Relaxed Ordered Data Structures: Faster and Better

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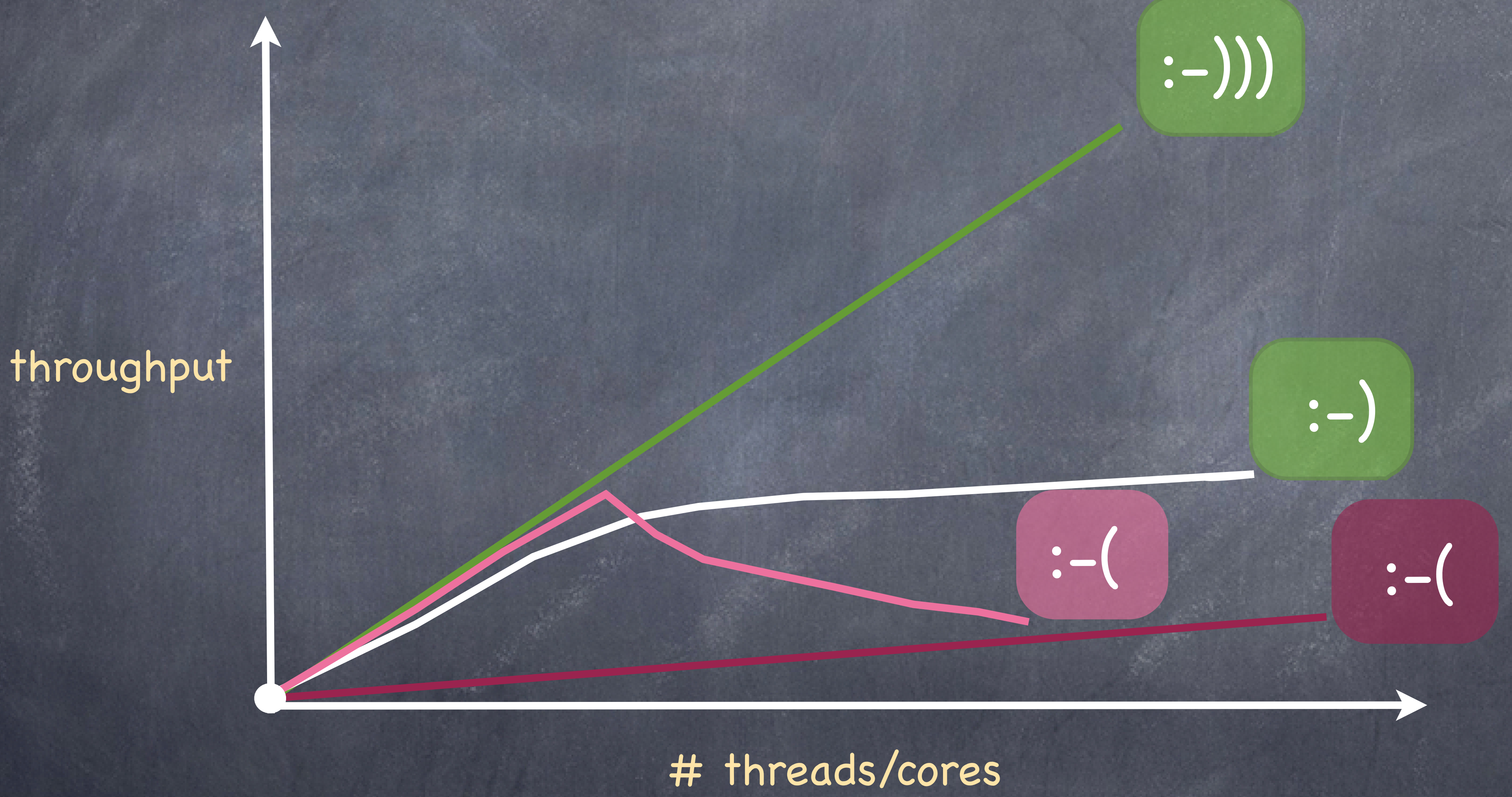
Concurrency Yak 21.1.2013

Performance and scalability



Semantics of concurrent data structures

- Sequential specification - set of legal sequences
- Correctness condition - linearizability

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Stack - legal sequence

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

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begin-push(a)begin-push(b) end-push(a) end-push(b)begin-pop(b)end-pop(b)

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we relax this

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Relaxations (POPL, Thursday)

- May trade correctness for performance
- In a controlled way with quantitative bounds

measure the error from correct behavior

Relaxations (POPL, Thursday)

Stack - incorrect behavior

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

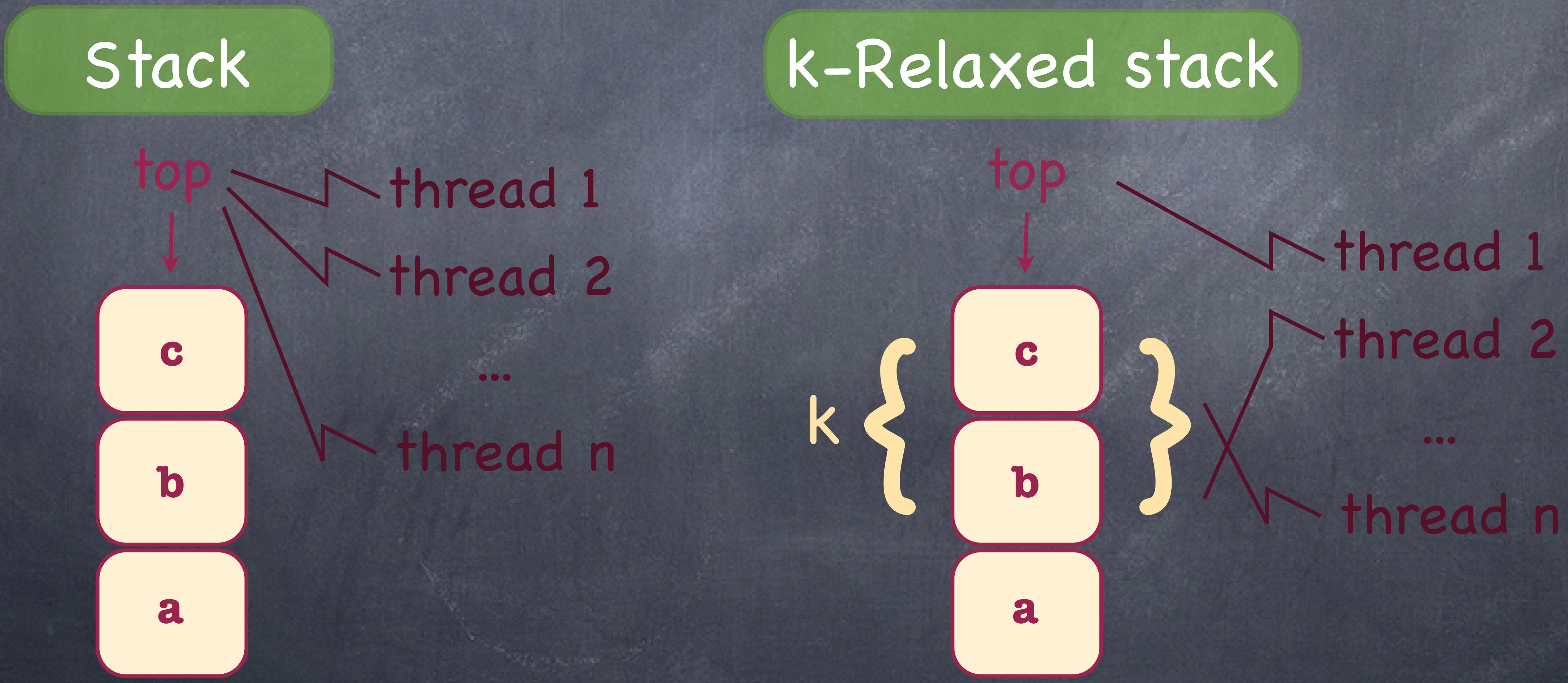
- May trade correctness for performance
- In a controlled way with quantitative bounds

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

measure the error from correct behavior

Why relax?

- It is interesting
- Provides potential for better performing concurrent implementations



What we have (POPL)

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

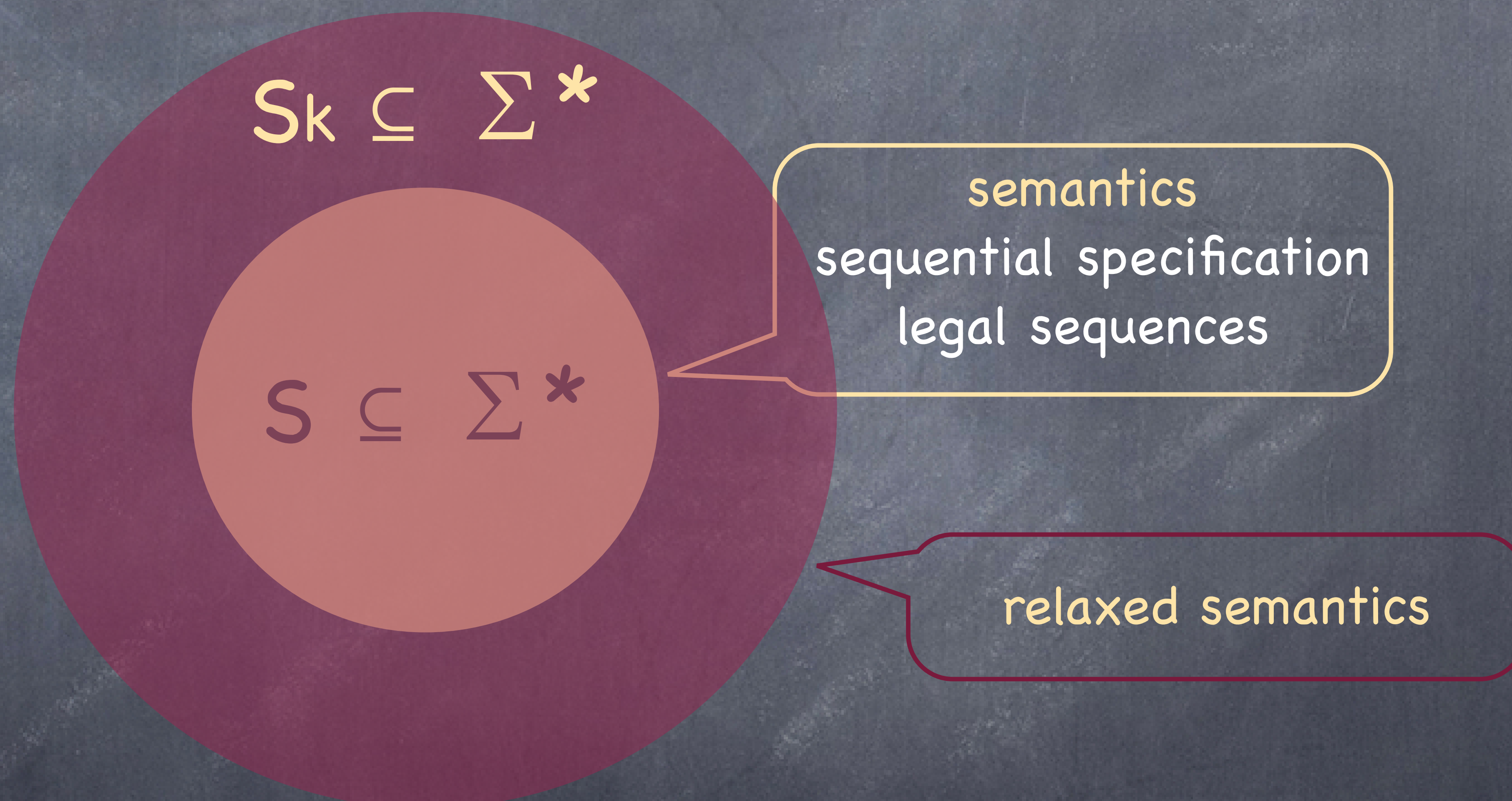
The big picture, briefly

$S \subseteq \Sigma^*$

semantics
sequential specification
legal sequences

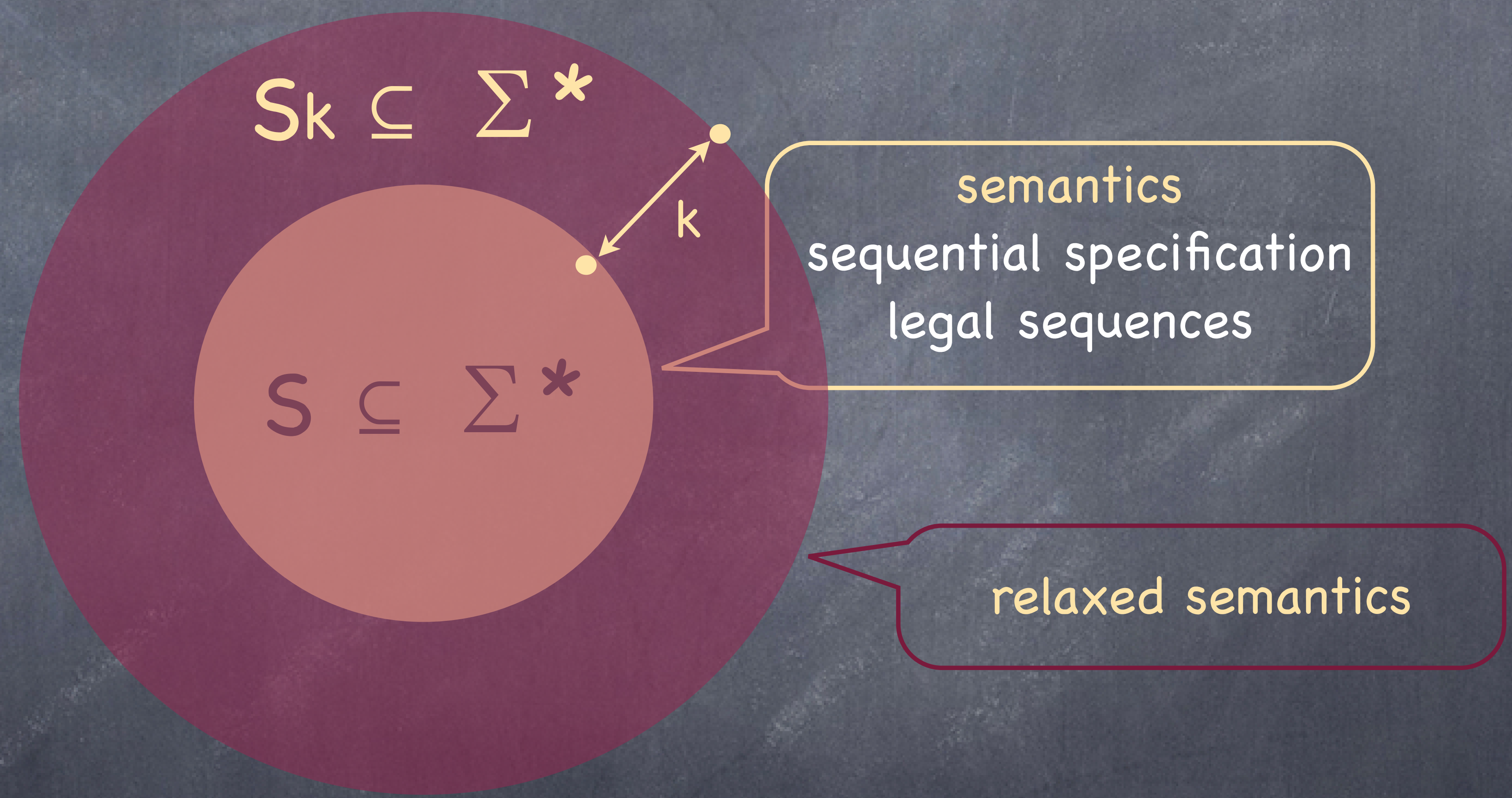
Σ - methods with arguments

The big picture, briefly



Σ - methods with arguments

The big picture, briefly



Σ - methods with arguments

distance!

Out-of-order relaxation

... is a natural concrete one

Stack

Each **pop** pops one of the (k+1)-youngest elements

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Queue

Each **deq** deques one of the (k+1)-youngest elements

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k-out-of-order relaxation

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Each **pop** pops one of the (k+1)-youngest elements

k-out-of-order relaxation

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What is the distance?

Syntactic distances do not help

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

is a 1-out-of-order stack sequence

Spoiler --- more about it on Thursday!

its permutation distance is min(n,m)

Framework for semantic distances (POPL)

- Identify states, build LTS(S)
- Add incorrect transitions with transition costs
- Fix a path cost function

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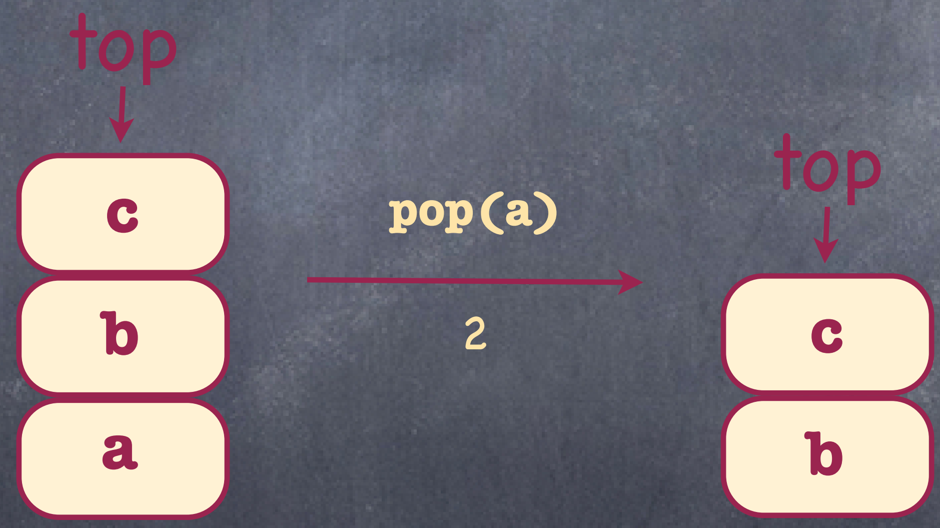
doable in a generic way !!!
(also for out-of-order)

Out-of-order stack

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

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



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

Out-of-order queue

Sequence of **enq**'s with no matching **deq**

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

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

How useful are these relaxations?

Performance?

Lessons learned

The way from sequential specification to concurrent implementation is hard

Being relaxed not necessarily means better performance

Well-performing implementations of relaxed specifications do exist!

Our current interests

- Study applicability

- Learn from efficient implementations

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which applications tolerate relaxation ?

maybe there is nothing to tolerate!

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towards synthesis

lock-free universal construction ?

Observed non-determinism

enq(a)

t1

t2

t3

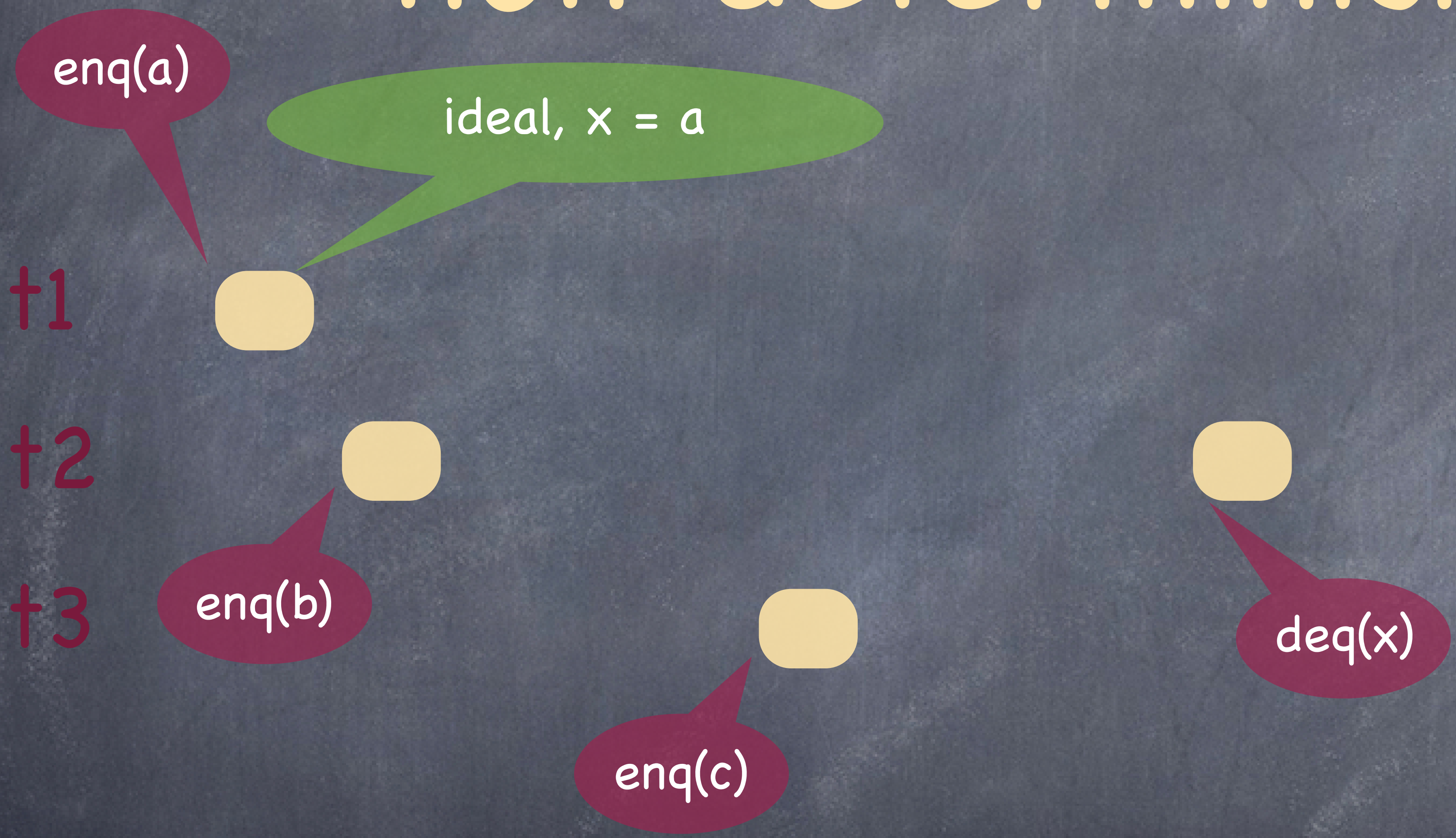
enq(b)

deq(x)

enq(c)

Input sequence: enq(a)enq(b)enq(c)deq(x)

Observed non-determinism



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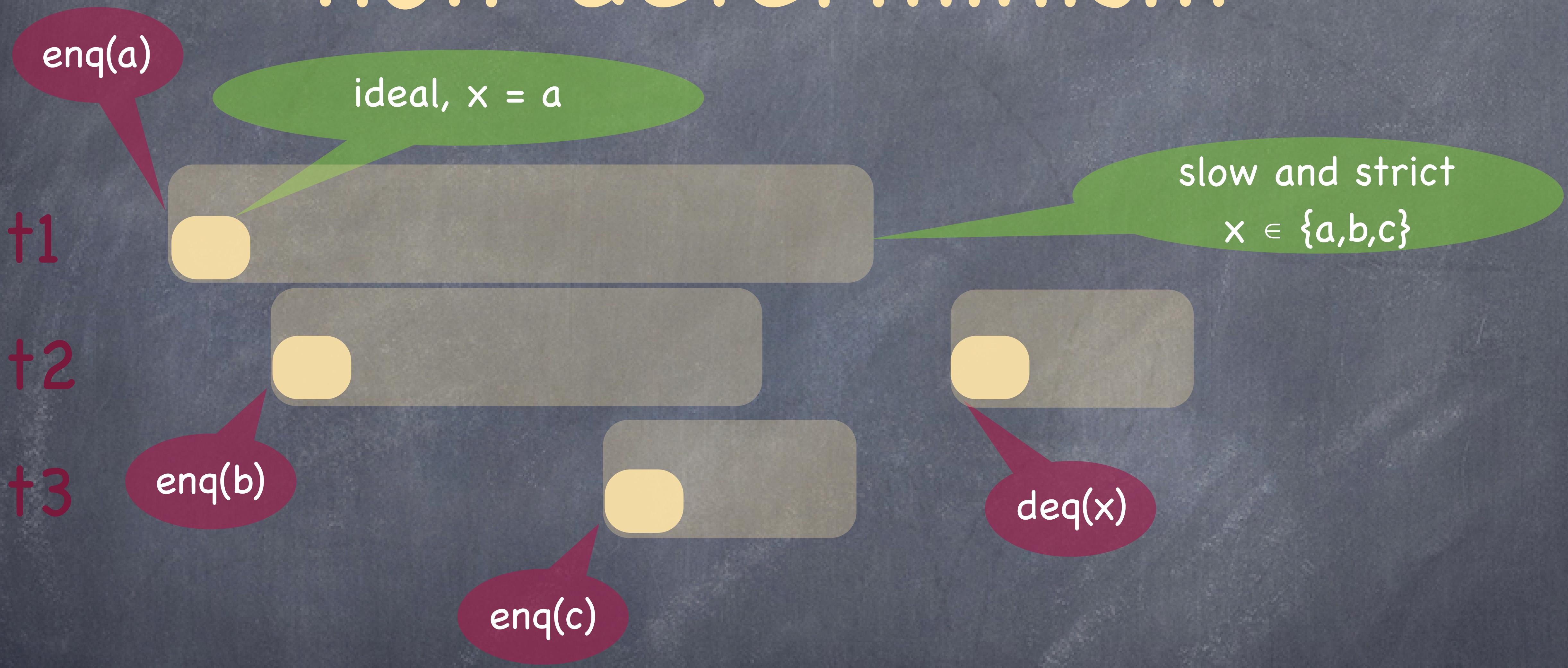

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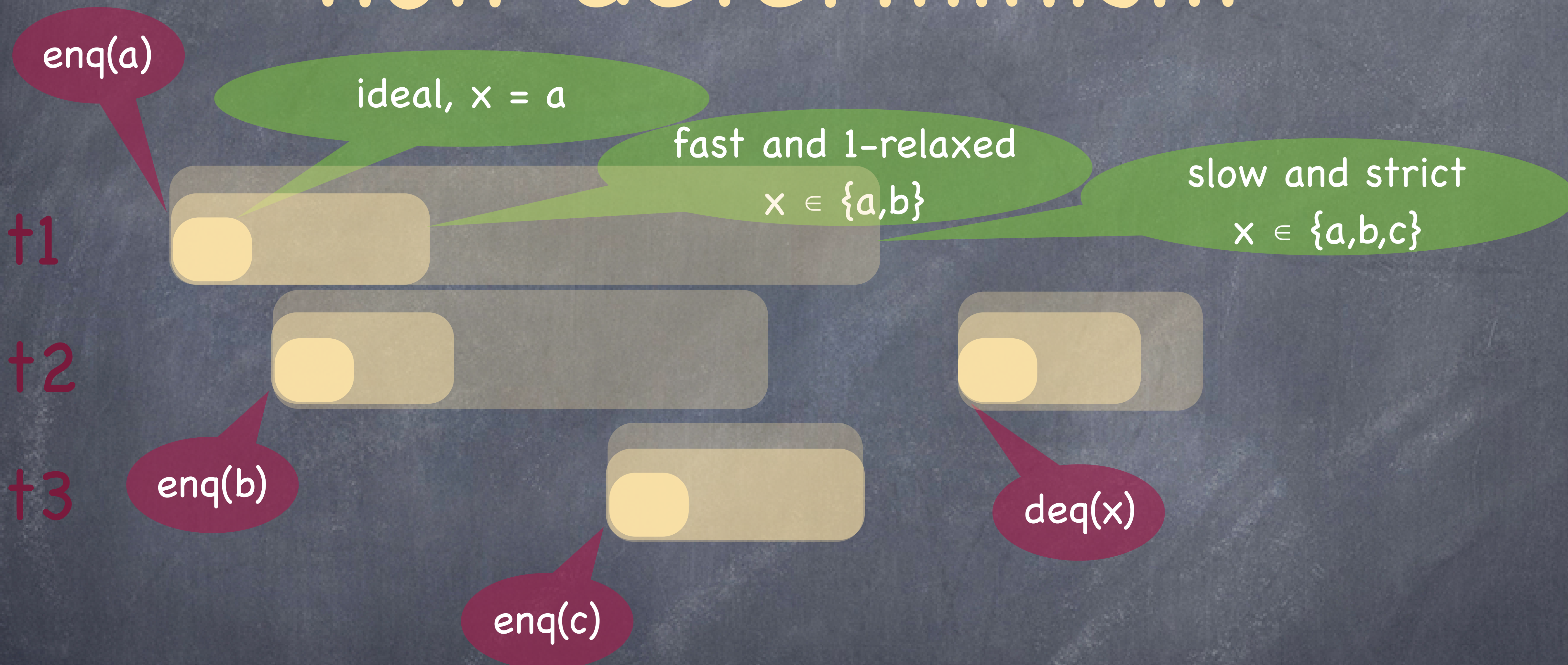

Input sequence: enq(a)enq(b)enq(c)deq(x)

Observed non-determinism

Two reasons

- Relaxation (the more relaxed, the more...)
- Linearizability (the slower, the more...)

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Connection between relaxation and performance

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Connection between relaxation and performance

What is it really?
Measure for performance?

Relaxation vs. performance

Performance index
(of a concurrent history)
= number of overlaps

Fixed input sequence w

R: $\mathbb{N} \longrightarrow \mathbb{N}$

R(n) = min k s.t. a linearization of a concurrent history with input w and performance index n is in S_k

P: $\mathbb{N} \longrightarrow \mathbb{N}$

P(k) = min n s.t. a linearization of a concurrent history with input w and performance index n is in S_k

R vs. P graph

Fixed input sequence w

$\{(n, R(n) \mid n \in \mathbb{N}\} \cup \{(P(k), k) \mid k \in \mathbb{N}\}$

R vs. P graph

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R vs. P graph

Fixed input sequence w

One of P or R is sufficient for the P vs. R graph

$R(n) = \min \{k \mid P(k) \leq n\}$

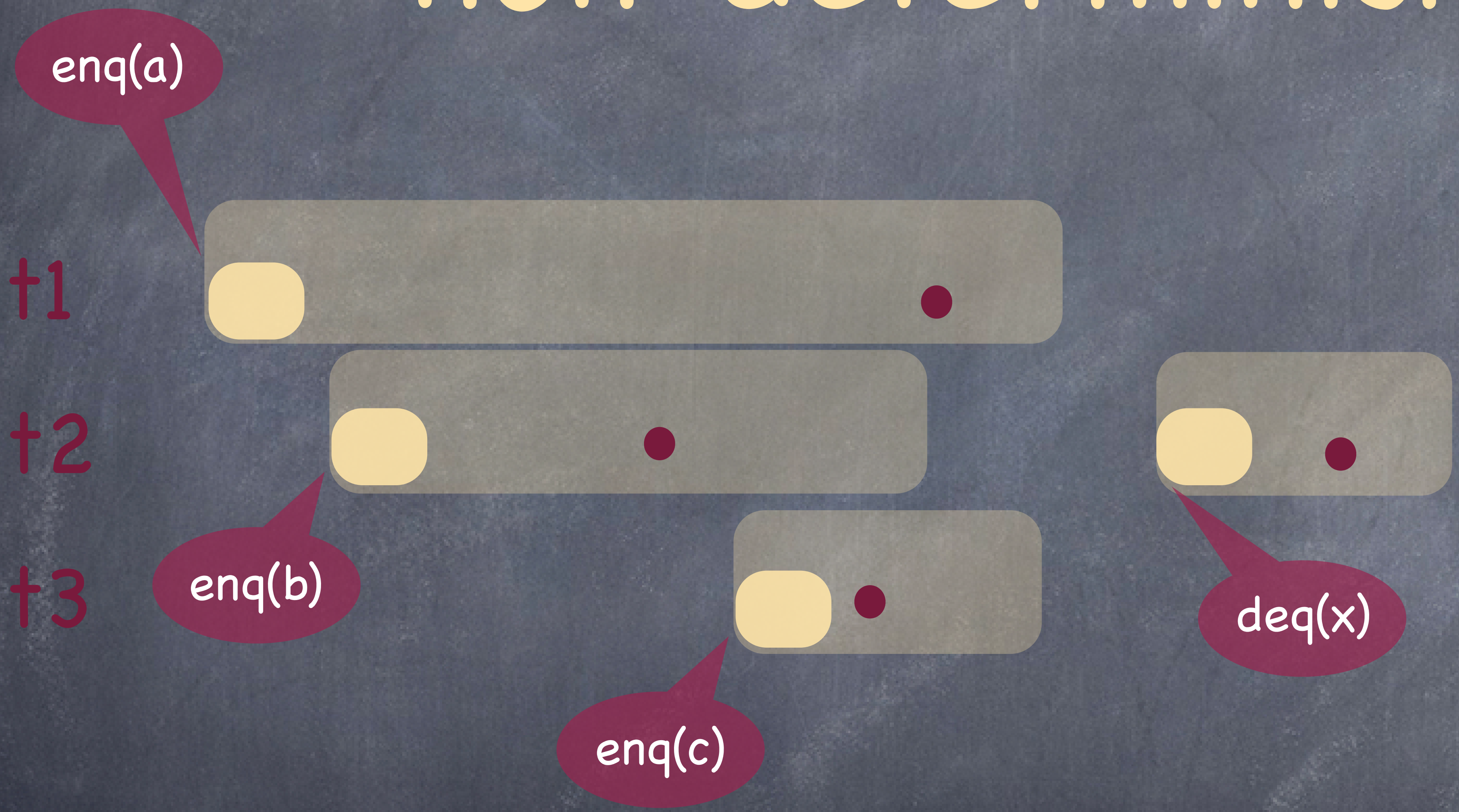
$P(k) = \min \{n \mid R(n) \leq k\}$

Back to measuring observed non-determinism

Implementations around...

- SCAL queues [KPRS'11]
- Quasi linearizability (SQ, RDQ) theory and implementations [AKY'10]
- Some straightforward implementations [HKPSS'12]
- Efficient lock-free segment queue k-FIFO [KLP'12]
- Efficient lock-free segment stack k-Stack [POPL]
- Efficient distributed queues DQ (relatives to SCAL)

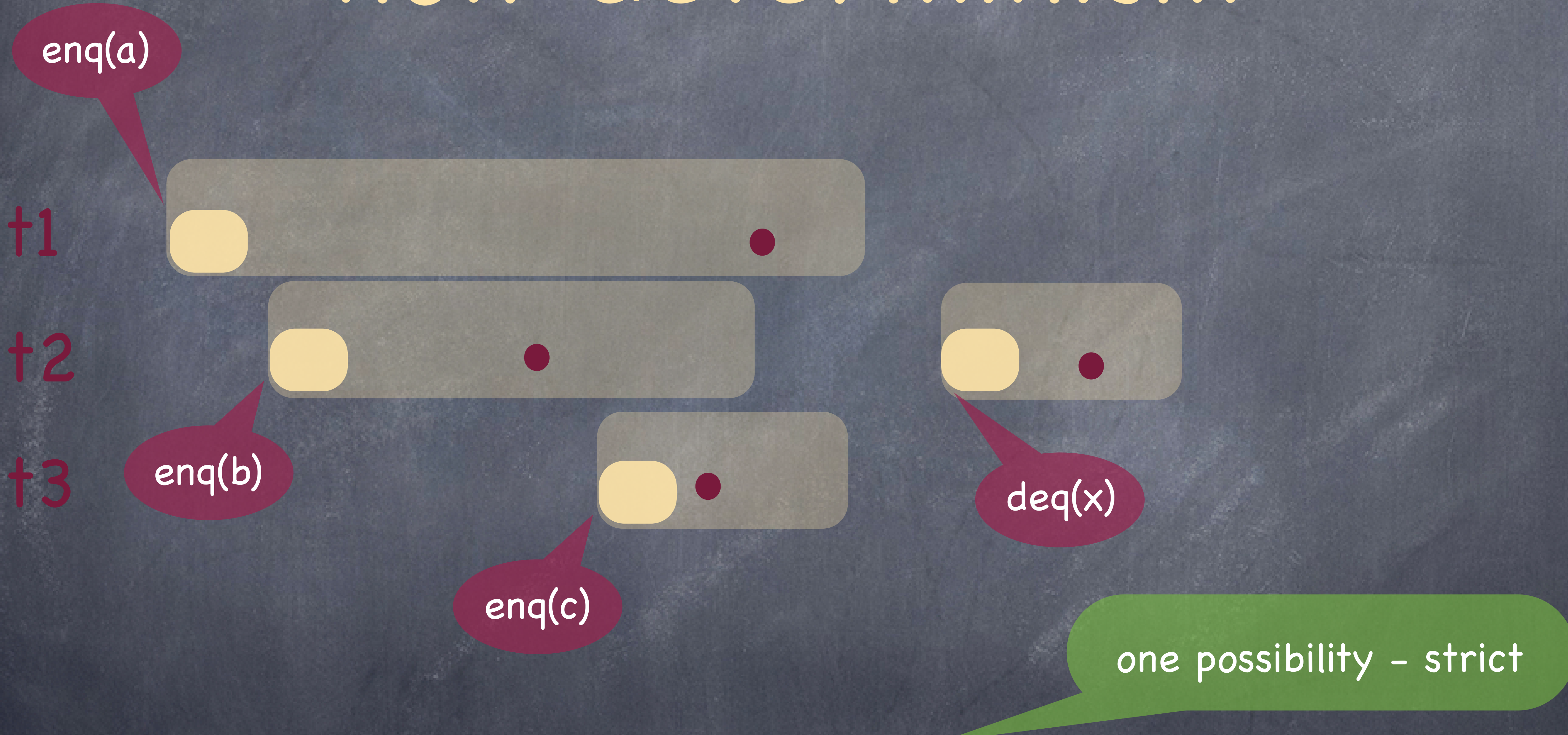
Back to measuring observed non-determinism



Actual-time sequence: enq(b)enq(c)enq(a)deq(b)

Zero-time sequence: enq(a)enq(b)enq(c)deq(b)

Back to measuring observed non-determinism



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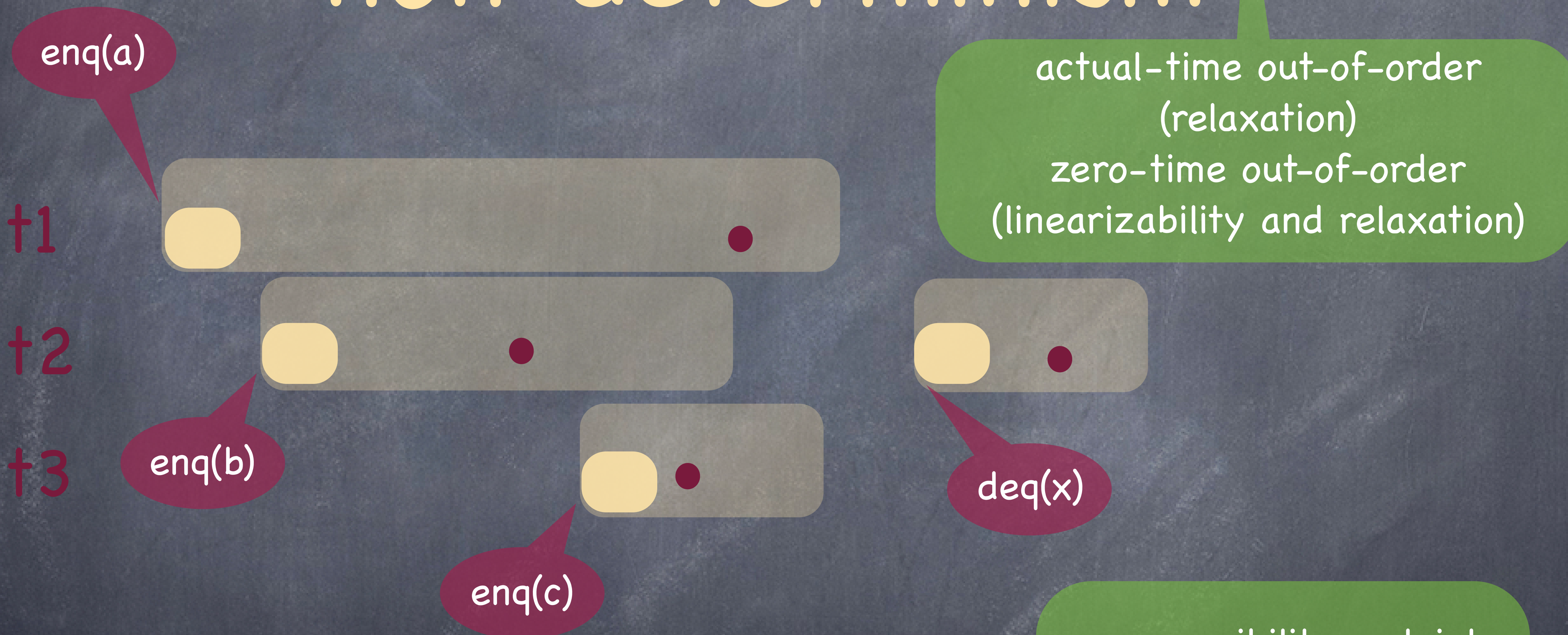

one possibility - strict

Actual-time sequence: enq(b)enq(c)enq(a)deq(b)

Zero-time sequence: enq(a)enq(b)enq(c)deq(b)

The experiments look good

- Relaxed efficient implementations perform/scale well (also better than pools)
  DQs are the best
- Performance index is a reasonable indicator of performance
- All show comparable observed non-determinism (also strict implementations)

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THANK YOU

Any real applications that use concurrent queues / stacks ?