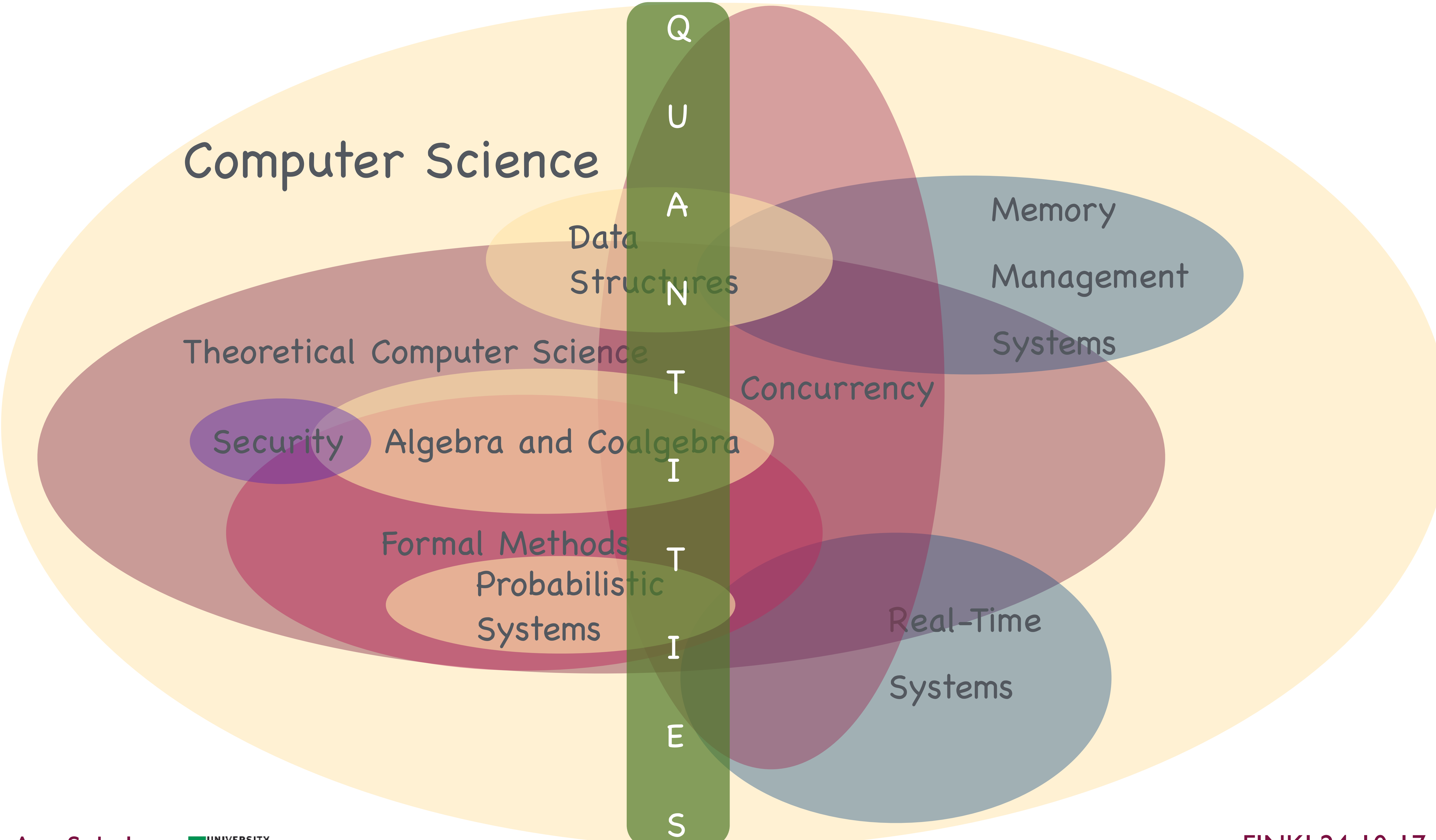
Concurrent Data Structures: Semantics and Relaxations

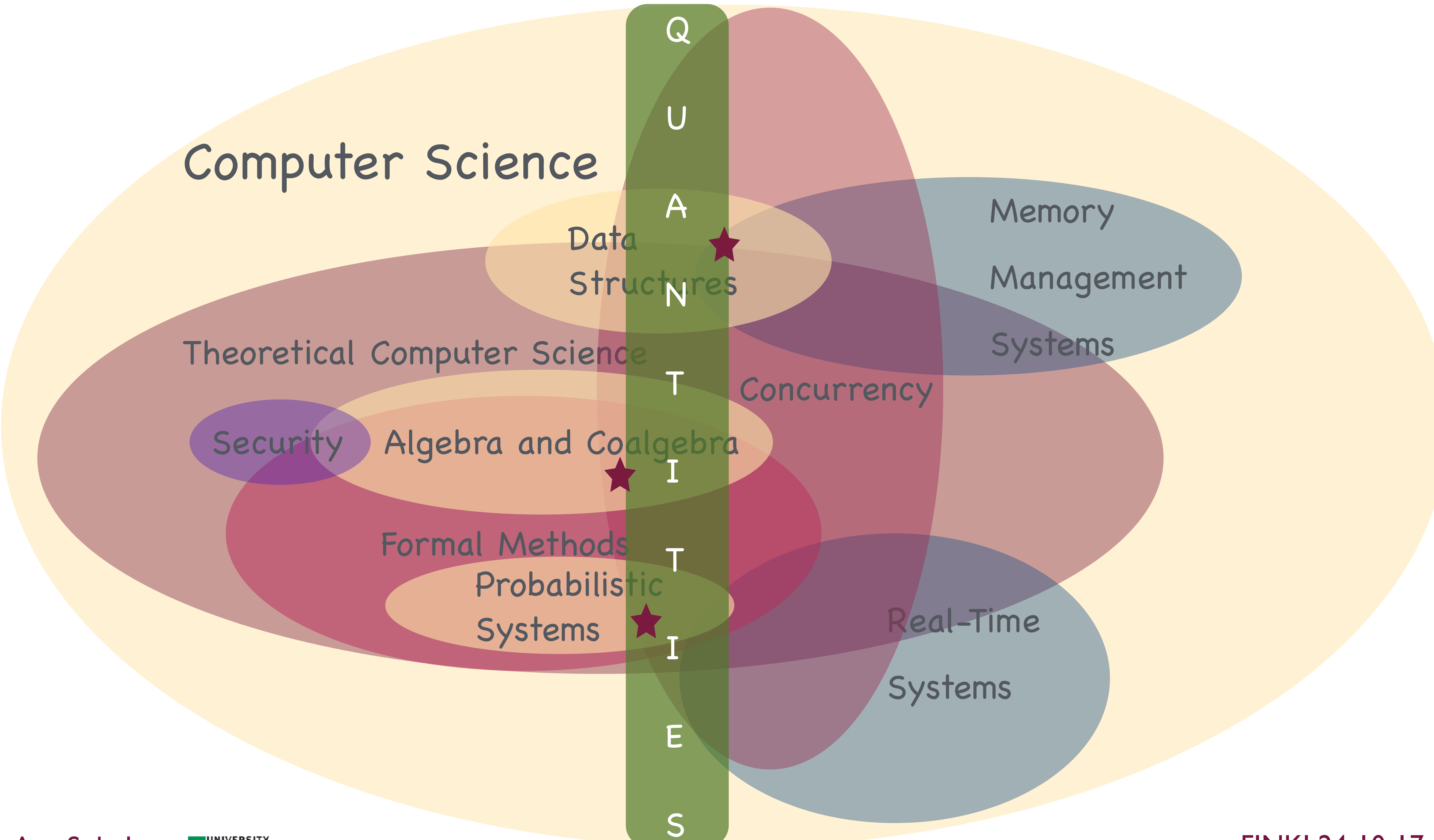
Ana Sokolova UNIVERSITY of SALZBURG

FINKI, Skopje, 24.10.17

Background big picture



Favourites



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Concurrent Data Structures: Semantics and Relaxations

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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)

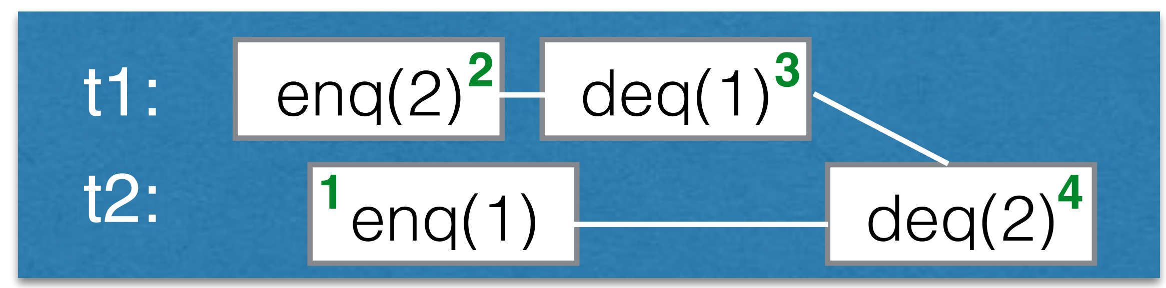
- Consistency condition = e.g. linearizability / sequential consistency

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]



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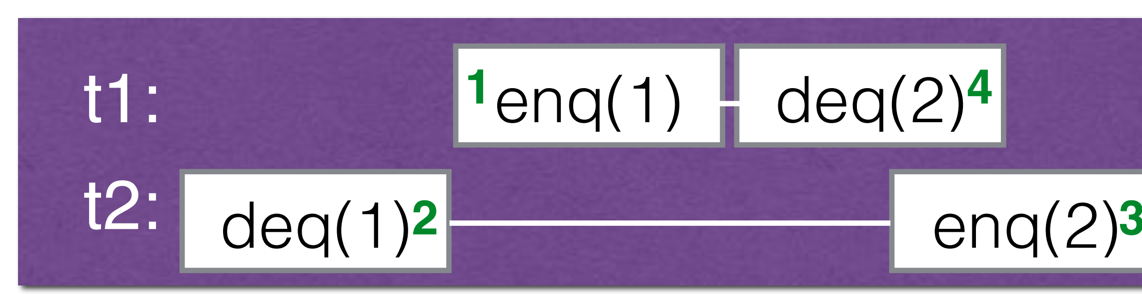
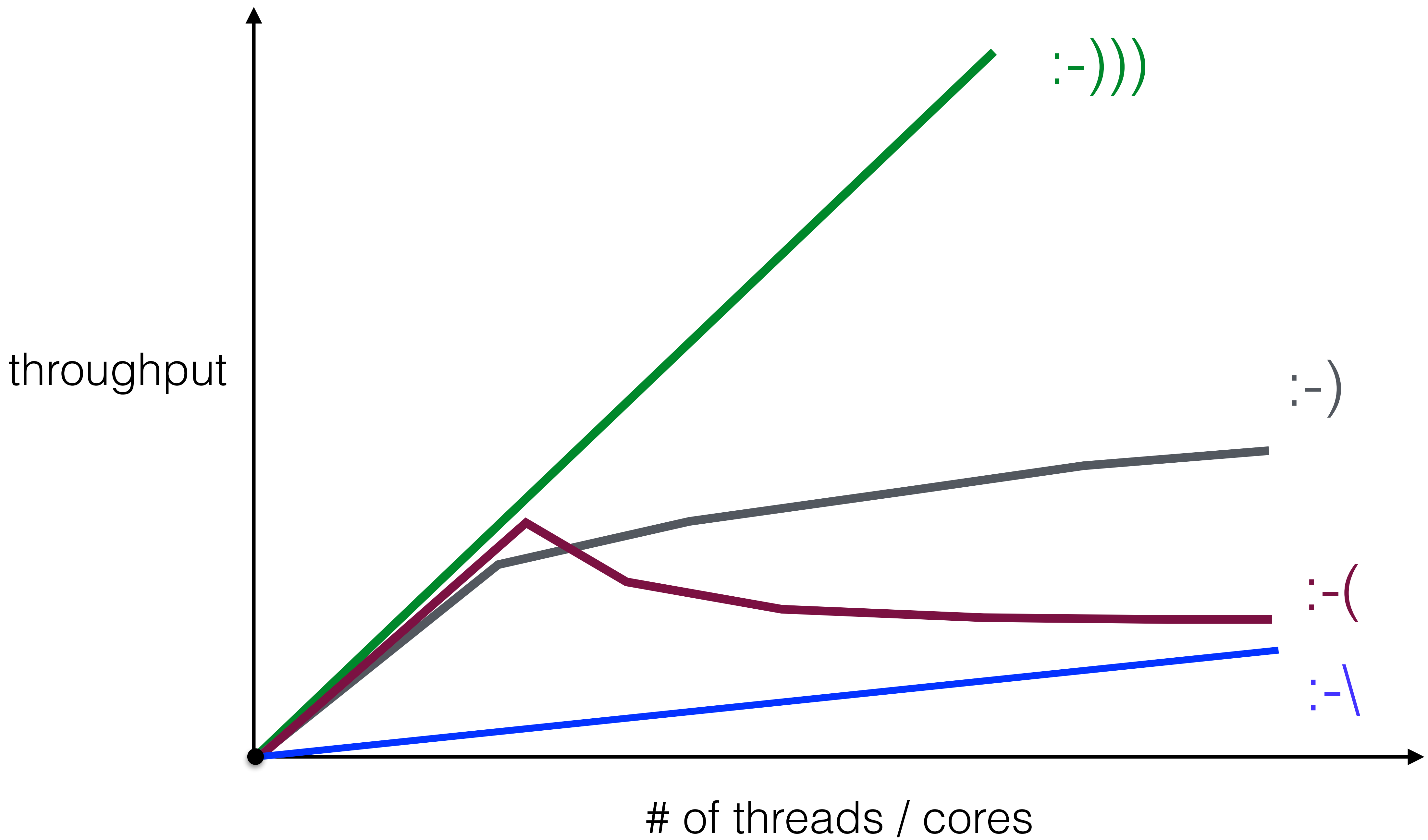
Sequential Consistency [Lamport'79]

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
POPL13

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

Local linearizability
CONCUR16

too weak

for queues/stacks only
(feel free to ask for more)

Relaxing the sequential specification

Quantitative relaxations (POPL13)

Goal

Stack - incorrect behavior

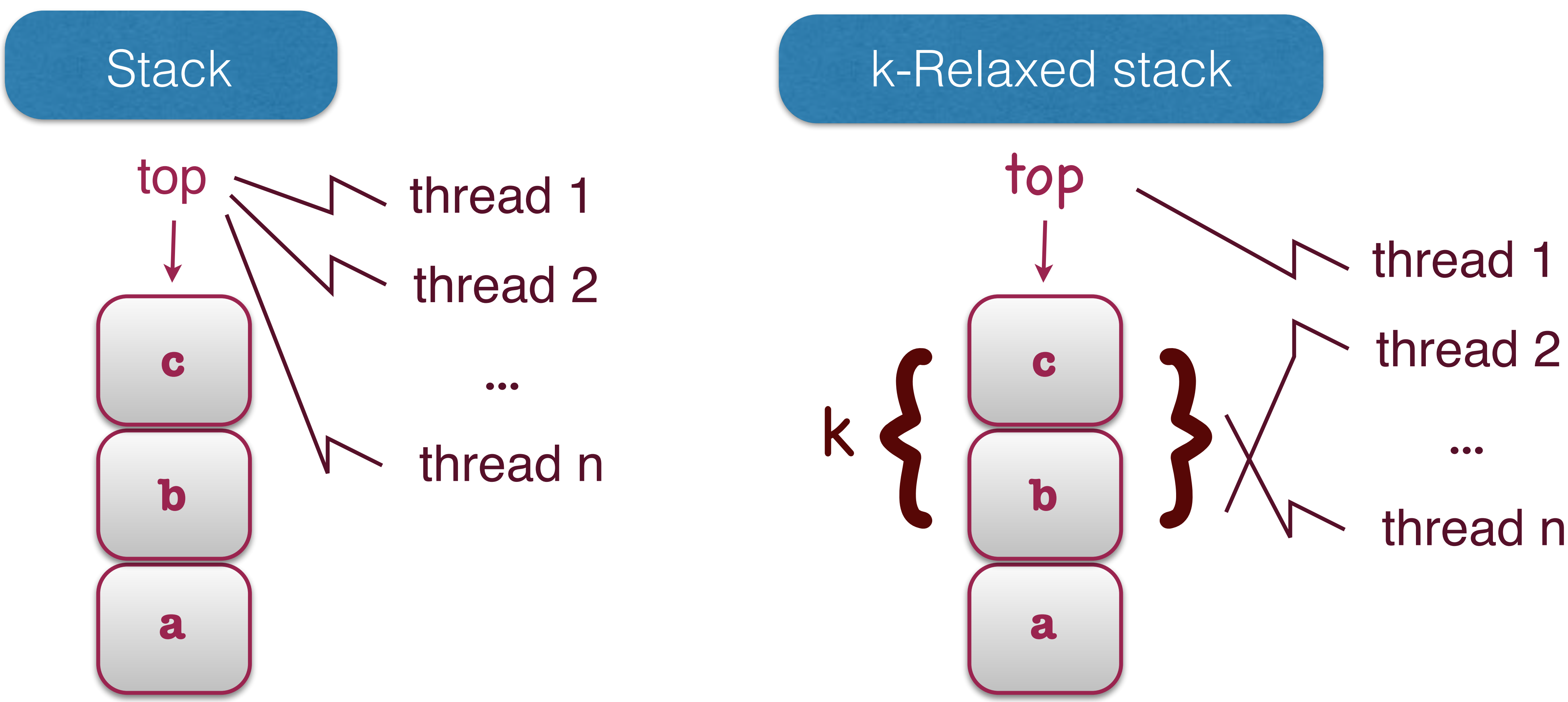
push(a)push(b)push(c)pop(a)pop(b)

- trade correctness for performance
- in a controlled way with quantitative bounds

measure the error from correct behaviour

correct in a relaxed stack
... 2-relaxed? 3-relaxed?

How can relaxing help?



What we have

- Framework
- Generic examples
- Concrete relaxation examples
- Efficient concurrent implementations

for semantic relaxations

out-of-order / stuttering

stacks, queues, priority queues,.. / CAS, shared counter

of relaxation instances

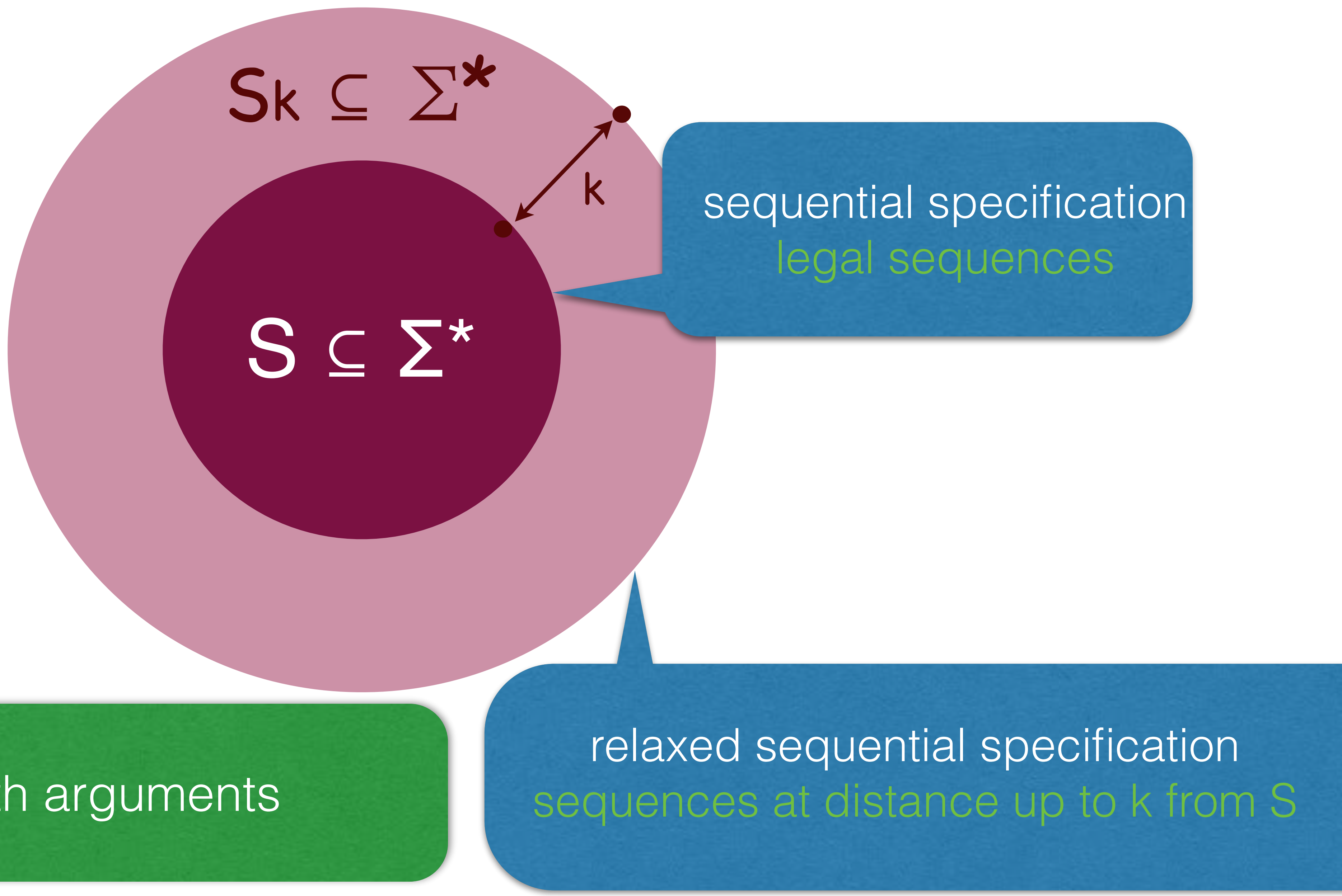
The big picture

$S \subseteq \Sigma^*$

sequential specification
legal sequences

Σ - methods with arguments

The big picture

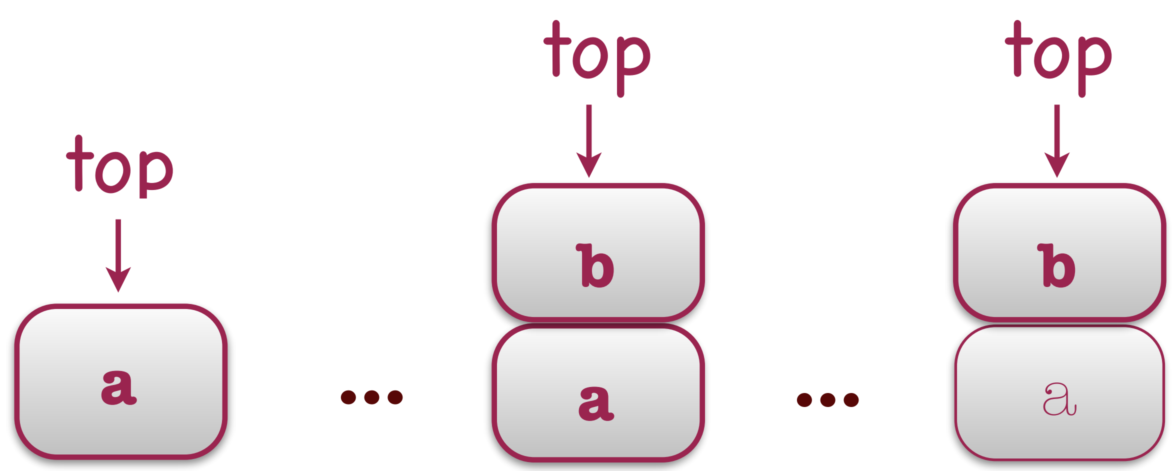


Σ - methods with arguments

Syntactic distances do not help

$$\text{push}(a)[\text{push}(i)\text{pop}(i)]^n\text{push}(b)[\text{push}(j)\text{pop}(j)]^m\text{pop}(a)$$

is a 1-out-of-order stack sequence



its permutation distance is min(2n,2m)

Semantic distances need a notion of state

state

top

c

a

- States are equivalence classes of sequences in S

example: for stack

push(a)push(b)pop(b)push(c) ≡ push(a)push(c)

- Two sequences in S are equivalent iff they have an indistinguishable future

$$x \equiv y \quad \Leftrightarrow \quad \forall u \in \Sigma^*.\, (xu \in S \;\Leftrightarrow\; yu \in S)$$

Semantics goes operational

$S \subseteq \Sigma^*$ is the sequential specification

states

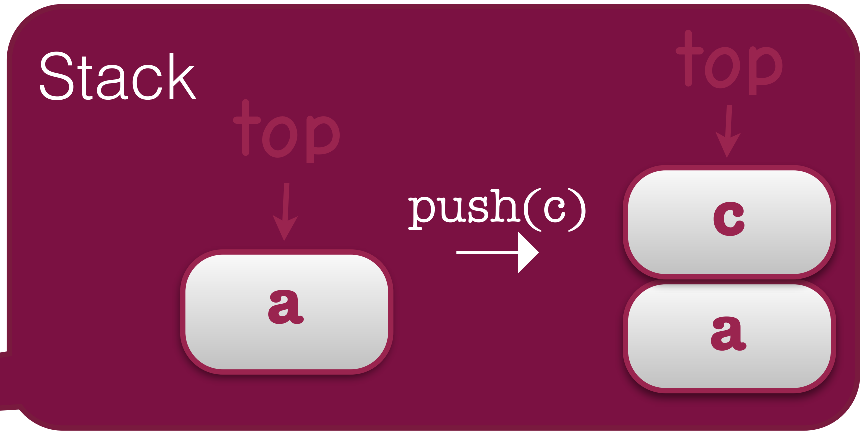
labels

initial state

$LTS(S) = (S/_\equiv, \Sigma, \rightarrow, [\varepsilon]_\equiv)$ with

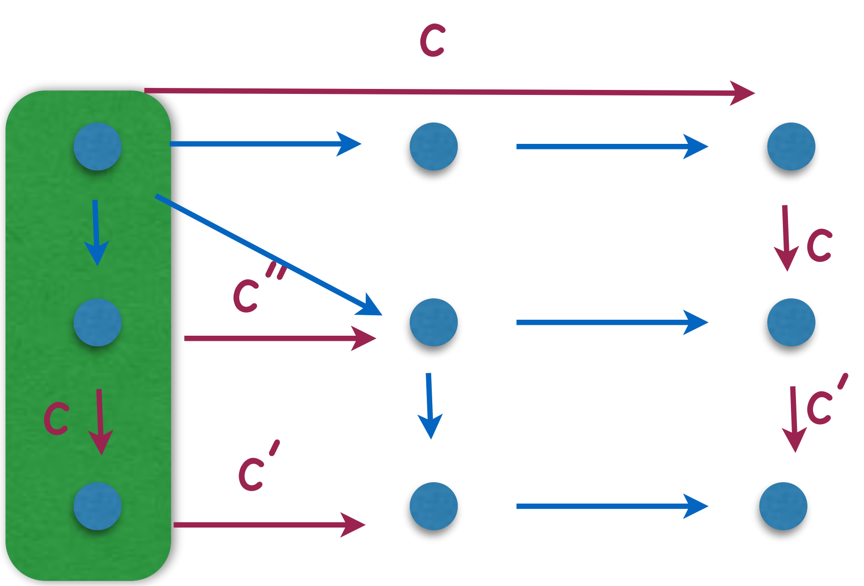
transition relation

$$[s]_\equiv \xrightarrow{m} [sm]_\equiv \quad \Leftrightarrow \quad sm \in S$$



The relaxation framework

- Start from LTS(S)
- Add transitions with transition costs
- Fix a path cost function



distance - minimal cost on all paths labelled by the sequence

Generic out-of-order

$\texttt{segment\_cost}(\, q \xrightarrow{m} q' \,) = |\mathbf{v}|$

transition cost

Where **v** is a sequence of minimal length s.t.

removing **v** enables a transition

or

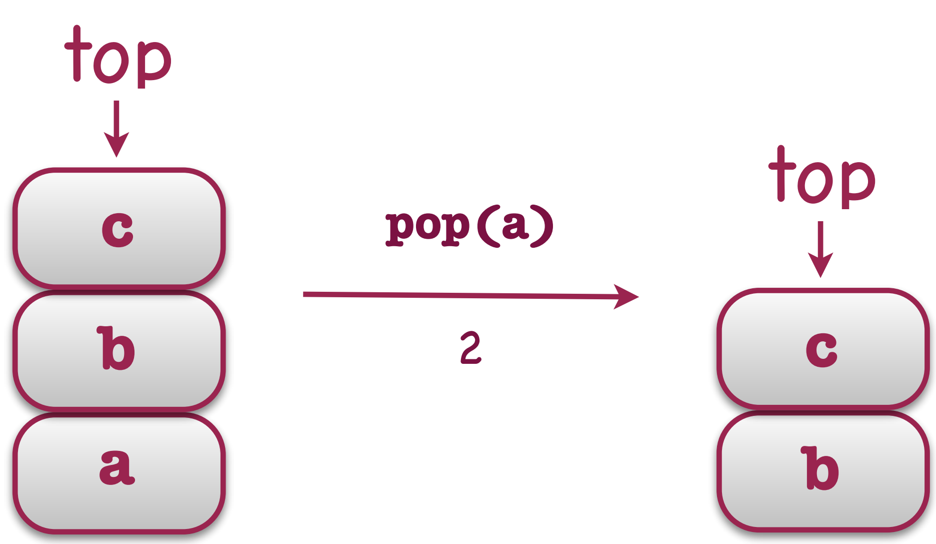
inserting **v** enables a transition

goes with different path costs

Out-of-order stack

Sequence of **push**'s with no matching **pop**

- Canonical representative of a state
- Add incorrect transitions with segment-costs



- Possible path cost functions max, sum,...

also more advanced

Relaxing the Consistency Condition

Local Linearizability (CONCUR16)

Local Linearizability main idea

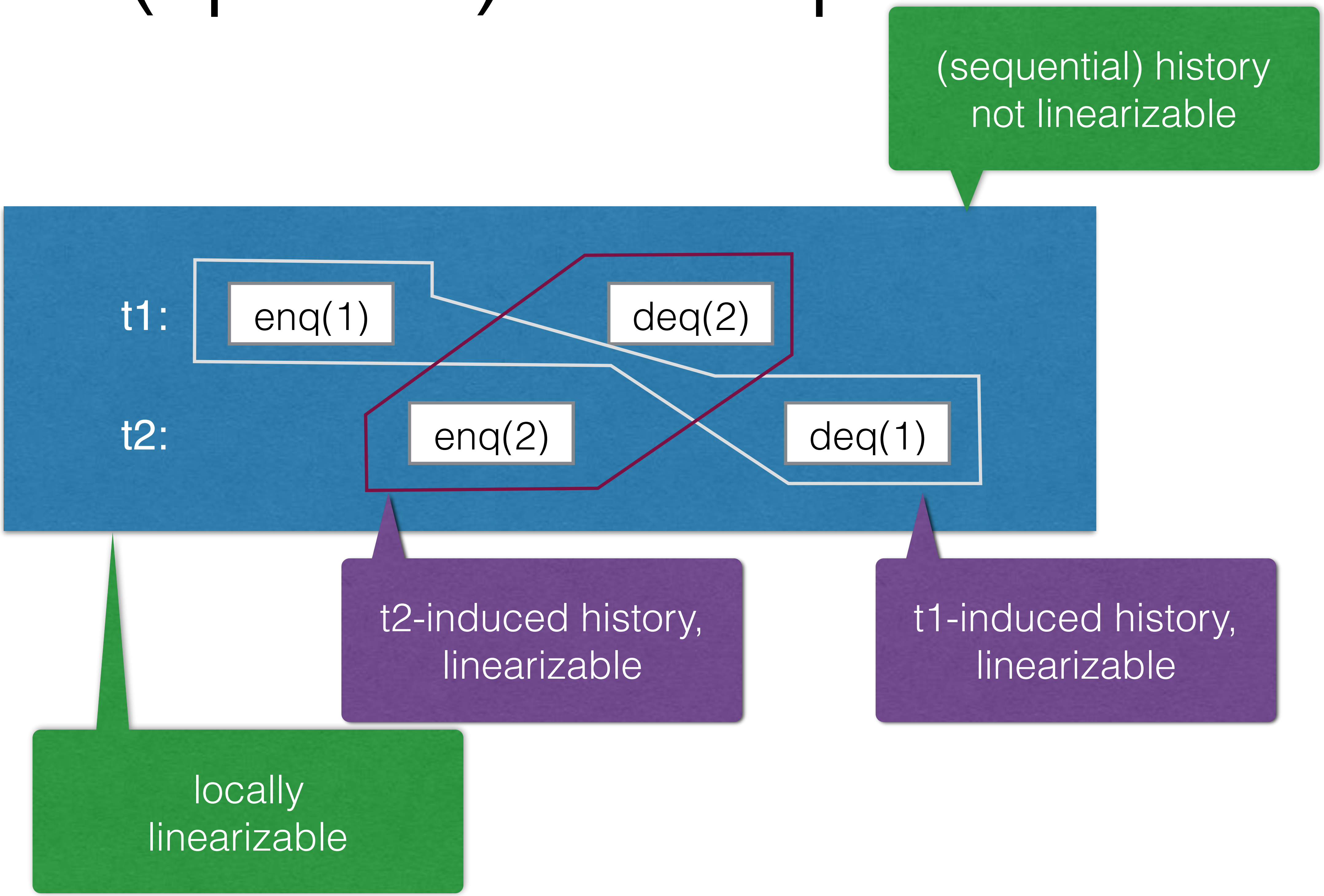
Already present in some shared-memory consistency conditions
(not in our form of choice)

- 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

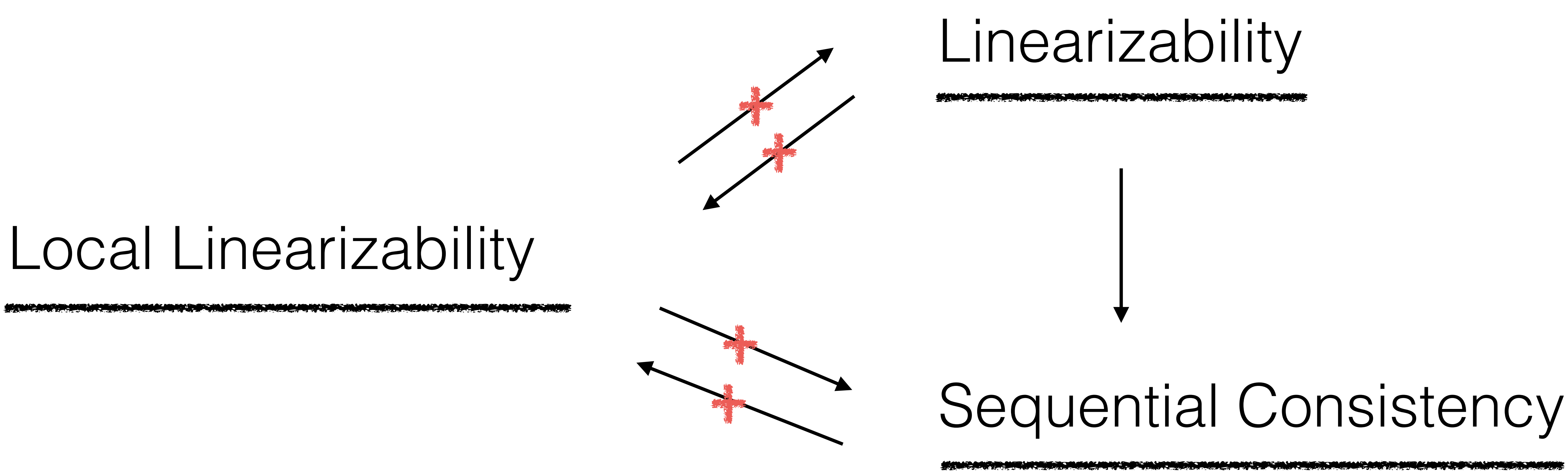
h is locally linearizable iff every thread-induced history

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

is linearizable.

Where do we stand?

In general



Where do we stand?

For queues (and most container-type data structures)

Linearizability

Local Linearizability

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

↓

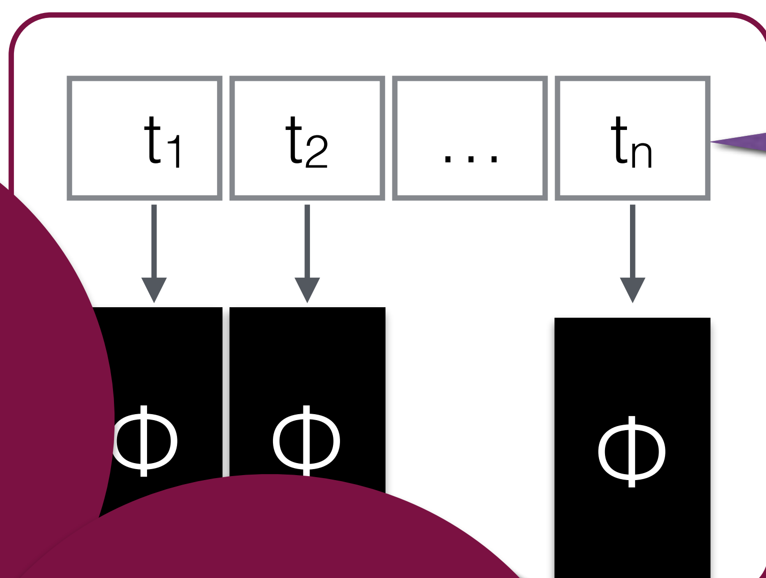
may allow for modular verification

Generic Implementations

Your favorite linearizable data structure implementation

Φ

turns into a locally linearizable implementation by:



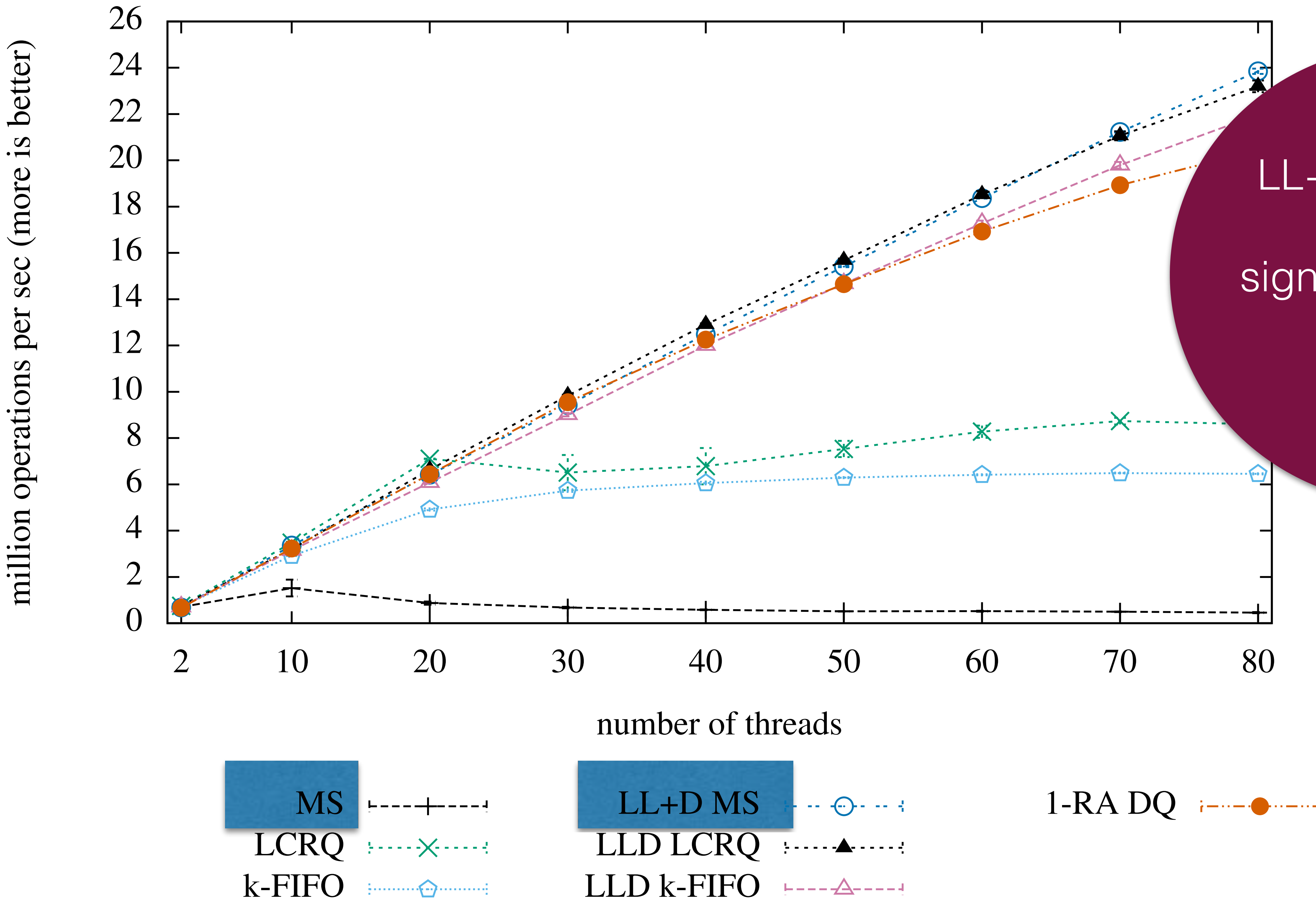
segment of possibly dynamic size (n)

LLD Φ (locally linearizable)

LL+D Φ (also pool linearizable)

local inserts / global (randomly distributed) removes

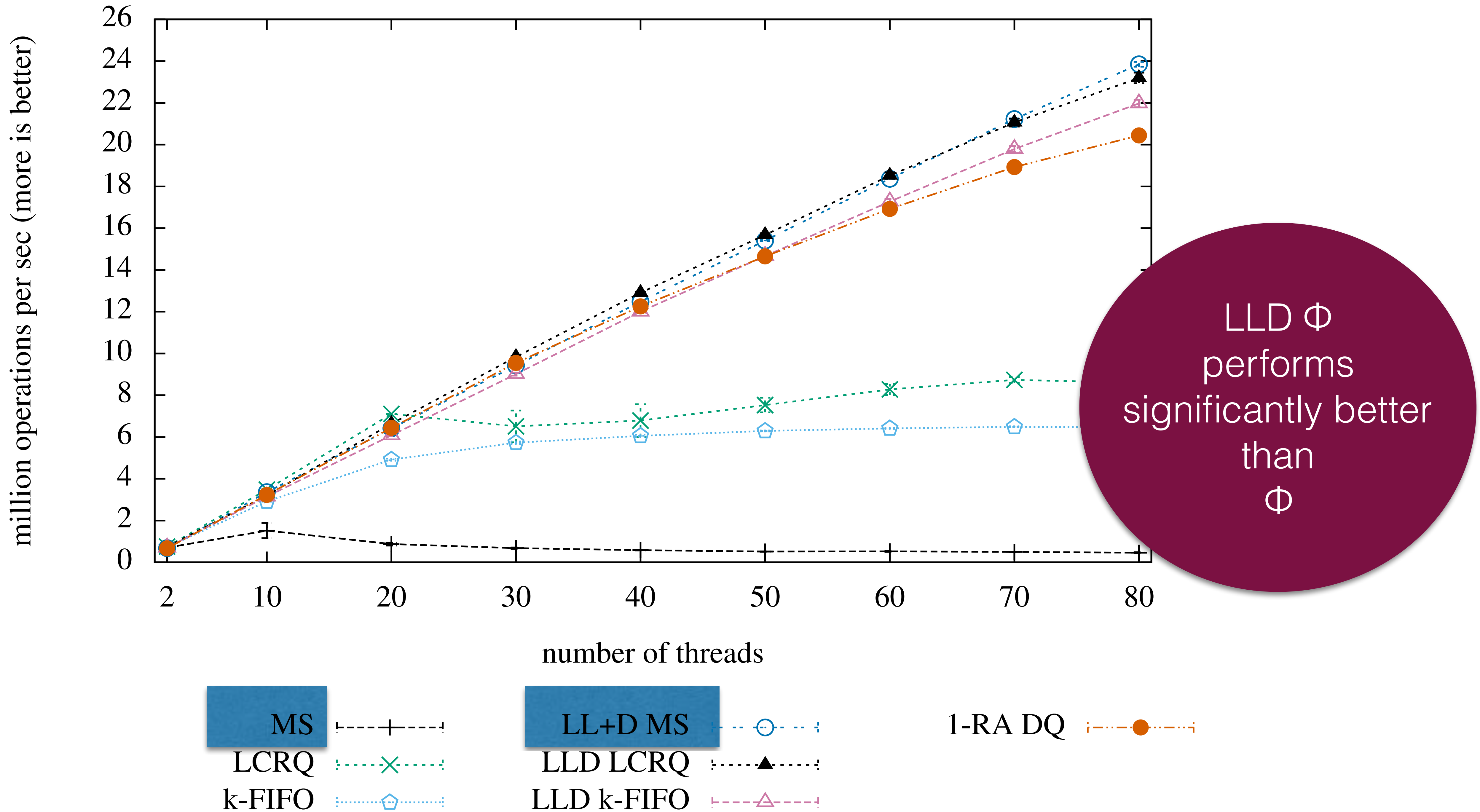
Performance



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

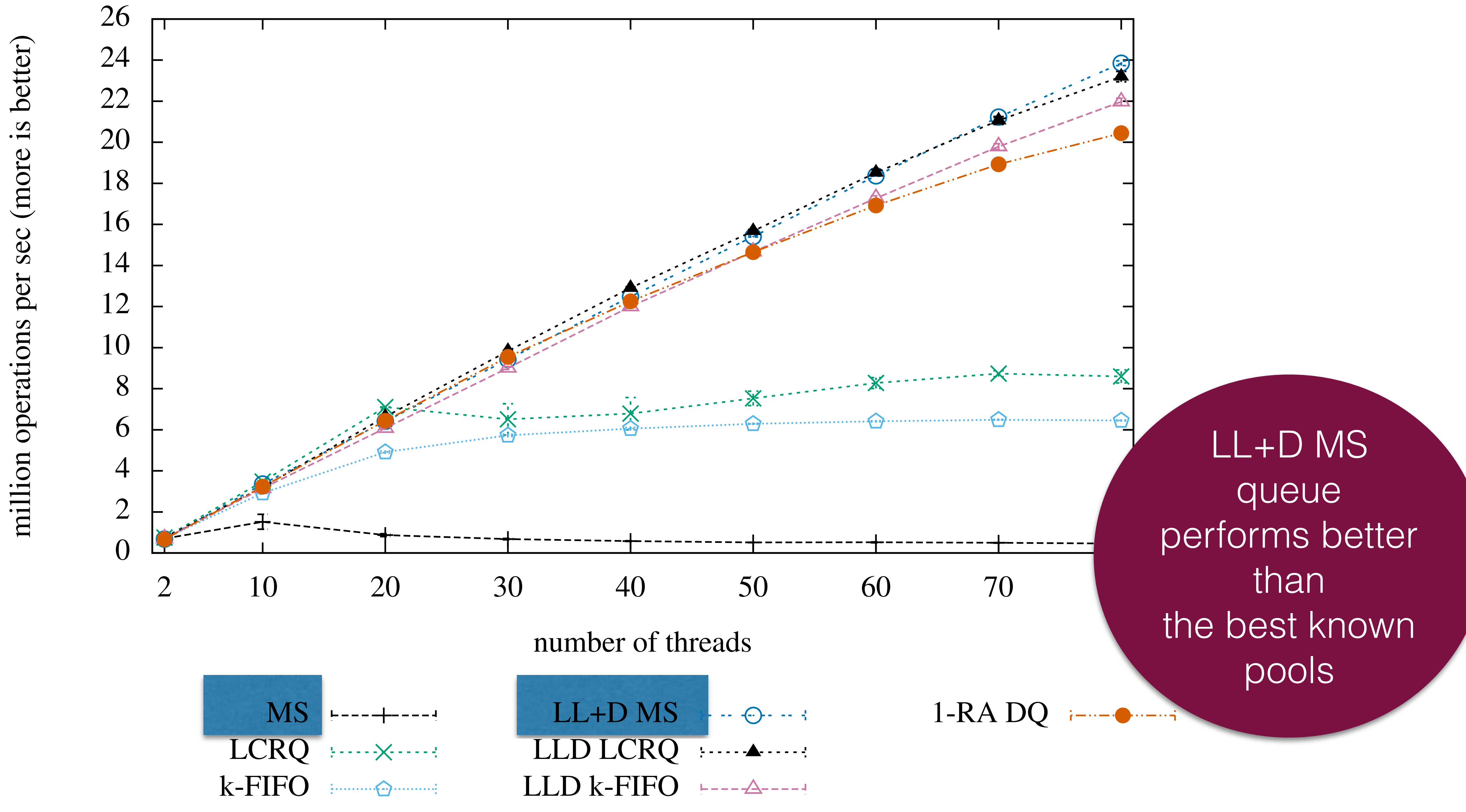
LL+D MS queue performs significantly better than MS queue

Performance



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

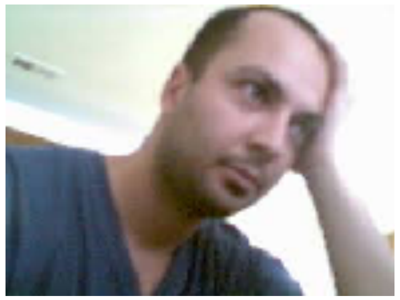
Performance



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

Thank You!

and many thanks to my dear coauthors



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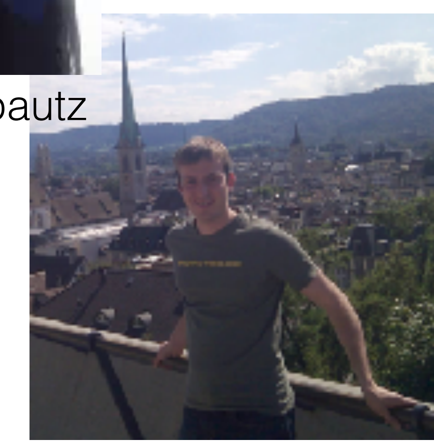

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