Concurrent Data Structures

Semantics and Quantitative Relaxations

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Semantics of sequential data structures

e.g. pools, queues, stacks

- Sequential specification - set of legal sequences

Stack - legal sequence

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

Semantics of concurrent data structures

Stack - legal sequence

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

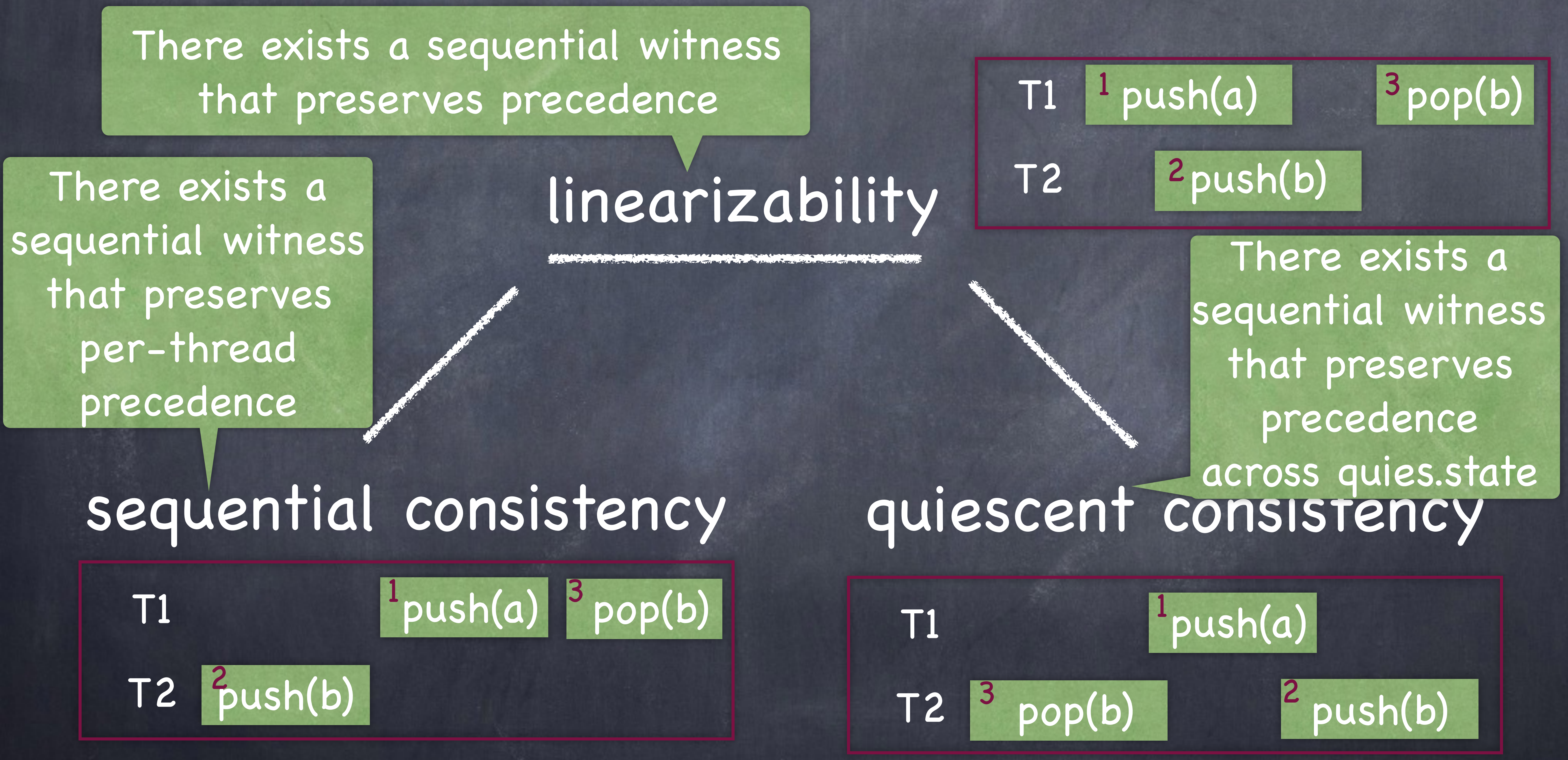
- Sequential specification - set of legal sequences
- Consistency condition - e.g. linearizability

linearizable wrt seq.spec.

Stack - concurrent history

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

Consistency conditions



There exists a sequential witness that preserves precedence

linearizability

T1 [1] push(a) [3] pop(b)

T2 [2] push(b)

There exists a sequential witness that preserves per-thread precedence

sequential consistency

T1 [1] push(a) [3] pop(b)

T2 [2] push(b)

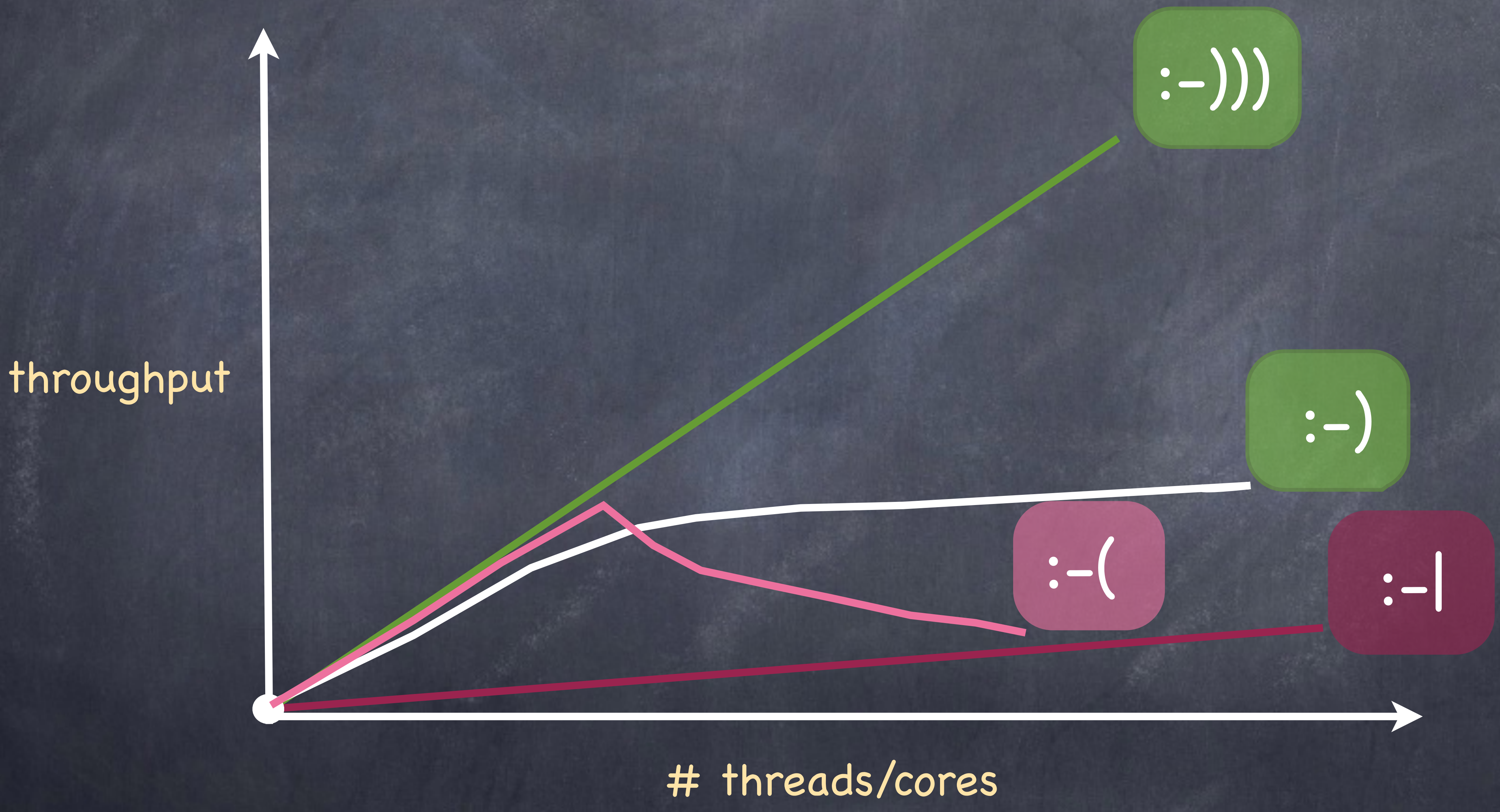
There exists a sequential witness that preserves precedence across quies.state

quiescent consistency

T1 [1] push(a)

T2 [3] pop(b) [2] push(b)

Performance and scalability



Relaxations allow

Stack - incorrect behavior

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

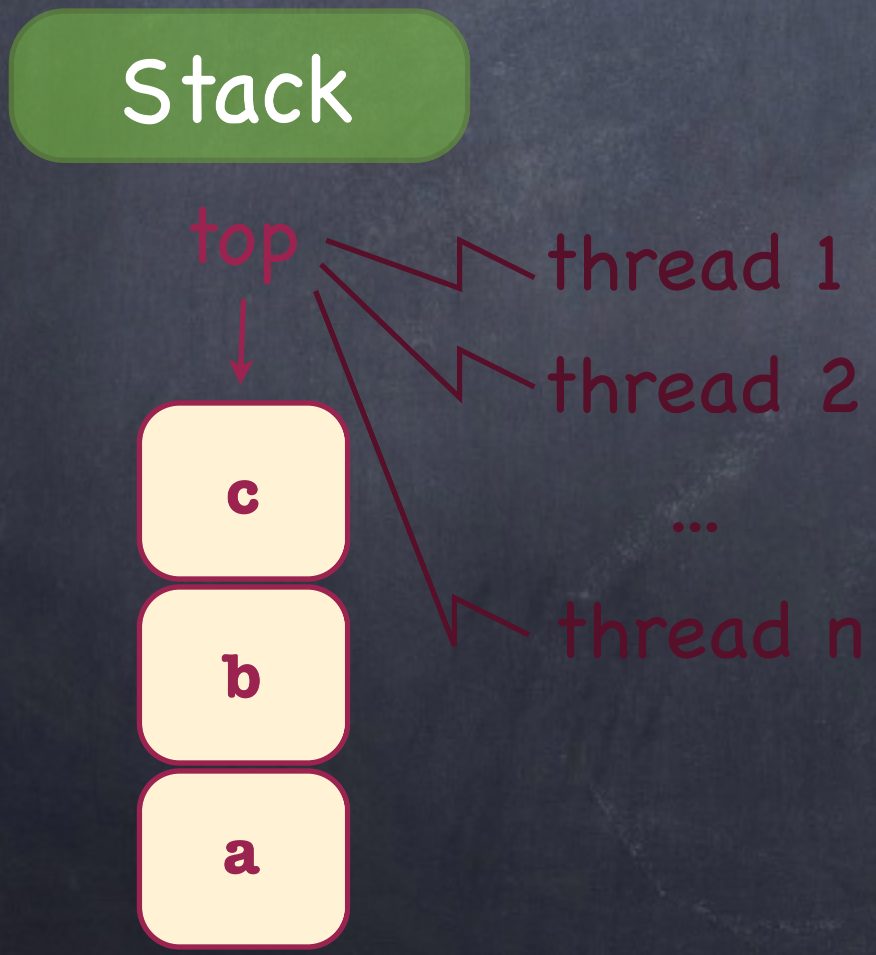
- Trading correctness for performance
- In a controlled way with quantitative bounds

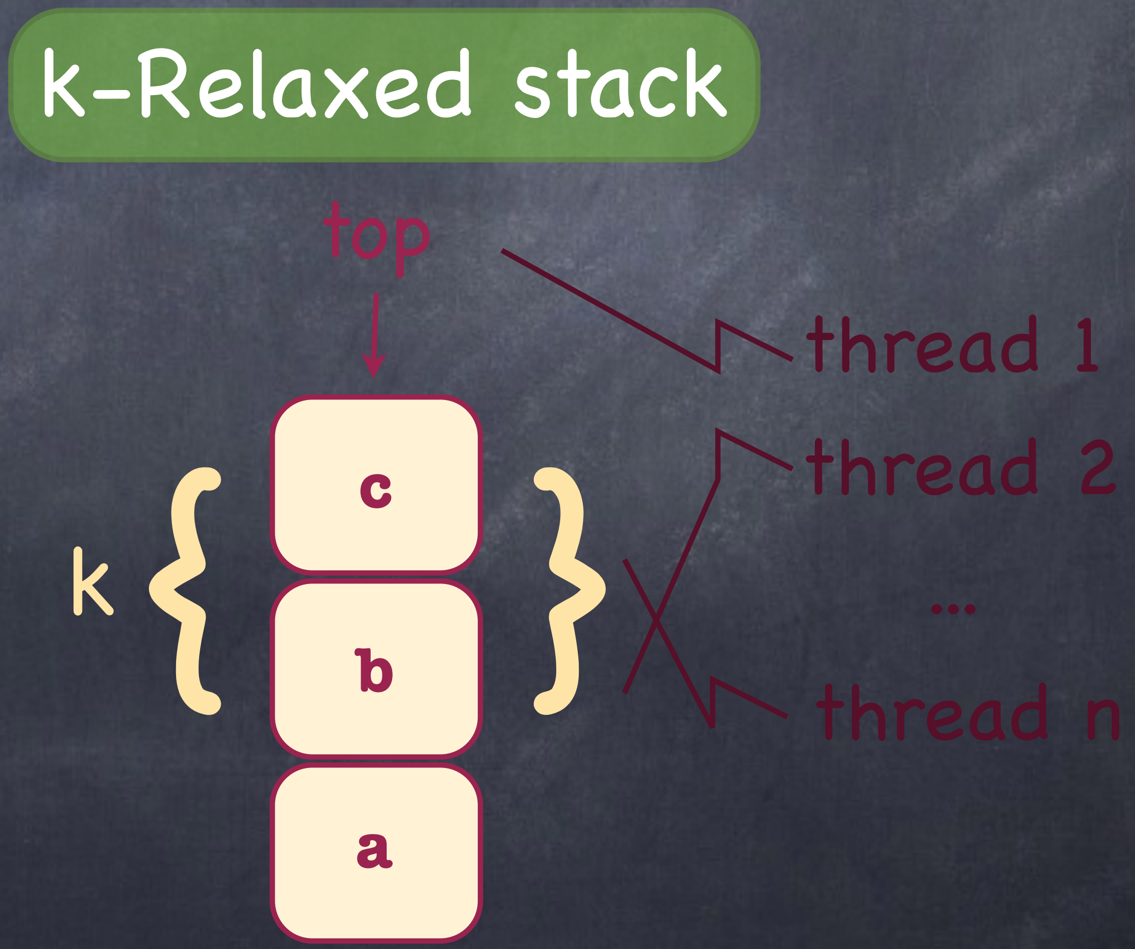
correct in a relaxed stack
... 2-relaxed? 3-relaxed?

measure the error from correct behavior

Why relax?

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





Relaxations of concurrent data structures

Quantitative relaxations
Henzinger, Kirsch, Payer, Sezgin, S.
POPL 2013

- Sequential specification - set of legal sequences
- Consistency condition - e.g. linearizability

(Quantitative) relaxations
Dodds, Sezgin, S.
work in progress

What we have

- Framework

  for semantic relaxations

- Generic examples

  out-of-order / stuttering

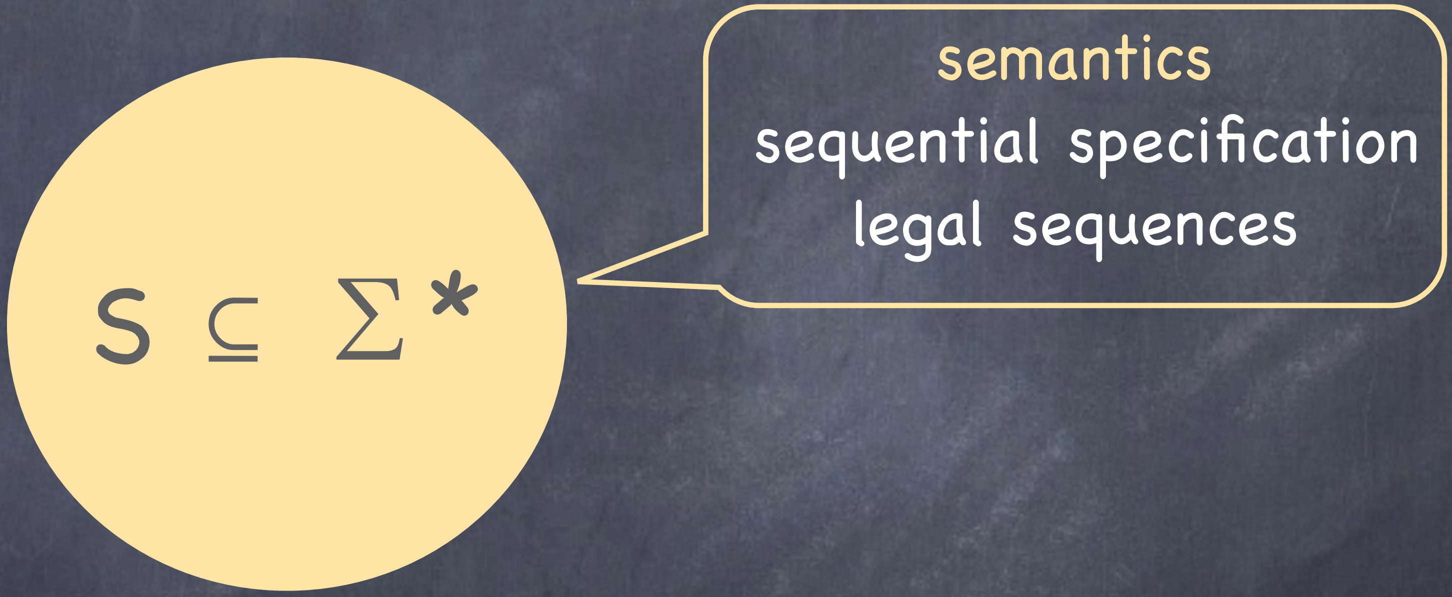
- Concrete relaxation examples

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

- Efficient concurrent implementations

  of relaxation instances

The big picture

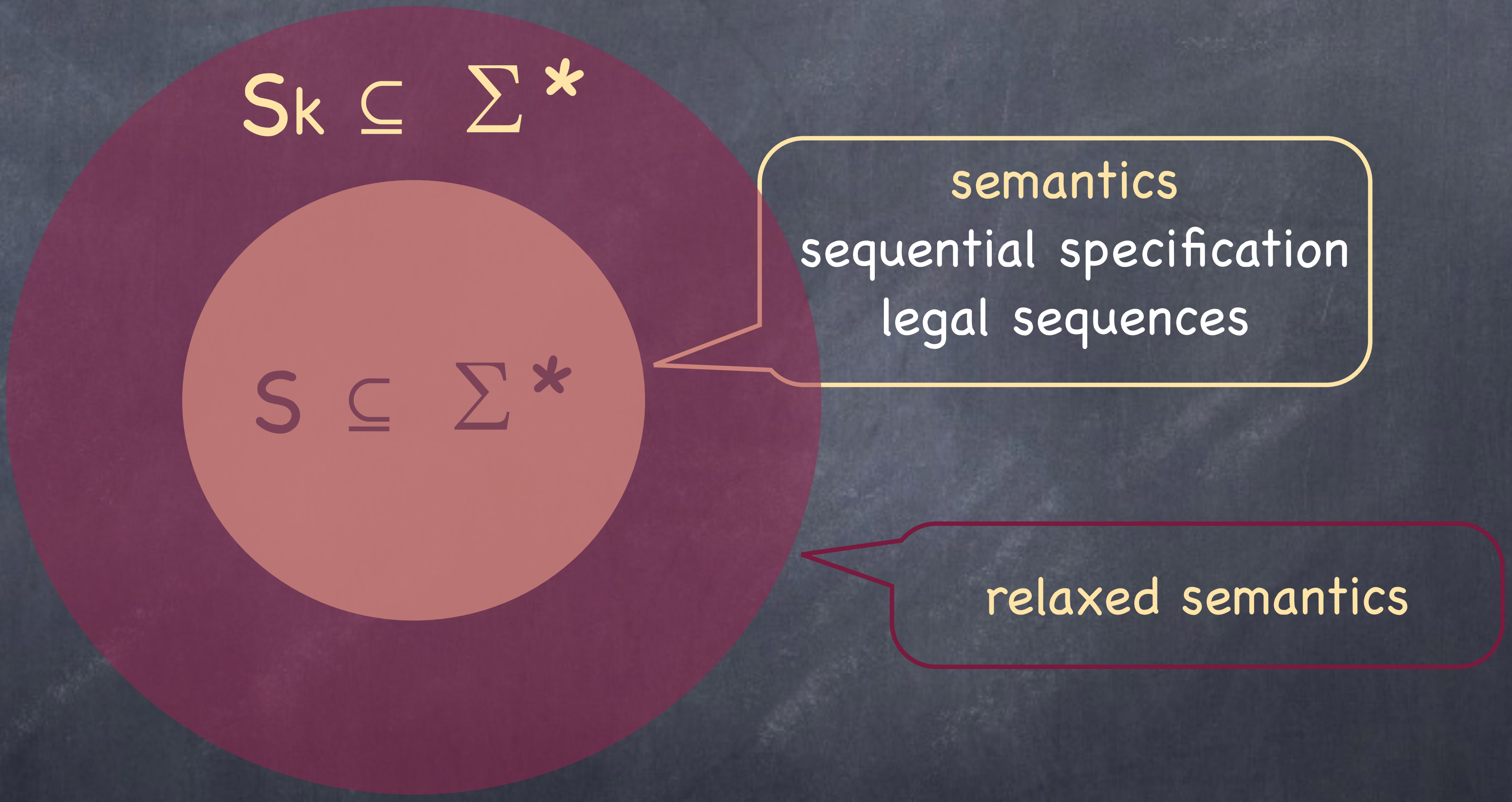


$S \subseteq \Sigma^*$

semantics
sequential specification
legal sequences

Σ - methods with arguments

The big picture



$S_k \subseteq \Sigma^*$

$S \subseteq \Sigma^*$

semantics
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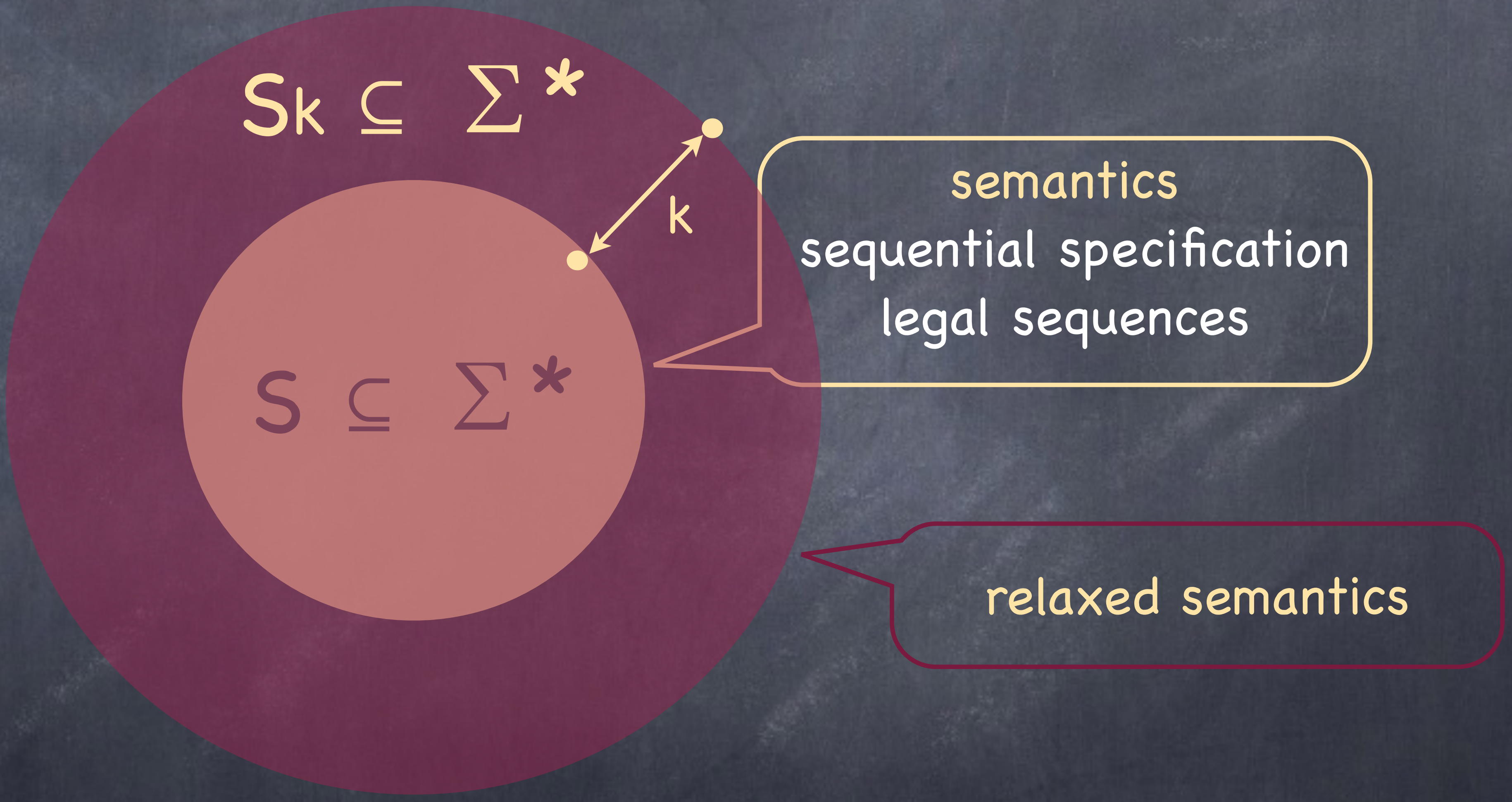
relaxed semantics

Σ - methods with arguments

The big picture



semantics
sequential specification
legal sequences

relaxed semantics

Σ - methods with arguments

distance?

Challenge

There are natural concrete relaxations...

Stack

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

Each **push** pushes .....

k-out-of-order relaxation

Challenge

There are natural concrete relaxations...

Stack

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

Each **push** pushes .....

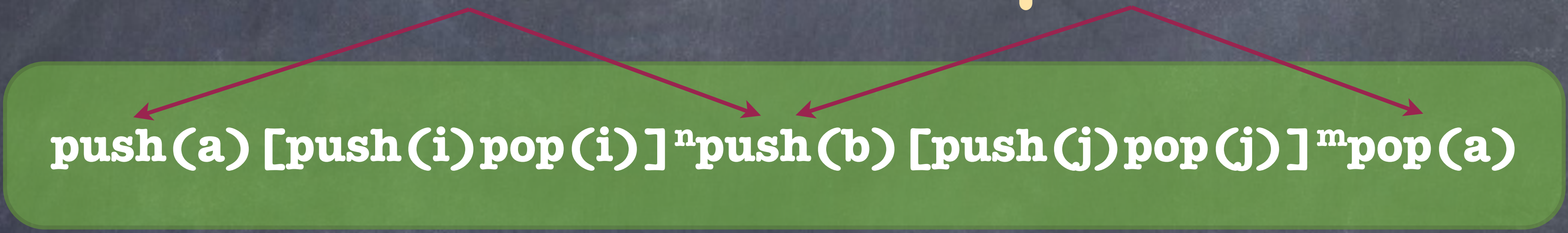
k-out-of-order relaxation

makes sense also for queues, priority queues, ...

How is it reflected by a distance between sequences?

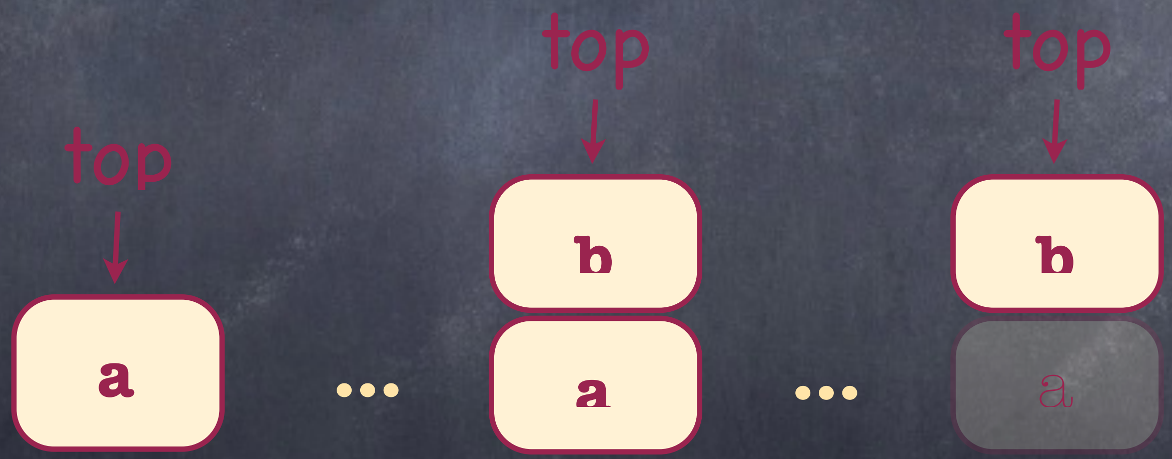
one distance for all?

Syntactic distances do not help



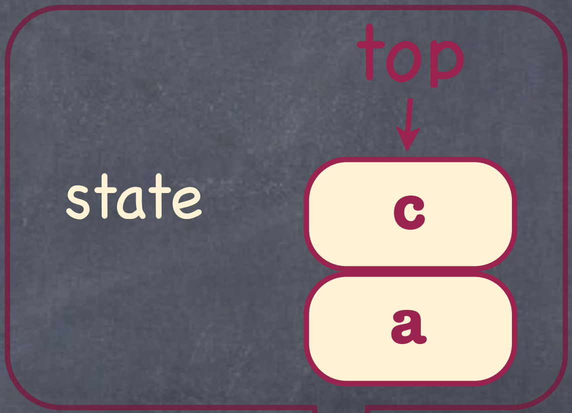
$\mathbf{push(a)[push(i)pop(i)]^{n}push(b)[push(j)pop(j)]^{m}pop(a)}$

is a 1-out-of-order stack sequence



its permutation distance is min(n,m)

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 if they have an indistinguishable future

$$\mathbf{x} \equiv \mathbf{y} \iff \forall \mathbf{u} \in \mathbf{\Sigma}^*. (\mathbf{xu} \in \mathbf{S} \iff \mathbf{yu} \in \mathbf{S})$$

Semantics goes operational

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

states

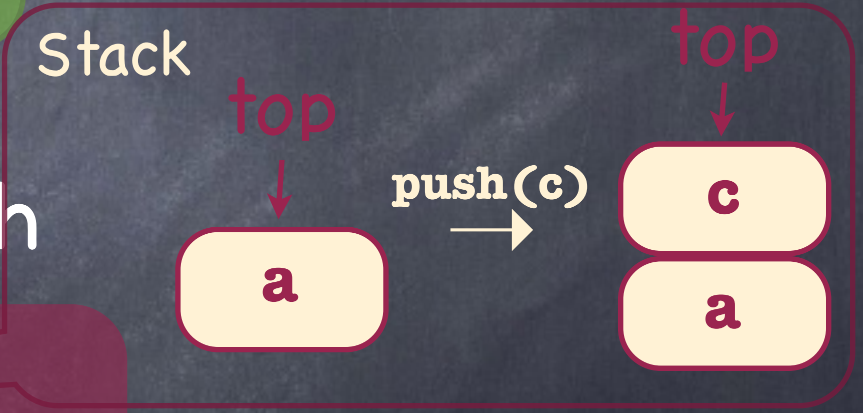
labels

initial state

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

transition relation

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



The framework

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

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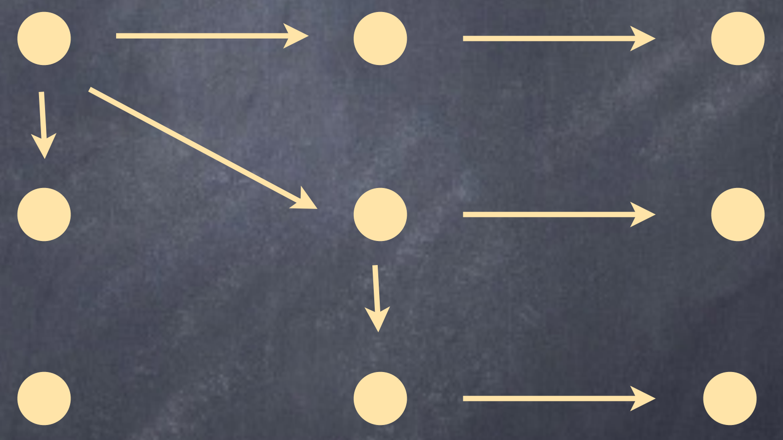
Σ - singleton



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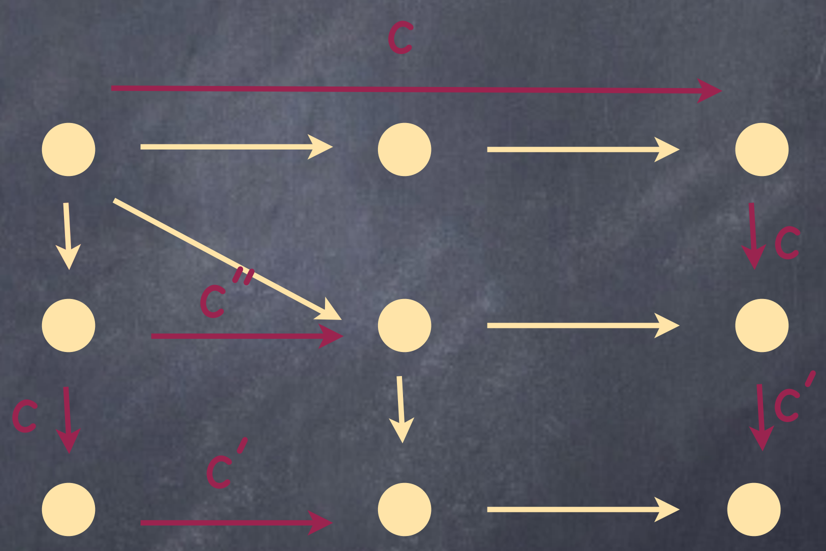

The framework

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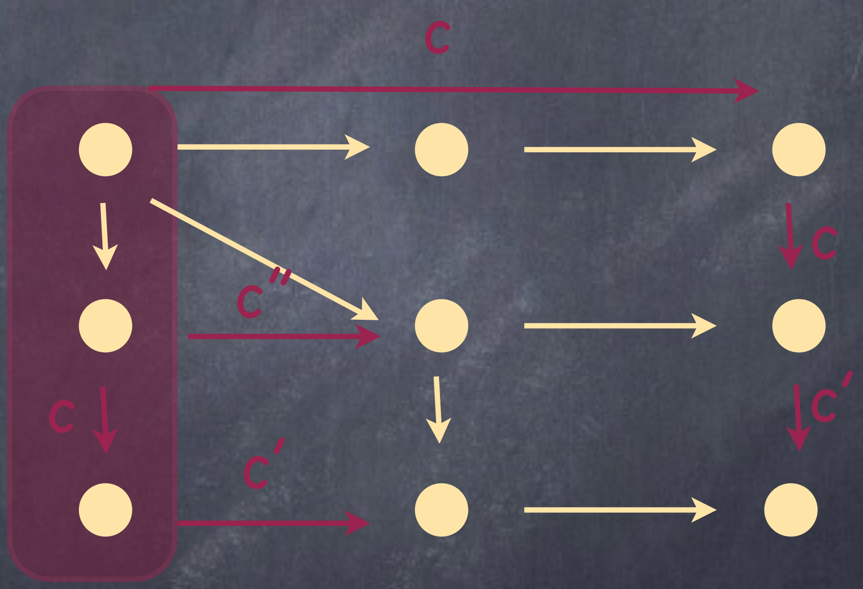
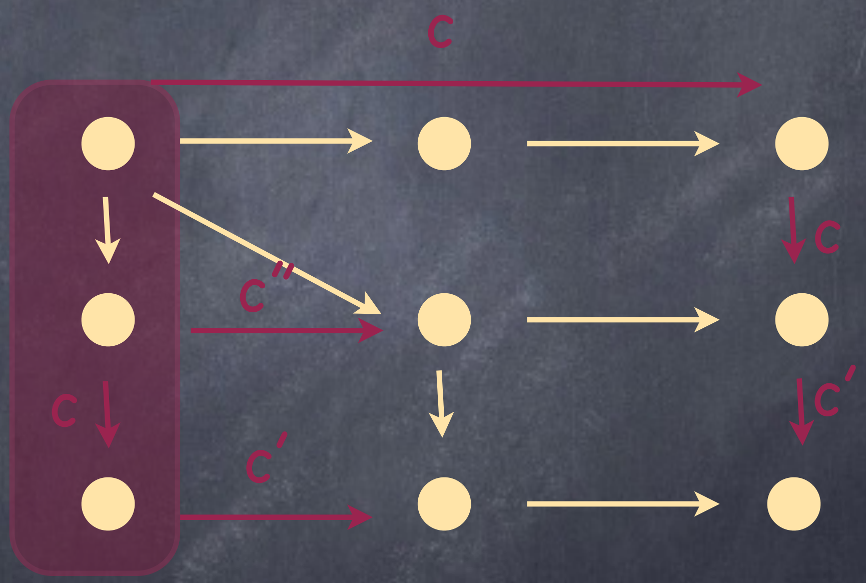


The framework

- Start from LTS(S)
- Add transitions with transition costs



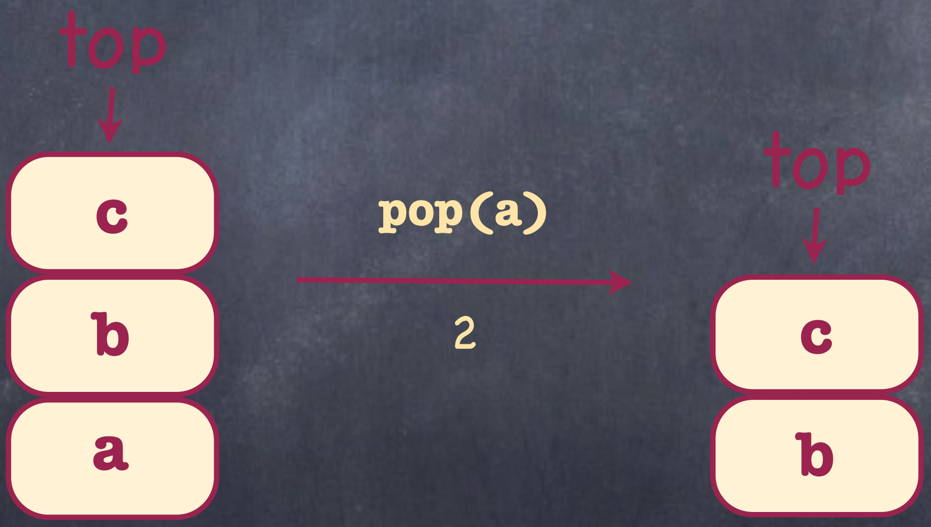
- Fix a path cost function

distance - minimal cost on all paths labelled by the sequence

Out-of-order stack

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

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



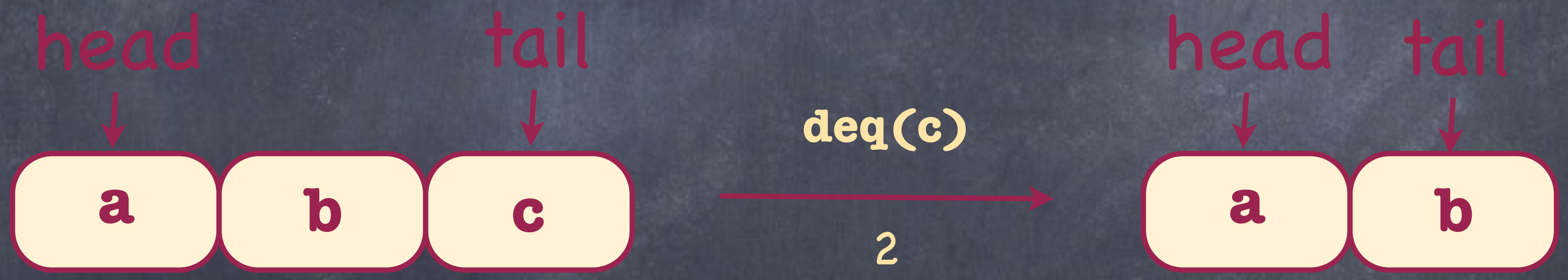
- Possible path cost functions max, sum,...

also more advanced

Out-of-order queue

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

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



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

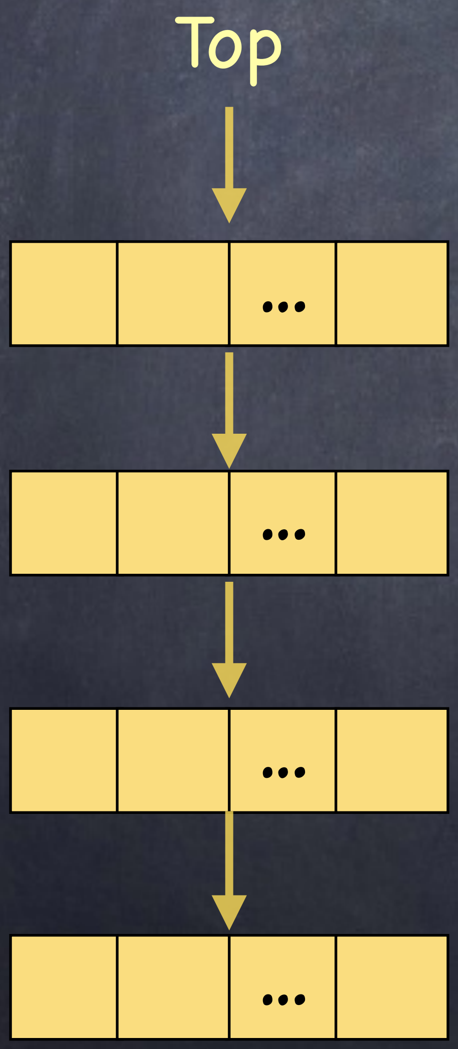
also more advanced

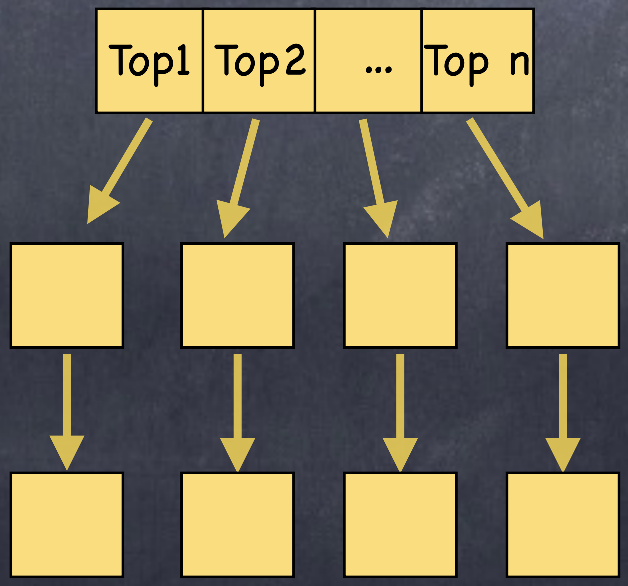
Implementations and Performance

Relaxed implementations

k-Stack
Henzinger, Kirsch, Payer, Sezgin, S.
POPL 2013

Distributed queues / stacks
Haas, Henzinger, Kirsch, Lippautz, Payer, Sezgin, S.
CF 2013

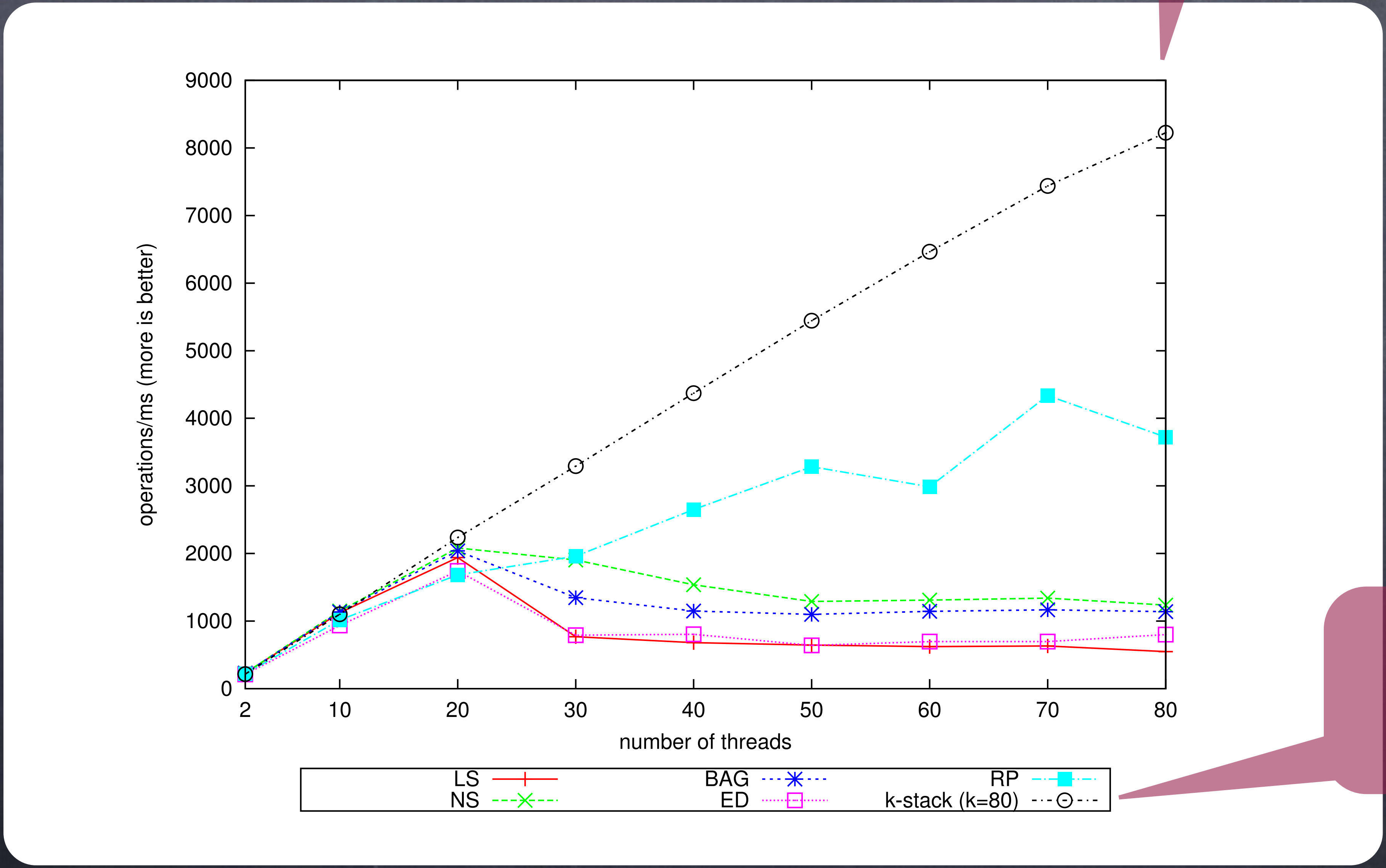




k-Stack

Performance and Scalability comparison

“80”-core machine



lock-free segment stack

Distributed queues

Performance and Scalability comparison

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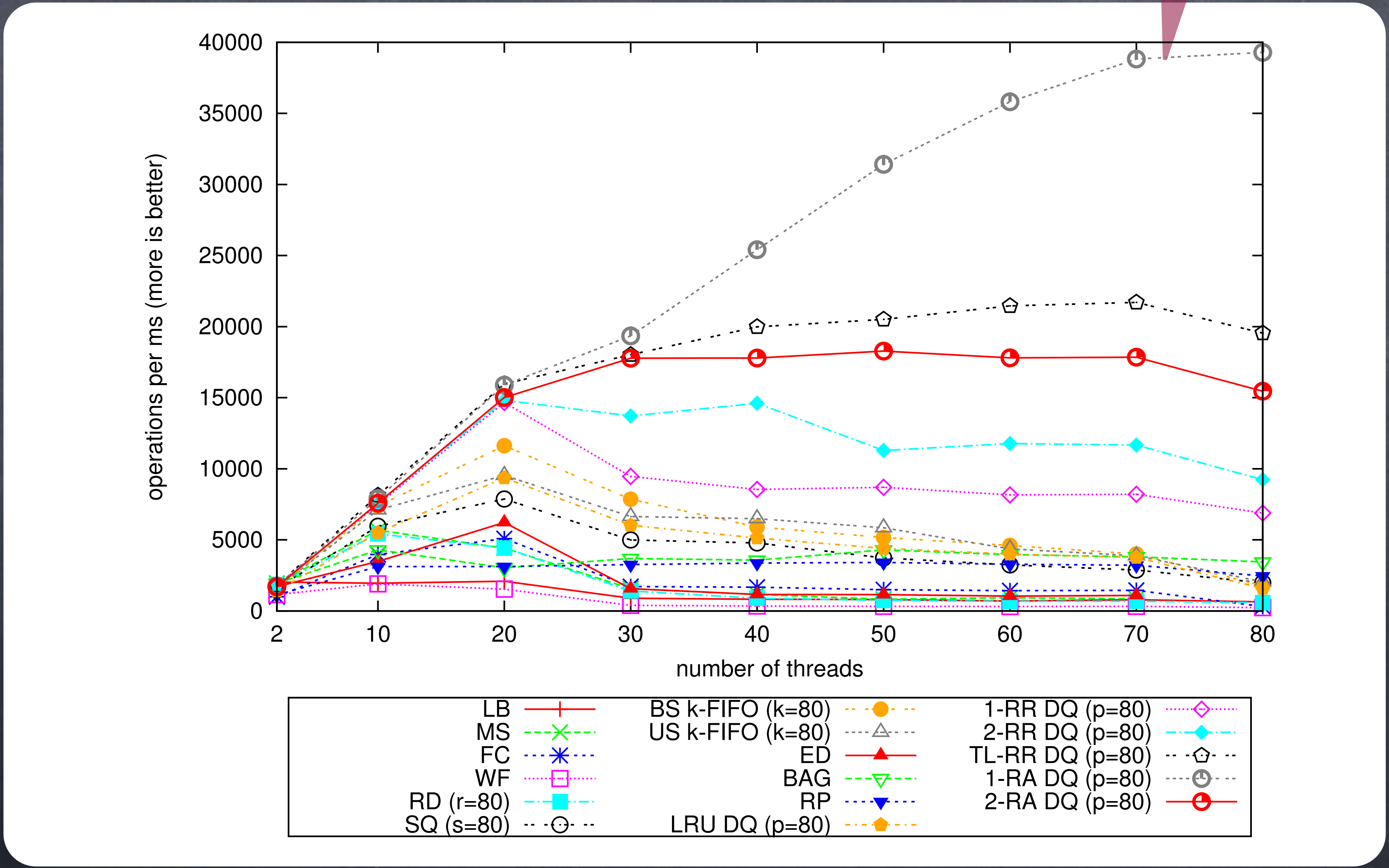
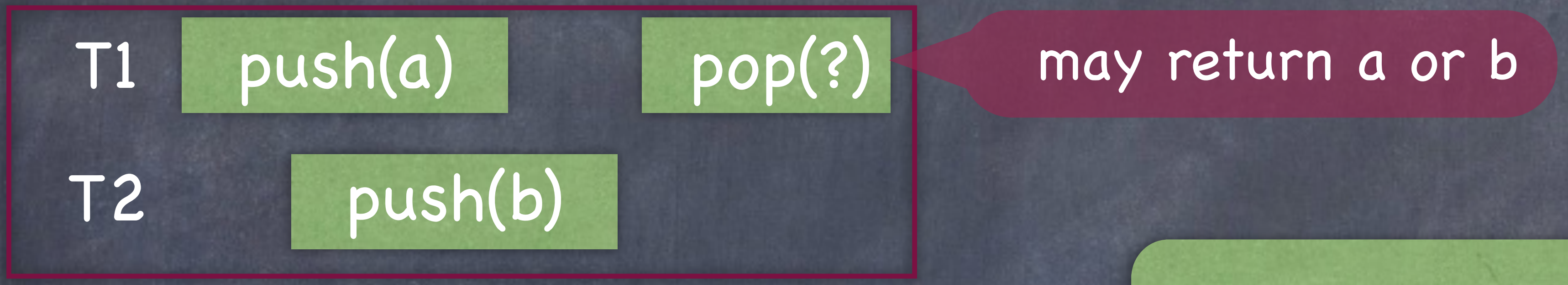
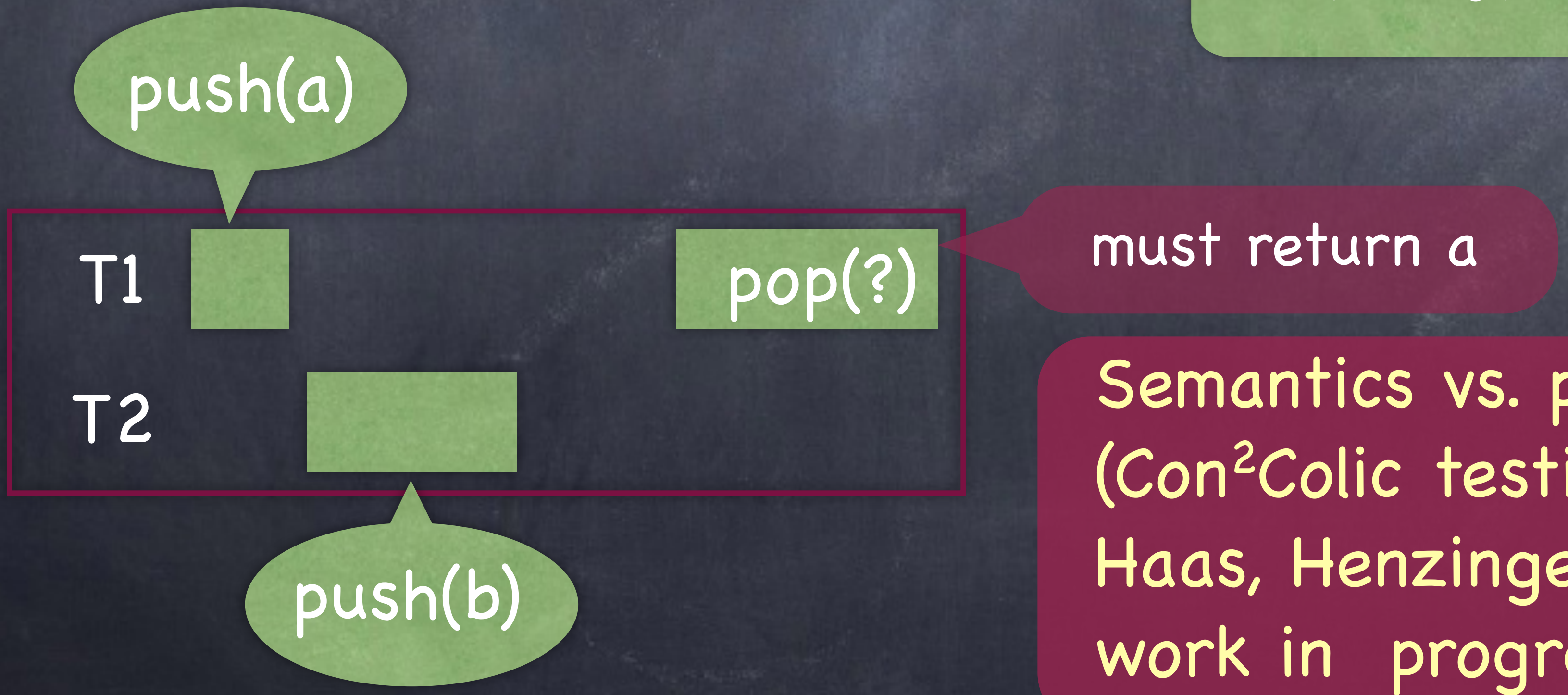


Bad performance also relaxes semantics



The slower the implementation, the more nondeterminism



Semantics vs. performace comparison (Con^{2}Colic testing)
Haas, Henzinger, Holzer, Kirsch, … S.
work in progress