Dual Data Structures. Fast Semaphore.

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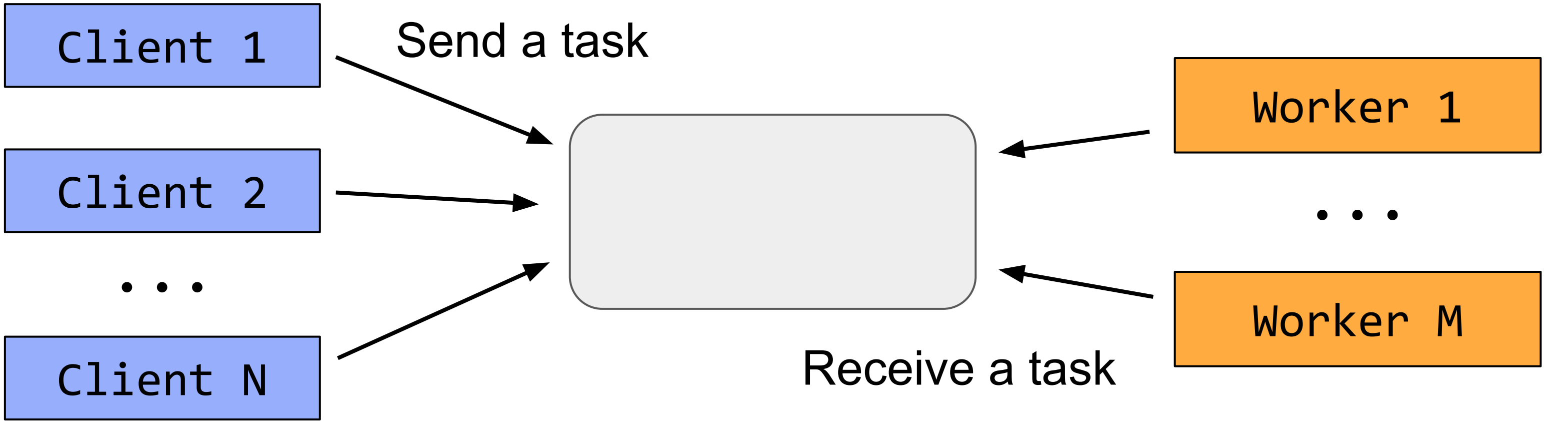
ИТМО, 2019

Dual Data Structures. Synchronous Queues.

Producer-Consumer Problem



Synchronous Queue aka Rendezvous Channel

```
interface SynchronousQueue<E> {
    suspend fun send(element: E)
    suspend fun receive(): E
}
```

Senders and receivers perform a rendezvous handshake as a part of their protocol (senders wait for receivers and vice versa)

Producer-Consumer Problem Solution

1. Let’s create a synchronous queue

```kotlin
val tasks = SynchronousQueue<Task>()
```

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val tasks = SynchronousQueue<Task>()
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2. Clients send tasks to workers through this channel

```
val task = Task(...)
tasks.send(task)
```

Producer-Consumer Problem Solution

1. Let's create a synchronous queue

```
val tasks = SynchronousQueue<Task>()
```

2. Clients send tasks to workers through this channel

```
val task = Task(...)
tasks.send(task)
```

3. Workers receive tasks in an infinite loop

```
while(true) {
    val task = tasks.receive()
    processTask(task)
}
```

Rendezvous Channel Semantics

Client 1

```
val task = Task(...)
tasks.send(task)
```

Client 2

```
val task = Task(...)
tasks.send(task)
```

Worker

```
while(true) {
  val task = tasks.receive()
  processTask(task)
}
```

```
val tasks = SynchronousQueue<Task>()
```

Rendezvous Channel Semantics

Client 1

```
val task = Task(...)
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Client 2

```
val task = Task(...)
tasks.send(task)
```

Have to wait for send

Worker

```
while(true) {
1   val task = tasks.receive()
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val tasks = SynchronousQueue<Task>()
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val task = Task(...)
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```
while(true) {
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Client 1

```
val task = Task(...)
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```

Worker


```
while(true) {
  val task = tasks.receive()
  processTask(task)
}
```

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```
val tasks = SynchronousQueue<Task>()
```

Rendezvous Channel Semantics

Rendezvous!

Client 1

```
val task = Task(...)
tasks.send(task)
```

2

Worker

```
while(true) {
    val task = tasks.receive()
    processTask(task)
}
```

1

Client 2

```
val task = Task(...)
tasks.send(task)
```

```
val tasks = SynchronousQueue<Task>()
```

Rendezvous Channel Semantics

Client 1

```
  val task = Task(...)
2 tasks.send(task)
```

Client 2

```
val task = Task(...)
tasks.send(task)
```

Worker

```
  while(true) {
1   val task = tasks.receive()
3   processTask(task)
  }
```

```
val tasks = SynchronousQueue<Task>()
```

Rendezvous Channel Semantics

Client 1

```
  val task = Task(...)
2 tasks.send(task)
```

Worker

```
  while(true) {
1   val task = tasks.receive()
3   processTask(task)
  }
```

Client 2

```
  val task = Task(...)
4 tasks.send(task)
```

Have to wait for receive

```
val tasks = SynchronousQueue<Task>()
```

Rendezvous Channel Semantics

Client 1

```
  val task = Task(...)
2 tasks.send(task)
```

Worker

```
  while(true) {
1   val task = tasks.receive()
3   processTask(task)
  }
```

Client 2


```
  val task = Task(...)
4 tasks.send(task)
```

```
val tasks = SynchronousQueue<Task>()
```

Rendezvous Channel Semantics

Client 1

```
  val task = Task(...)
2 tasks.send(task)
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Worker

```
    while(true) {
5 1   val task = tasks.receive()
  3   processTask(task)
    }
```

Client 2

```
  val task = Task(...)
4 tasks.send(task)
```

Rendezvous!

```
val tasks = SynchronousQueue<Task>()
```

Coroutines Management

Coroutines Management

```
class Coroutine {
    var element: Any?
    ...
}

fun curCoroutine(): Coroutine { ... }

suspend fun suspend(c: Coroutine) { ... }
fun resume(c: Coroutine) { ... }
```

Element to be sent

Returns the current coroutine

Functions to manipulate with coroutines

Sequential Rendezvous Channel Implementation

```
class Coroutine {
   var element: Any?
   ...
}

fun curCoroutine(): Coroutine { ... }

suspend fun suspend(c: Coroutine) { ... }
fun resume(c: Coroutine) { ... }



val senders   = Queue<Coroutine>()
val receivers = Queue<Coroutine>()
```

Queues of suspended `send` and `receive` invocations

Sequential Rendezvous Channel Implementation

```
class Coroutine {
    var element: Any?
    ...
}

fun curC

suspend fun suspend(c: Coroutine) { ... }
fun resume(c: Coroutine) { ... }


val senders   = Queue<Coroutine>()
val receivers = Queue<Coroutine>()
```

Check if there is no receiver and suspends

Rendezvous: retrieve the first receiver

```
suspend fun send(element: T) {
    if (receivers.isEmpty()) {
        val curCor = curCoroutine()
        curCor.element = element
        senders.enqueue(curCor)
        suspend(curCor)
    } else {
        val r = receivers.dequeue()
        r.element = element
        resume(r)
    }
}
```

Sequential Rendezvous Channel Implementation

```
suspend fun receive(): T {
    if (senders.isEmpty()) {
        val curCor = curCoroutine()
        receivers.enqueue(curCor)
        suspend(curCor)
        return curCor.element
    } else {
        val s = senders.dequeue()
        val res = s.element
        resume(s)
        return res
    }
}
```

```
suspend fun send(element: T) {
    if (receivers.isEmpty()) {
        val curCor = curCoroutine()
        curCor.element = element
        senders.enqueue(curCor)
        suspend(curCor)
    } else {
        val r = receivers.dequeue()
        r.element = element
        resume(r)
    }
}
```

Rendezvous Channel: Golang

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Uses per-channel locks

```
suspend fun send(element: T) = channelLock.withLock {
   if (receivers.isEmpty()) {
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       curCor.element = element
       senders.enqueue(curCor)
       suspend(curCor)
   } else {
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       r.element = element
       resume(receiver)
   }
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        r.element = element
        resume(receiver)
    }
}
```
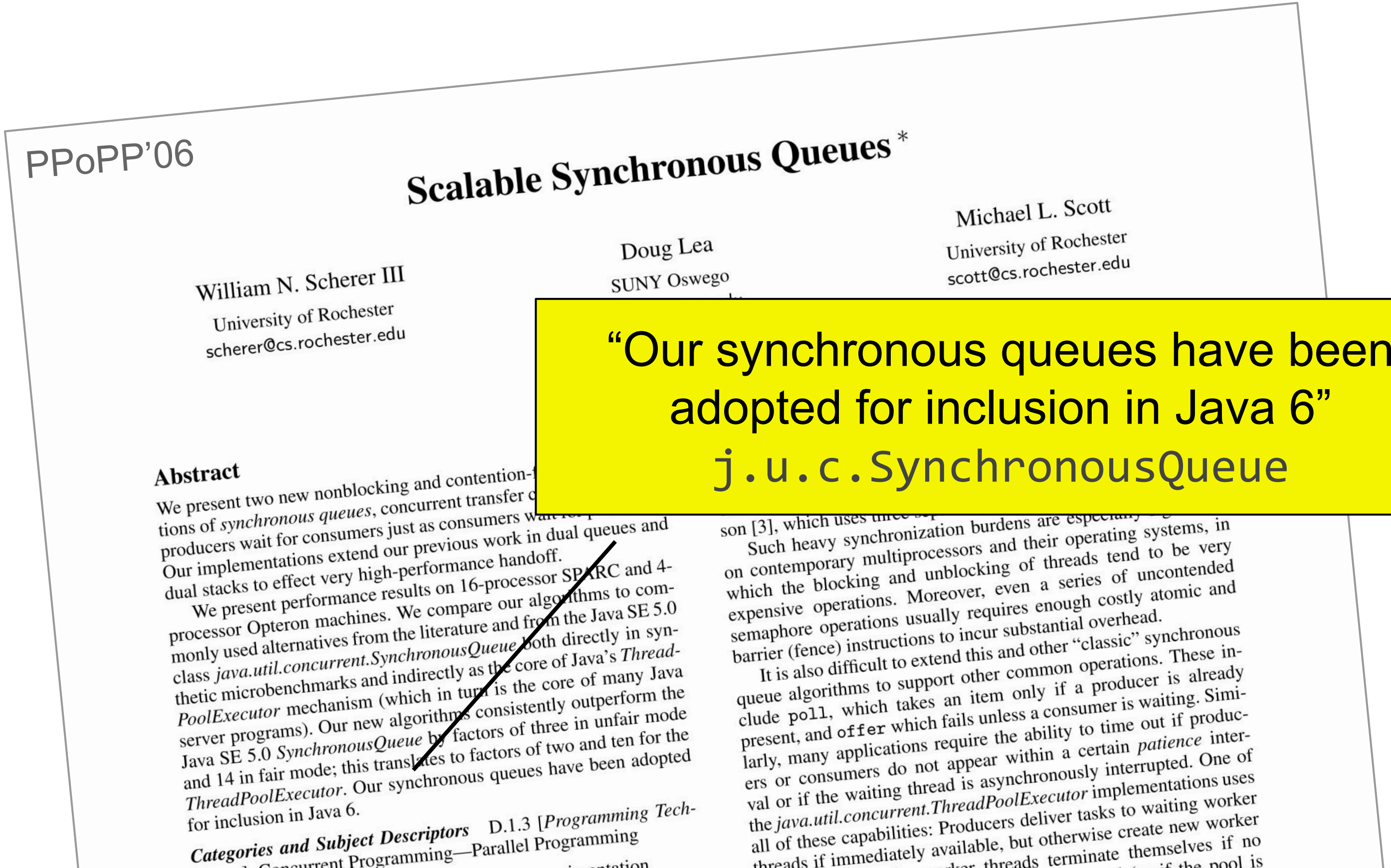

Non-scalable, no progress guarantee...

Rendezvous Channel: Java


PPoPP'06

Scalable Synchronous Queues *

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Doug Lea
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Michael L. Scott
University of Rochester
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Abstract

We present two new nonblocking and contention-
tions of *synchronous queues*, concurrent transfer
producers wait for consumers just as consumers wait
Our implementations extend our previous work in dual queues and dual stacks to effect very high-performance handoff.

We present performance results on 16-processor SPARC and 4-processor Opteron machines. We compare our algorithms to commonly used alternatives from the literature and from the Java SE 5.0 class *java.util.concurrent.SynchronousQueue* both directly in synthetic microbenchmarks and indirectly as the core of Java's *ThreadPoolExecutor* mechanism (which in turn is the core of many Java server programs). Our new algorithms consistently outperform the Java SE 5.0 *SynchronousQueue* by factors of three in unfair mode and 14 in fair mode; this translates to factors of two and ten for the *ThreadPoolExecutor*. Our synchronous queues have been adopted for inclusion in Java 6.

Categories and Subject Descriptors D.1.3 [*Programming Techniques*]: Concurrent Programming—Parallel Programming

son [3], which uses three

Such heavy synchronization burdens are especially on contemporary multiprocessors and their operating systems, in which the blocking and unblocking of threads tend to be very expensive operations. Moreover, even a series of uncontended semaphore operations usually requires enough costly atomic and barrier (fence) instructions to incur substantial overhead.

It is also difficult to extend this and other "classic" synchronous queue algorithms to support other common operations. These include `poll`, which takes an item only if a producer is already present, and `offer` which fails unless a consumer is waiting. Similarly, many applications require the ability to time out if producers or consumers do not appear within a certain *patience* interval or if the waiting thread is asynchronously interrupted. One of the *java.util.concurrent.ThreadPoolExecutor* implementations uses all of these capabilities: Producers deliver tasks to waiting worker threads if immediately available, but otherwise create new worker threads terminate themselves if no

"Our synchronous queues have been adopted for inclusion in Java 6"
`j.u.c.SynchronousQueue`

Rendezvous Channel: Java

Based on Michael-Scott lock-free queue algorithm

the simplest known lock-free queue

Rendezvous Channel: Java

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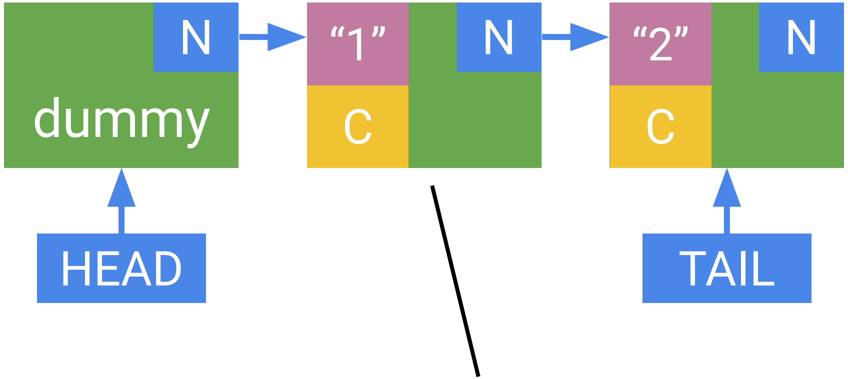
the simplest known lock-free queue

Either senders or receivers are in the queue!

Rendezvous Channel: Java

Based on Michael-Scott lock-free queue algorithm

the simplest known lock-free queue

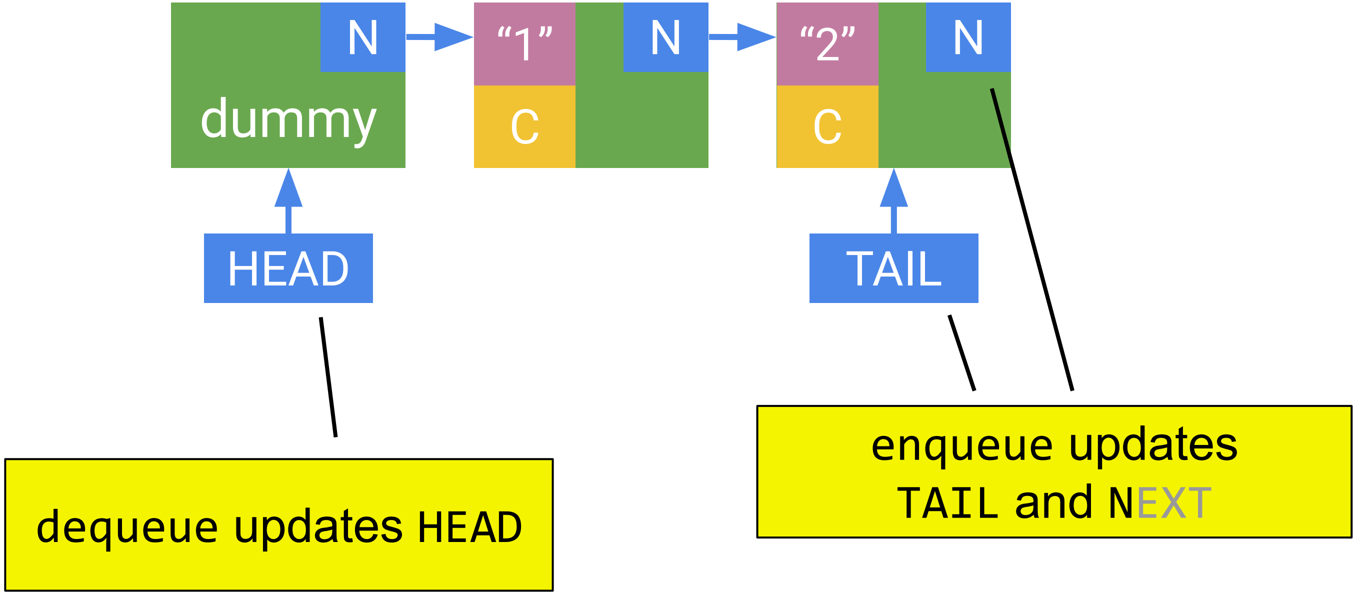


Stores both the element to be sent (`RECEIVE_EL` for `receive`) and the coroutine

Rendezvous Channel: Java

Based on Michael-Scott lock-free queue algorithm

the simplest known lock-free queue



Rendezvous Channel: Java

Based on Michael-Scott lock-free queue algorithm

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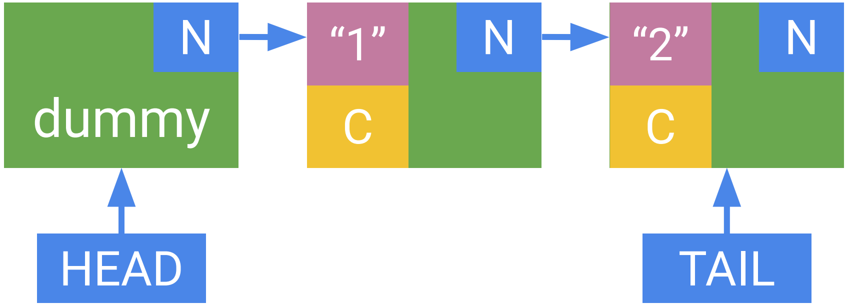
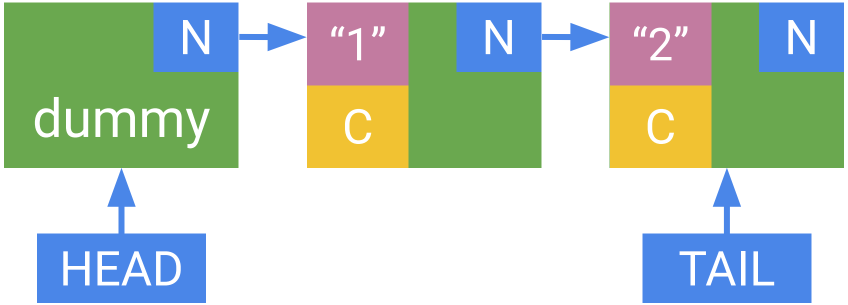



```
send(x):
  t := TAIL
  h := HEAD
  if t == h || t.isSender() {
    enqueueAndSuspend(t, x)
  } else {
    dequeueAndResume(h)
  }
```

Rendezvous Channel: Java

Based on Michael-Scott lock-free queue algorithm

the simplest known lock-free queue



Retry the whole operation on failures

```
send(x):
  t := TAIL
  h := HEAD
  if t == h || t.isSender() {
    enqueueAndSuspend(t, x)
  } else {
    dequeueAndResume(h)
  }
```

Does It Guarantee Linearizability?

```
val c = Channel<Int>()
```

c.send(4)	c.receive() // S + 4

`send` waits for `receive` and vice versa

Does It Guarantee Linearizability?

```
val c = Channel<Int>()
```

`c.send(4)`	`c.receive() // S + 4`

Non-linearizable because of suspension

```kotlin
val c = Channel<Int>()
```

	`c.receive(): // S + 4`
	register as a waiter
	suspend
`c.send(4)`	
	return element

Dual Data Structures*

```
val c = Channel<Int>()
```

	`c.receive(): // S + 4`
	register as a waiter } request
	suspend
`c.send(4)`	
	return element } follow-up

* “Nonblocking Concurrent Data Structures with Condition Synchronization” by Scherer, W.N. and Scott, M.L.

Fast Semaphore

https://github.com/Kotlin/kotlinx.coroutines/blob/master/kotlinx-coroutines-core/common/src/sync/Semaphore.kt

Mutex and Semaphore

Mutex: at most ONE thread in the critical section

- `lock` — acquires the mutex
- `unlock` — releases the mutex

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Semaphore(maxPermits = K): at most K threads in the critical section

- `acquire` — acquires a permit
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Mutex and Semaphore

Mutex: at most ONE thread in the critical section

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Semaphore(maxPermits = K): at most K threads in the critical section

- `acquire` — acquires a permit
- `release` — releases a permit

Mutex == Semaphore(maxPermits = 1)

AbstractQueuedSynchronizer?

~~AbstractQueuedSynchronizer?~~

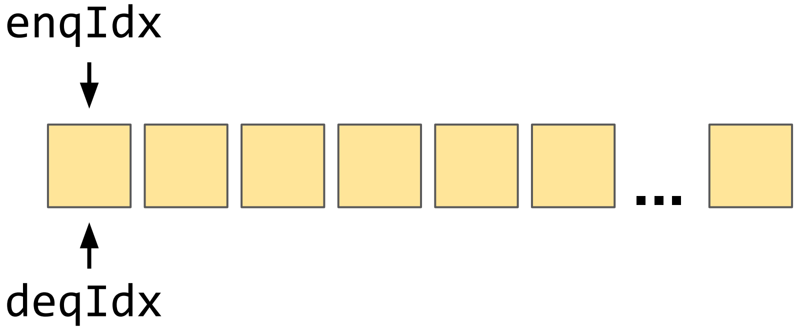
SegmentQueuedSynchronizer

```
fun suspend()
fun resumeNextWaiter()
```

Semaphore Algorithm via FAA

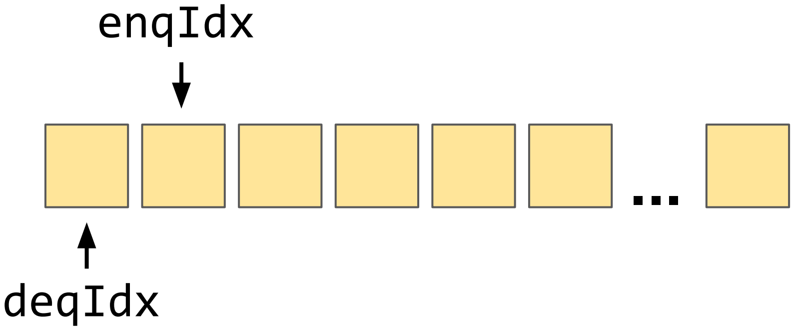
```
class Semaphore(maxPermits: Int) {
   var availablePermits = maxPermits

   fun acquire() {
       p := FAA(&availablePermits, -1)
       if (p > 0) return
       suspend() // wait for a permit
   }

   fun release() {
       p := FAA(&availablePermits, +1)
       if (p >= 0) return
       resumeNextWaiter()
   }
}
```

SegmentQueuedSynchronizer on Arrays

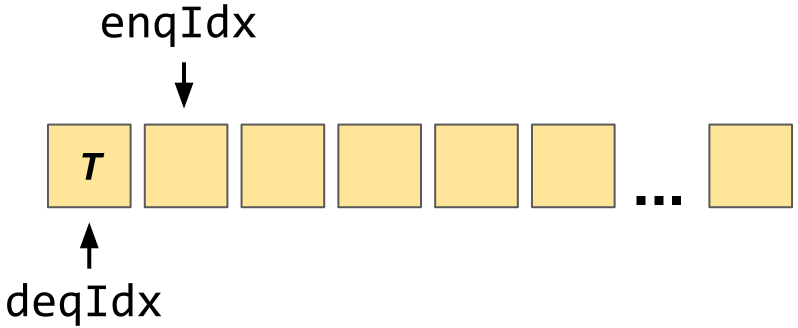


Бесконечный массив и указатели для enqueue и dequeue.
Сначала увеличиваем индекс, потом пишем/читаем

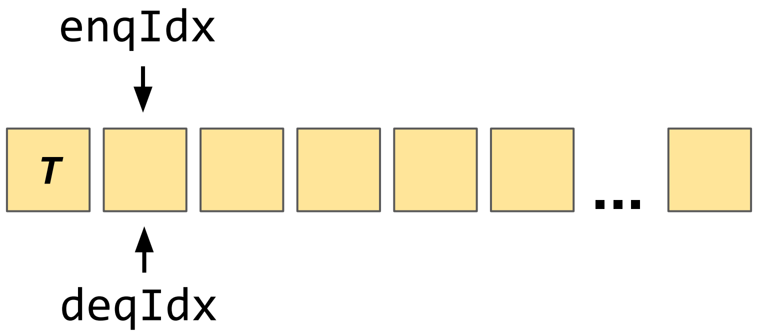
SegmentQueuedSynchronizer on Arrays



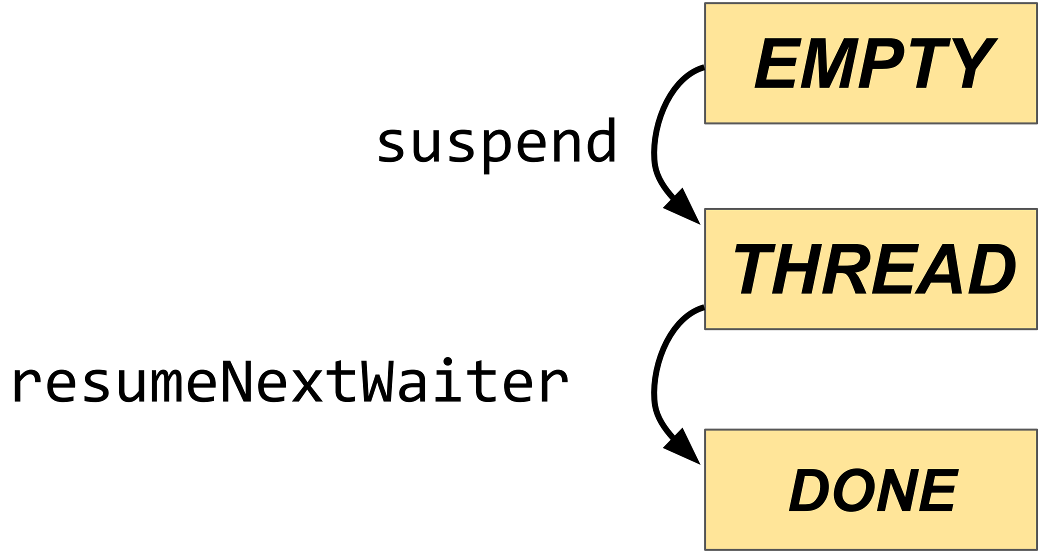
SegmentQueuedSynchronizer on Arrays



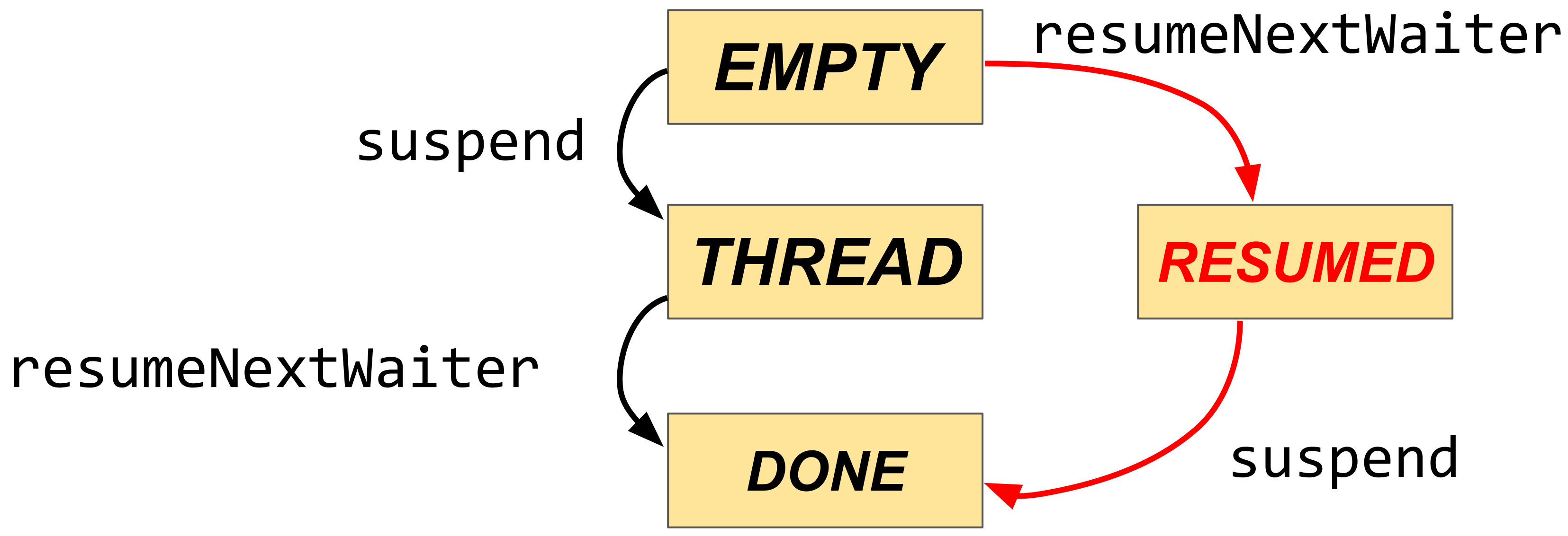
SegmentQueuedSynchronizer on Arrays



SegmentQueuedSynchronizer: Slot States



SegmentQueuedSynchronizer: Slot States



Let’s implement an infinite array similarly to the FAA-Based Queue

Assignment N. Blocking Stack

Let's implement a blocking stack via `SegmentQueuedSynchronizer`

`var size: Int` // #push - #pop

`push(x)` — increment `size` at first; resume next waiter if `size < 0`

`pop()` — decrement `size` at first; suspend if `size <= 0`