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 sequential witness that preserves precedence

Linearizability [Herlihy,Wing '90]

t1:	enq(2)[2]	deq(1)[3]		
t2:	[1]enq(1)		deq(2)[4]	

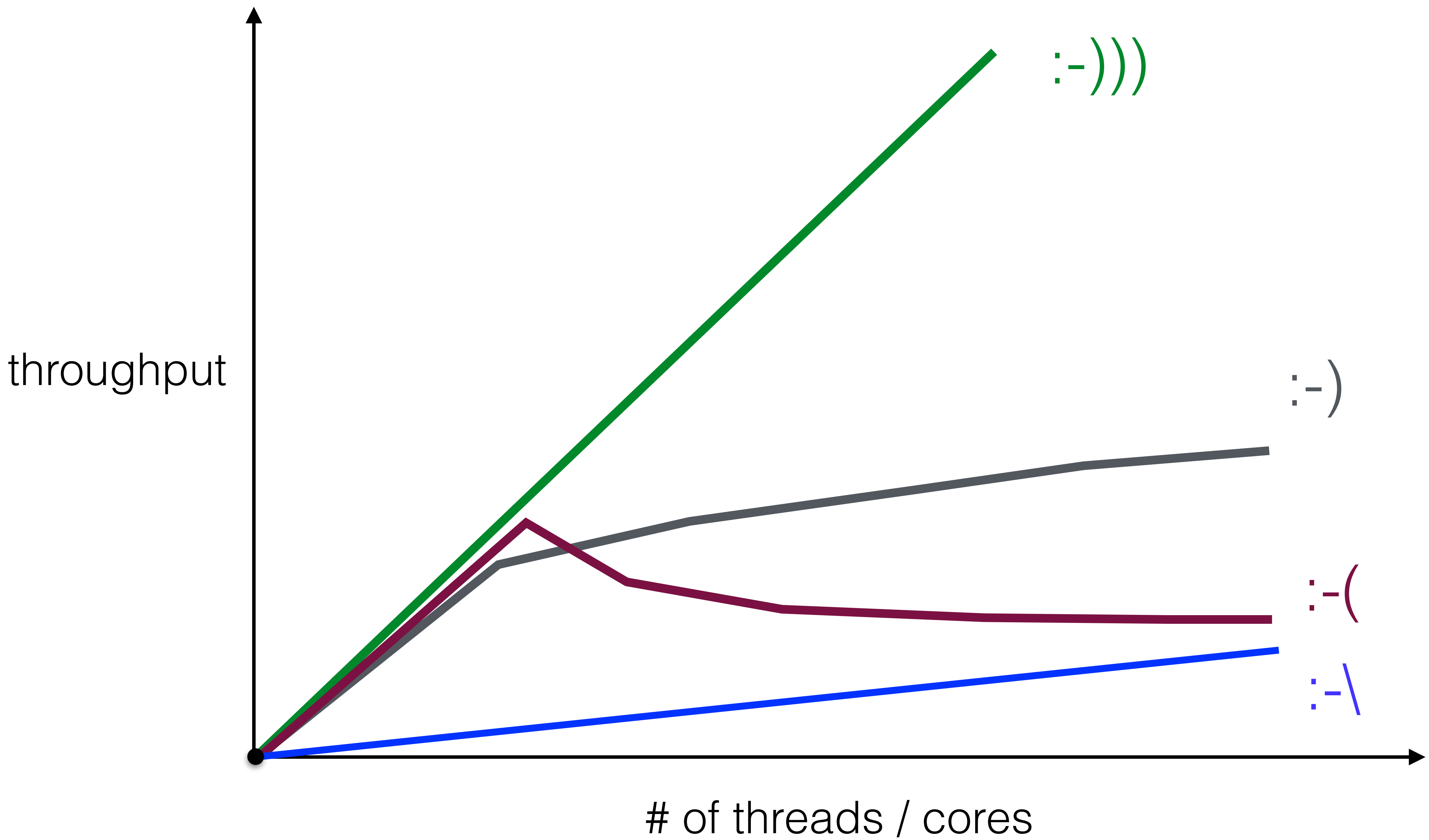
↓

Sequential Consistency [Lamport'79]

there exists a sequential witness that preserves per-thread precedence (program order)

t1:		[1]enq(1)	deq(2)[4]
t2:	deq(1)[2]		enq(2)[3]

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)

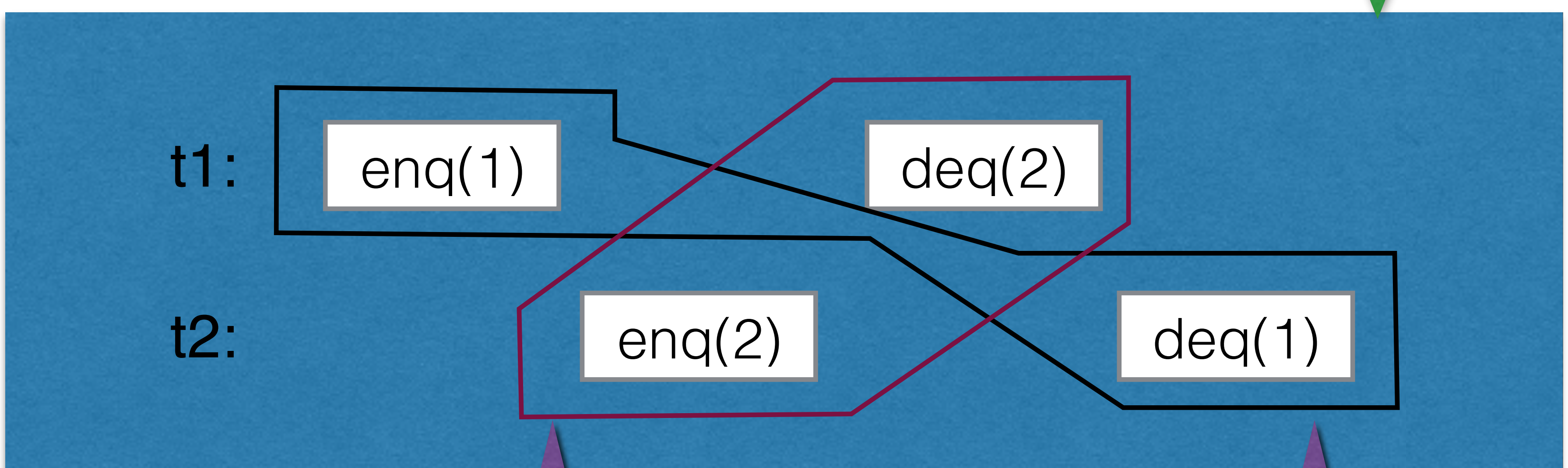
- Partition a history into a set of local histories
- Require linearizability per local history

no global witness

Local sequential consistency… is also possible

Local Linearizability (queue) example

(sequential) history not linearizable



t2-induced history, linearizable

t1-induced history, linearizable

locally linearizable

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 n threads, we put

$$In_{\mathbf{h}}(i) = \{enq(x)^i \in \mathbf{h} \mid x \in V\}$$

in-methods of thread i enqueues performed by thread i

$$Out_{\mathbf{h}}(i) = \{deq(x)^j \in \mathbf{h} \mid enq(x)^i \in In_{\mathbf{h}}(i)\} \cup \{deq(empty)\}$$

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

h is locally linearizable iff every thread-induced history

$$\mathbf{h}_i = \mathbf{h} \mid (In_{\mathbf{h}}(i) \cup Out_{\mathbf{h}}(i))$$

is linearizable.

Generalizations of Local Linearizability

Signature Σ

For a history **h** with n threads, choose

$In_{\mathbf{h}}(i)$

$Out_{\mathbf{h}}(i)$

in-methods of thread i, methods that go in $\mathbf{h}_i$

out-methods of thread i, dependent methods on the methods in $In_{\mathbf{h}}(i)$ (performed by any thread)

by increasing the in-methods, LL gradually moves to linearizability

h is locally linearizable iff every thread-induced history

$\mathbf{h}_i = \mathbf{h} \mid (In_{\mathbf{h}}(i) \cup Out_{\mathbf{h}}(i))$

is linearizable.

Where do we stand?

In general

Linearizability

Local Linearizability

Sequential Consistency

Where do we stand?

For queues (and all pool-like data structures)

Linearizability

Local Linearizability

Sequential Consistency

Where do we stand?

C: For queues

Linearizability

Local Linearizability
& Pool-seq.cons.

Sequential Consistency

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. $enq(x) <_{\mathbf{s}} enq(y) \;\wedge\; deq(y) \in \mathbf{s} \quad \Rightarrow \quad deq(x) \in \mathbf{s} \;\wedge\; deq(x) <_{\mathbf{s}} deq(y)$

Queue linearizability (axiomatic)

h is queue linearizable

iff

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

precedence order

Verification (queue)

Queue sequential specification (axiomatic)

s is a legal queue sequence

iff

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

Queue local linearizability (axiomatic)

h is queue locally linearizable

iff

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

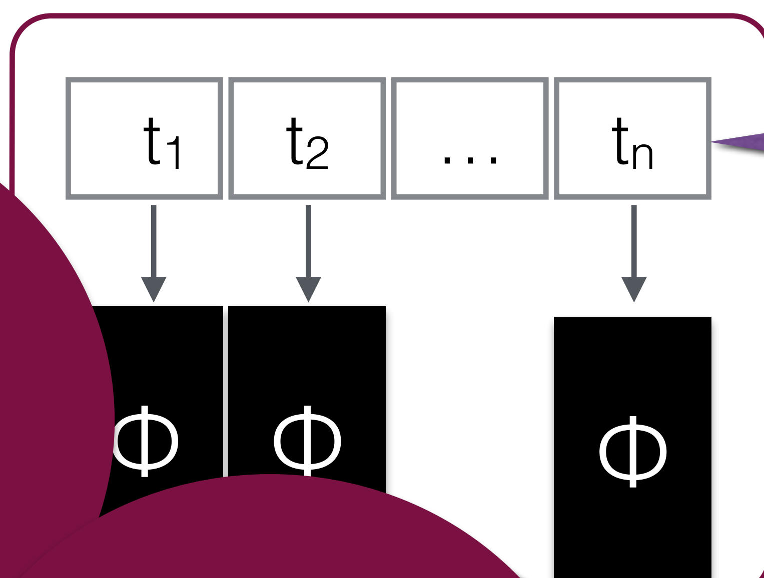
thread-local
precedence order

Generic Implementations

Your favorite linearizable data structure implementation

Φ

turns into a locally linearizable implementation by:



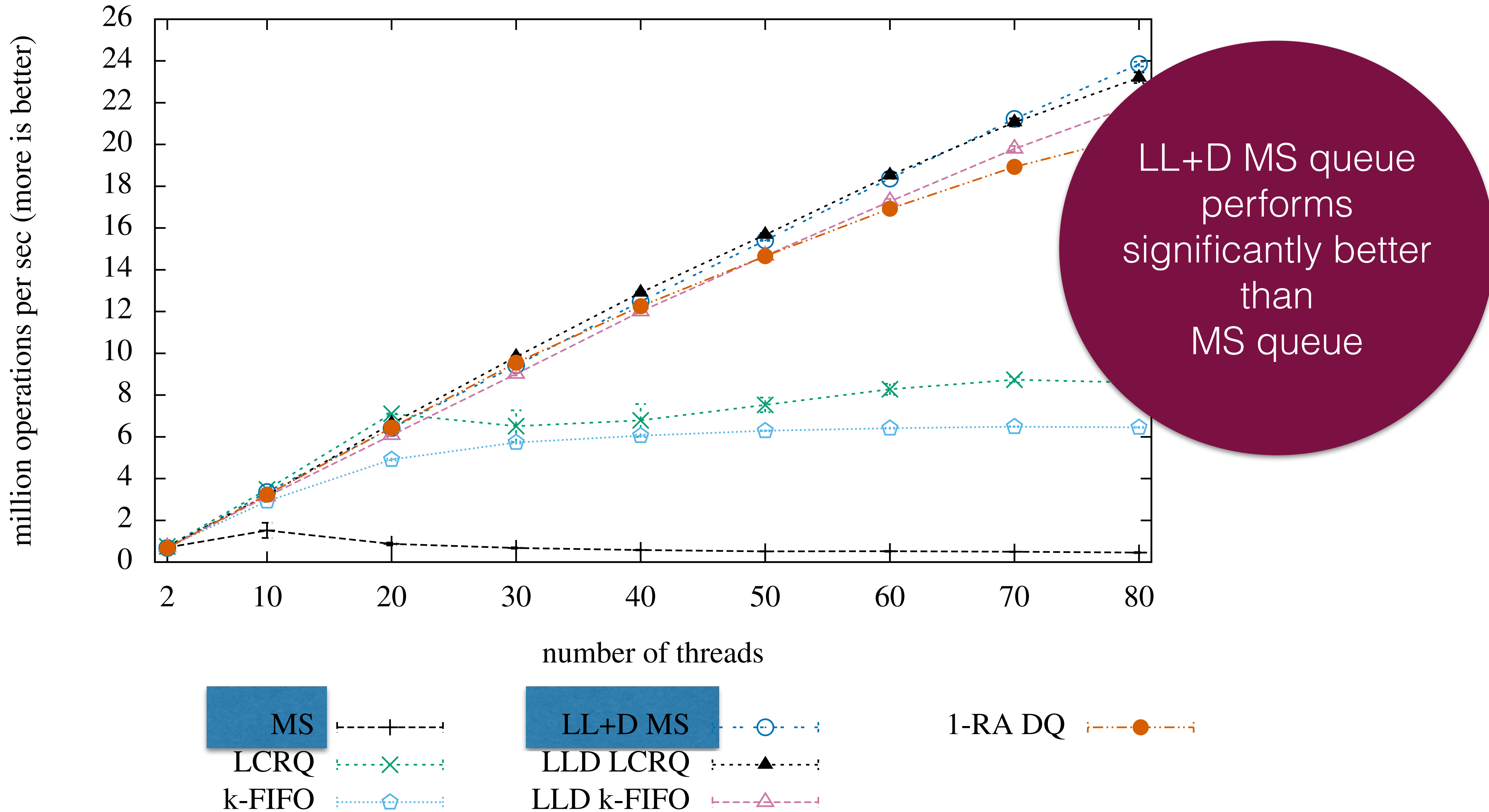
segment of dynamic size (n)

LLD Φ (locally linearizable)

LL+D Φ (also pool linearizable)

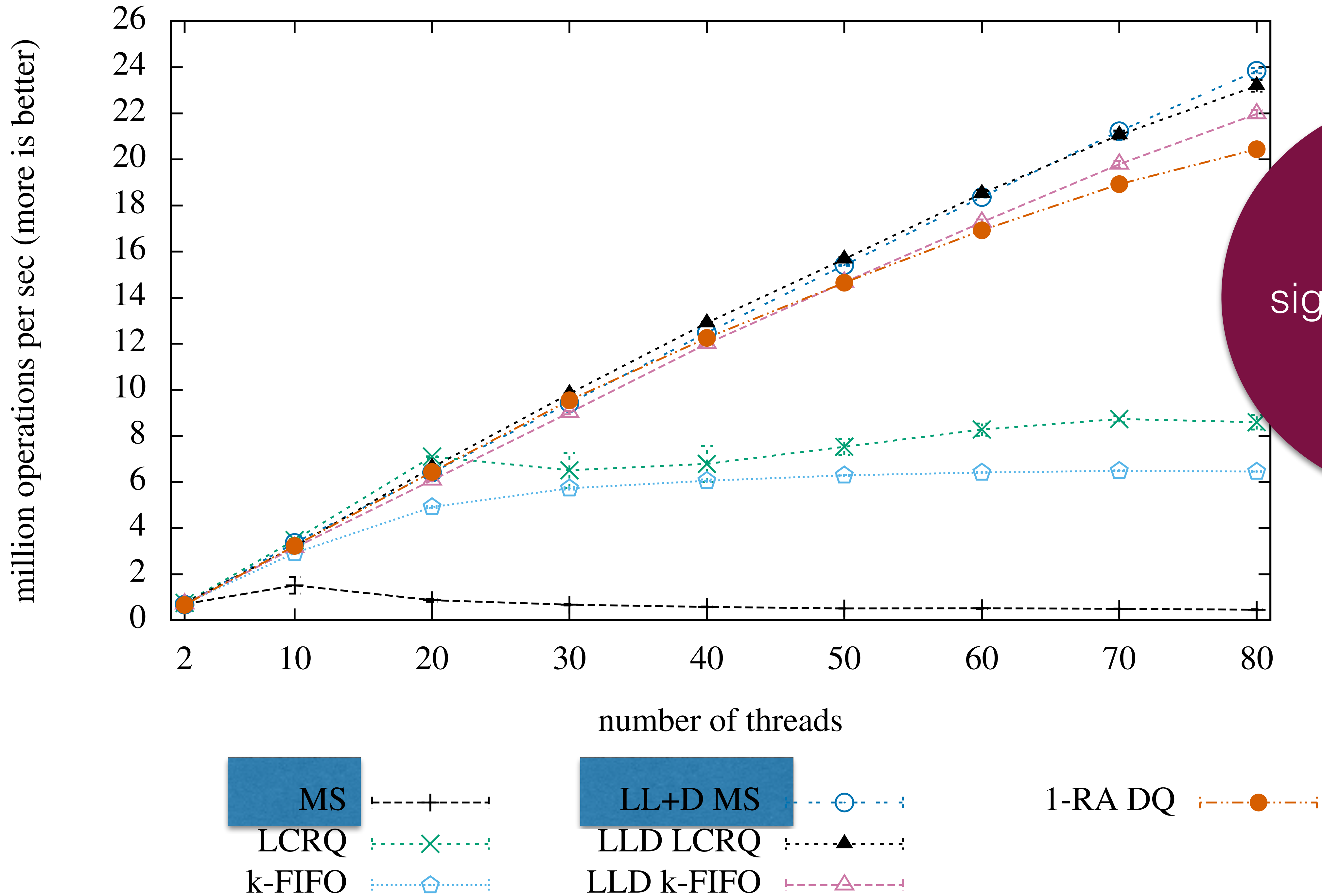
local inserts / global (randomly distributed) removes

Performance



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

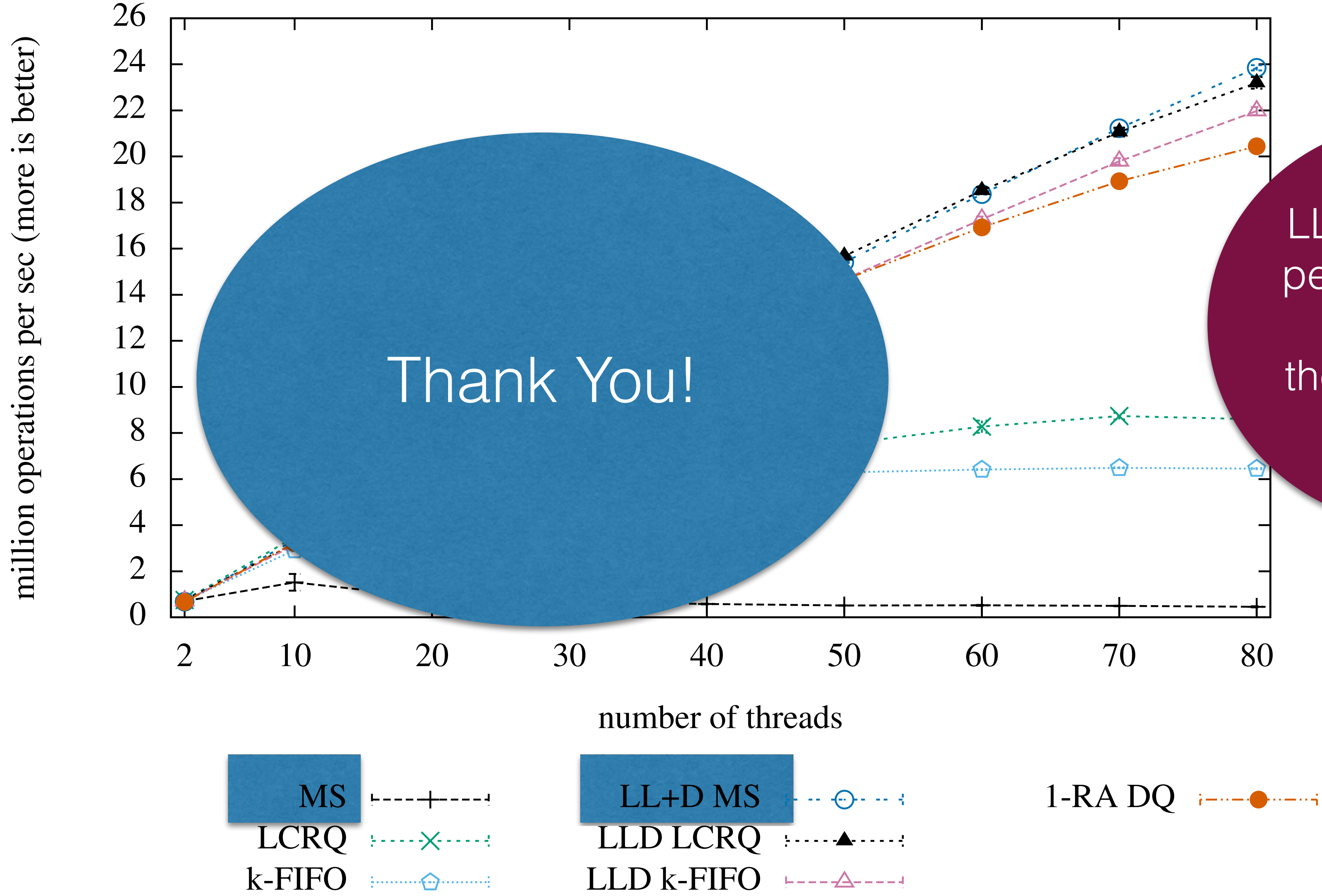
Performance



LLD Φ performs significantly better than Φ

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

Performance



Thank You!

LLD MS queue performs better than the best known pools

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