भारतीय प्रौद्योगिकी संस्थान हैदराबाद
Indian Institute of Technology Hyderabad

Proving Correctness of Concurrent Objects by Validating Linearization Points

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Outline

1. Introduction
   - Sequential Object and Sequential Specification
   - Sequential vs Concurrent History
2. Linearizability
3. Proposed Technique: Validating LPs
4. Conclusion
5. Future Work

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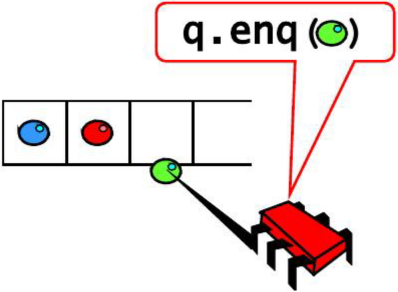
- Set of correct histories which can be generated by single threaded execution.
- Pre-condition : state before you call the method.
- Post-condition : other state after the method returns.

Introduction

Example of Sequential Specification

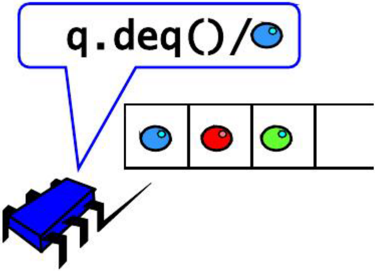
FIFO Queue: Enqueue Method



Introduction

Example of Sequential Specification

FIFO Queue: Dequeue Method



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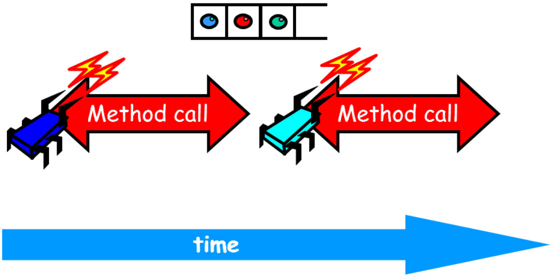


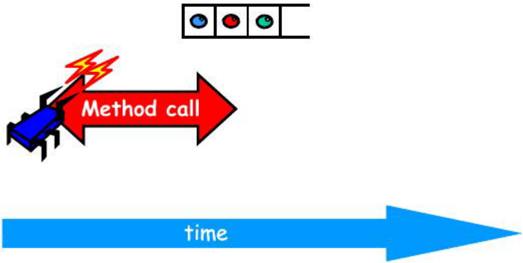
Figure: Sequential History

Sequential vs Concurrent History

Concurrent History

- Object methods can be invoked by concurrent processes.
- It is necessary to give a meaning to possible interleavings of operations invocation.

Concurrent Methods Take Overlapping Time



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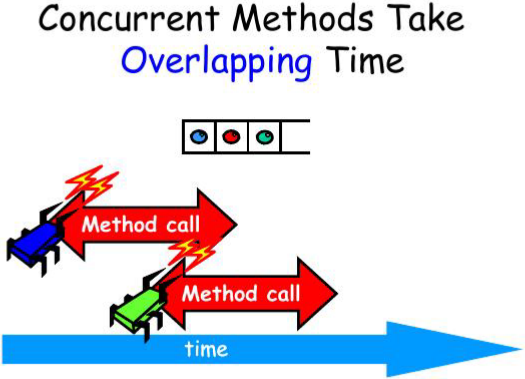

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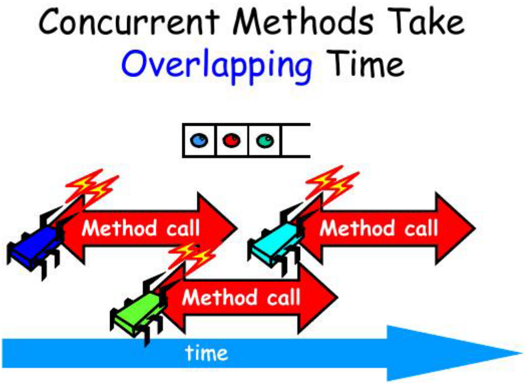

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What does it mean for a concurrent object to be correct?

Correctness Criteria: **Linearizability**.

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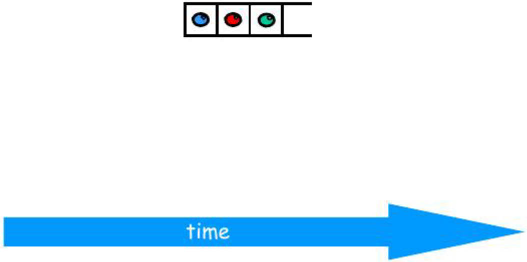
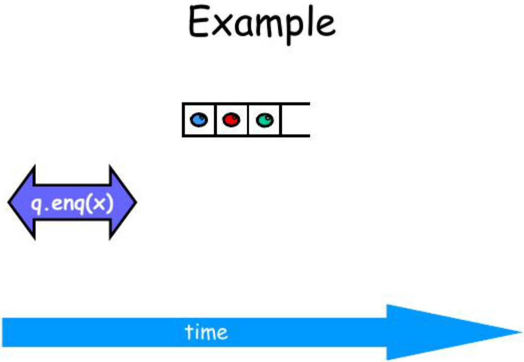
- Object is correct if it adheres to it's sequential specification.
- Any such concurrent object is *Linearizable*.

Linearizability

Example



Linearizability



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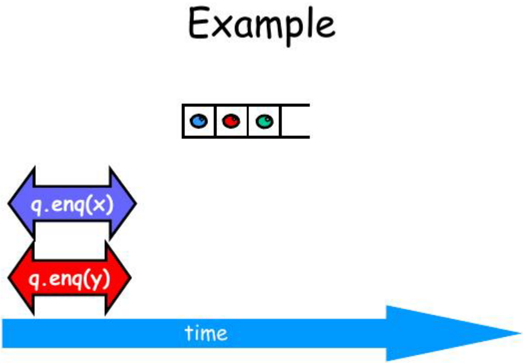

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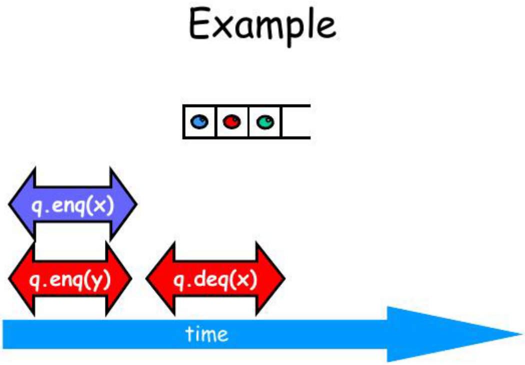

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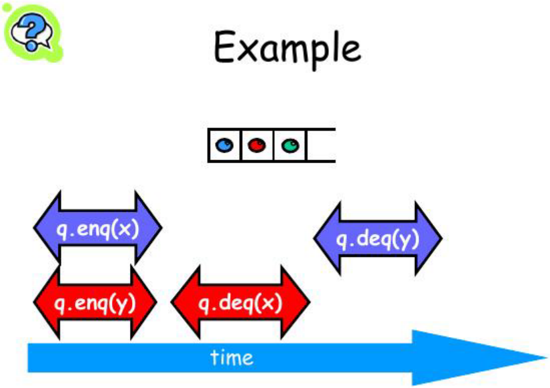

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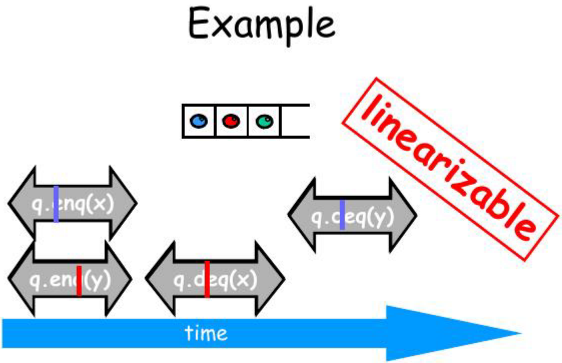

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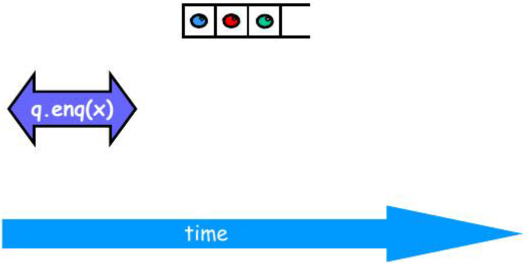

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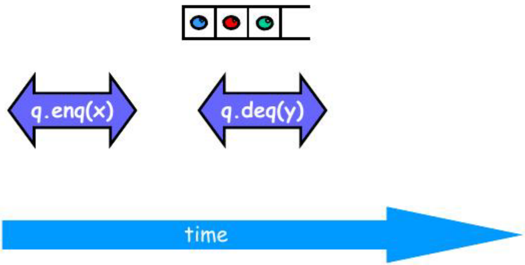

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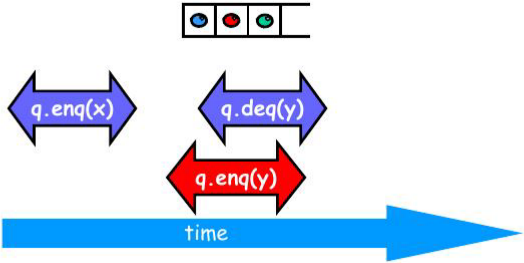

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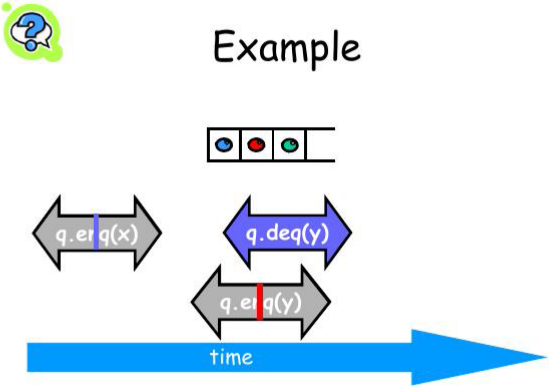

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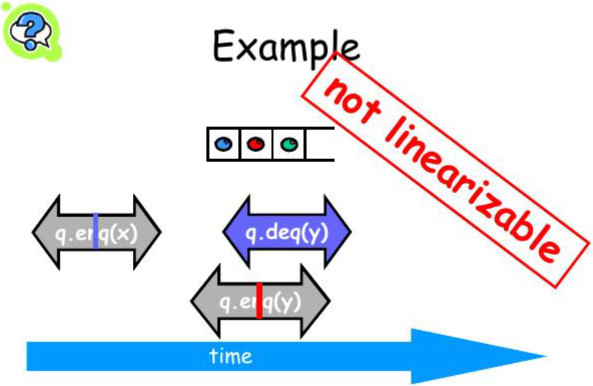

Proving Linearizability Manually

- Challenging even for simple data structures.

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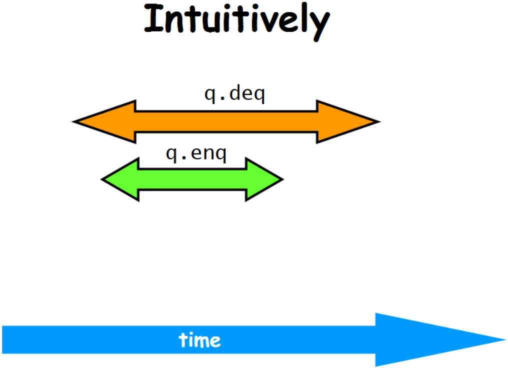
- Several techniques have been proposed
  - Linearization Points [HerlihyWing90]
  - Rely Guarantee [Vafeiadis, et al. 06]
  - Hindsight Lemma [O'Hearn10]
  - Base Point Analysis [KfirKeidar15]

Linearization Points [HerlihyWing90]

- Every operation "appears to happen" at some individual instruction between invocation and response.
- In coarse locks, LP could be anywhere in the critical section.



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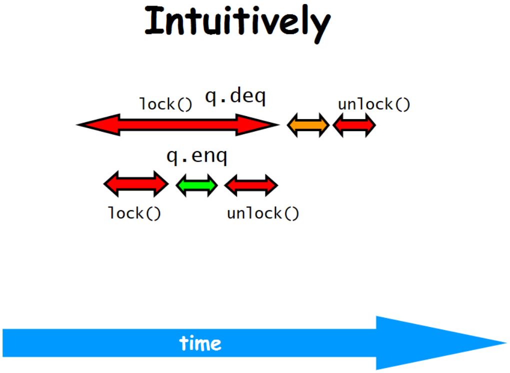

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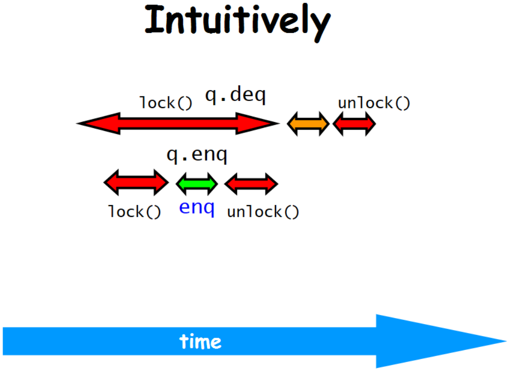

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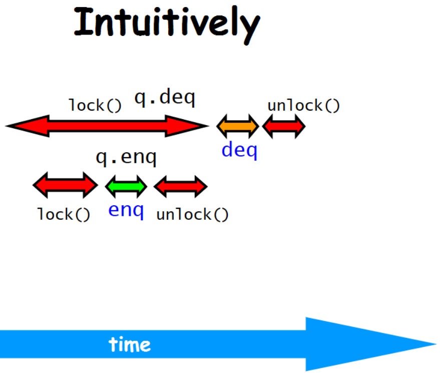

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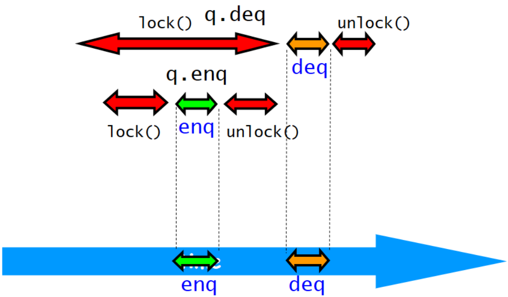
Intuitively



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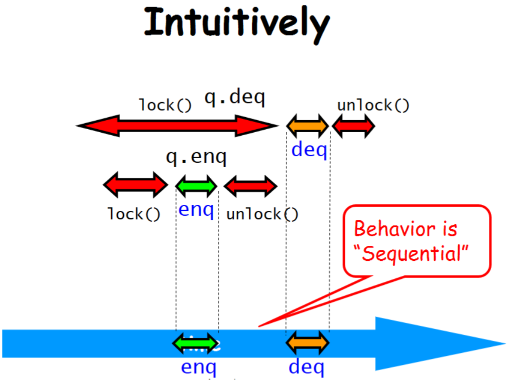

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Problem!

How do you know if you have identified the correct LPs indeed?

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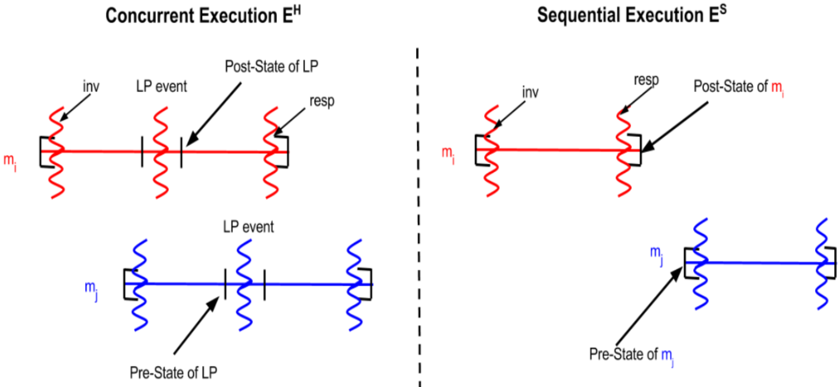
Proposed Technique: Validating LPs

Hand-crafted generic technique for validating LPs

- Terminology:
  - Events, Methods
  - State
  - History, Execution, Complete History
  - Abstract data structure (AbDS)



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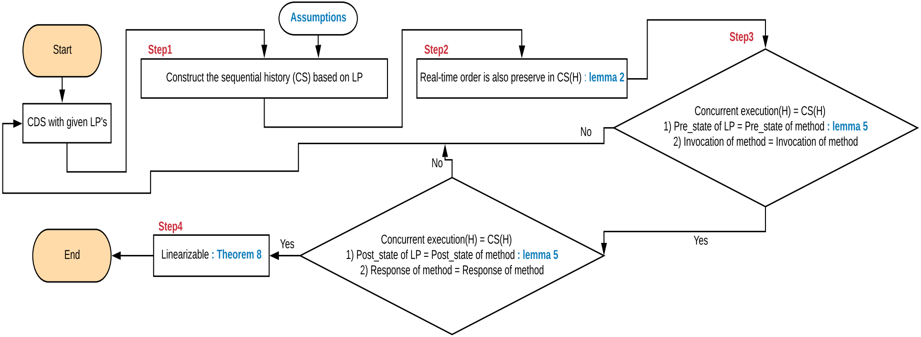

Start
CDS with given LP's
Step1
Construct the sequential history (CS) based on LP
Assumptions
Step2
Real-time order is also preserve in CS(H) : lemma 2
Step3
Concurrent execution(H) = CS(H)
1) Pre_state of LP = Pre_state of method : lemma 5
2) Invocation of method = Invocation of method
No
No
Yes
Concurrent execution(H) = CS(H)
1) Post_state of LP = Post_state of method : lemma 5
2) Response of method = Response of method
Yes
Step4
Linearizable : Theorem 8
End

Figure: Iterative steps to prove linearizability of a CDS with given LP's.

Proposed Technique: Validating LPs

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- Assumptions:
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  - Only the LP events of a method can change AbDS of CDS.

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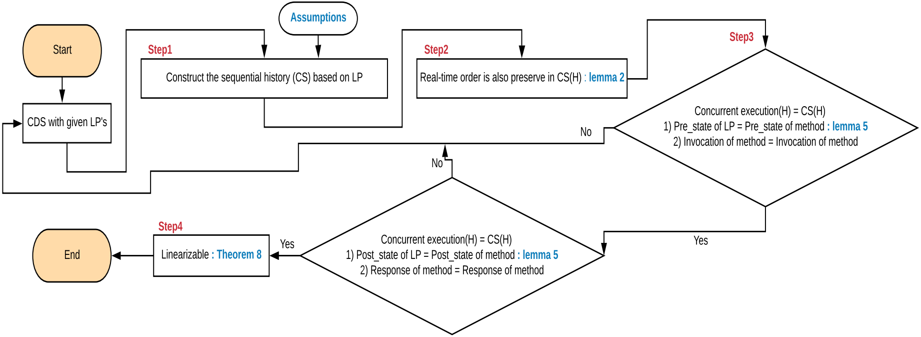

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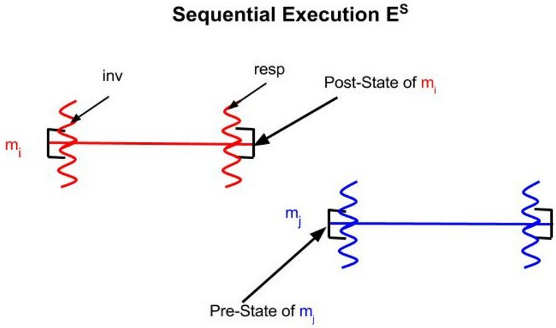

E^S : Post-state of m_i = Pre-state of m_j

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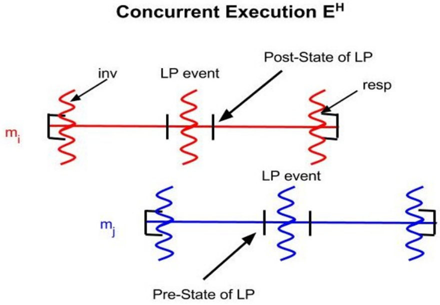

E^H : Post-state of $m_i.LP$ = Pre-state of $m_j.LP$

Proposed Technique: Validating LPs

Hand-crafted generic technique for validating LPs

$\forall m : \langle$ Pre-state of $E^H.m_i.LP =$ Pre-state of $E^S.m_i\rangle \wedge\langle E^H.m_i.inv = E^S.m_i.inv \rangle \rightarrow \langle$ Post-state of $E^H.m_i.LP =$ Post-state of $E^S.m_i\rangle \wedge\langle E^H.m_i.resp = E^S.m_i.resp \rangle$

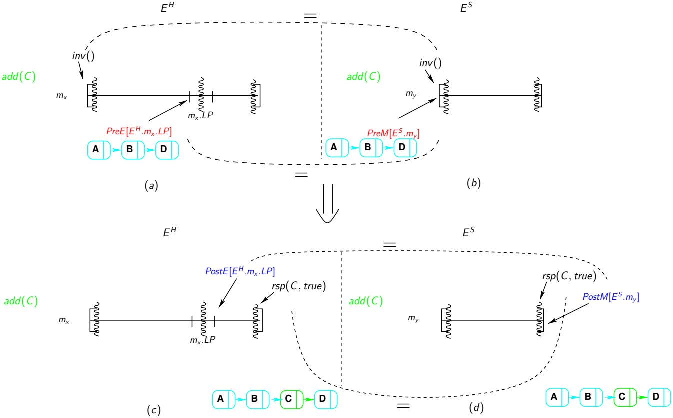

Figure: CDS Specific lemma

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- This technique will also offer the programmer some insight to develop more efficient variants of the CDS.

Conclusion

- In spite of various approaches for proving linearizability, LPs seem most intuitive & constructive; but are difficult to identify.
- We have developed a hand-crafted technique of proving correctness of the CDSs by validating it LPs.
- This technique will also offer the programmer some insight to develop more efficient variants of the CDS.
- We have shown the correctness of **lazy-list** and **hand-over-hand** locking list in technical report.

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- We will try to develope the automatic tool for validating LPs.

References

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Thank you for your attention!

Any Questions or Comments?

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