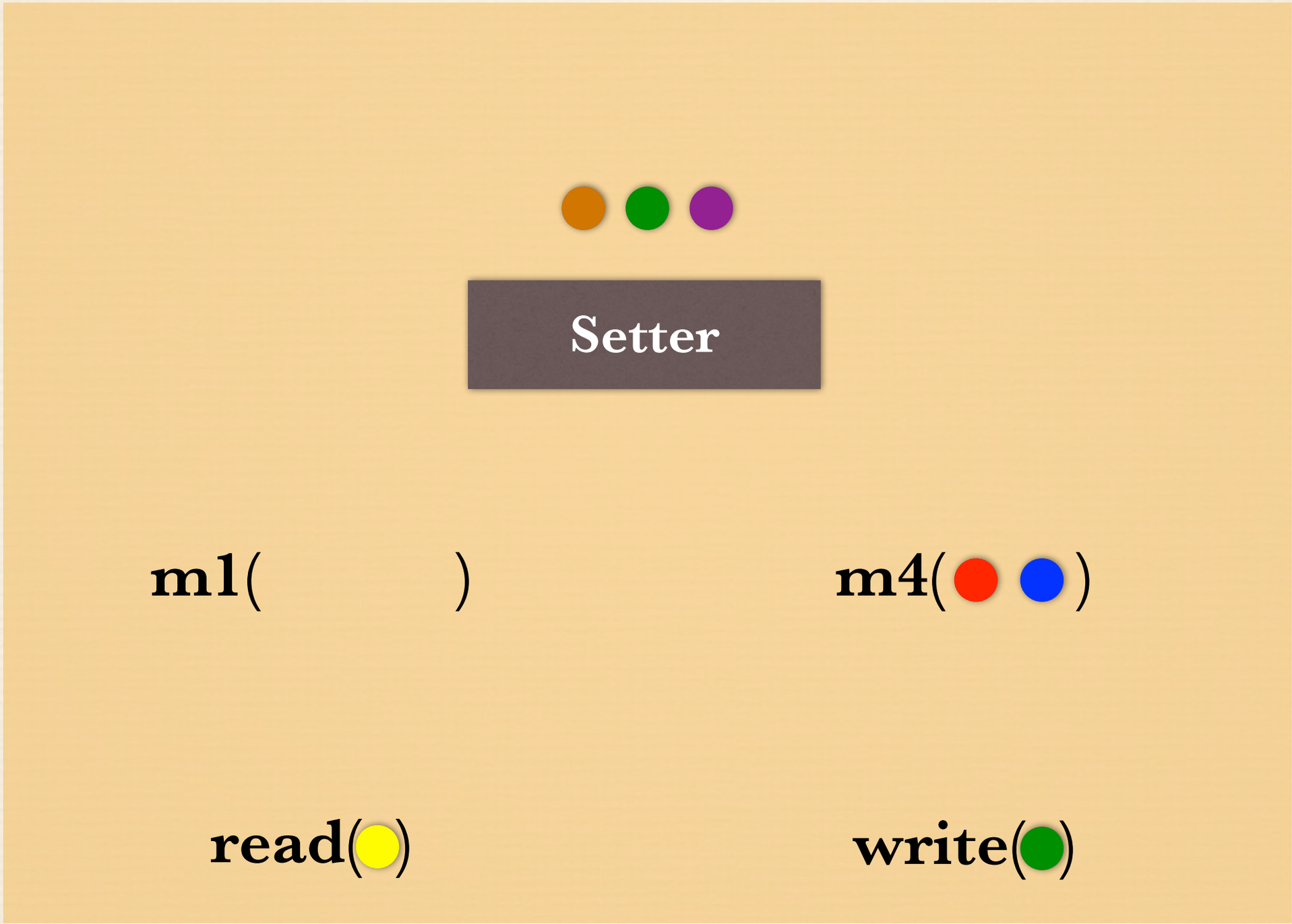

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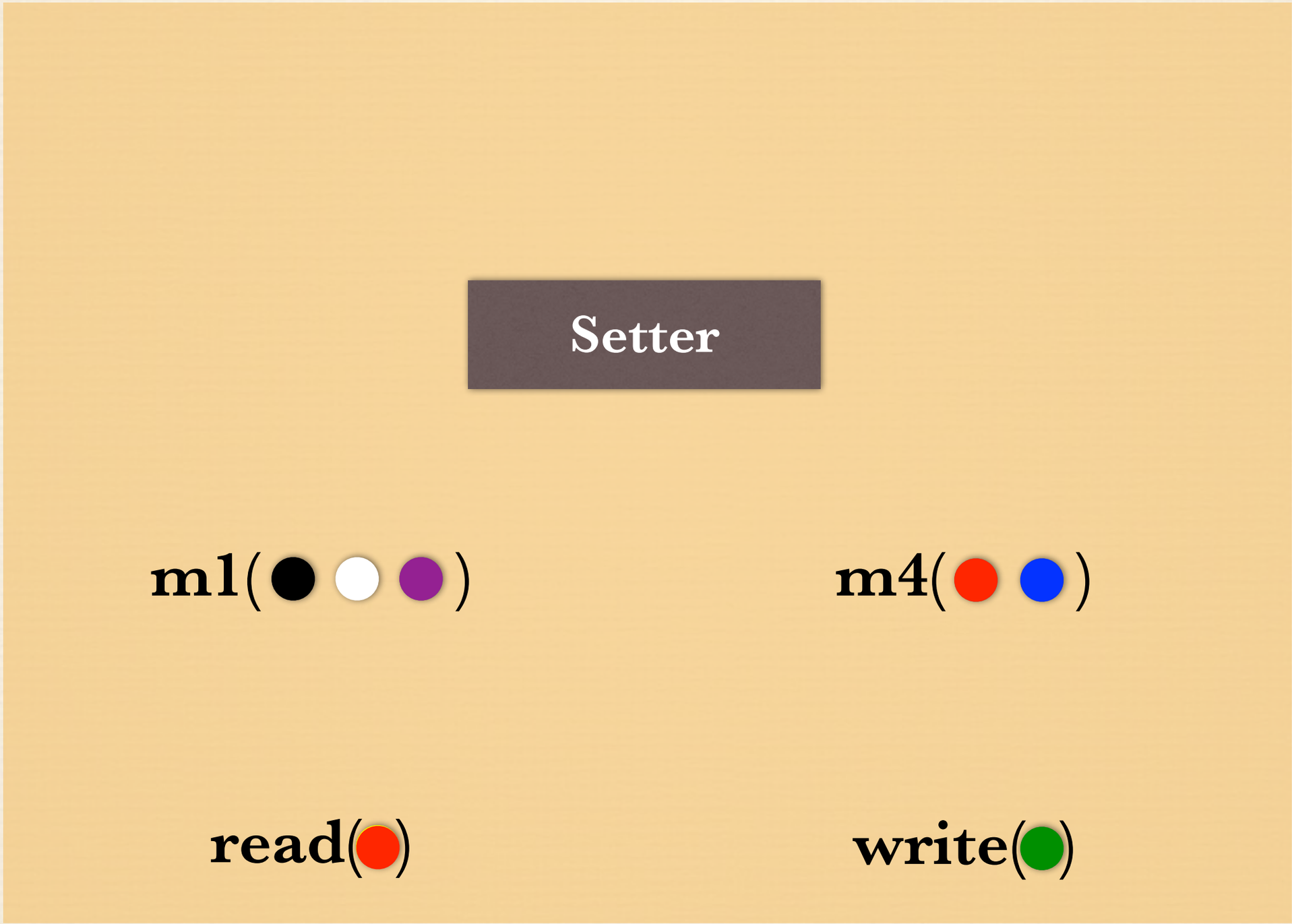

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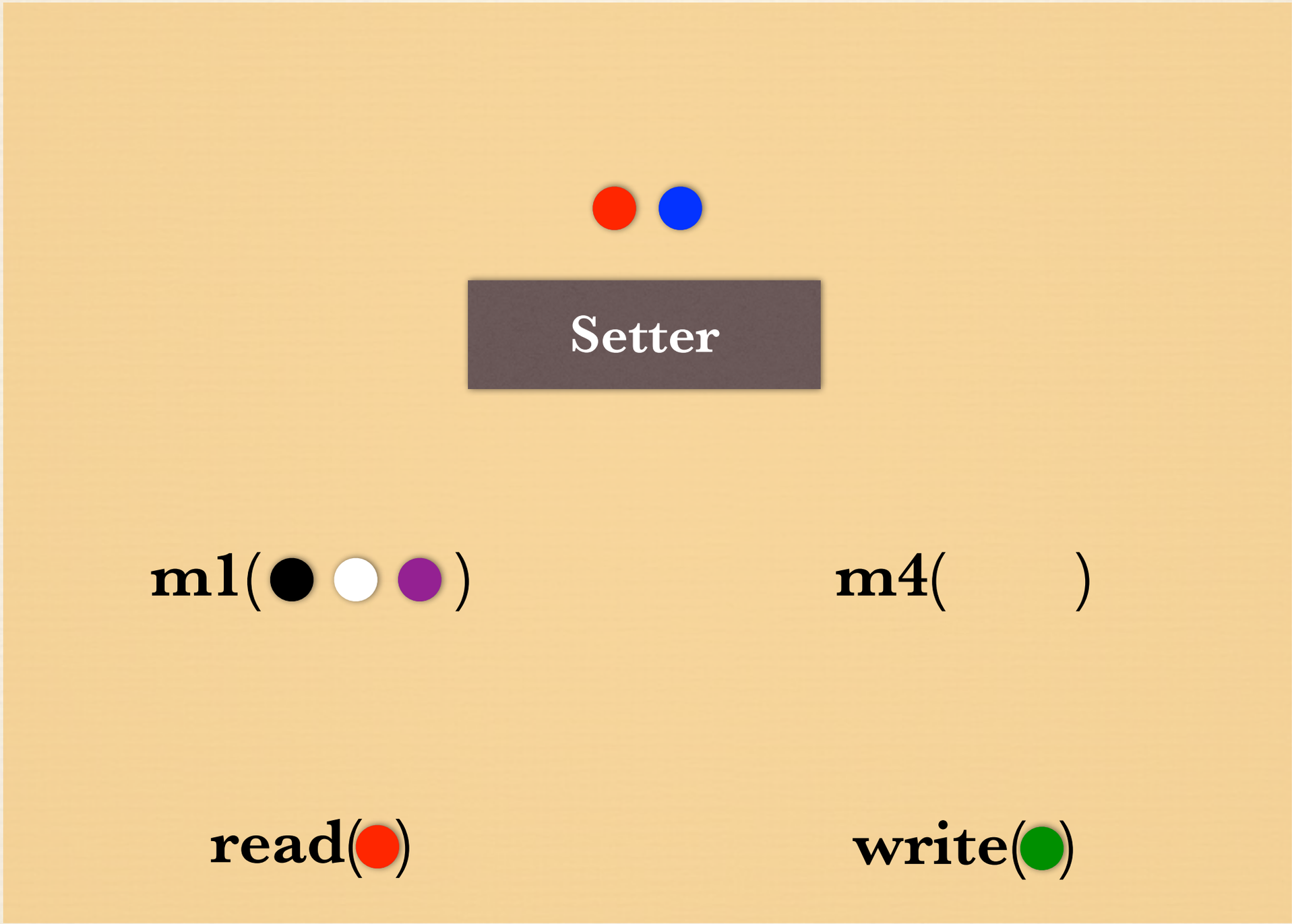

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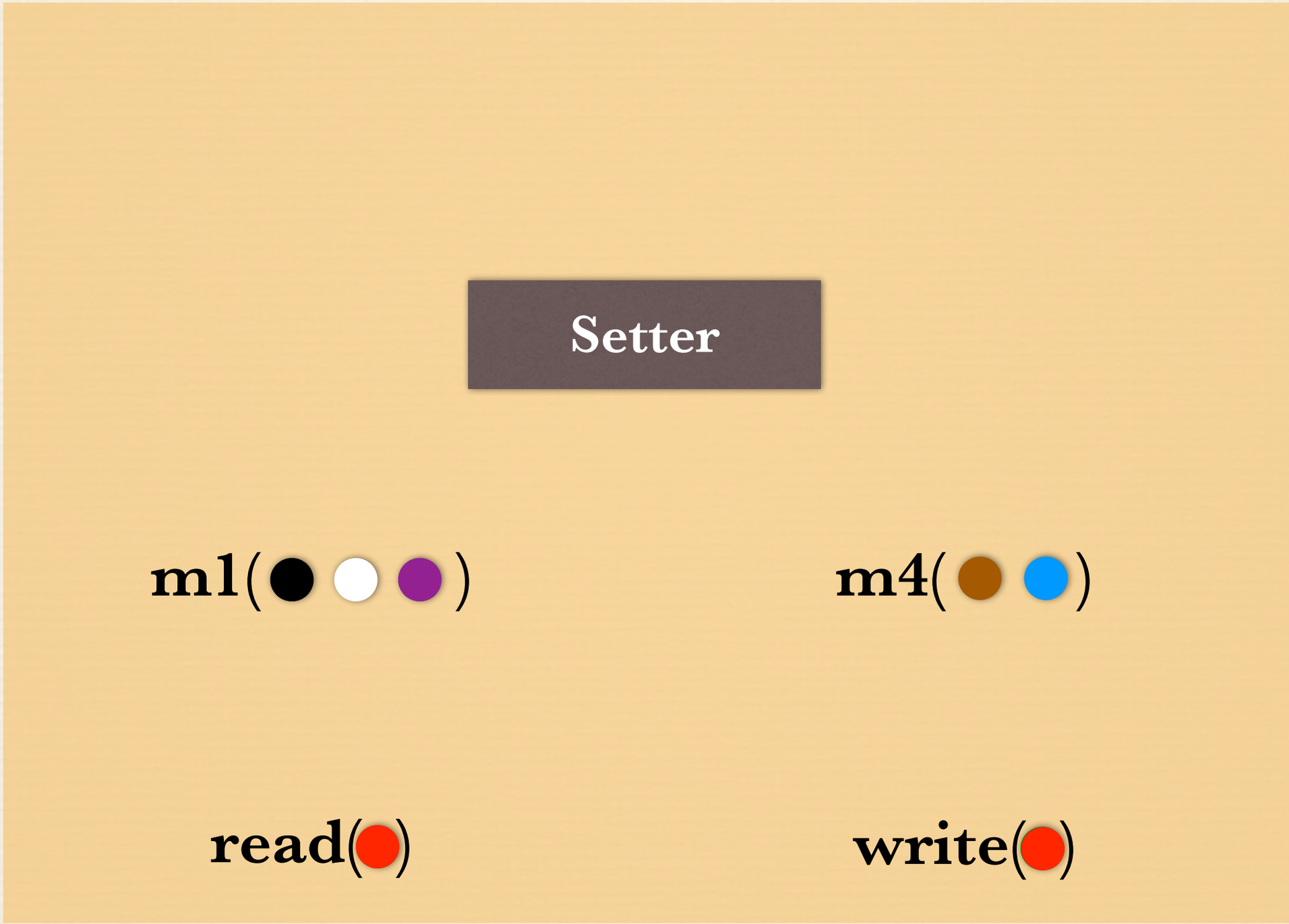
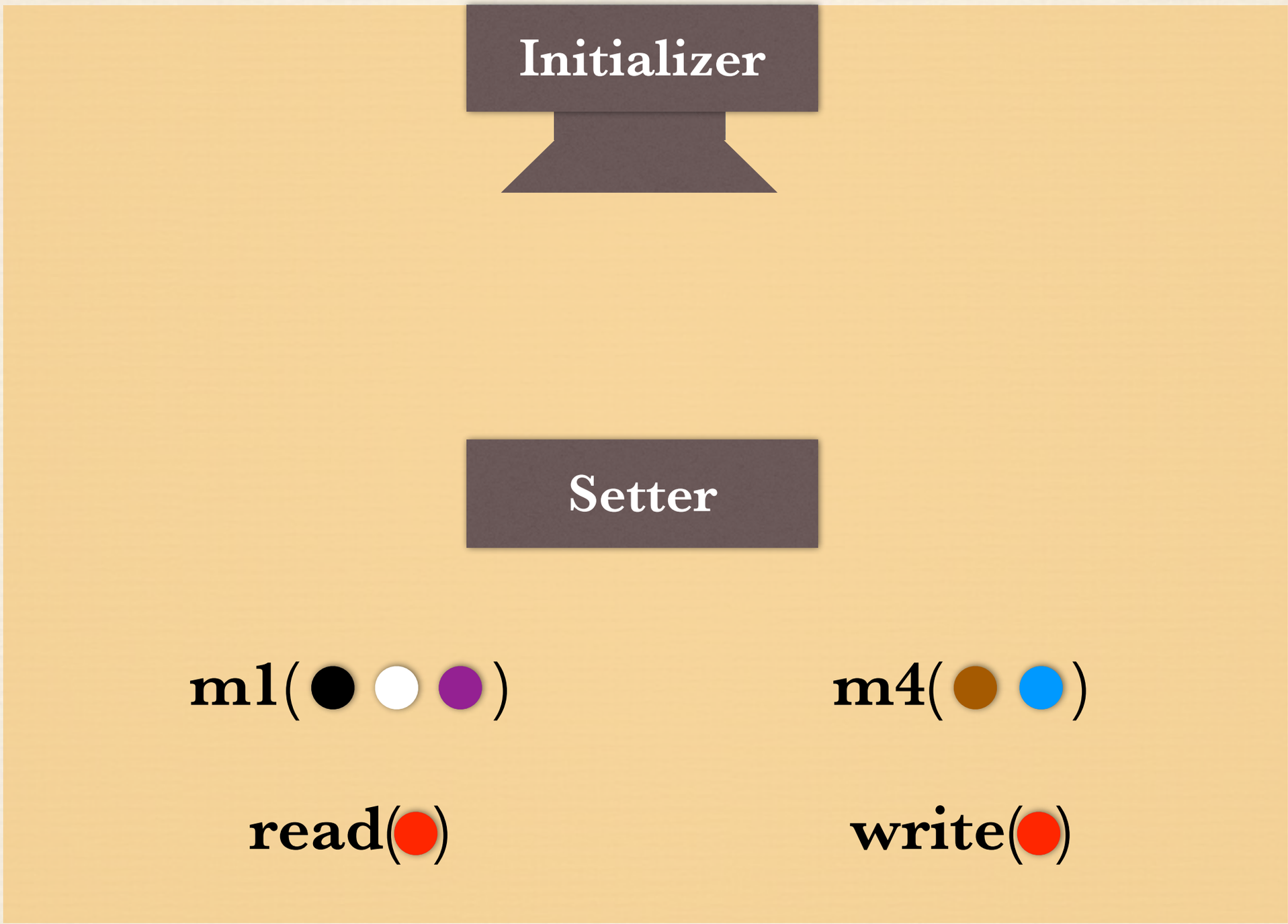


Challenge 4: Use legal object instances



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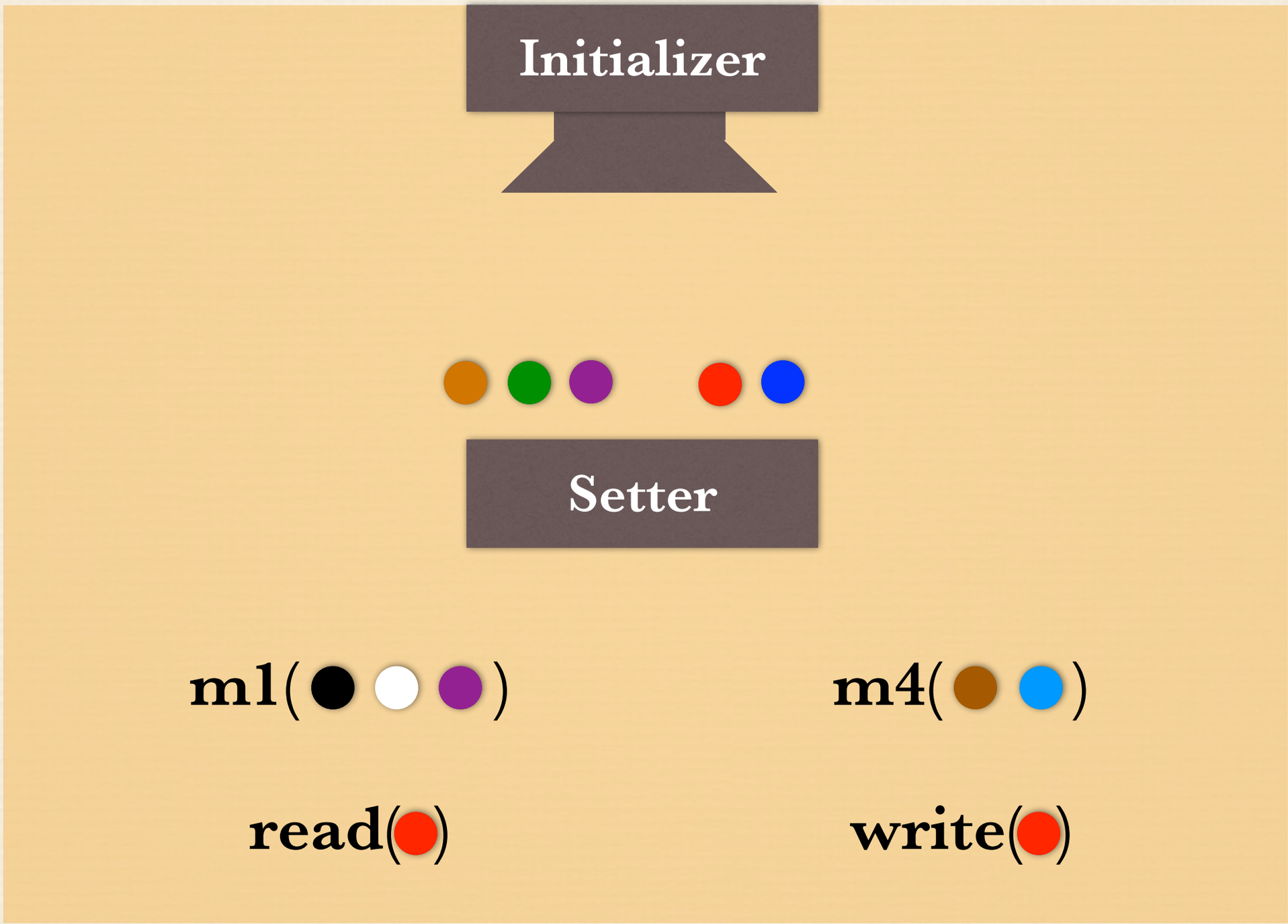

Summary of challenges

1. Identify access pairs
2. Identify the APIs to be invoked concurrently
3. Set the context
4. Use legal object instances

Identify access pairs

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update (Lib a) {
    11:  lock(a)
    12: Counter x = a.c
    13:  x.count = x.count +1
    14:  unlock(a)
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set (Lib a, Counter b) {
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Input Sequential Test

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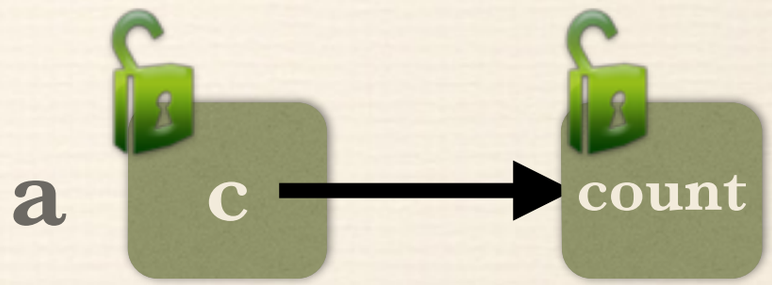

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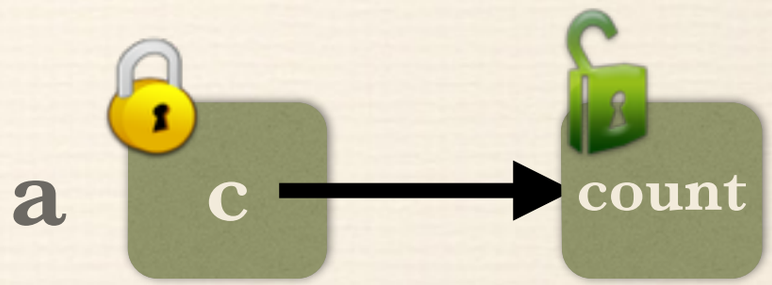

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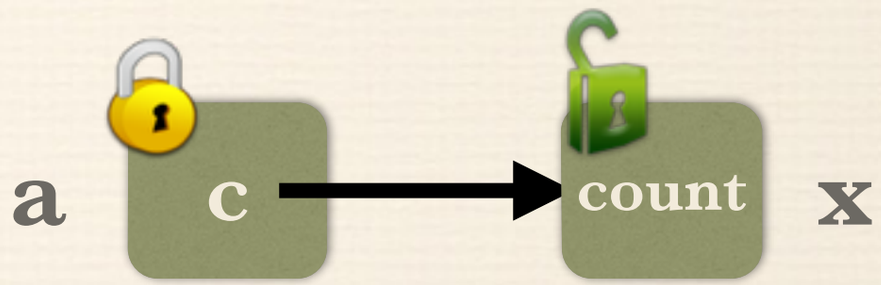

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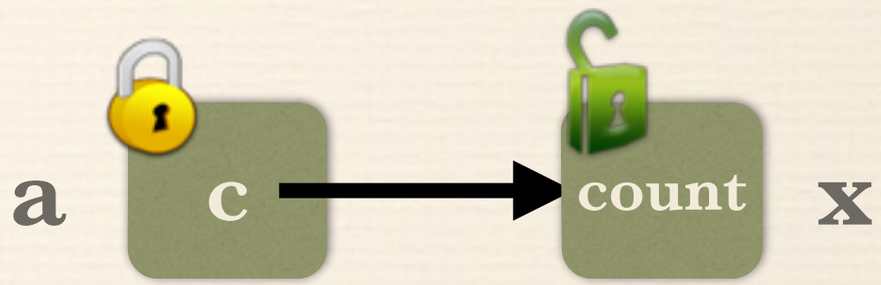

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Class : Lib Field : c

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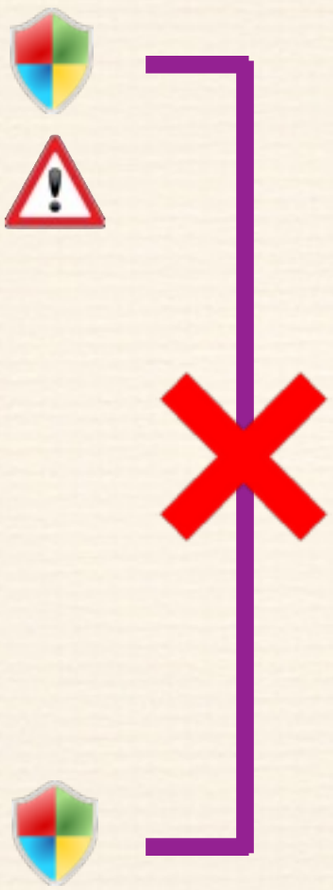

Input Sequential Test

update (a_1);

set (a_1, val);

Class : Lib Field : c

Identify access pairs

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Pairs :

1. **read 13 and write 13**

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Identify the APIs to be invoked concurrently

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→ **update & update**

Set the context

- Derive a sequence of method invocations
- Identify the parameter sharing between invocations

Set the context

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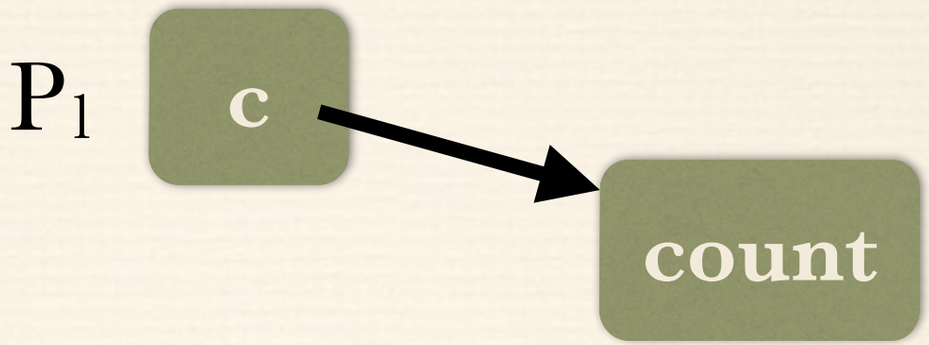

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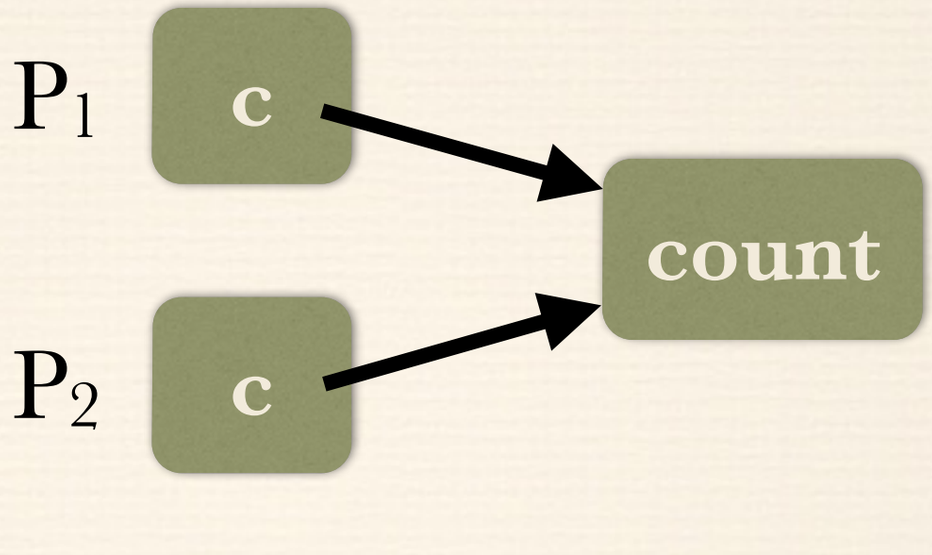

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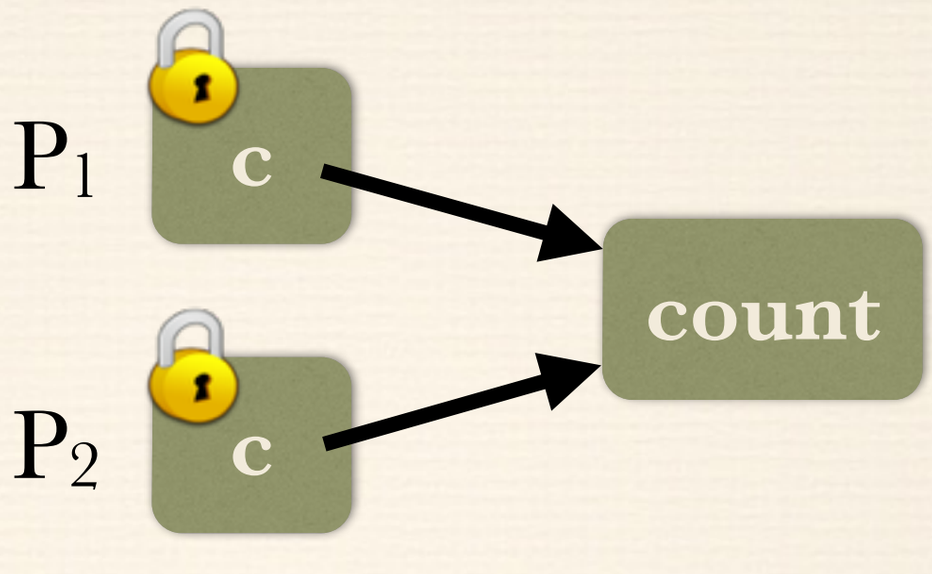

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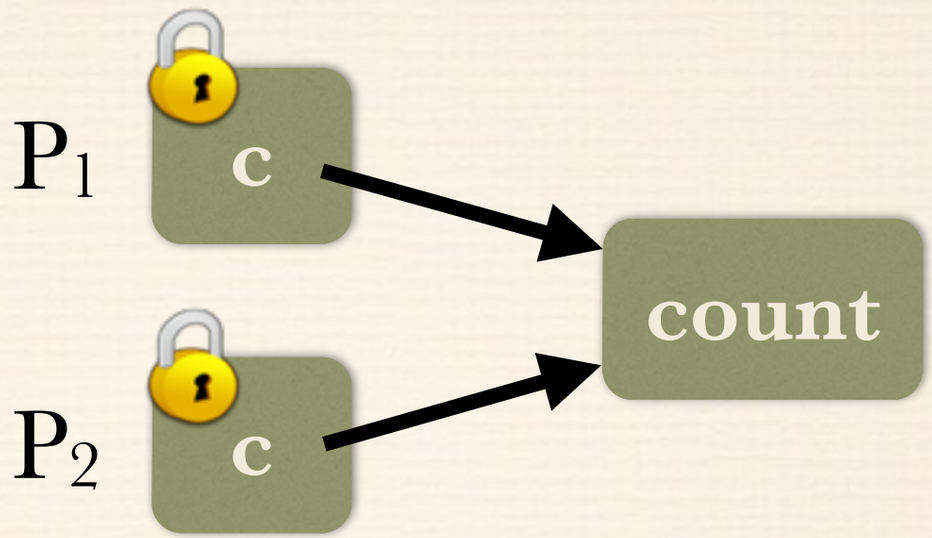

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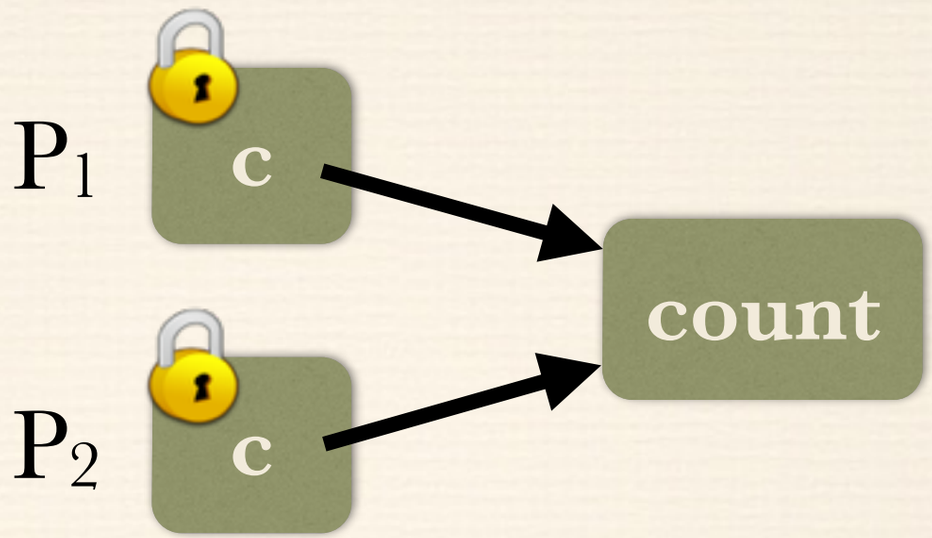

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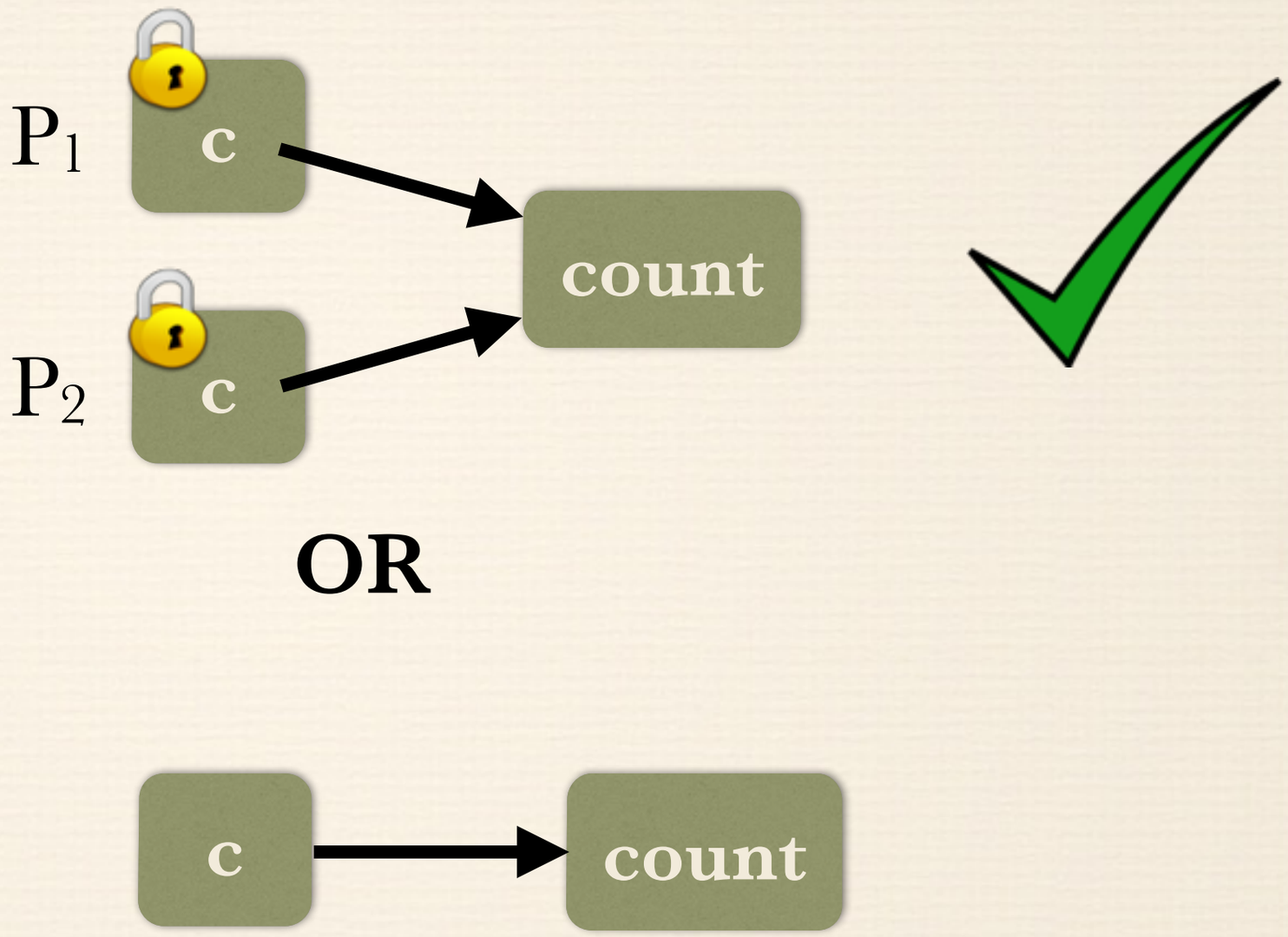

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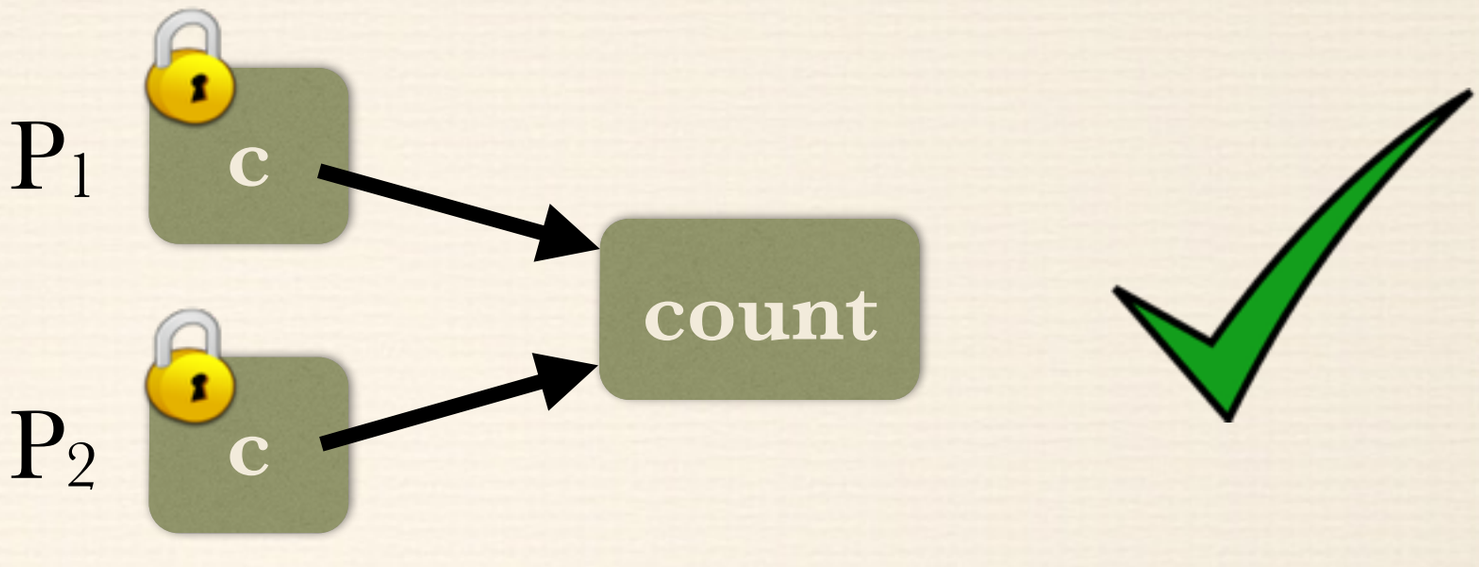

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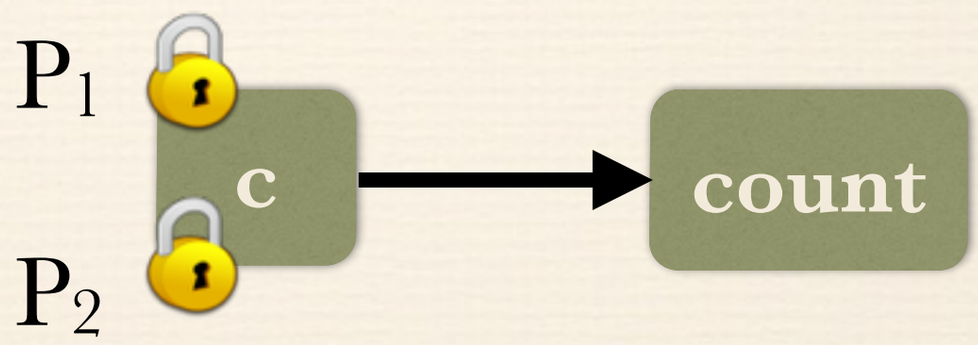

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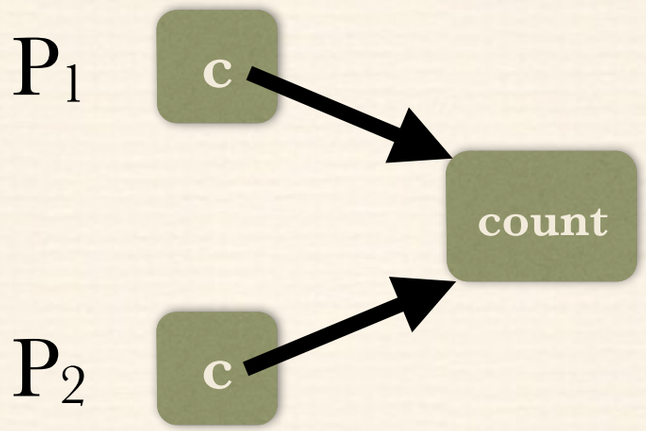

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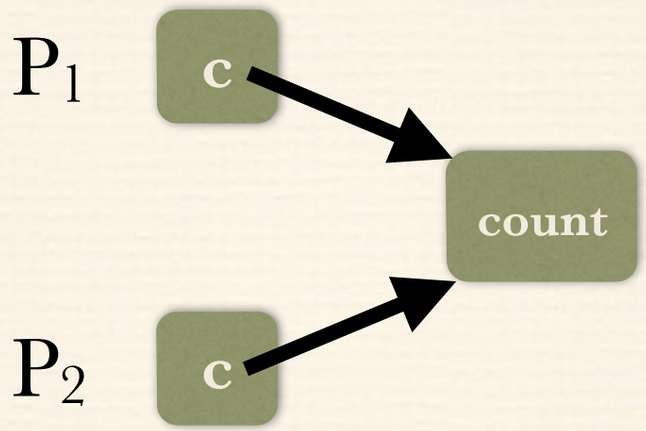

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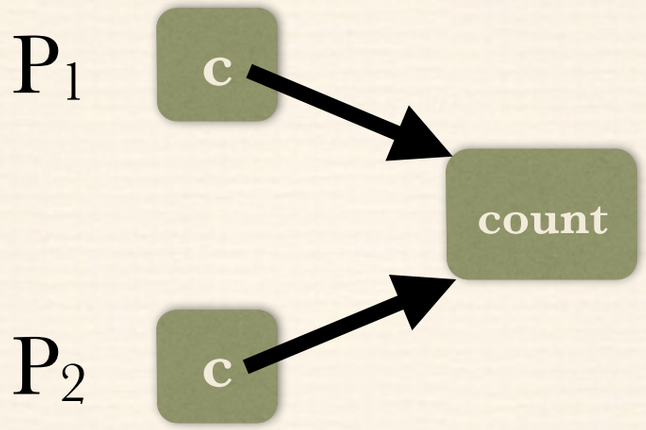

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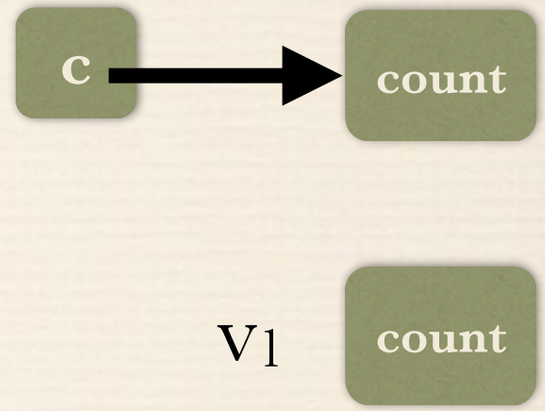

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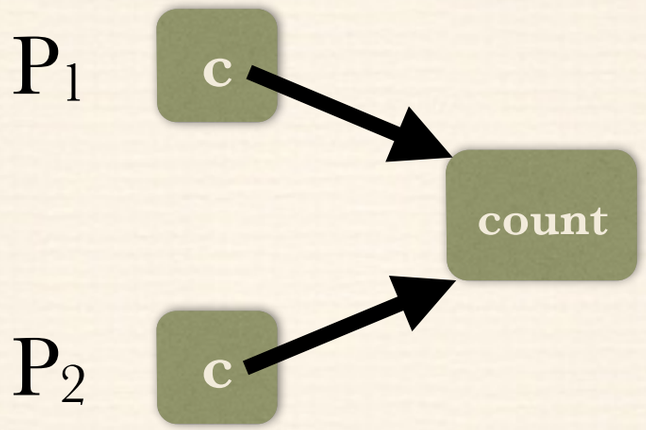

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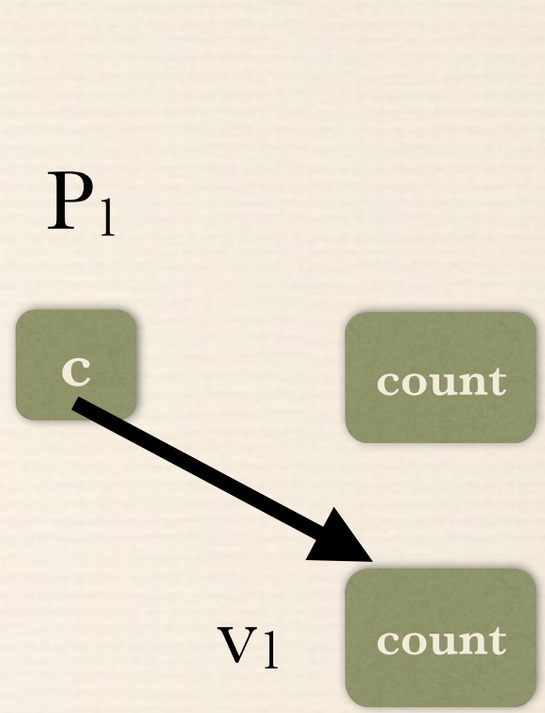

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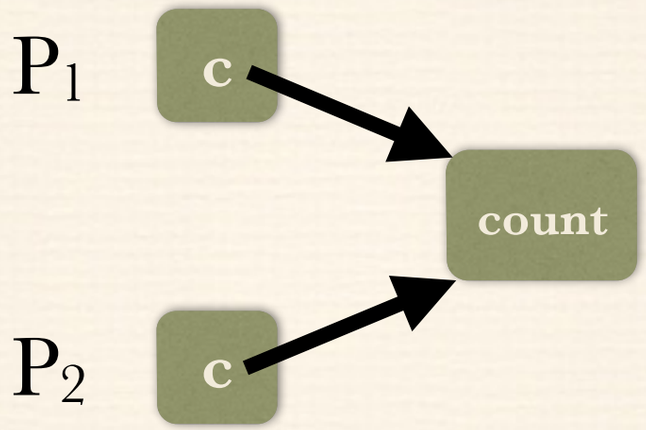

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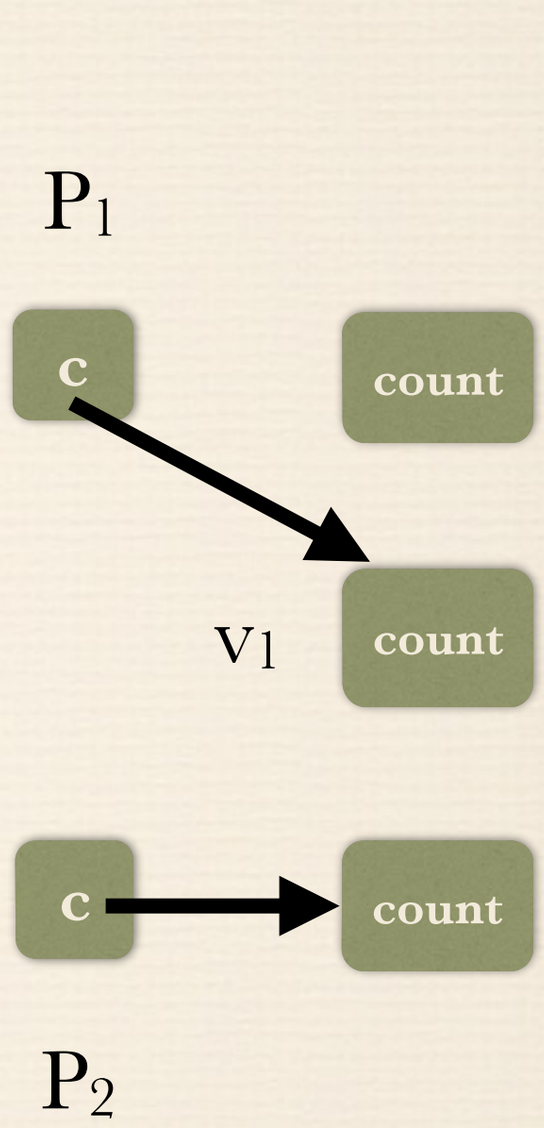

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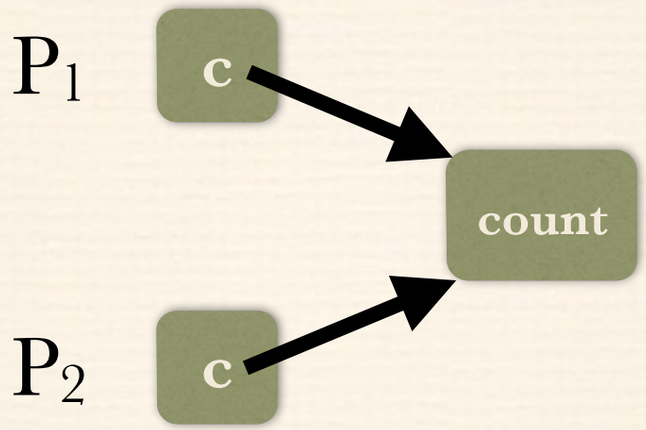

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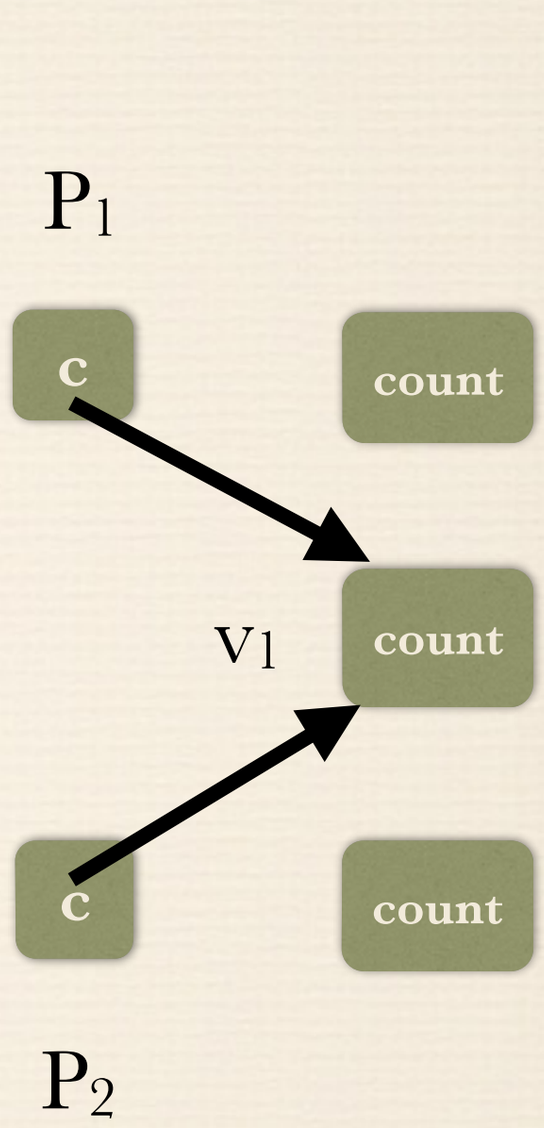

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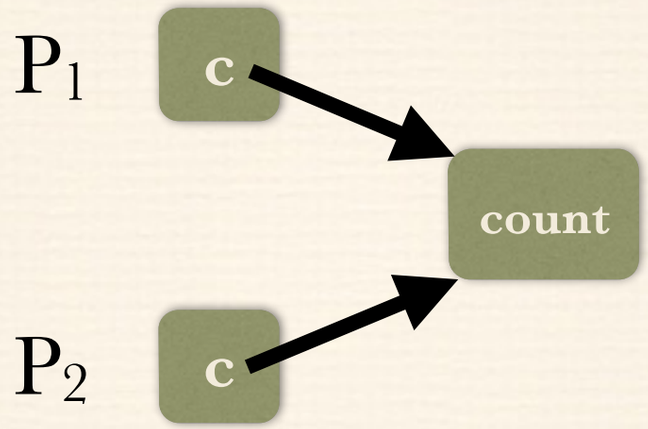

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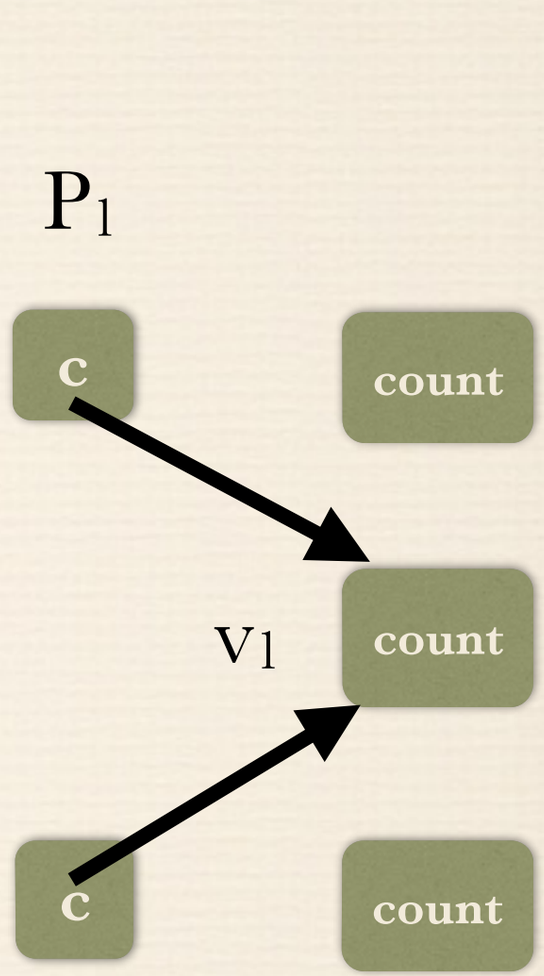

set(P_1, v_1)
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Use legal object instances

Execute sequential tests for obtaining object instances

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update (a_1);	update (a_1);	**update (a_1);**	**update (a_1);**
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set :

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update : **update :**

Use legal object instances

Execute sequential tests for obtaining object instances

update (a_1); **set (a_1, *val*);**	update (a_1); **set (a_1, *val*);**	**update (a_1);** set (a_1, *val*);	**update (a_1);** set (a_1, *val*);

set : (o_1, o_2)

set :

update : **update :**

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set : (o_1, o_2)

set : (o_3, o_4)

update : **update :**

Use legal object instances

Execute sequential tests for obtaining object instances

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set : (o_1, o_2)

set : (o_3, o_4)

update : (o_5) **update : (o_6)**

Generated Test

```
update (Lib a) {
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set (Lib a, Counter b) {
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}
```

Initializer ( )

set (o_5, o_2)

set (o_6, o_4)

t_1:	t_2:
update (o_5)	**update** (o_6)

Experimental Setup

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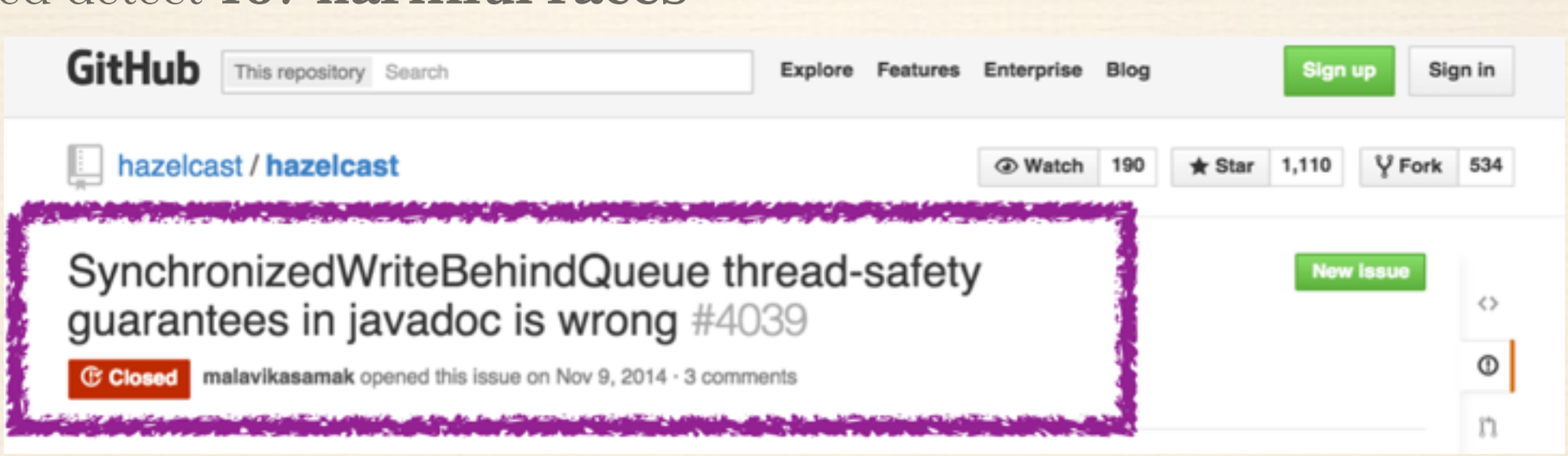

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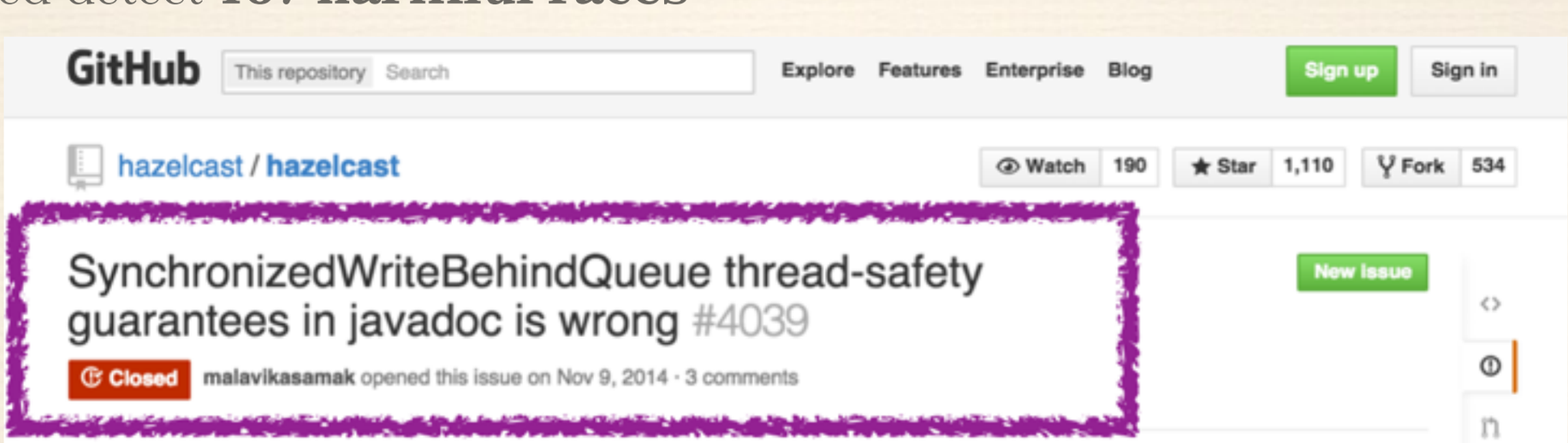
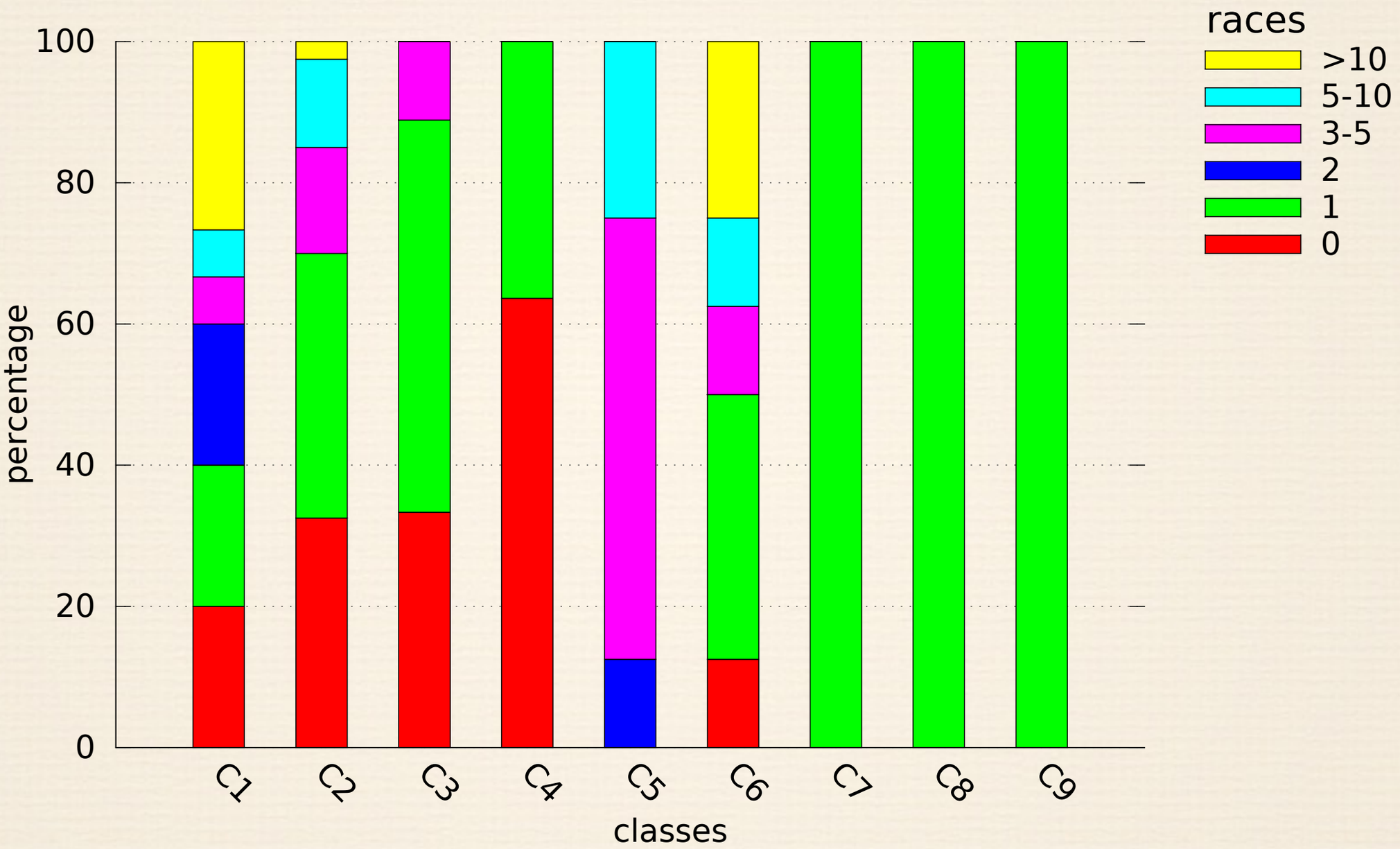


Distribution of Tests



Summary

- Designed a ***directed*** approach to synthesize racy tests
- NARADA: tool that incorporates the proposed design
- Validated using open source java libraries
- Helped detect harmful races
  - Negligible time overhead
- Tool: http://www.csa.iisc.ernet.in/~sss/tools/narada/