Reference Object Processing in On-The-Fly Garbage Collection

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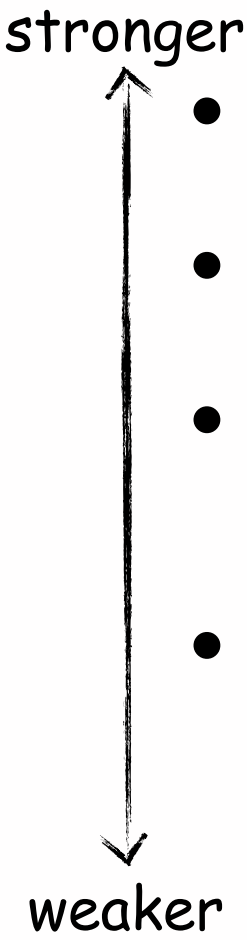
Weak Pointers

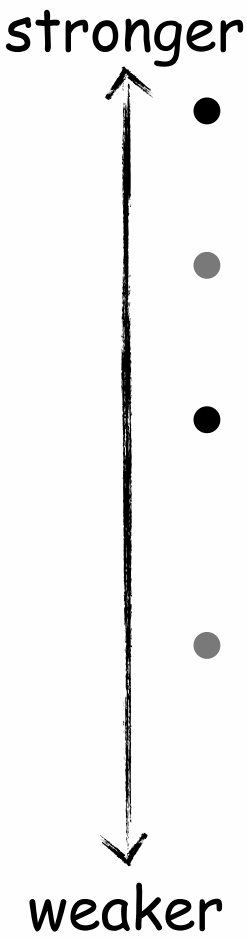
- Weak pointers are a mechanism to allow mutators to communicate with GC
- java.lang.ref.Reference
  - Specification requires us to process weak references atomically from the view point of mutators
  - Fully concurrent (on-the-fly) GC never stops all mutators

Java reference types



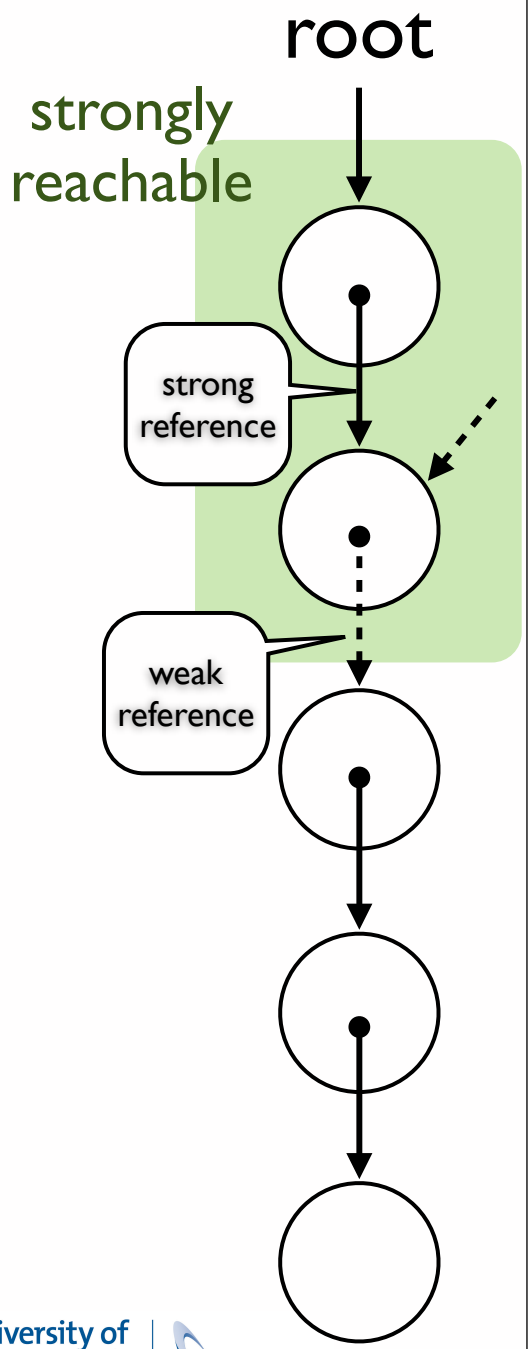
- Strong - usual references.
- Soft - used for caches that the GC can reclaim.
- Weak - used for canonicalize mappings (e.g., interned strings) that do not prevent GC from reclaiming their keys or values.
- Phantom - used for scheduling pre-mortem cleanup actions more flexibility than finalisers.

Java reference types



- Strong - usual references.
- Soft - used for caches that the GC can reclaim.
  → reduce to strong/weak references
- Weak - used for canonicalize mapping (e.g., interned strings) that do not prevent GC from reclaiming their keys or values.
- Phantom - used for scheduling pre-mortem cleanup actions more flexibility than finalisers.
  → no interaction with mutators

Reachability

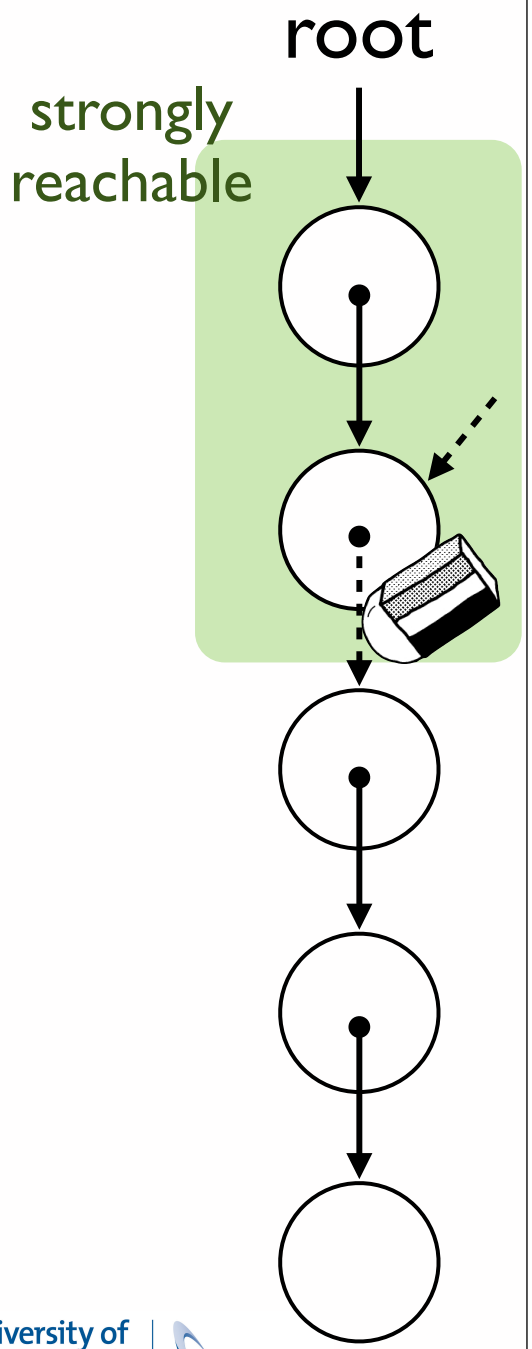


Strongly - can be reached without traversing any other references.

Weakly - not strongly reachable but can be reached by traversing weak references.

- No formal specification
  - Specification is written in English.
  - There are errors in implementations
- We formalised the specification

GC actions

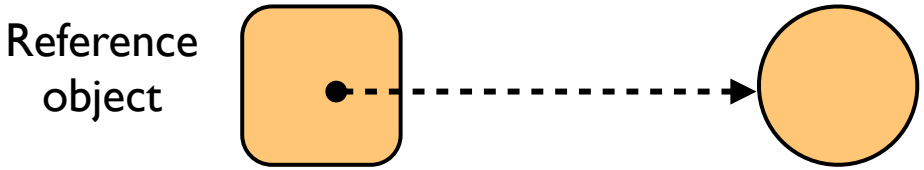


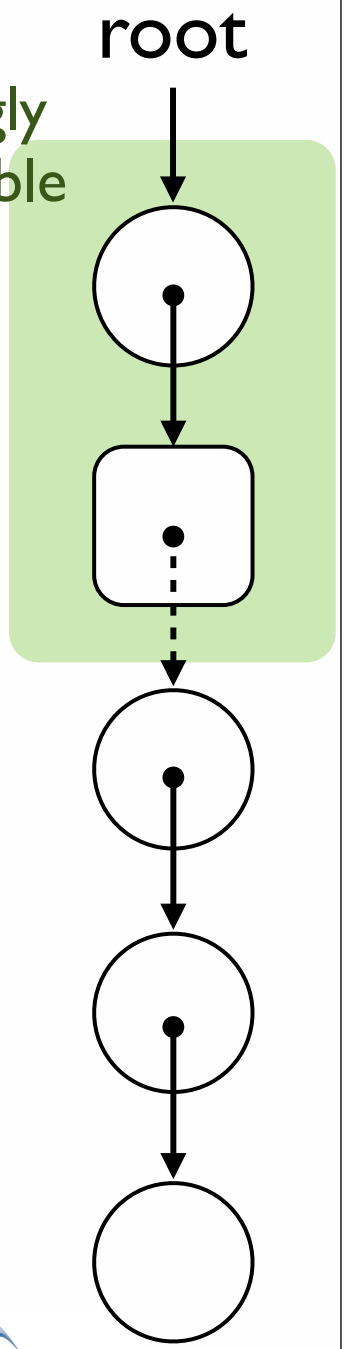
The GC finds all strongly reachable objects and reclaims others.

The GC "clears" references whose referents are weakly reachable.

- Weak reference to Strongly - to be retained
- Weak reference to Weakly - to be cleared

Reference.get()

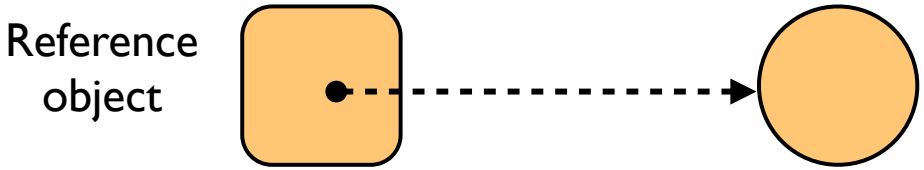


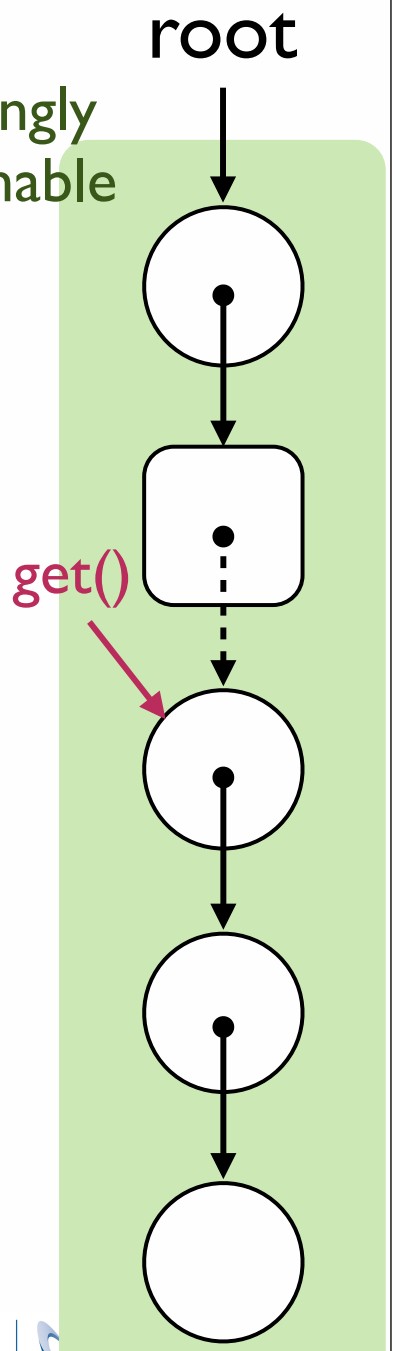


Reference.get() - returns a strong reference to its target or null if the GC has cleared.

get() may make some objects that were weakly reachable strongly reachable.

Reference.get()





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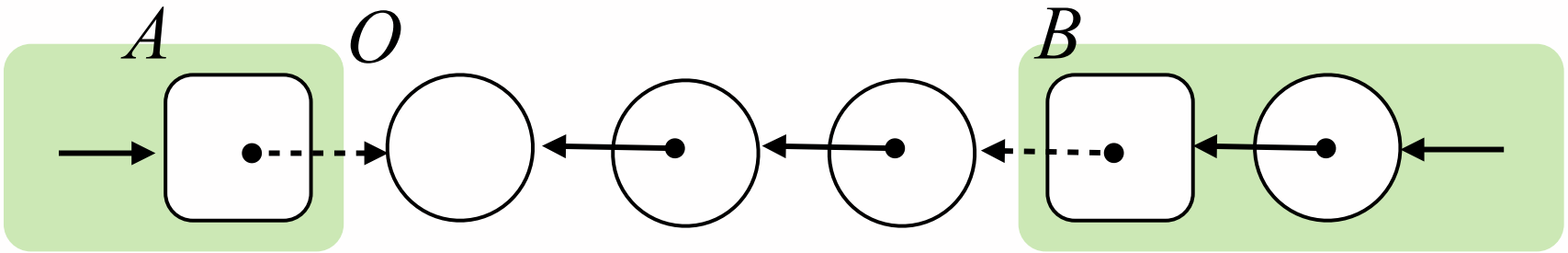
Race



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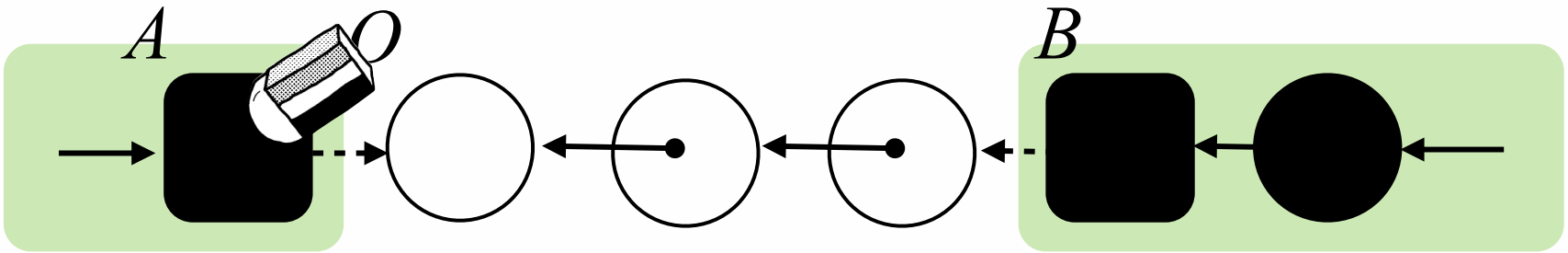
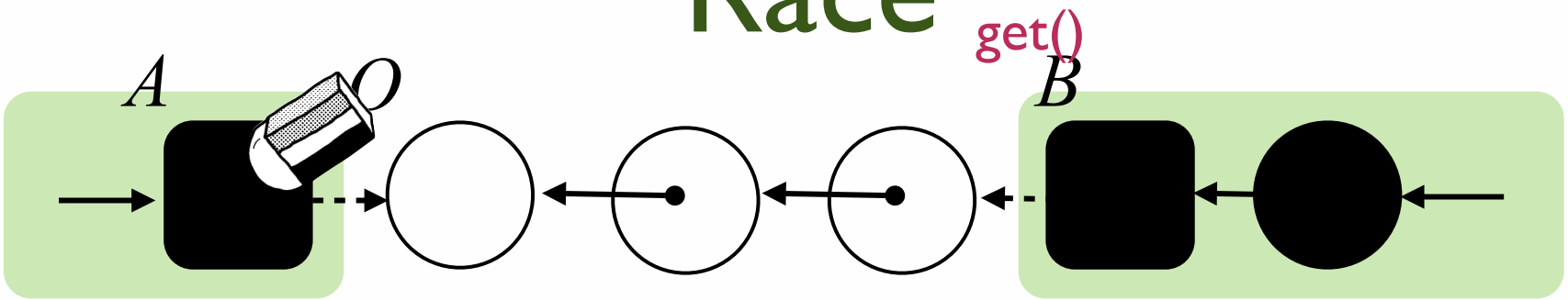


- Collector clears weak reference A

Race



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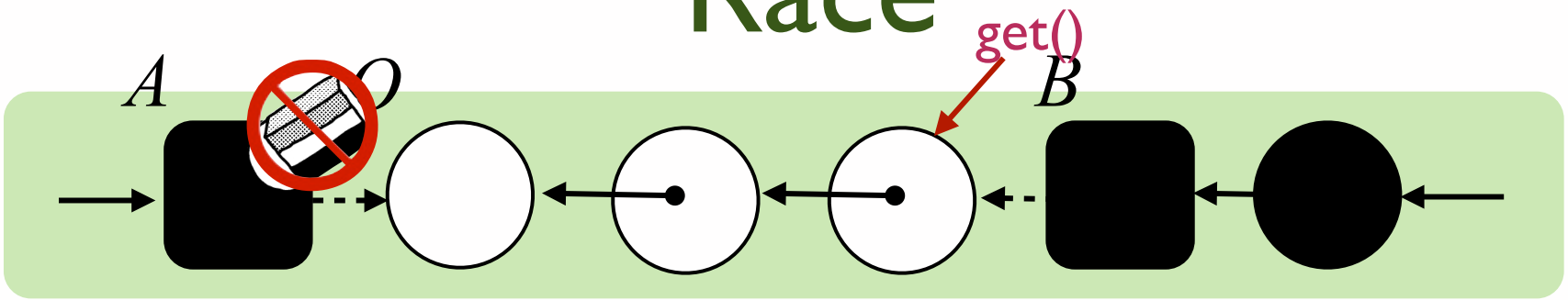
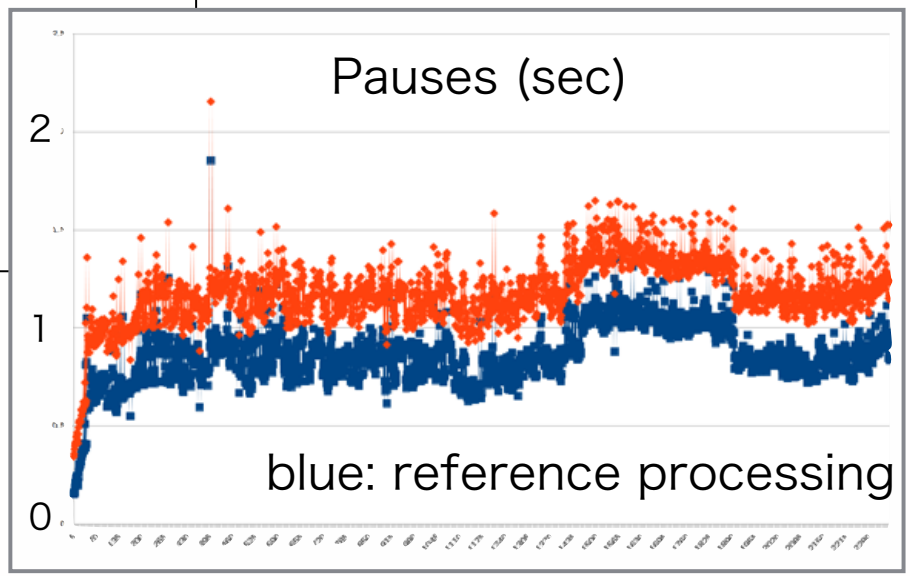


- Collector clears weak reference A
- Mutator makes O strongly reachable by creating a strong reference to the upstream

from the OpenJDK mailing list

"I've been tuning a Java 7u51, Solaris 10, T4 system with 24G heap. My customer is not very happy with the remark pauses of up to 2 seconds." Thomas Viessmann

"It looks like the application is using a lot of Reference objects. The time spent in remark is dominated by reference processing." Bengt Rutisson



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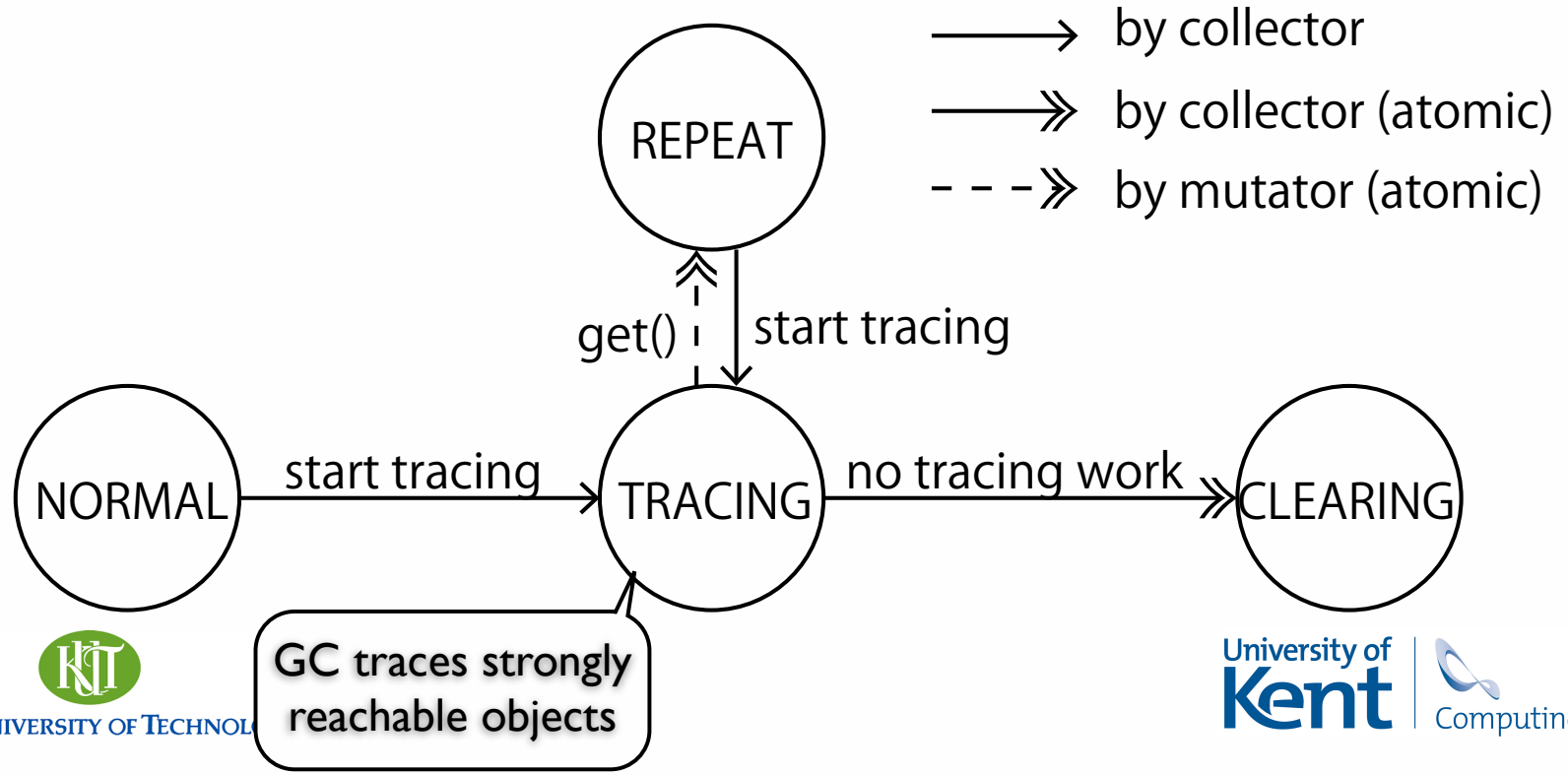
Solutions

- Stop the world - Pauseless GC [Click et al., 2005], Staccato [McCloskey et al., 2008]
  - Stop all mutators and process references
- Lock - "On-the-fly" GC [Domani et al., 2000]
  - Block any mutator that calls get()
- On-the-fly - Metronome-TS [Auerbach et al., 2008]
  - Implementation technique is not public

Global GC State

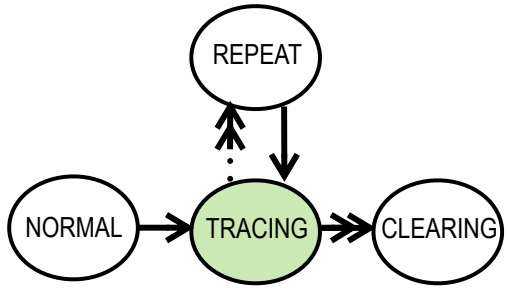
GC and mutator race in TRACING

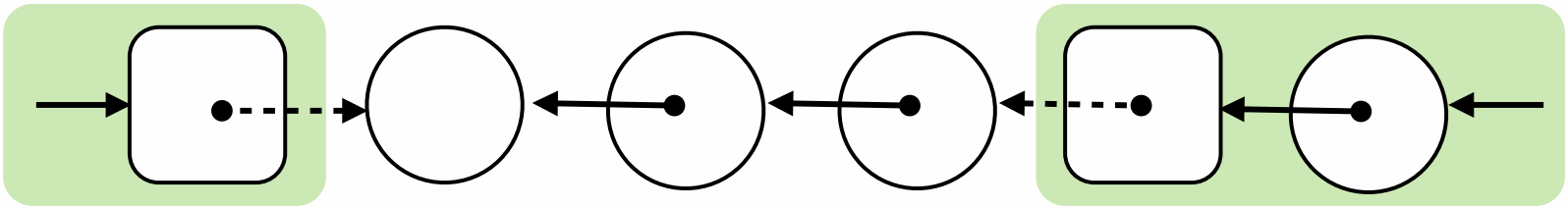
- GC want to finish tracing and then start clearing
- Mutator force GC to do more work



TRACING State

- GC traverses strong references
  - to colour strongly reachable objects black
- Write barrier
  - insertion barrier [Dijkstra]
  - deletion barrier (a.k.a. snapshot) [Yuasa]
- Read barrier for Reference.get()





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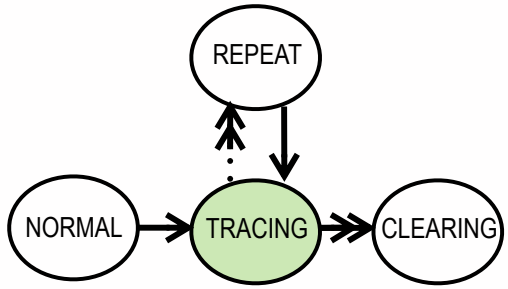
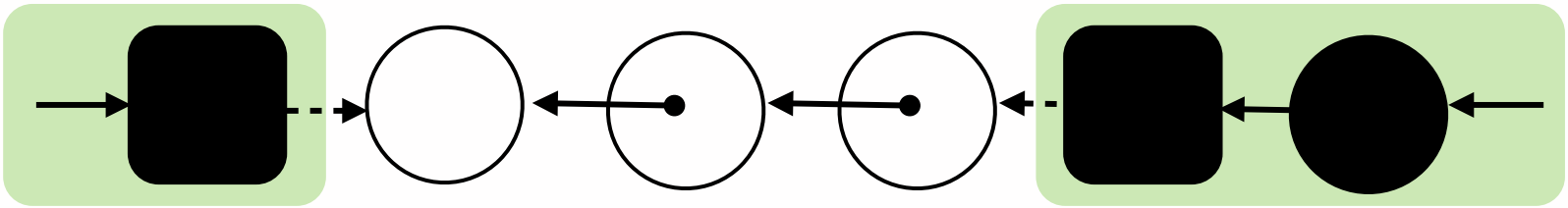
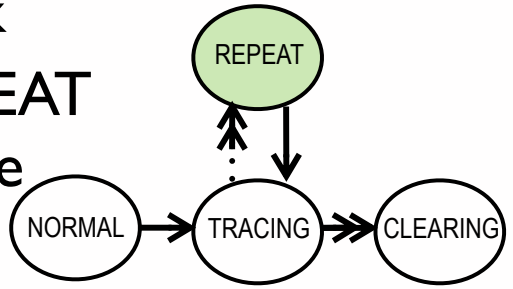


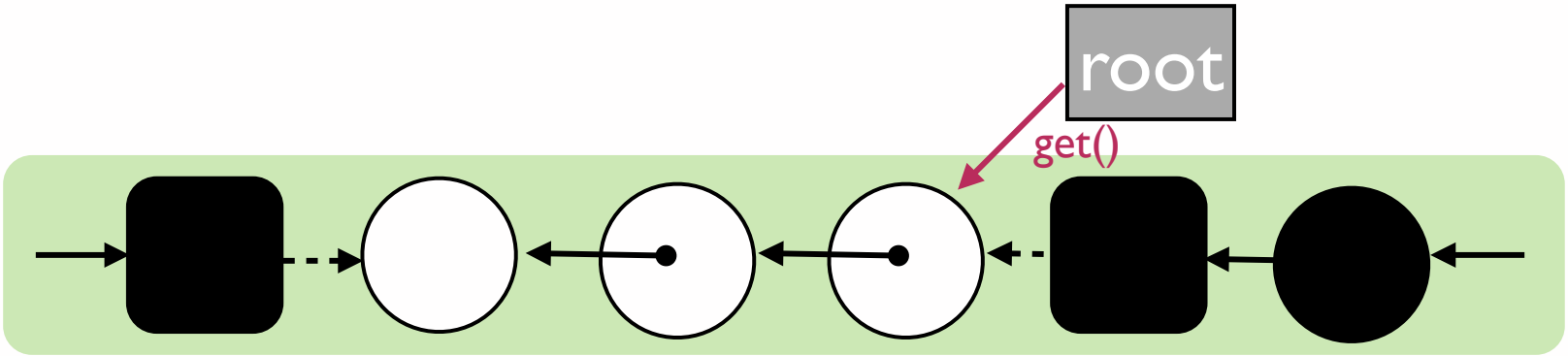


Insertion Barrier

INVARIANT: Root is grey (allows root to refer to white objects)

- GC repeat tracing until it finds root black
- Reference.get() changes the state to REPEAT to notify the GC that the root may not be black

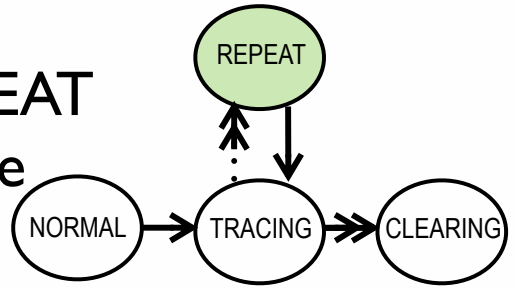


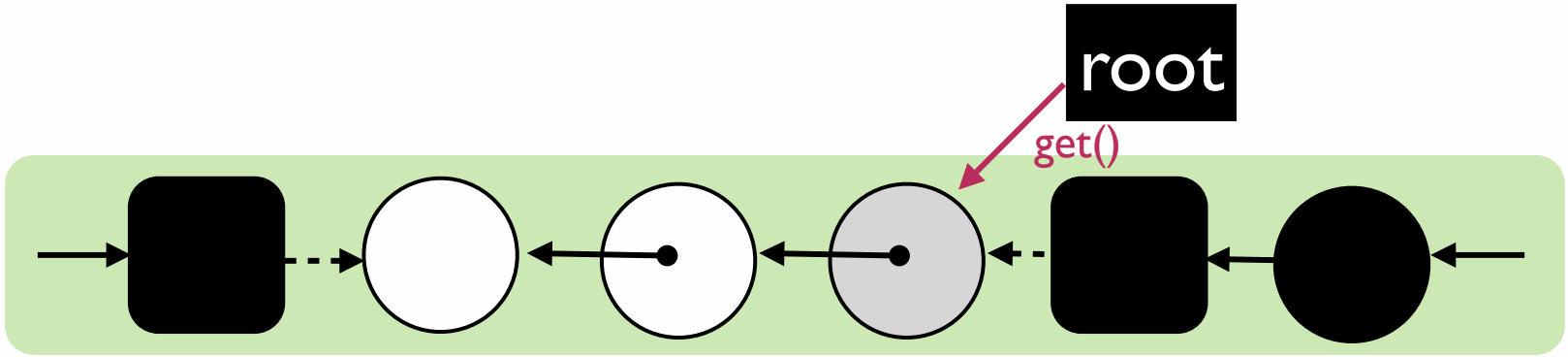


Deletion Barrier

INVARIANT: Root is black --- root is never rescanned

- Reference.get() colours target grey
- Reference.get() changes the state to REPEAT to notify the GC that the root may not be black

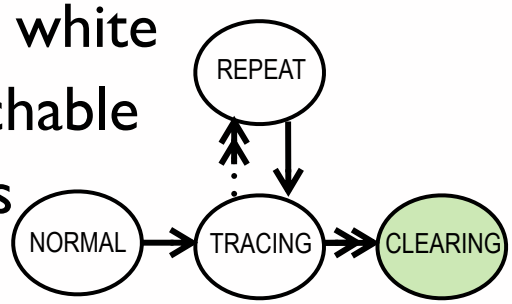


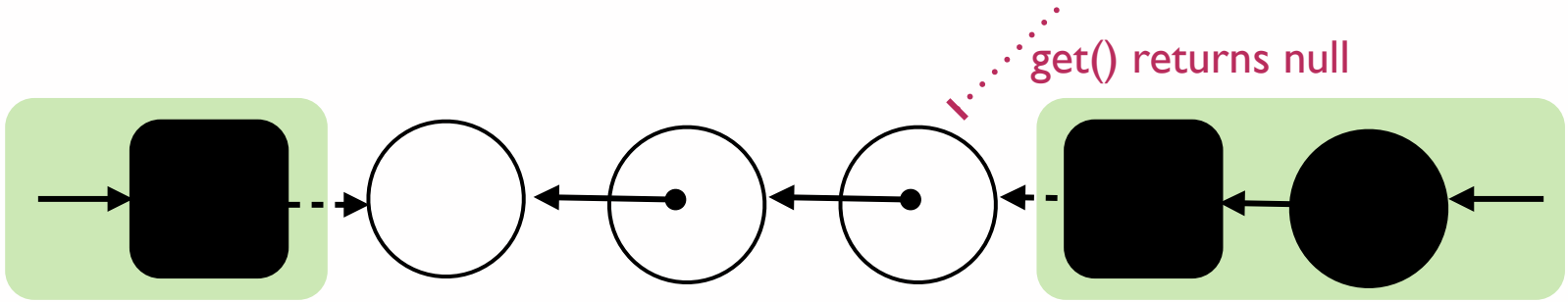


CLEARING

Once GC enters CLEARING state

- Reference.get() returns null if its target is white
  - no more objects become strongly reachable
- GC clears weak references whose targets are white



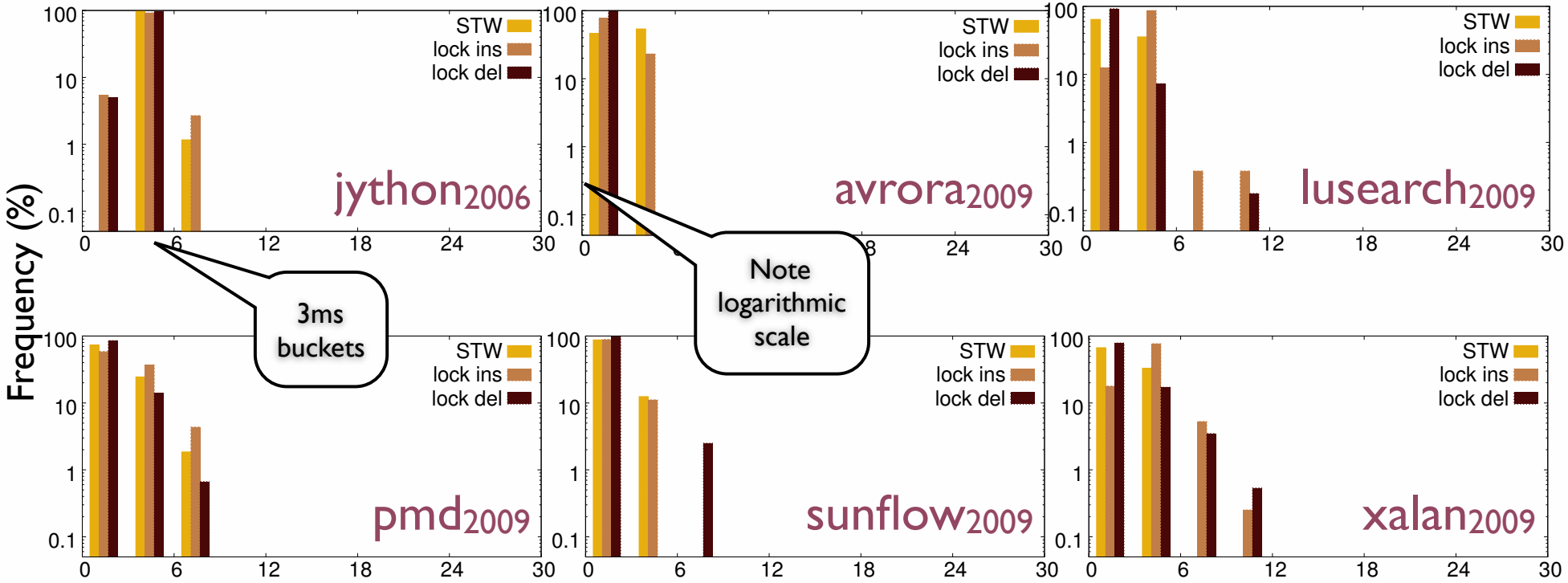


Evaluation

- Jikes RVM
  - Sapphire on-the-fly copying collector
  - Trigger GC immediately after the previous GC completes
- Configuration
  - Core i7-4770 (4-core, 3.4 GHz)
  - 1 GB heap
  - 2 collector threads

Pause Time distribution

- Stop-the-world GC, *or*
- Block mutator.get() with “lock”



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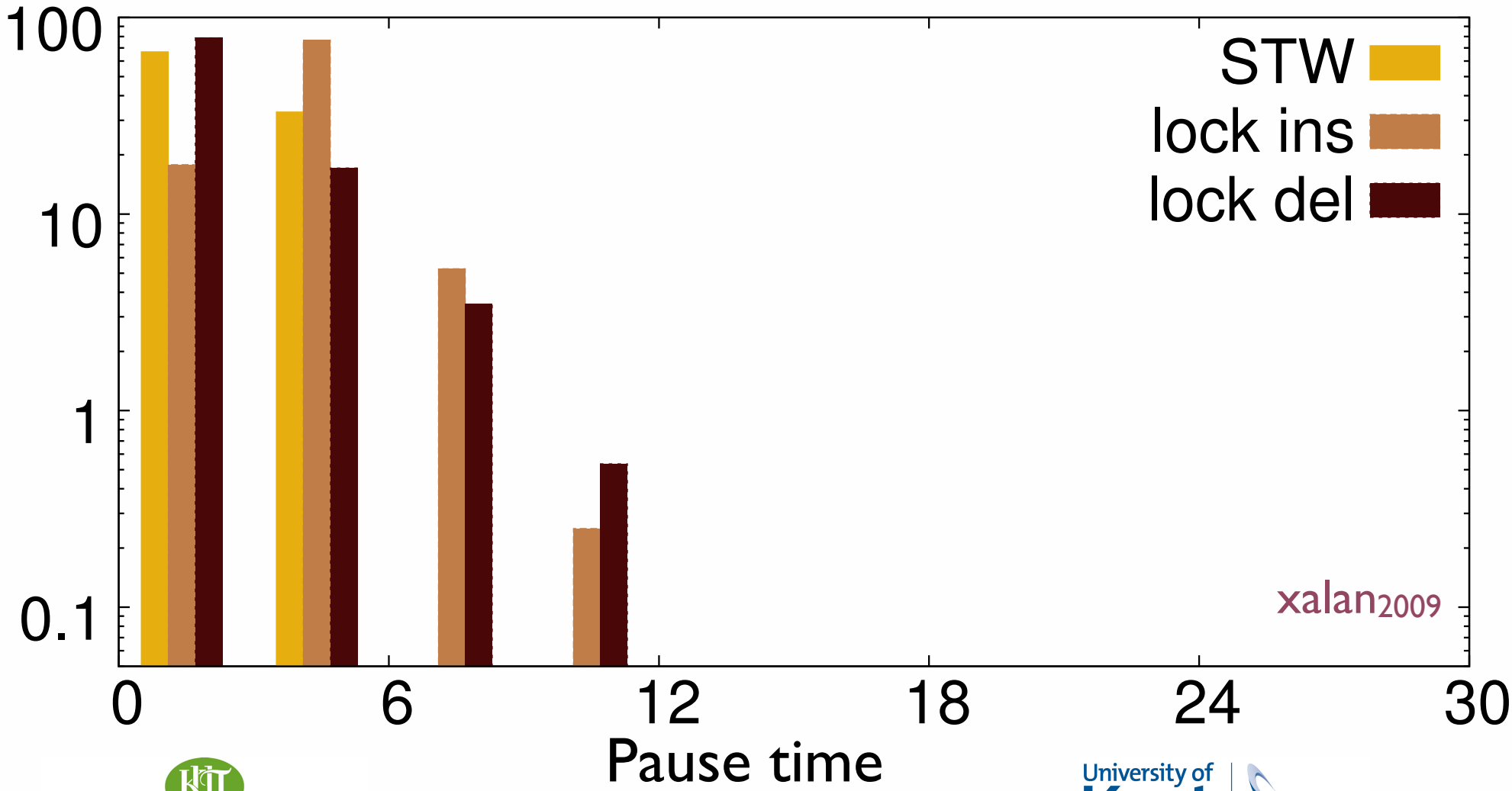
Pause Time distribution



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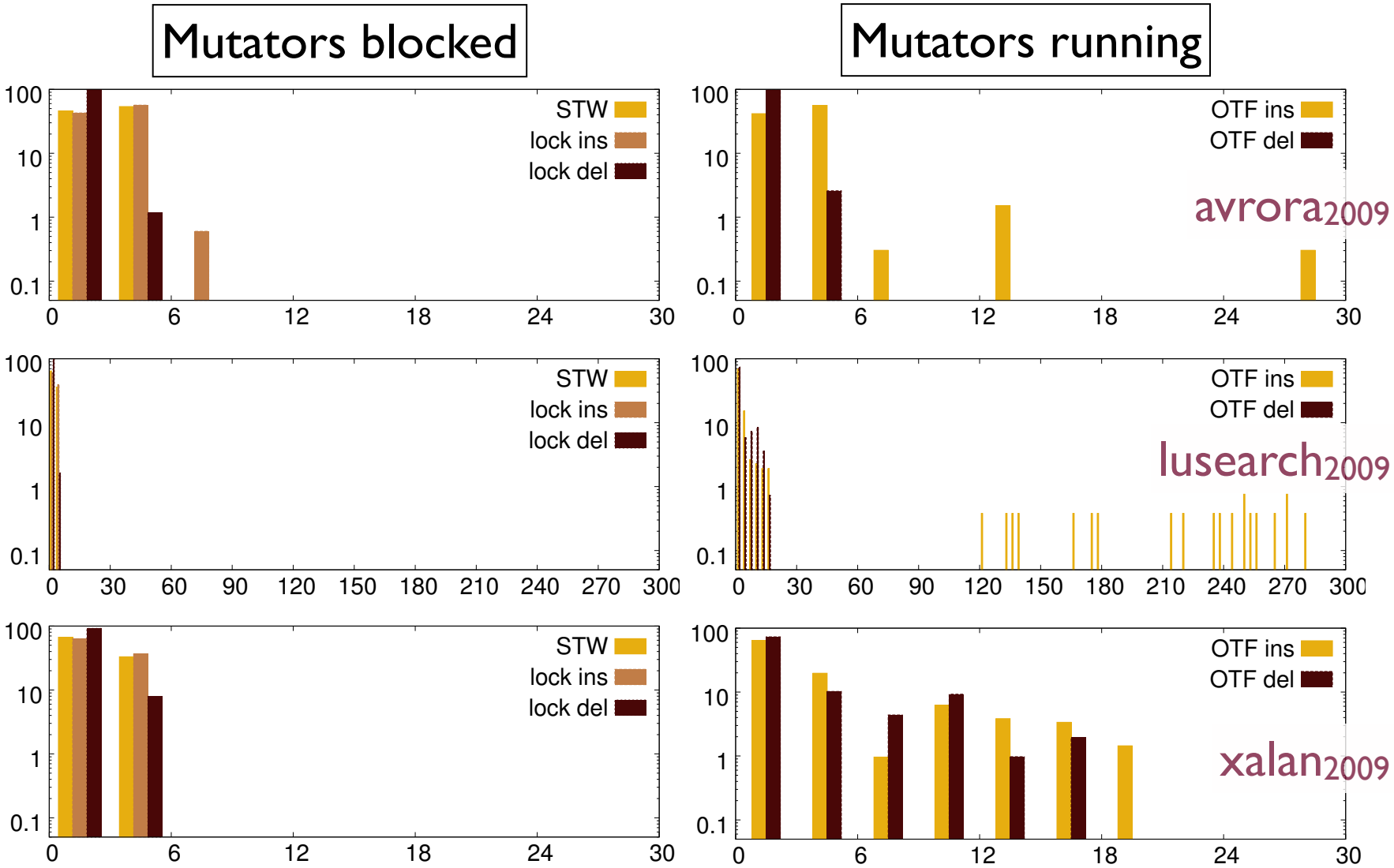
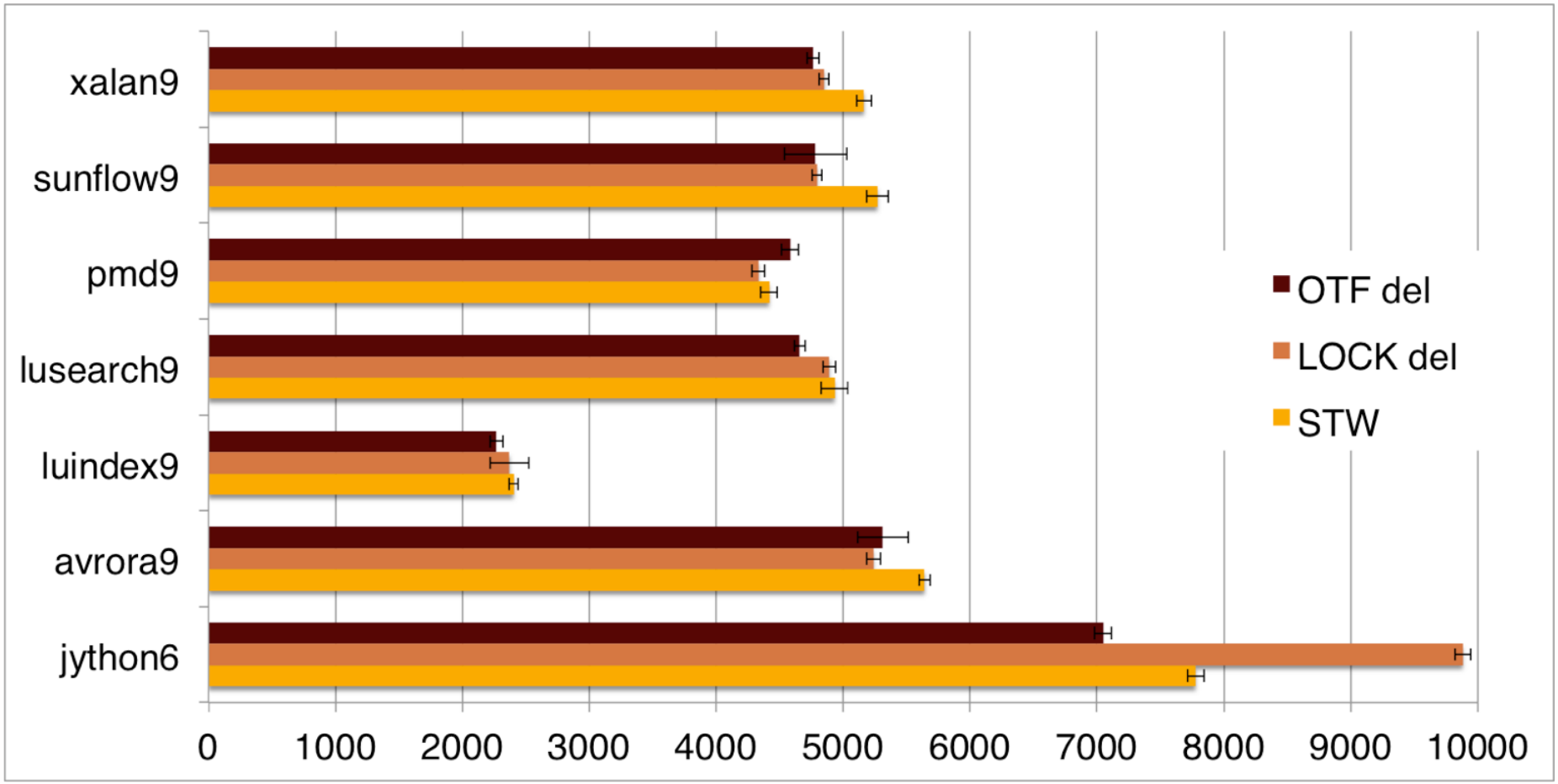
Reference Processing *Phase* Time



Execution times



Conclusion

- Reference types are frequently used in a significant number of programs.
  - *On-the-fly GC must not ignore reference types.*
- Formalised the definition of reference types.
- On-the-fly reference processing.
  - Model checked with SPIN.
  - Implemented in Jikes RVM.
    - *On-the-fly reference processing phases are longer in the worst case, but with deletion barrier, not by much.*
    - *Overall execution time is not increased significantly by processing references on-the-fly, and is often reduced.*

http://github.com/perlfu/sapphire

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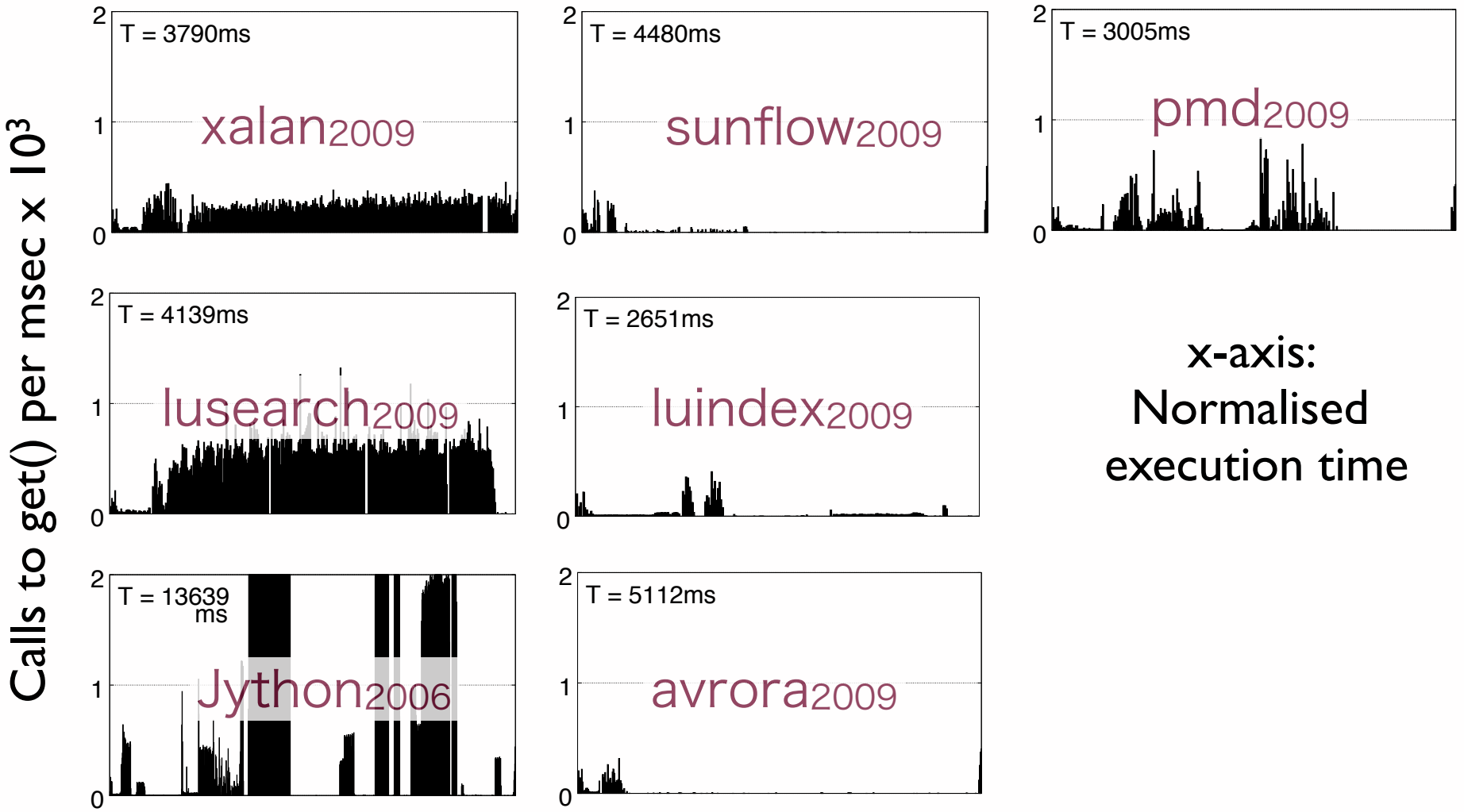
Questions?

Reference type usage



x-axis:
Normalised
execution time

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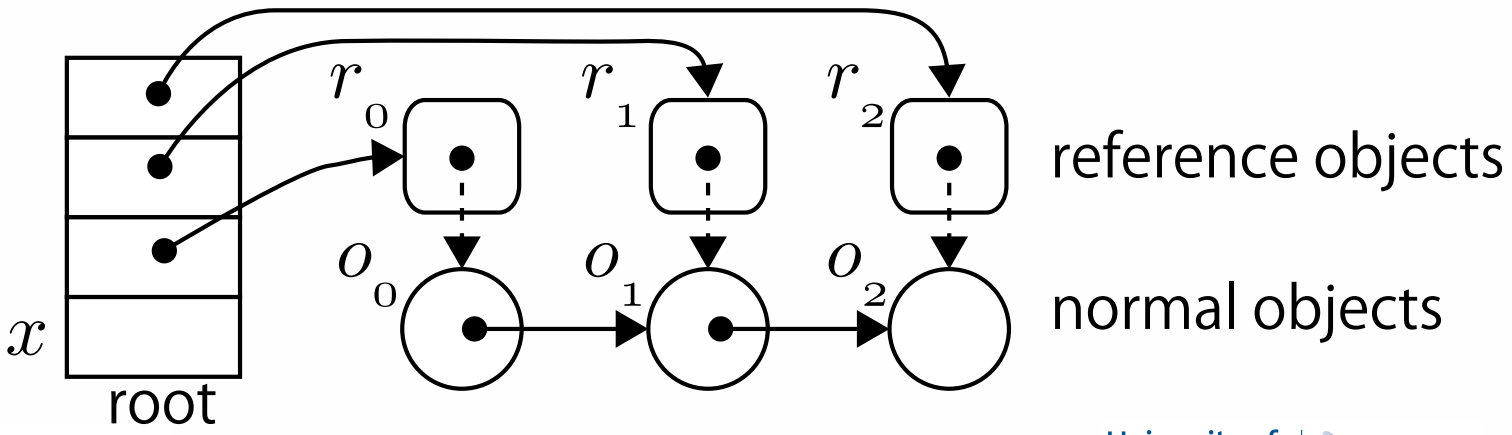
Model Checking

- Model checked with SPIN
  - Correctness:
    appears to mutators to be processed by GC atomically
  - Terminates only with deletion barrier



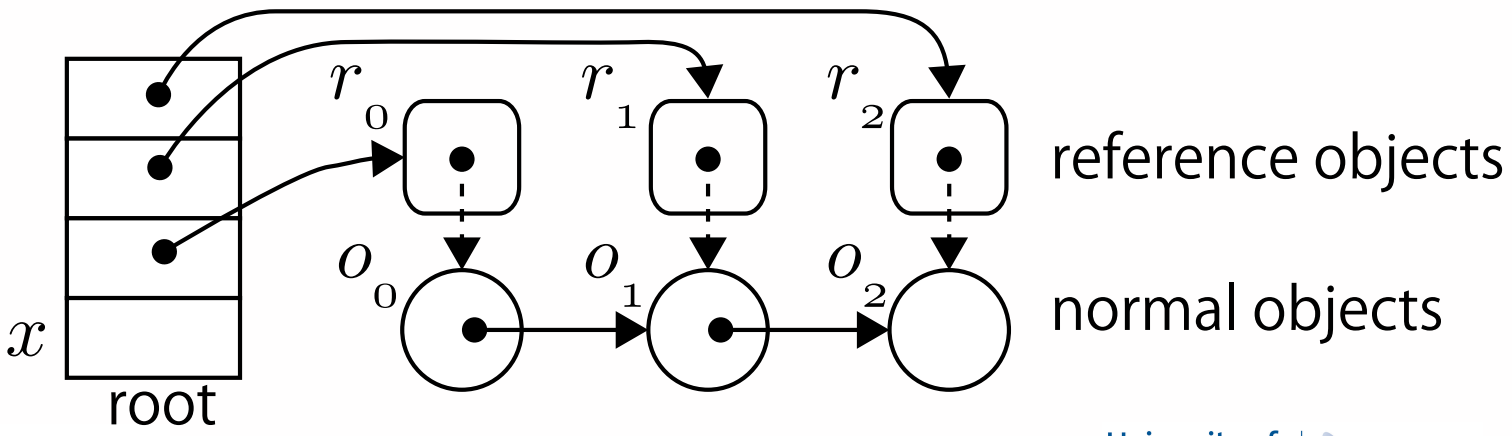
Properties

- No dangling pointer is created
  - If a variable is not null, its target has not been reclaimed

P1 $\Box((x \neq \texttt{NULL}) \implies (\texttt{mark}[x] \neq \texttt{RECLAIMED}))$

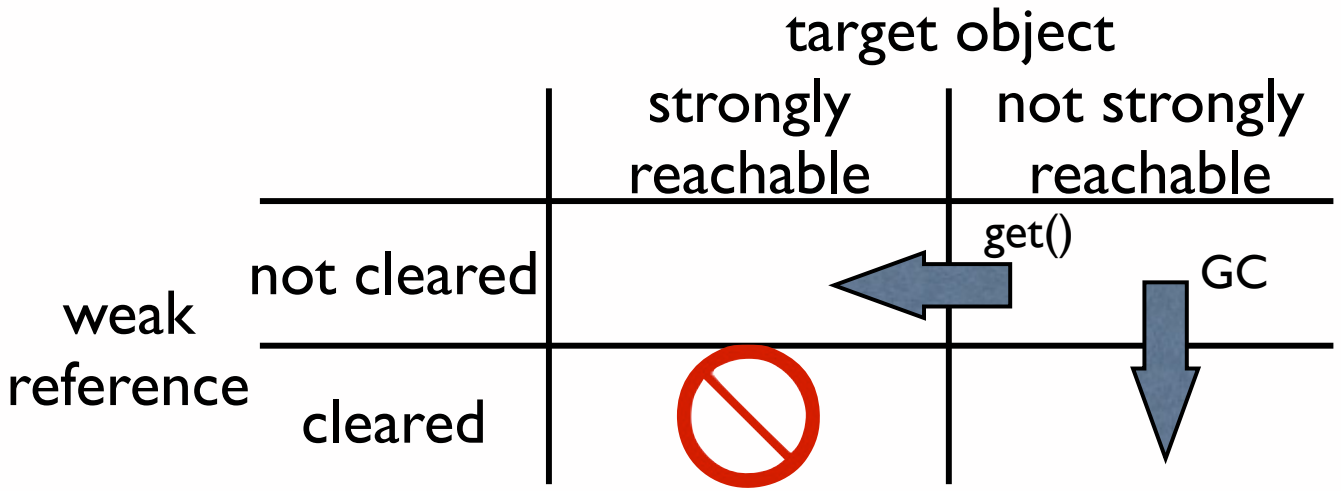
- Once get() of a Reference returns null, it will never returns its target

P2 $\Box(\texttt{RETNULL}_i \implies \neg\Diamond(x = i))\ \ (i = 1, 2, 3)$



Race

- Mutator makes an object strongly reachable
- Collector clears weak reference



Answer

- Handshake ensure that GC changes to TRACING after the get() that change the state to REPEAT returned
- Second handshake ensures all mutators acknowledge GC is in TRACING
- CAS tells which thread won the race