Local Linearizability

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Concurrent Data Structures
Correctness and Performance

Semantics of concurrent data structures

t1: enq(2) deq(1)
t2: enq(1) deq(2)

e.g. pools, queues, stacks

- Sequential specification = set of legal sequences

e.g. queue legal sequence
enq(1)enq(2)deq(1)deq(2)

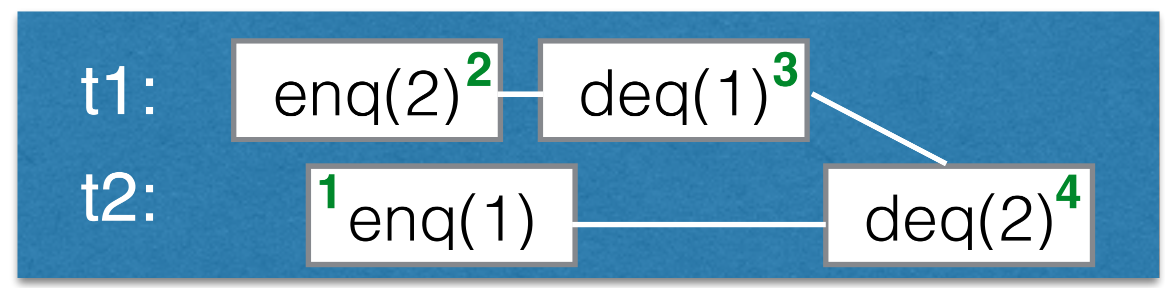
- Consistency condition = e.g. linearizability / sequential consistency

e.g. the concurrent history above is a linearizable queue concurrent history

Consistency conditions

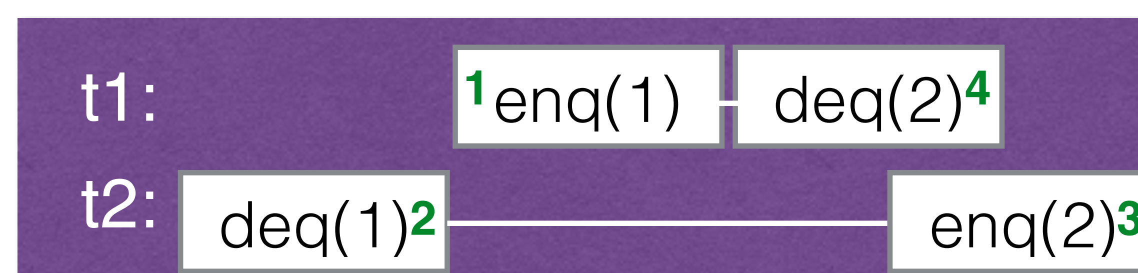
there exists a legal sequence that preserves precedence

Linearizability [Herlihy,Wing '90]

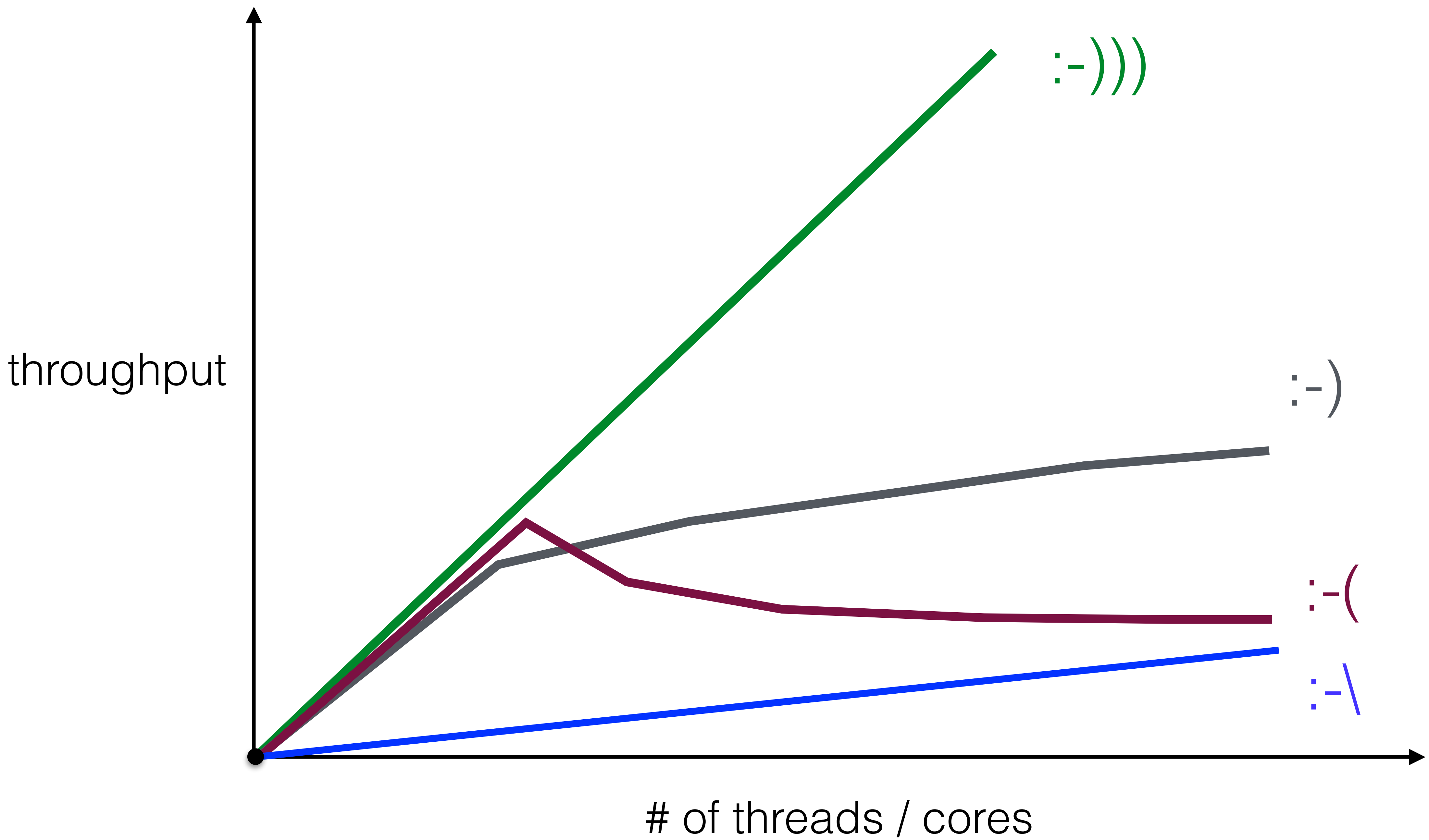


Sequential Consistency [Lamport'79]

there exists a legal sequence that preserves per-thread precedence (program order)



Performance and scalability



Relaxations allow trading

correctness
for
performance

provide the potential for better-performing implementations

Relaxing the Semantics

not "sequentially correct"

Quantitative relaxations
Henzinger, Kirsch, Payer, Sezgin,S. POPL13

- Sequential specification = set of legal sequences
- Consistency condition = e.g. linearizability / sequential consistency

Local linearizability
in this talk

for queues only
(feel free to ask for more)

too weak

Local Linearizability main idea

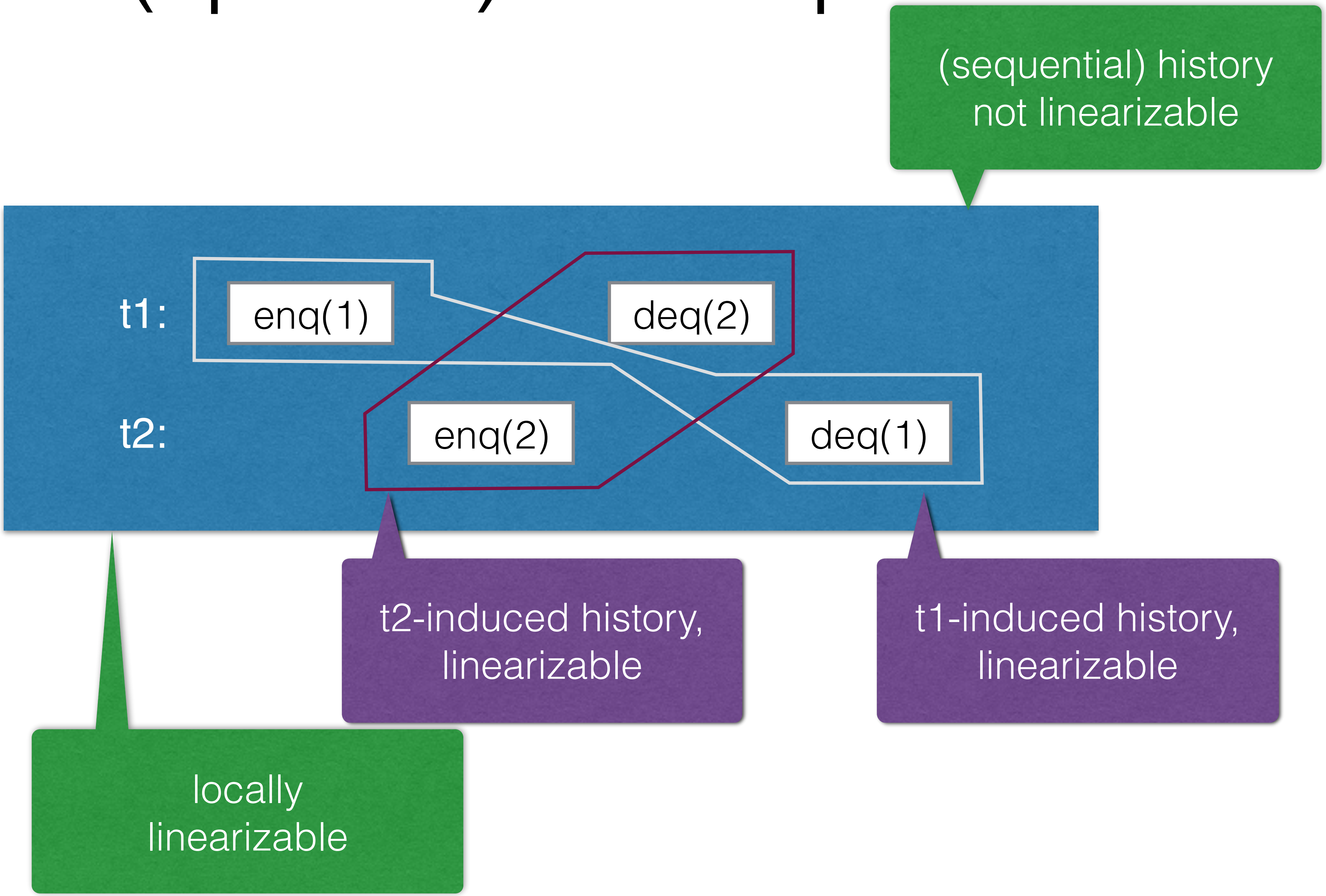
Already present in some shared-memory consistency conditions
(not in our form of choice)

- Partition a history into a set of local histories
- Require linearizability per local history

no global witness

Local sequential consistency… is also possible

Local Linearizability (queue) example



Local Linearizability (queue) definition

Queue signature $\Sigma = \{enq(x) \mid x \in V\} \cup \{deq(x) \mid x \in V\} \cup \{deq(empty)\}$

For a history **h** with a thread T, we put

$$I_T = \{enq(x)^T \in \mathbf{h} \mid x \in V\}$$

in-methods of thread T are enqueues performed by thread T

$$O_T = \{deq(x)^{T'} \in \mathbf{h} \mid enq(x)^T \in I_T\} \cup \{deq(empty)\}$$

out-methods of thread T are dequeues (performed by any thread) corresponding to enqueues that are in-methods

h is locally linearizable iff every thread-induced history

$$\mathbf{h}_T = \mathbf{h} \mid (I_T \cup O_T)$$

is linearizable.

Local Linearizability for Container-Type DS

Signature $\Sigma = Ins \cup Rem \cup SOb \cup DOb$

For a history **h** with a thread T, we put

$$I_T = \{m^T \in \mathbf{h} \mid m \in Ins\}$$

$$O_T = \{m(a) \in \mathbf{h} \cap Rem \mid i(a)^T \in I_T\} \cup \{m(e) \mid e \in Emp\} \cup \{m(a) \in \mathbf{h} \cap DOb \mid i(a)^T \in I_T\}$$

in-methods of thread T
are
inserts performed by
thread T

out-methods of thread T
are removes and data-observations
(performed by any thread)
n-methods

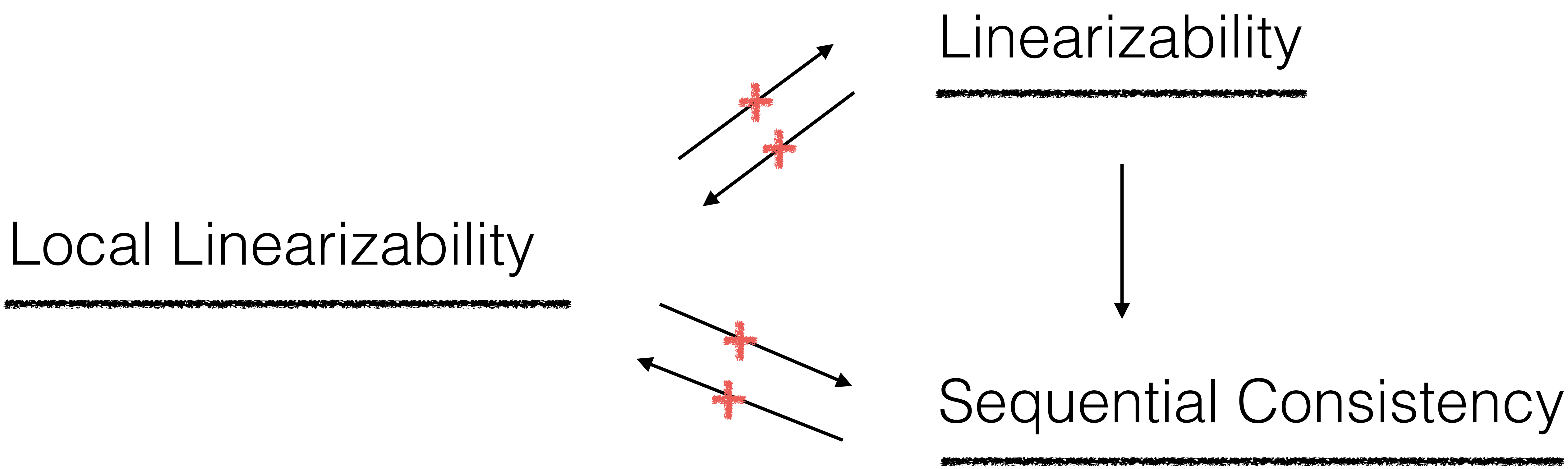
h is locally linearizable iff every thread-induced history

$$\mathbf{h}_T = \mathbf{h} \mid (I_T \cup O_T)$$

is linearizable.

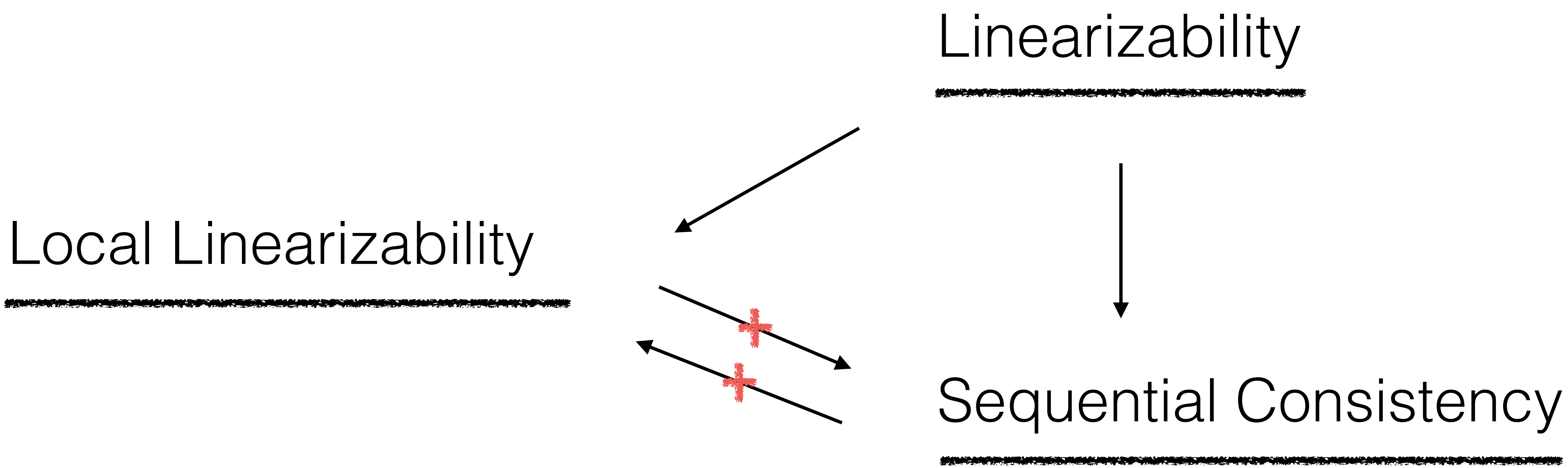
Where do we stand?

In general



Where do we stand?

For queues (and most container-type data structures)



Properties

Local linearizability is compositional

like linearizability
unlike sequential consistency

h (over multiple objects) is locally linearizable

iff

each per-object subhistory of **h** is locally linearizable

Local linearizability is modular / "decompositional"

uses decomposition into smaller histories, by definition

↓

may allow for modular verification

Verification (queue)

Queue sequential specification (axiomatic)

s is a legal queue sequence

iff

1. **s** is a legal pool sequence, and
2. $enq(x) <_s enq(y) \;\wedge\; deq(y) \in s \;\Rightarrow\; deq(x) \in s \;\wedge\; deq(x) <_s deq(y)$

Queue linearizability (axiomatic)

Henzinger, Sezgin, Vafeiadis CONCUR13

h is queue linearizable

iff

1. **h** is pool linearizable, and
2. $enq(x) <_h enq(y) \;\wedge\; deq(y) \in h \;\Rightarrow\; deq(x) \in h \;\wedge\; deq(y) \not<_h deq(x)$

precedence order

Verification (queue)

Queue sequential specification (axiomatic)

s is a legal queue sequence

iff

1. **s** is a legal pool sequence, and
2. $enq(x) <_{\mathbf{s}} enq(y) \;\wedge\; deq(y) \in \mathbf{s} \;\Rightarrow\; deq(x) \in \mathbf{s} \;\wedge\; deq(x) <_{\mathbf{s}} deq(y)$

Queue local linearizability (axiomatic)

h is queue locally linearizable

iff

1. **h** is pool locally linearizable, and
2. $enq(x) <_{\mathbf{h}}^{i} enq(y) \;\wedge\; deq(y) \in \mathbf{h} \;\Rightarrow\; deq(x) \in \mathbf{h} \;\wedge\; deq(y) \not<_{\mathbf{h}} deq(x)$

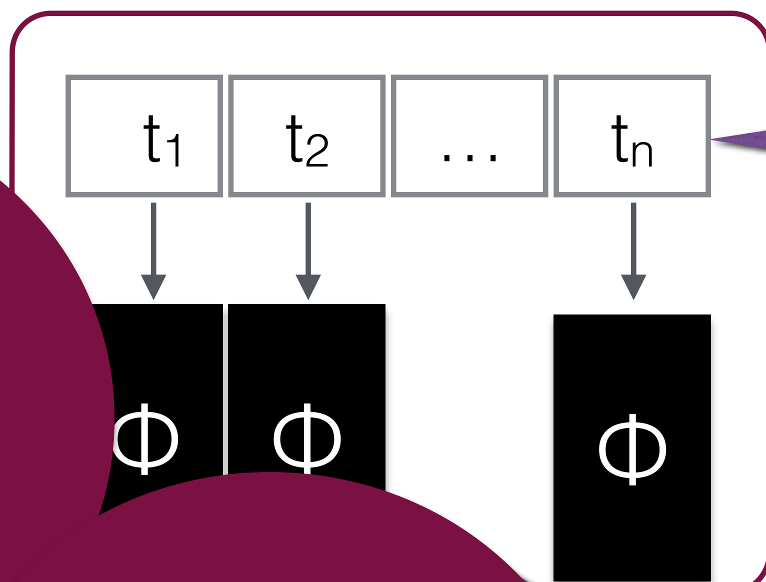
thread-local
precedence order

Generic Implementations

Your favorite linearizable data structure implementation

Φ

turns into a locally linearizable implementation by:



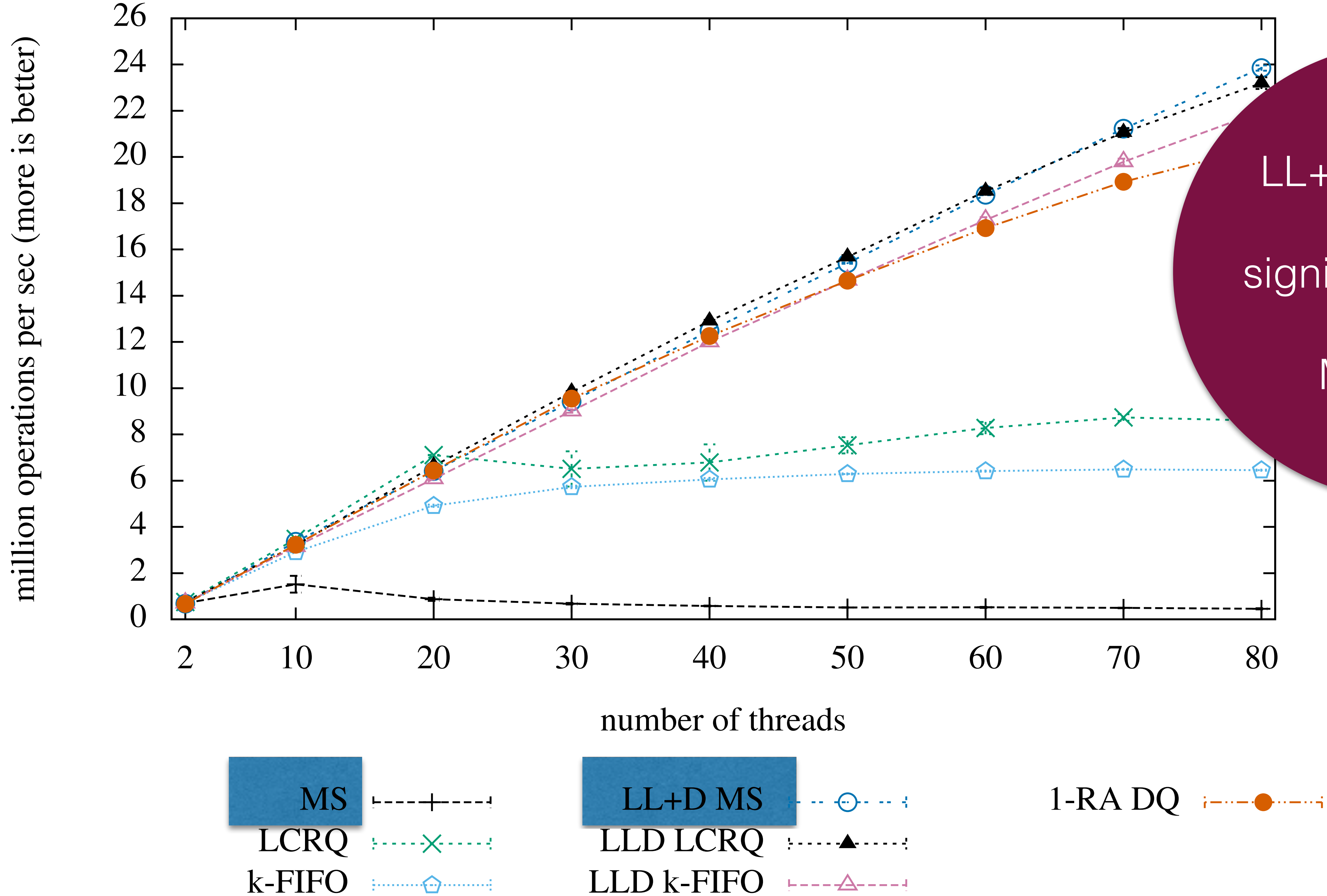
segment of possibly dynamic size (n)

LLD Φ (locally linearizable)

LL+D Φ (also pool linearizable)

local inserts / global (randomly distributed) removes

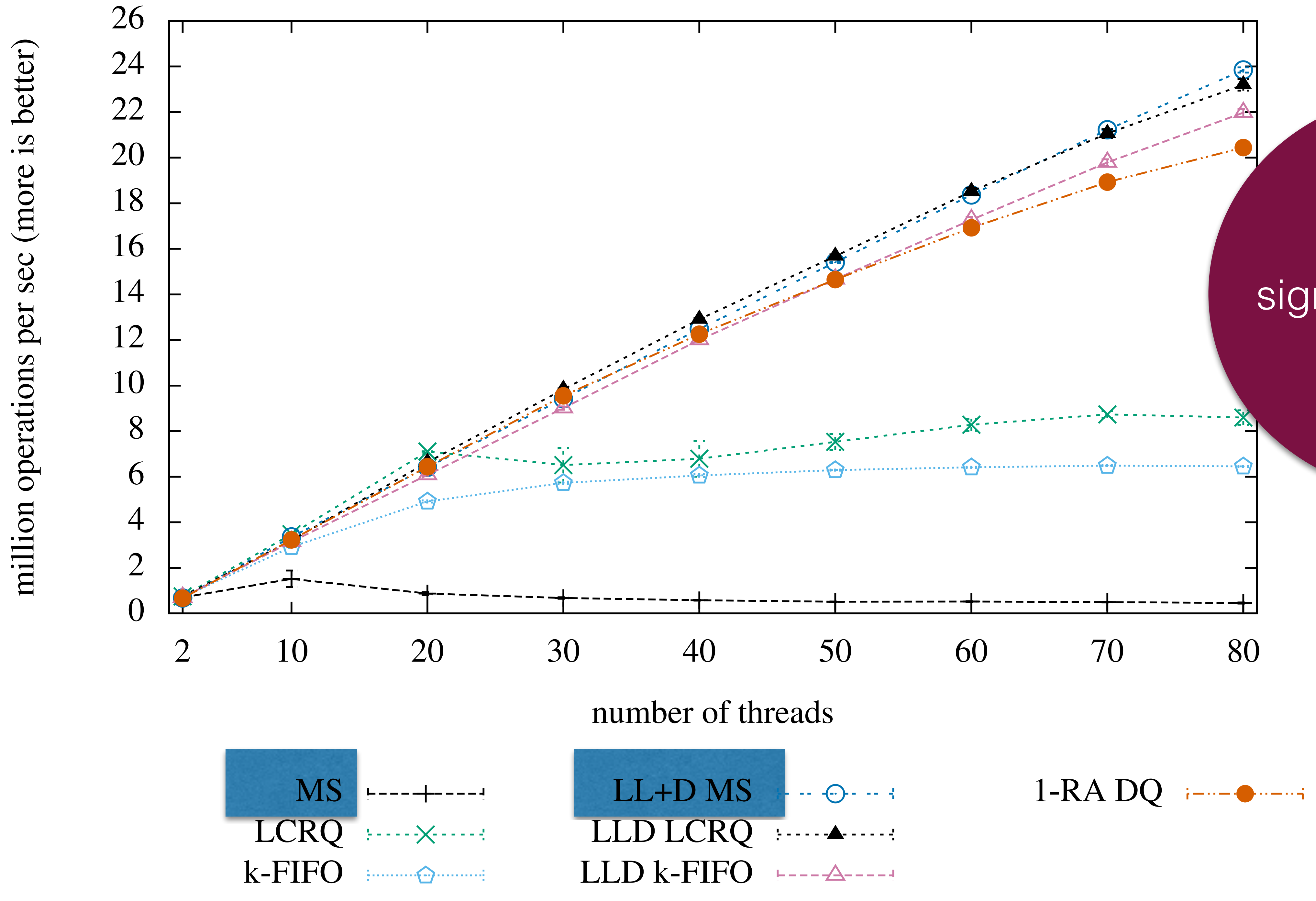
Performance



LL+D MS queue performs significantly better than MS queue

(a) Queues, LL queues, and "queue-like" pools

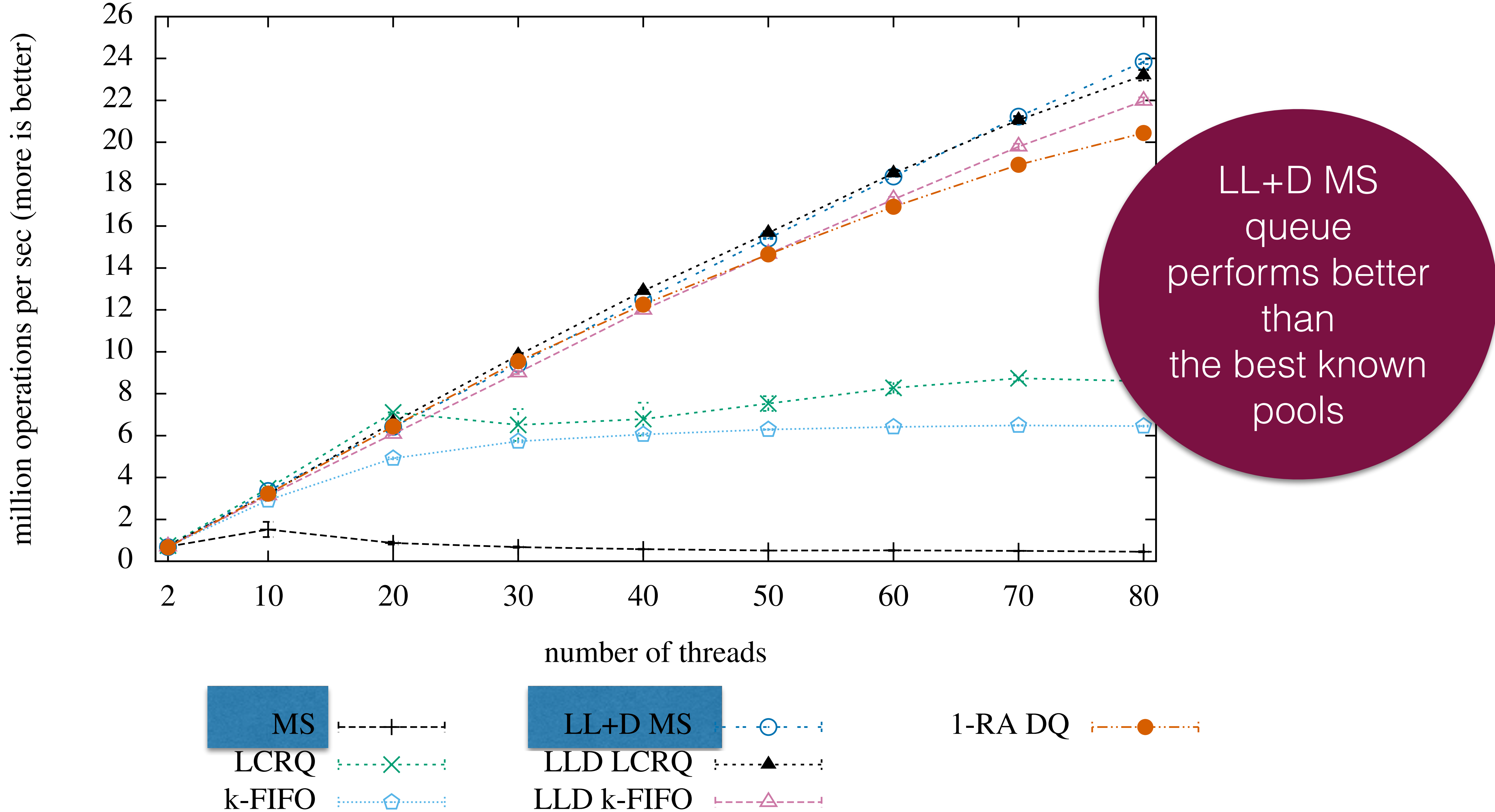
Performance



(a) Queues, LL queues, and "queue-like" pools

LLD Φ performs significantly better than Φ

Performance



(a) Queues, LL queues, and "queue-like" pools

Thank You!

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