The Continuing Saga of the Lock-free Queue
Part 3 of N

Tony Van Eerd C++Now May 2018

CHRISTIE

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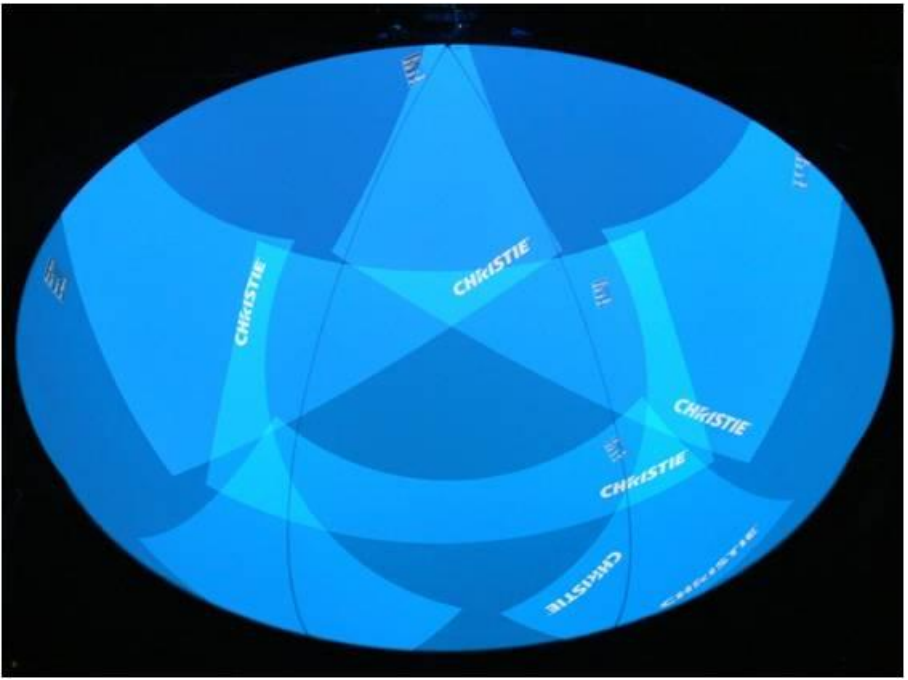
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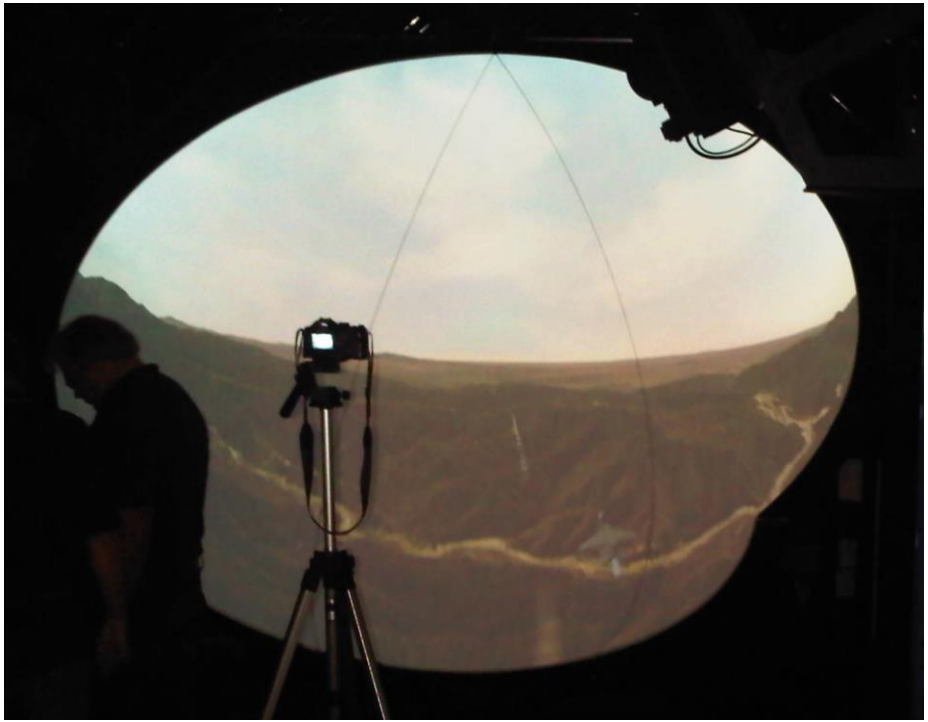


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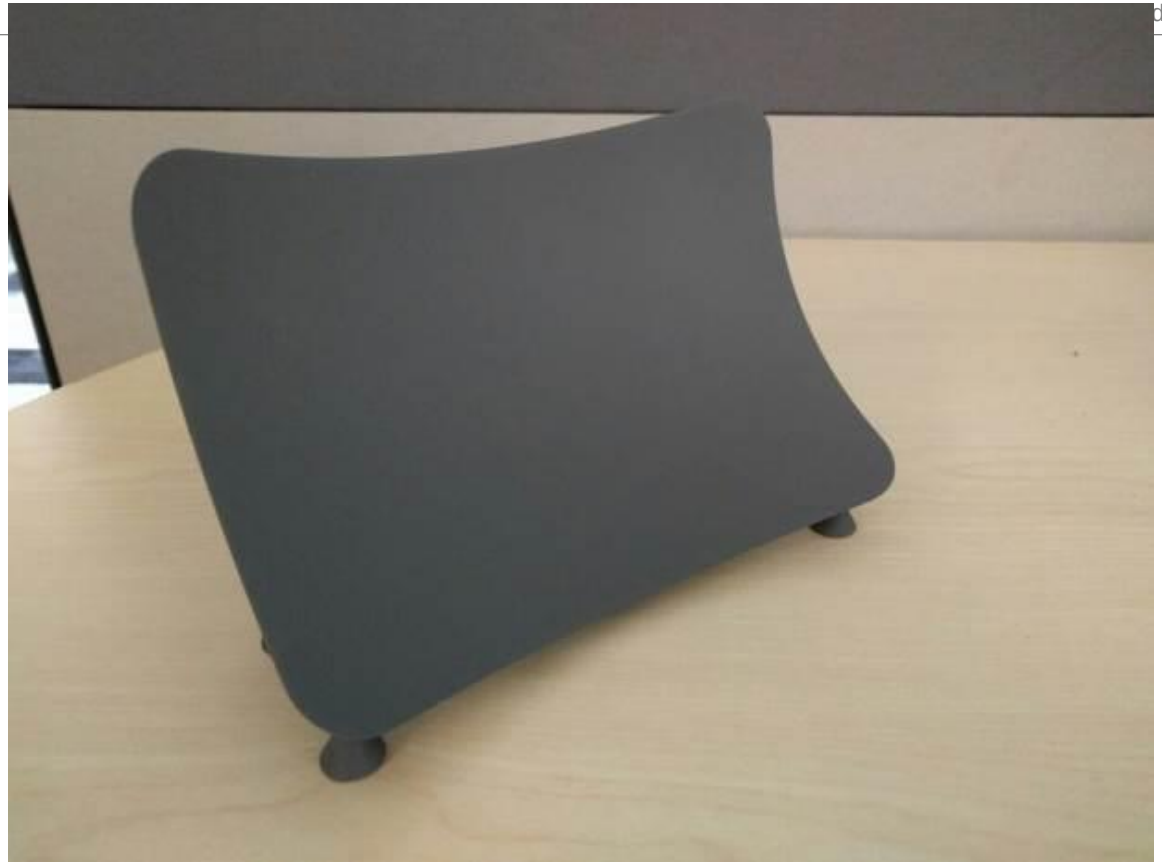


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Guide to Threaded Coding

Guide to Threaded Coding

1. Stop Sharing (forget what you learned in kindergarten)
2. OK, well Use Locks then
   (don't call unknown code while holding a lock)
3. Measure
4. Measure
5. Change your Algorithm
6. GOTO 1

∞. Lock-free

Lock-free coding is the last thing you want to do.

Guide to Threaded Coding

1. Stop Sharing (forget what you learned in kindergarten)
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∞. Lock-free
∞+1. Measure. Measure.

Lock-free coding is the last thing you want to do.

Guide to Threaded Coding

Don’t Share
Use Locks

Rules of Lock-free Coding

1.

Rules of Lock-free Coding

1. Don’t talk about lock-free coding

Guide to Coding

Guide to Coding

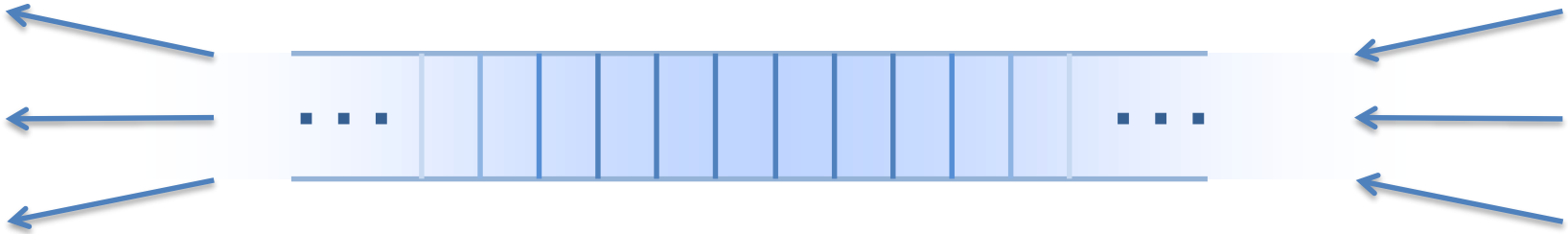
MACROS_ARE_EVIL

Notes:

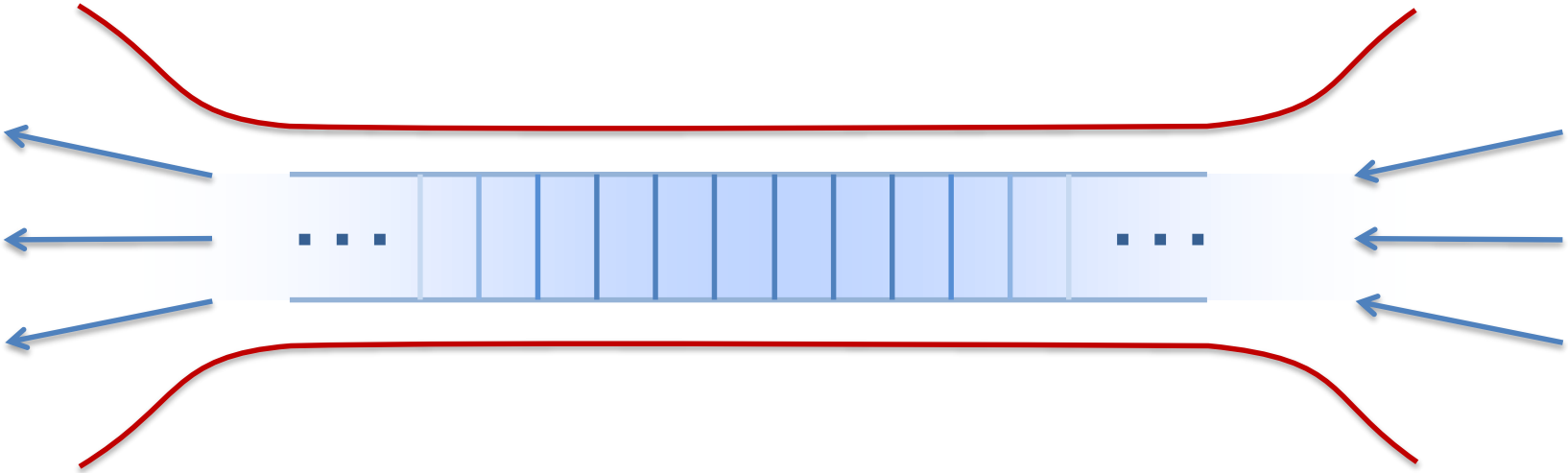
acquire = std::memory_order_acquire
release = std::memory_order_release
(etc)
CAS = “Compare and Set/Swap” = std::compare_exchange() and friends

Not my coding style/structure

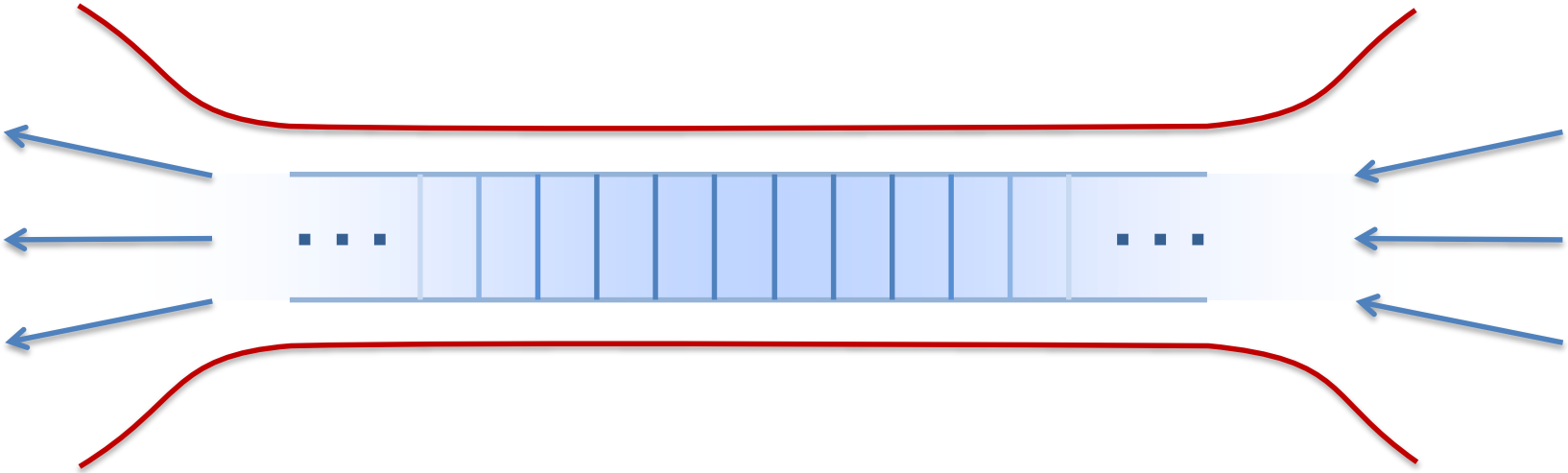
MPMC Queue

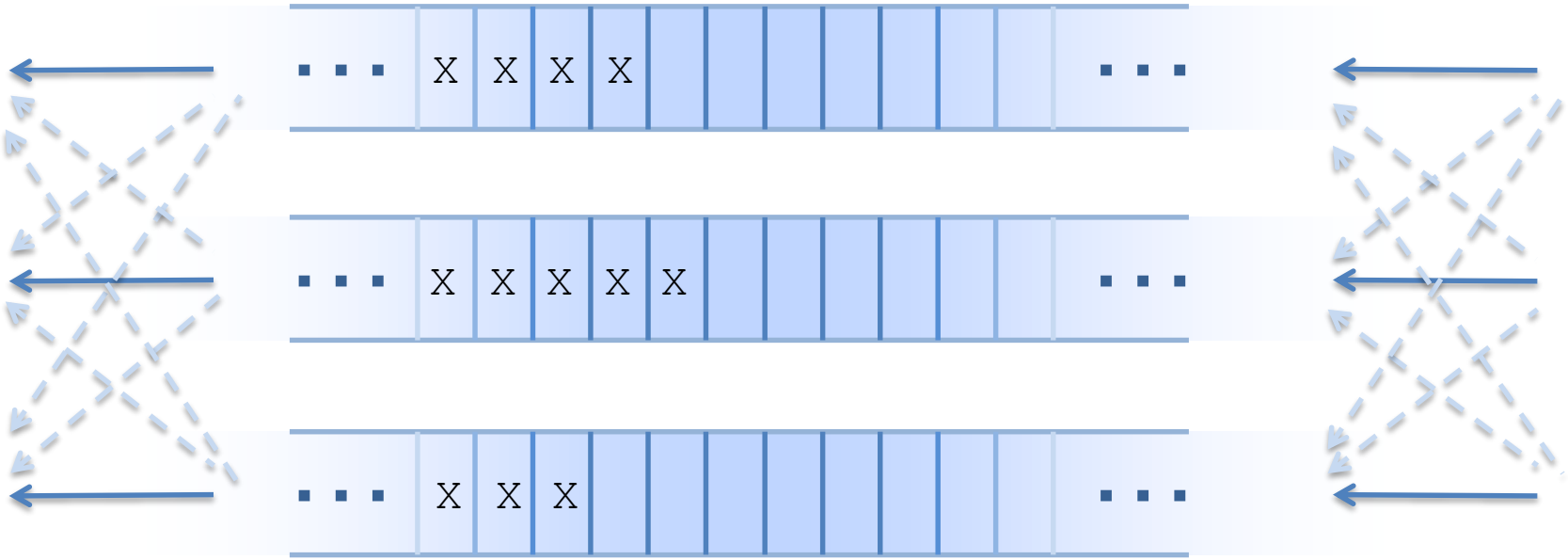


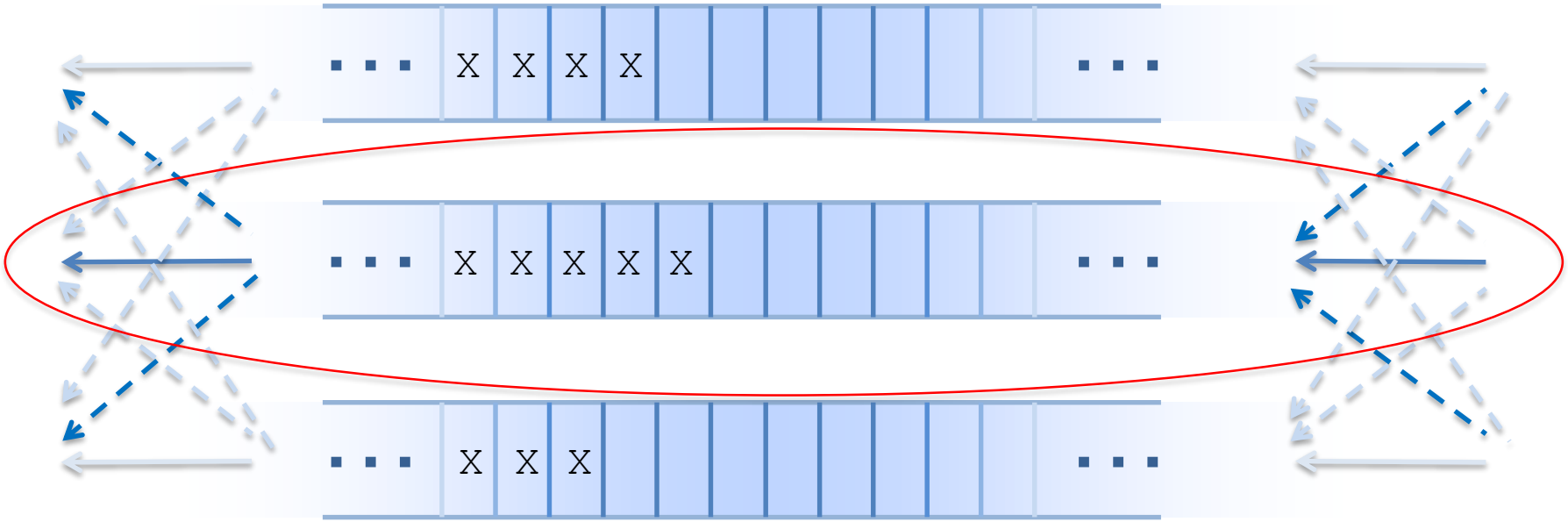
MPMC Queue



Bottleneck




X X X X
X X X X X
X X X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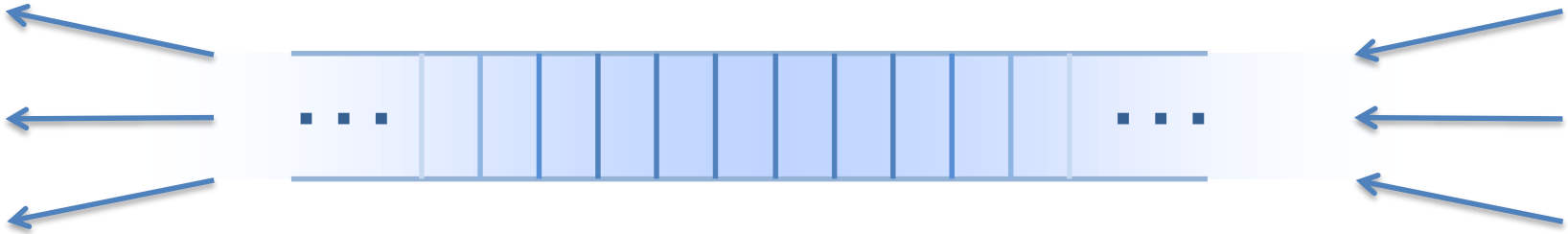
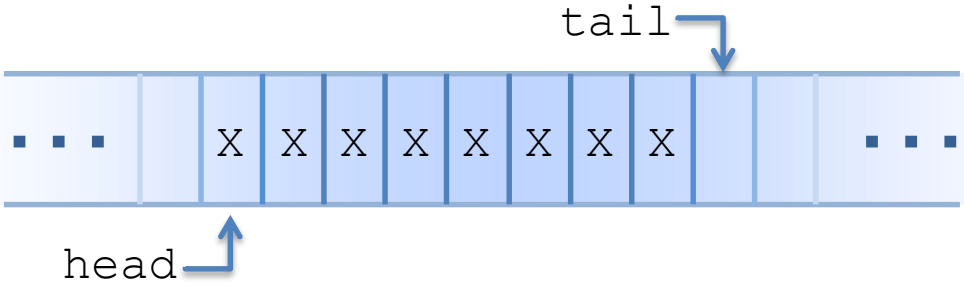
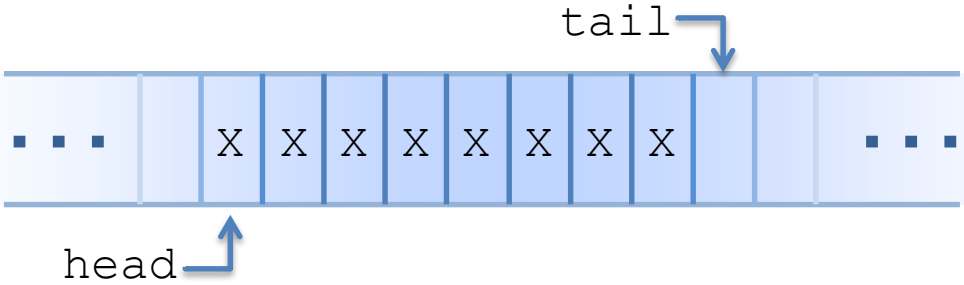


Review



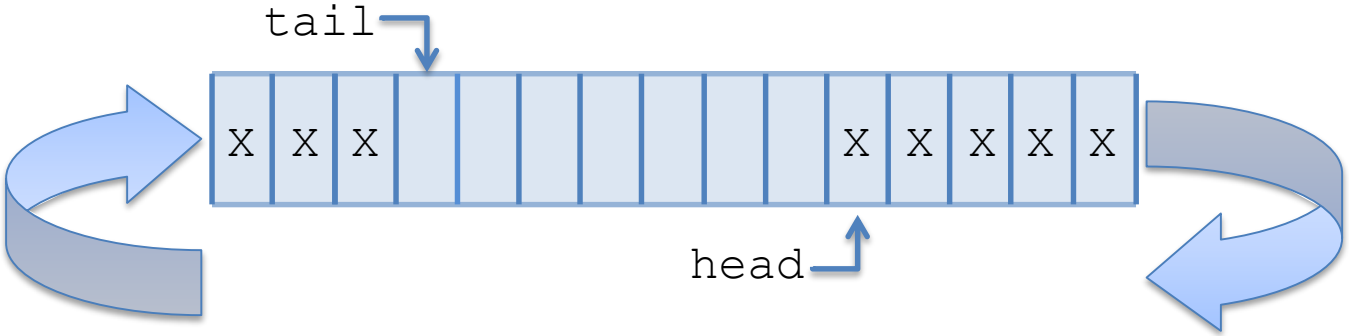
Review

```
class Queue {
    ?
};
```



Review

```
class Queue {
 T buffer[SIZE];
 int head;
 int tail;
};
```



Review

Compromise

```
class Queue {
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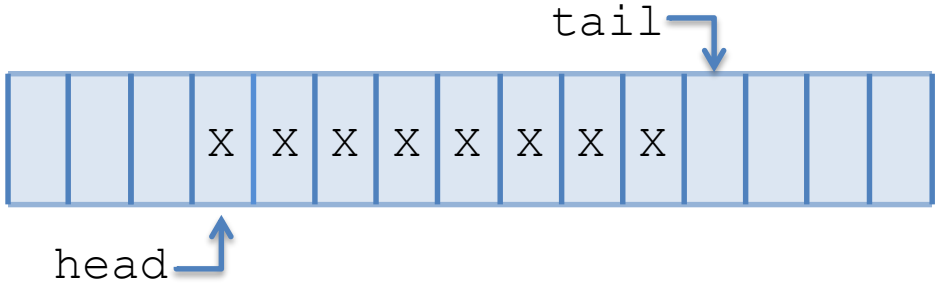
```



Review

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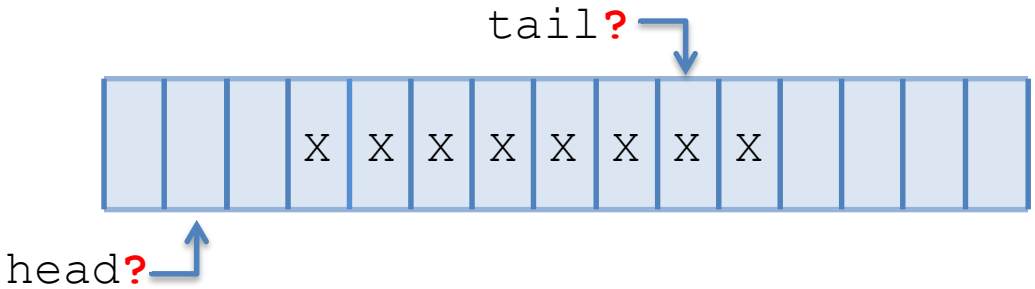

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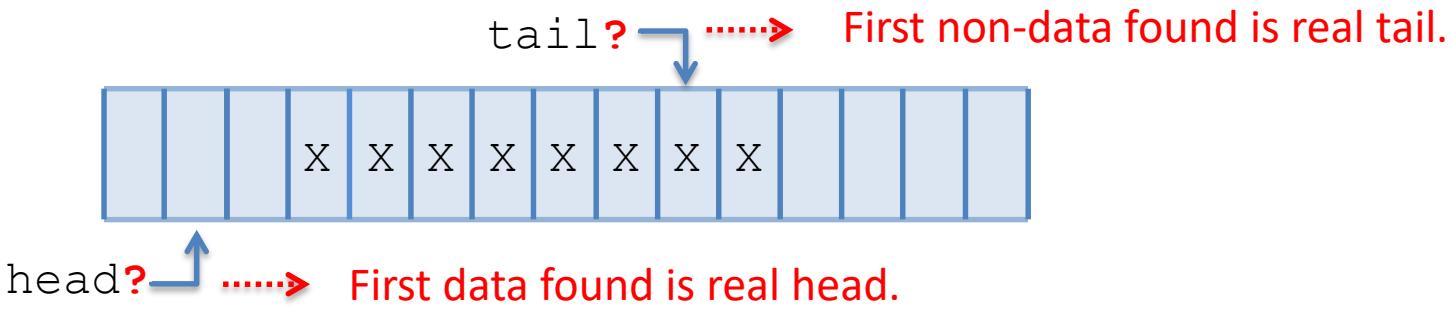

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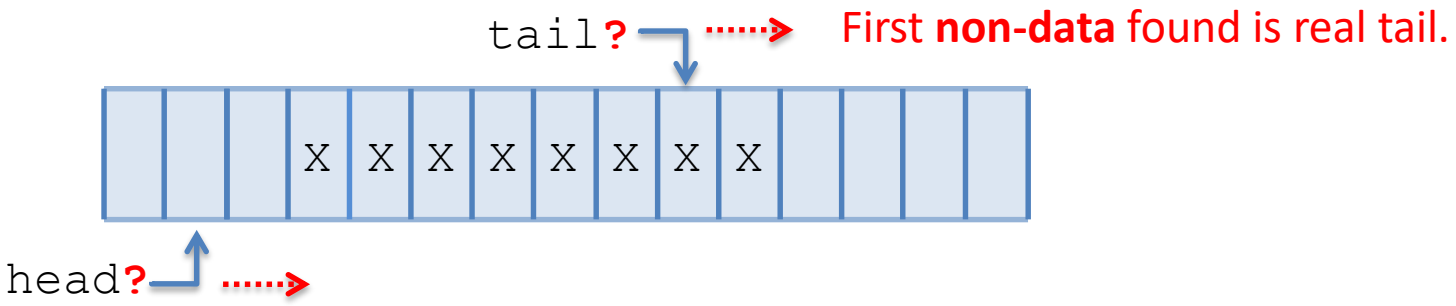

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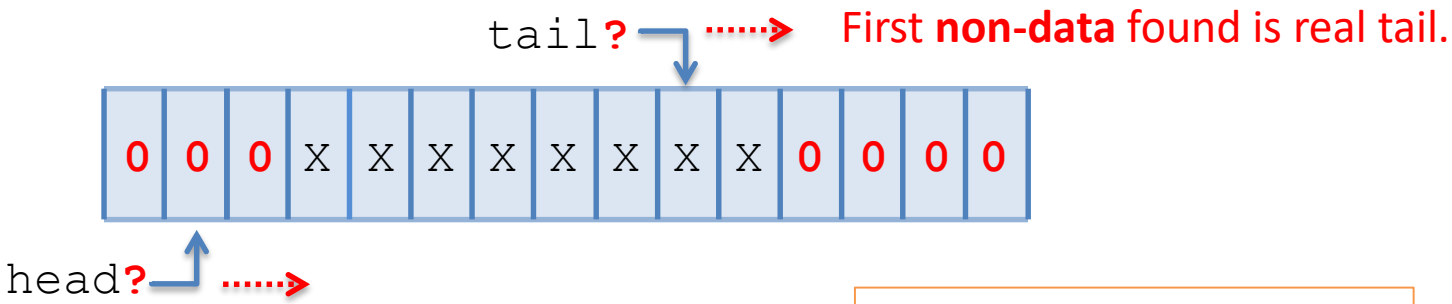

Data == 0

Review

```
class Queue {
 int buffer[SIZE];
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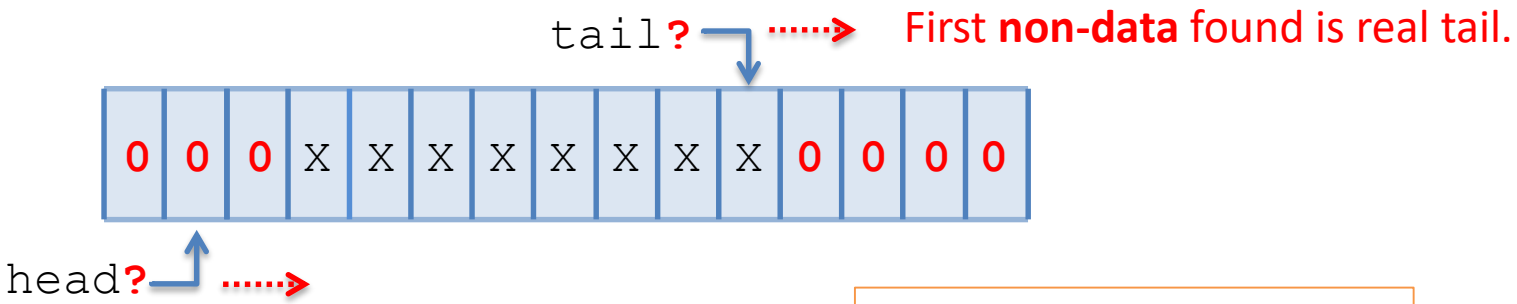
};
```



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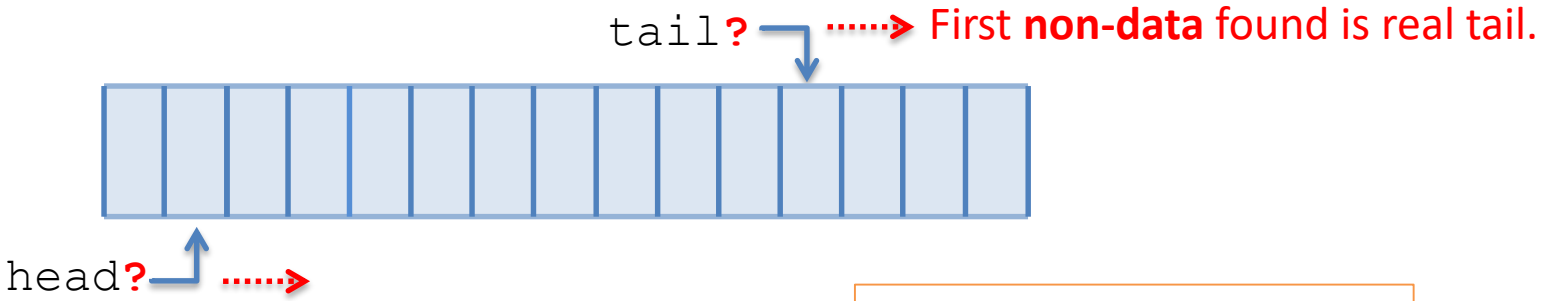

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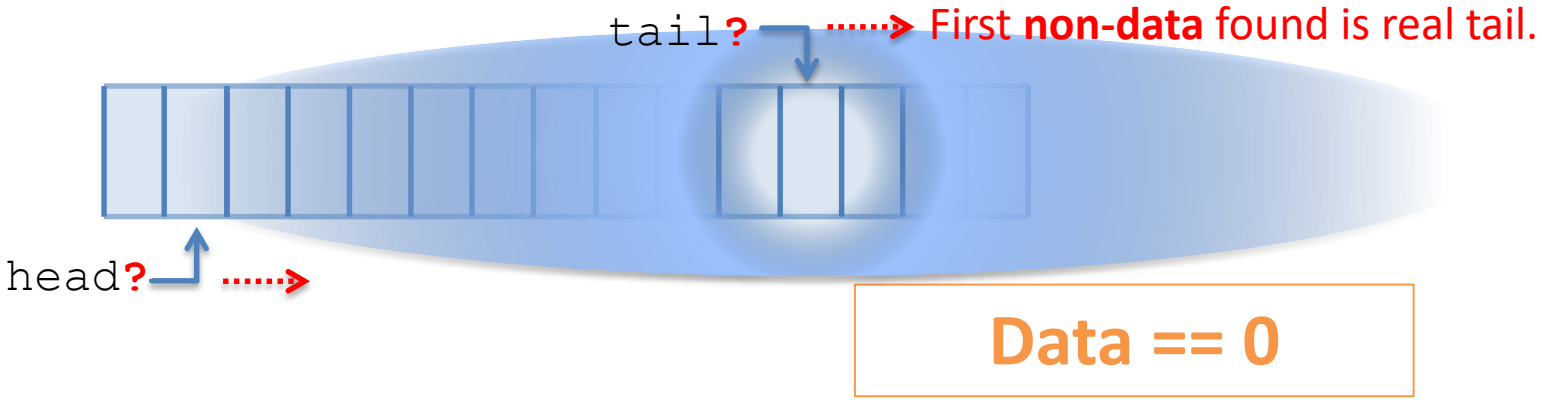

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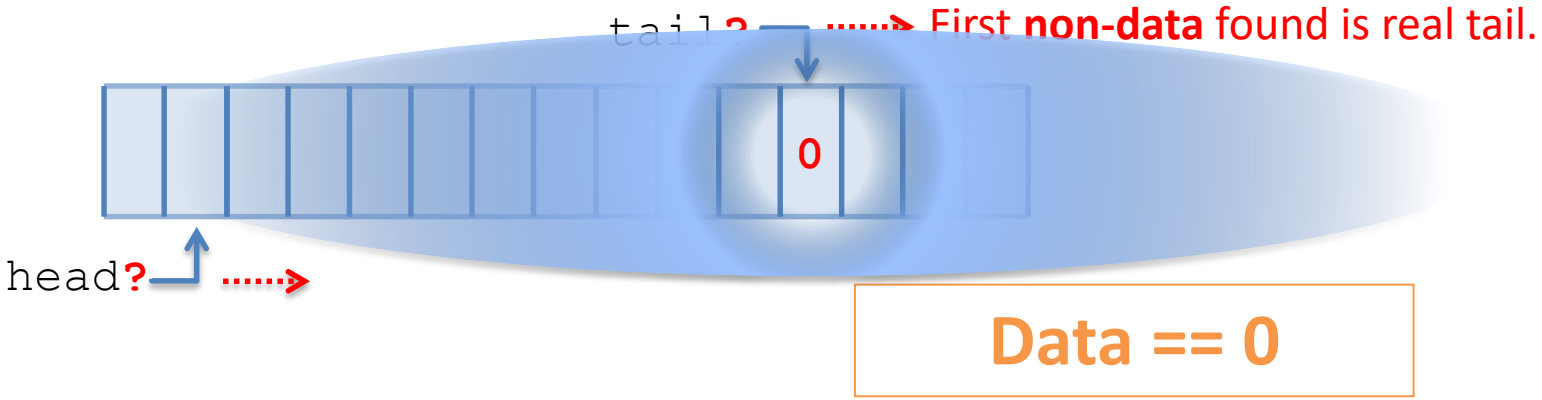

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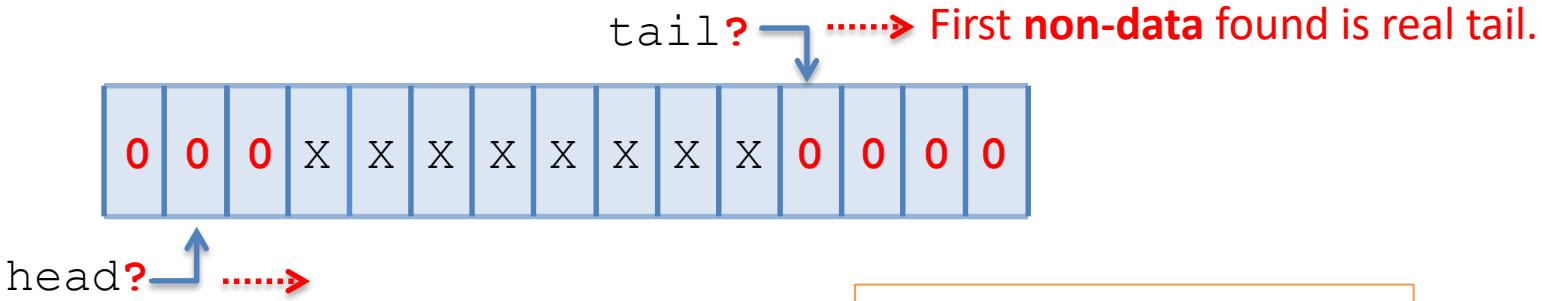

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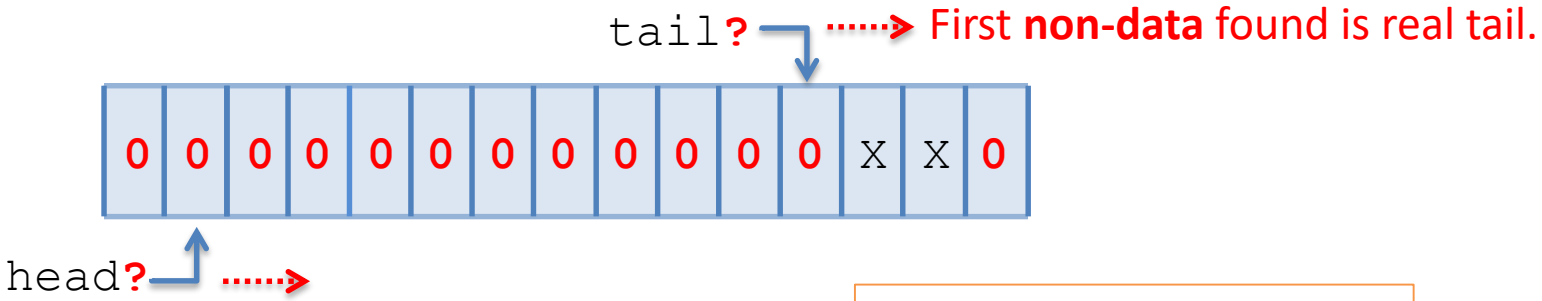

Data == 0

Review

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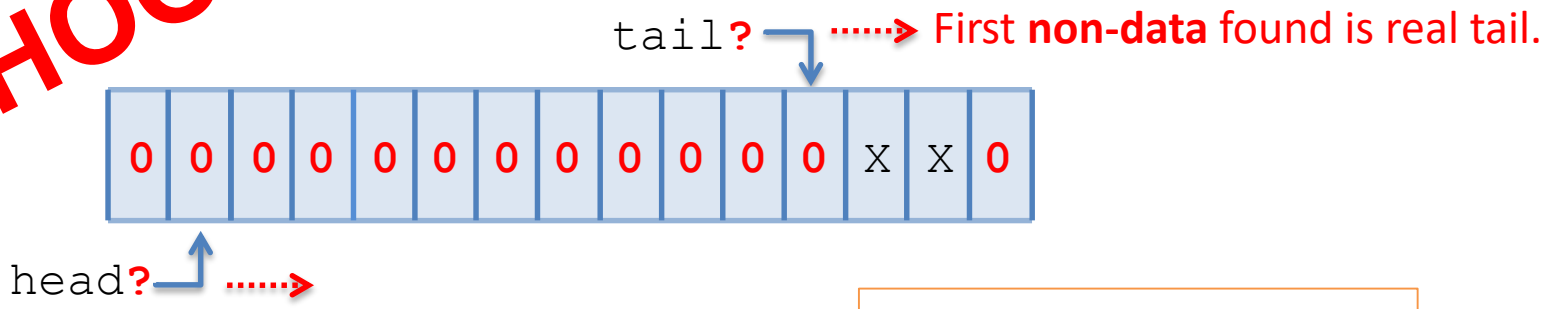
```

WHOOPS!



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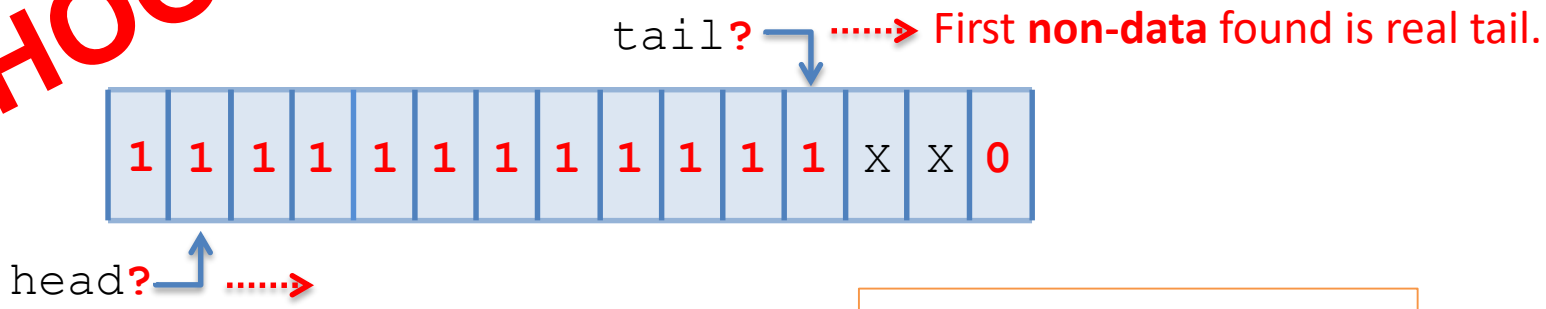

Compromise

Review

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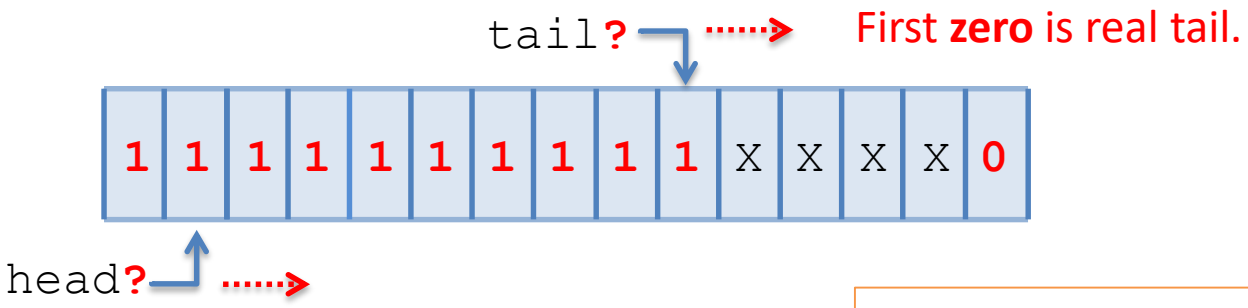

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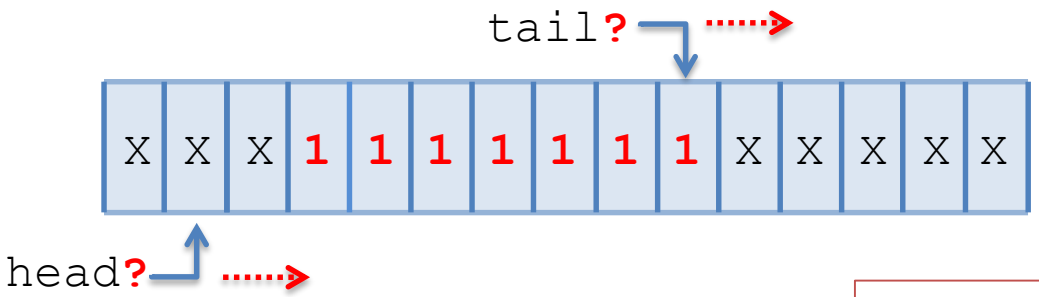

Circular Buffer

Review

```
class Queue {
 int buffer[SIZE];
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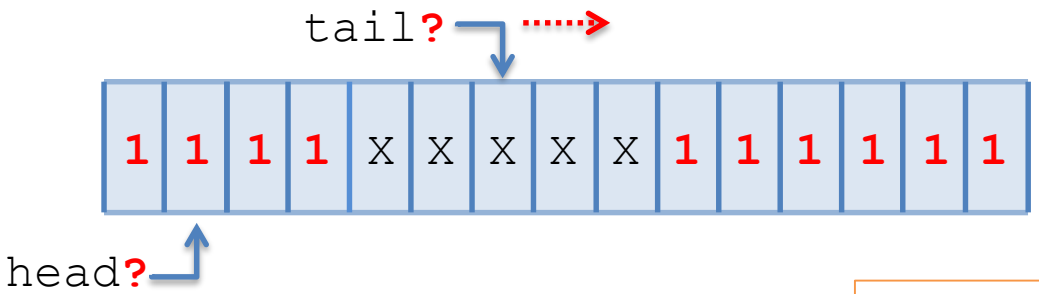
};
```



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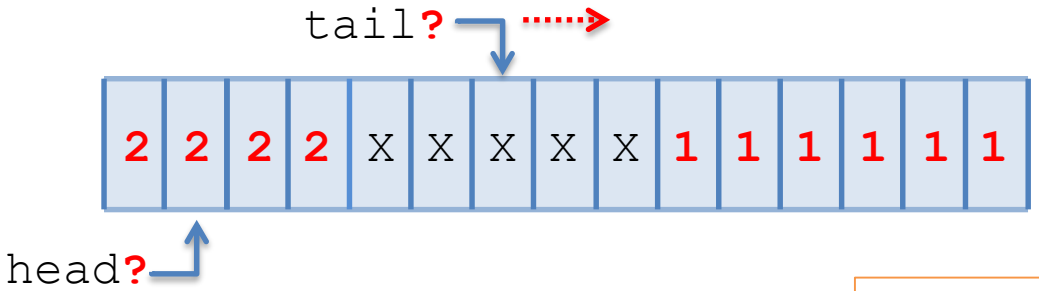

Compromise

Review

```
class Queue {
 int buffer[SIZE];
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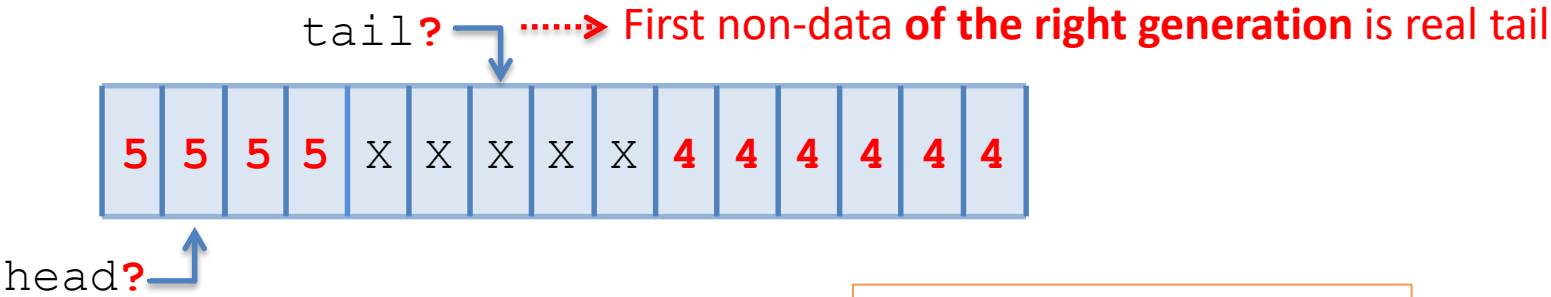

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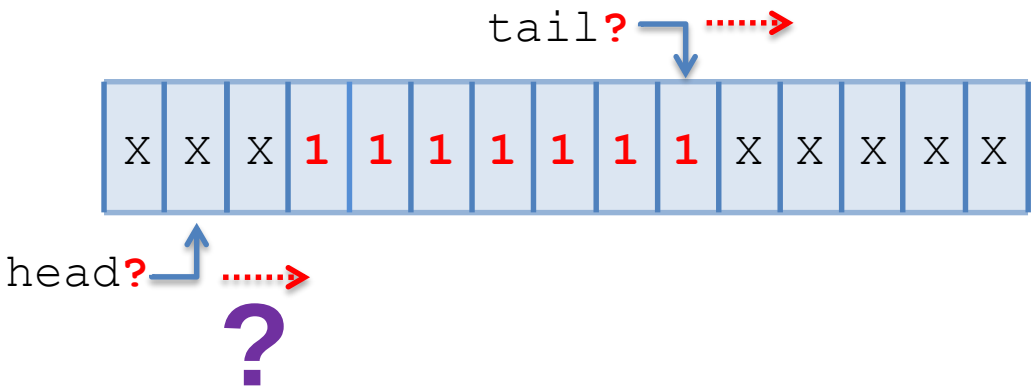

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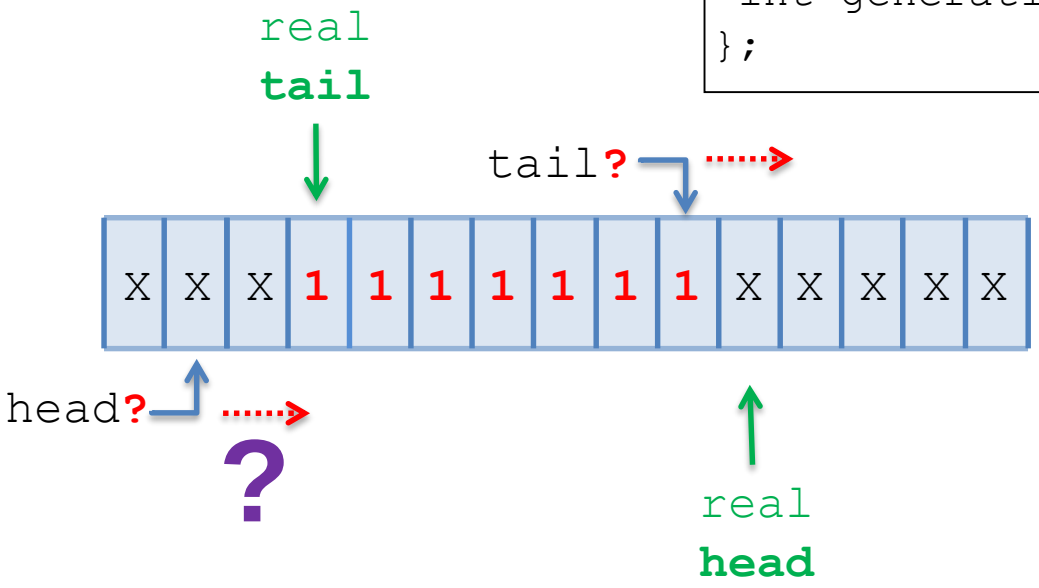

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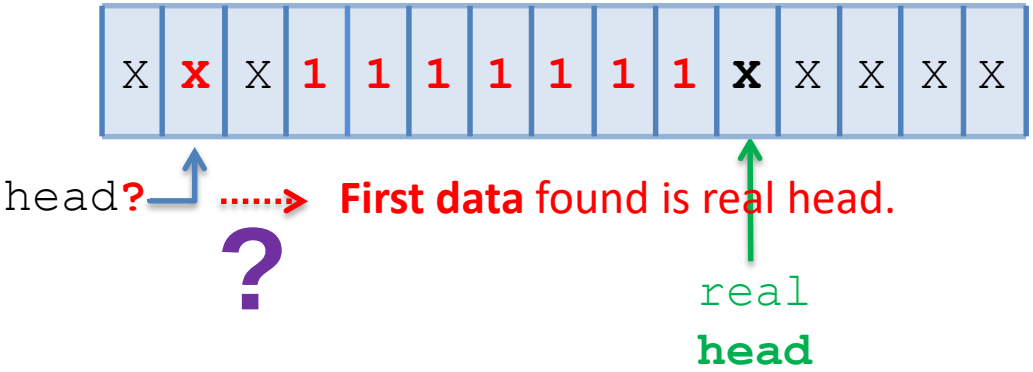

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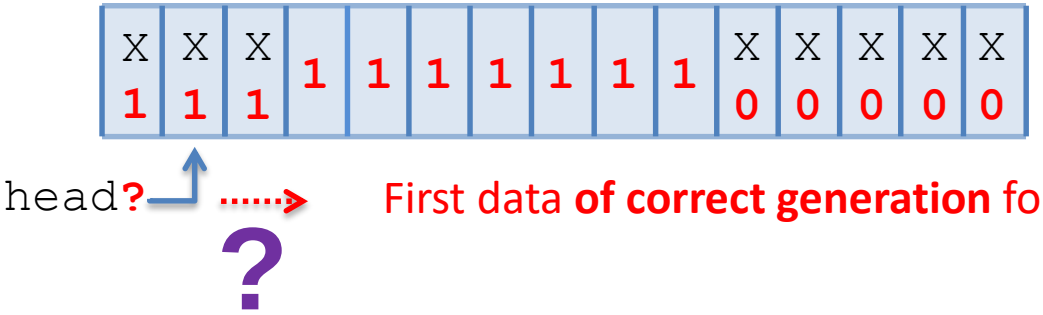

First data **of correct generation** found is real head.

Review

```
class Queue {
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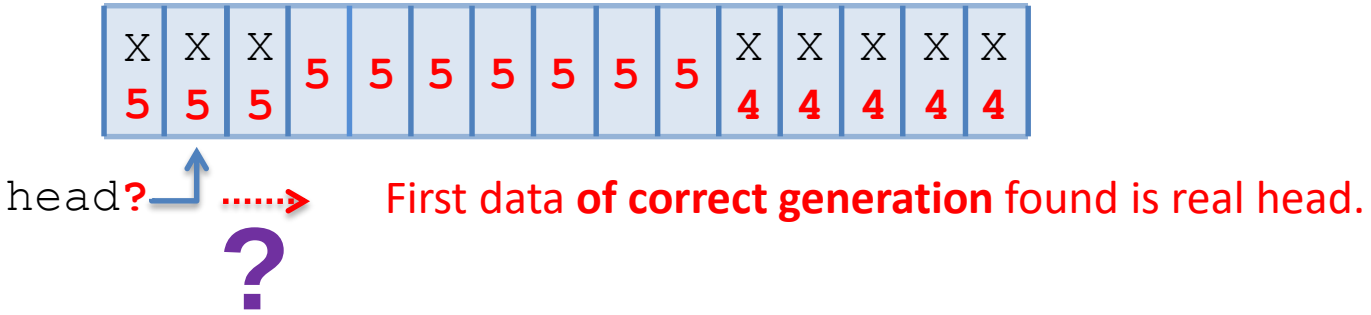
 int tailish;
 int generation;
};
```

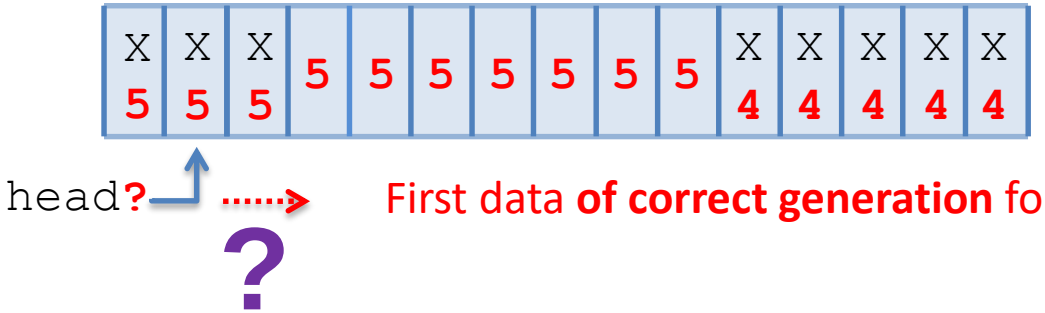


Review

```
struct entry {
 int data;
 int generation;
};
```

```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```

Compromise



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Review

```
struct entry {
 int data;
 int generation;
};
```

```
class Queue {
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 int headish;
 int tailish;
 int generation;
};
```

Also: data != 0

X	X	X	0	0	0	0	0	0	0	X	X	X	X	X
5	5	5	5	5	5	5	5	5	5	4	4	4	4	4

head? ?

First data **of correct generation** found is real head.

Review

```
class Queue {
 entry buffer[SIZE];
 int headish;
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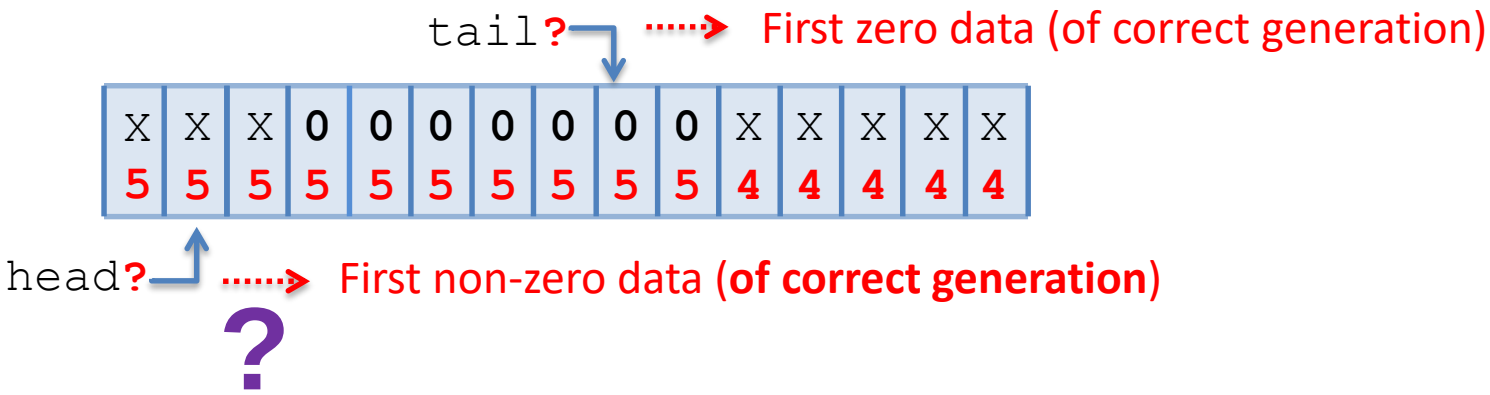
};
```



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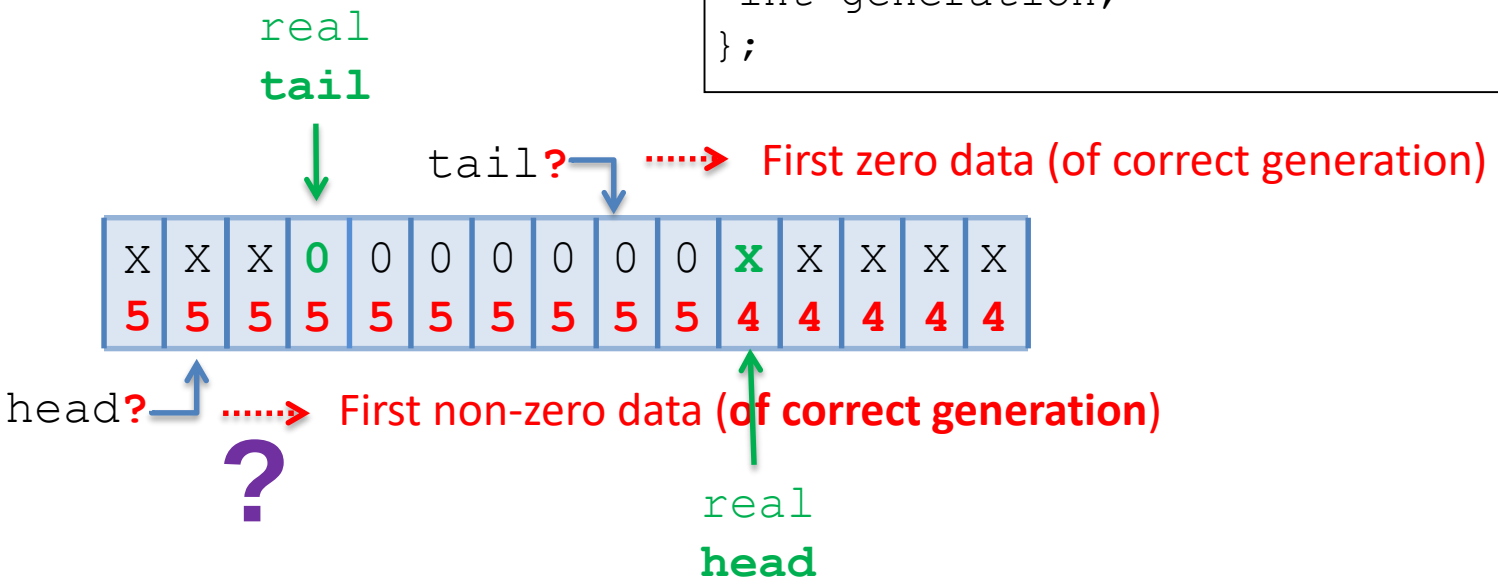

Examples

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 int generation;
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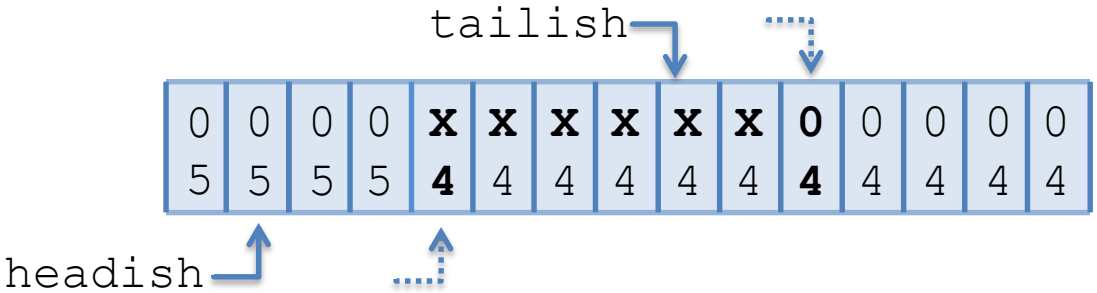

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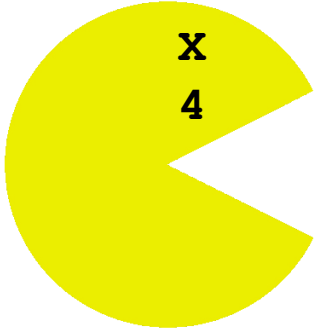

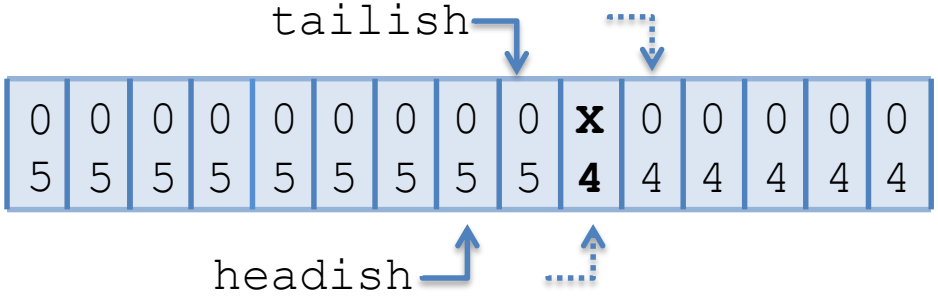

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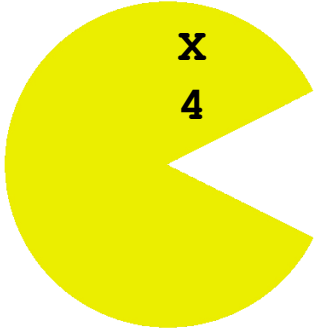

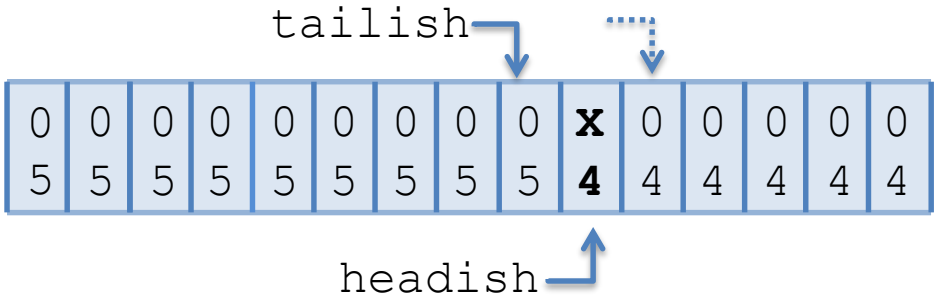

Examples

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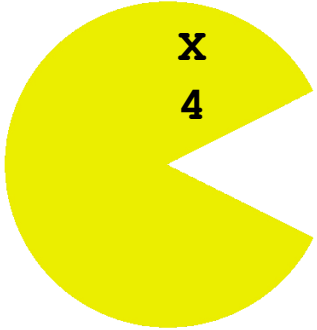

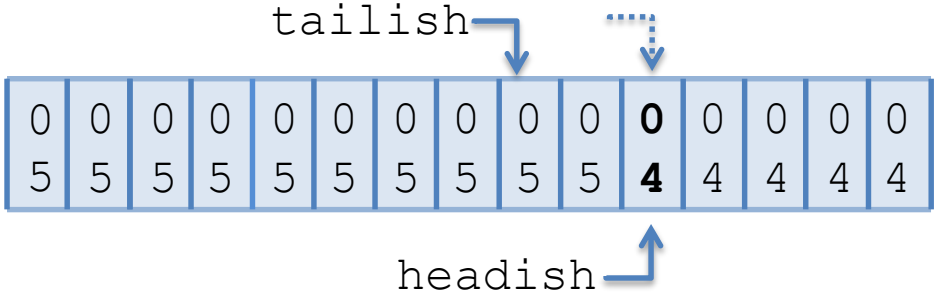

Examples

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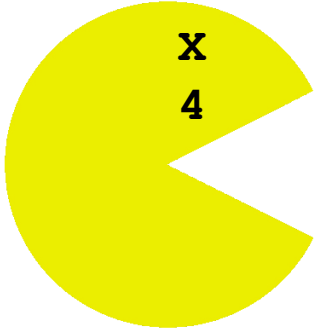
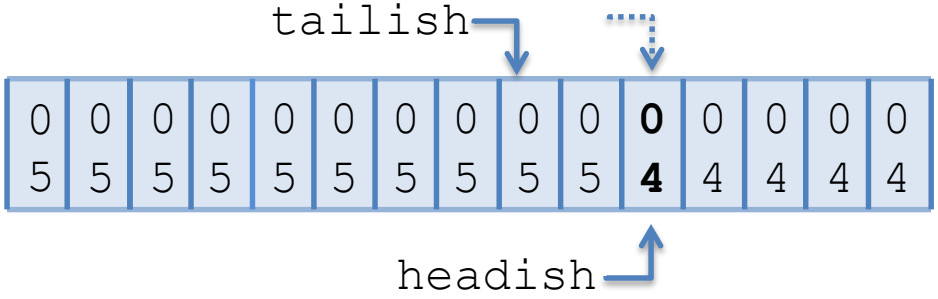
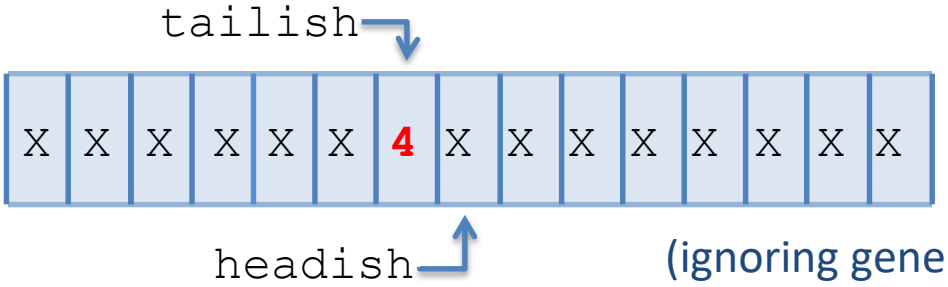




Queue is Empty!

Examples

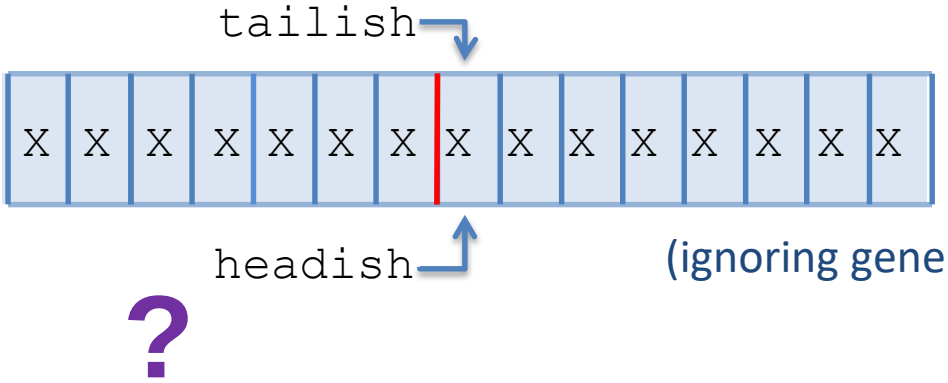
```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```



(ignoring generation for a moment)

Examples

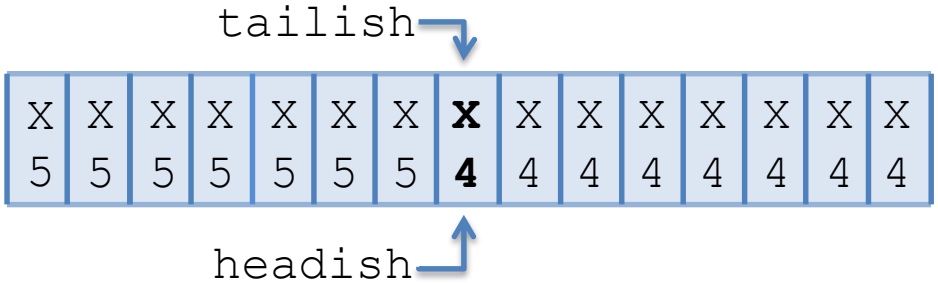
```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```



(ignoring generation for a moment)

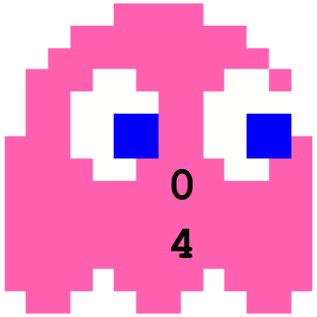
Examples

```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```

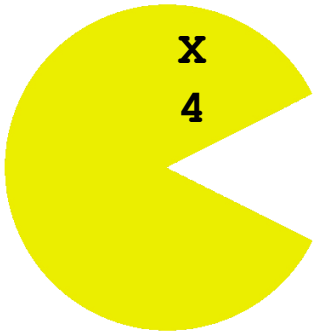


Queue is Full!

Examples




```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```

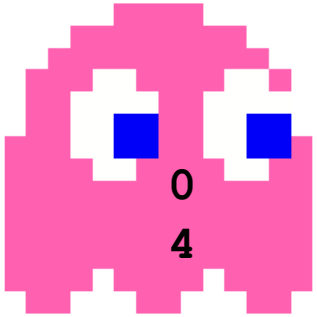


tailish

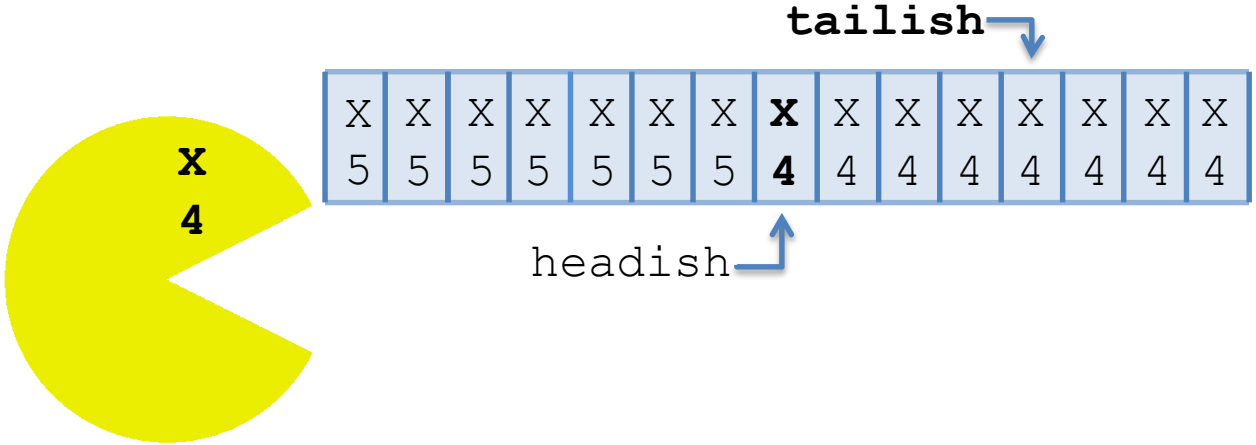
X	X	X	X	X	X	X	**X**	X	X	X	X	X	X	X
5	5	5	5	5	5	5	**4**	4	4	4	4	4	4	4

headish

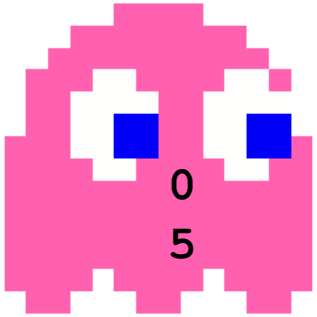
Examples



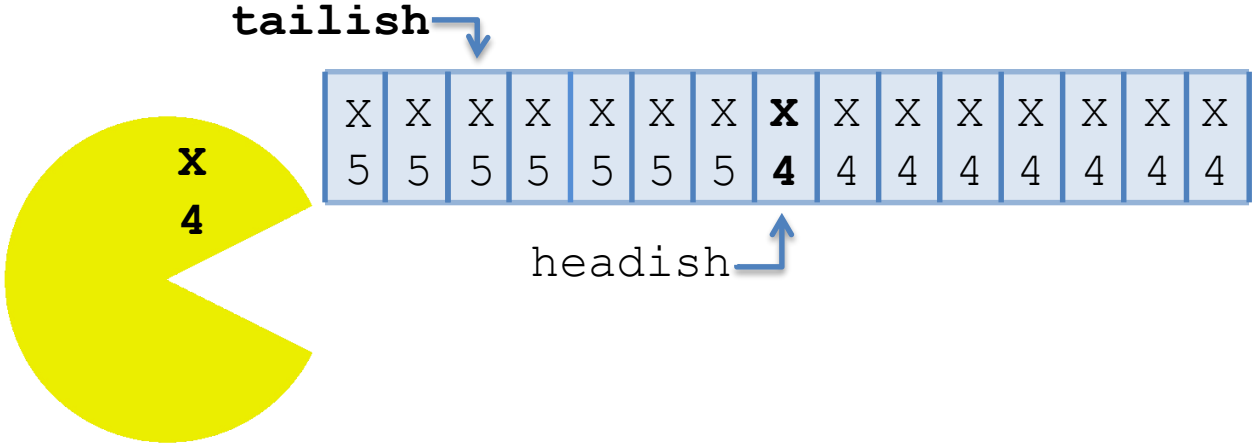

```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```



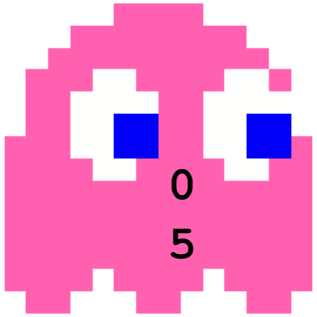
Examples




```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```



Examples



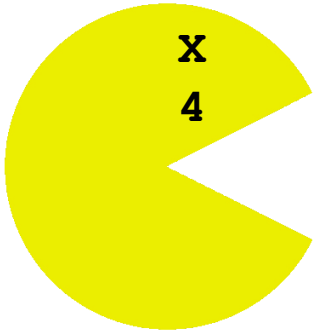

```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```

tailish

4 < 5

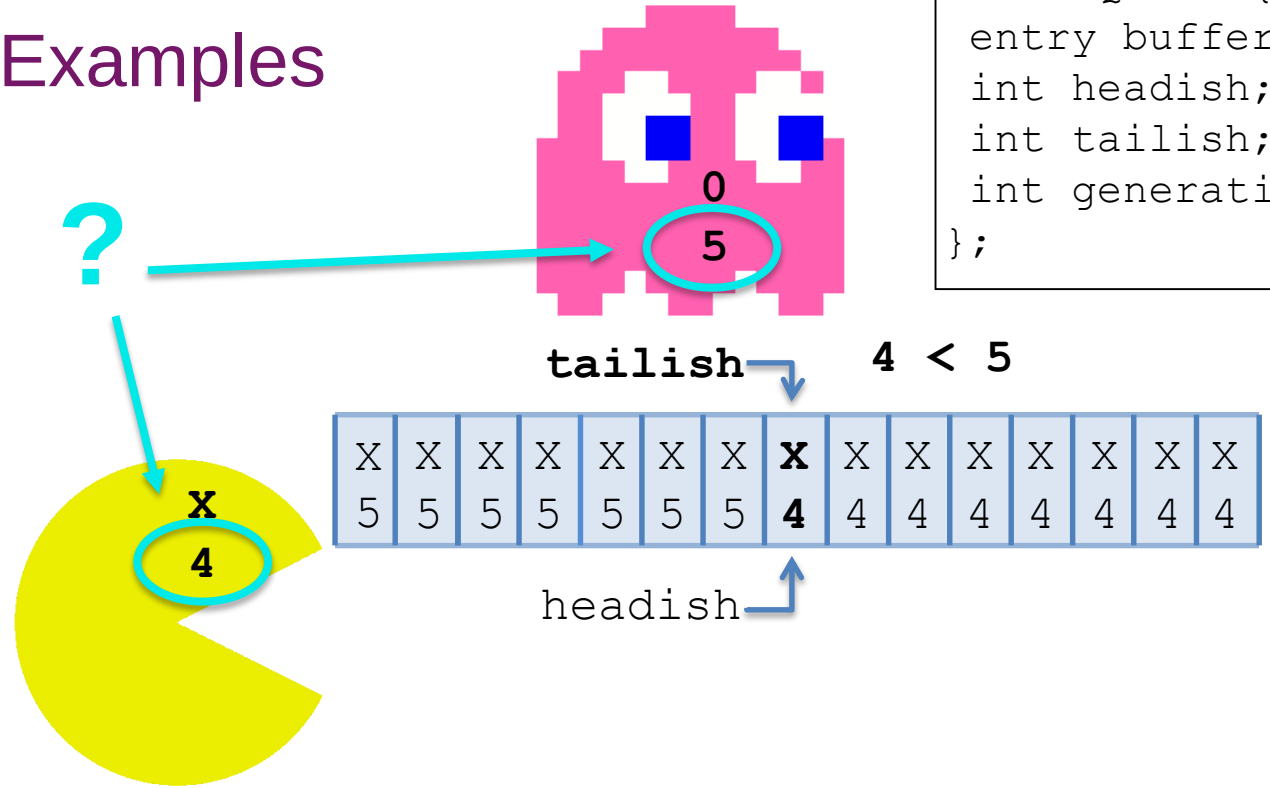
X	X	X	X	X	X	X	**X**	X	X	X	X	X	X	X
5	5	5	5	5	5	5	**4**	4	4	4	4	4	4	4

headish



Queue is Full!

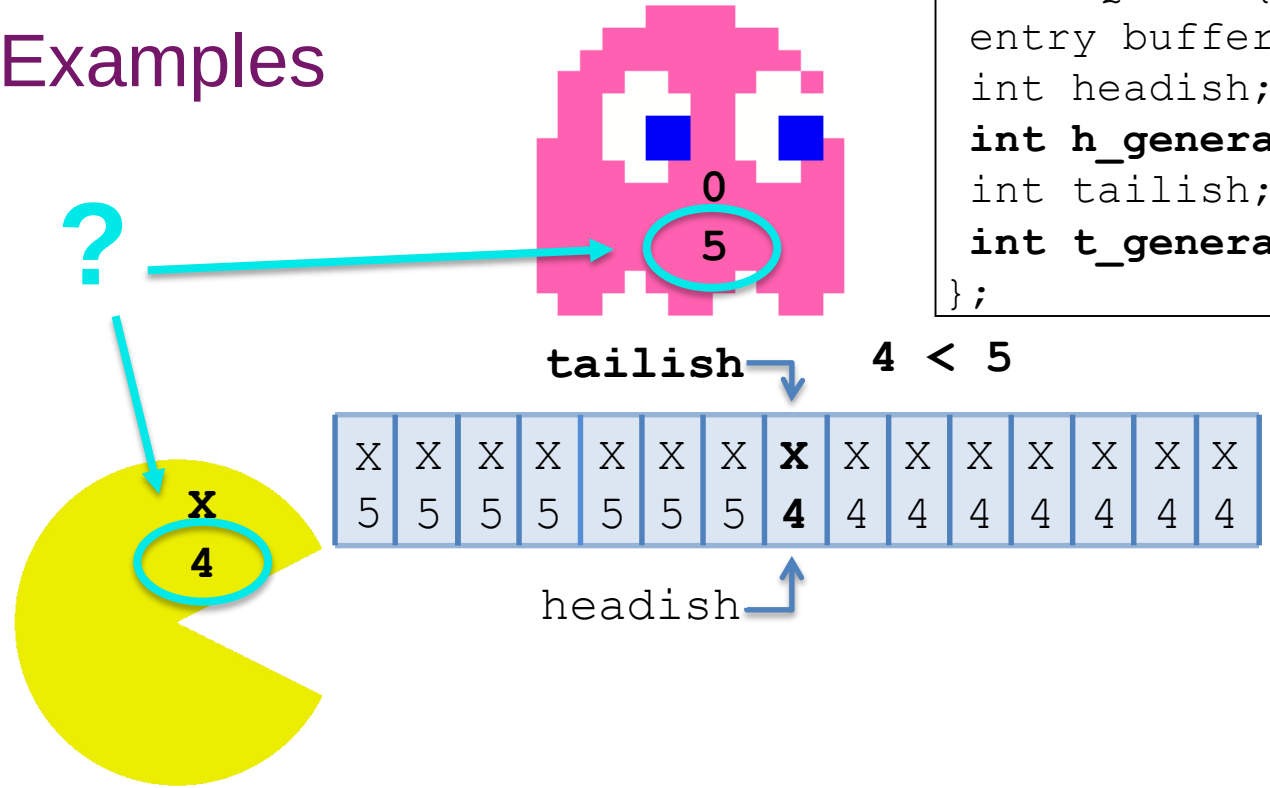
Examples




```
class Queue {
 entry buffer[SIZE];
 int headish;
 int tailish;
 int generation;
};
```

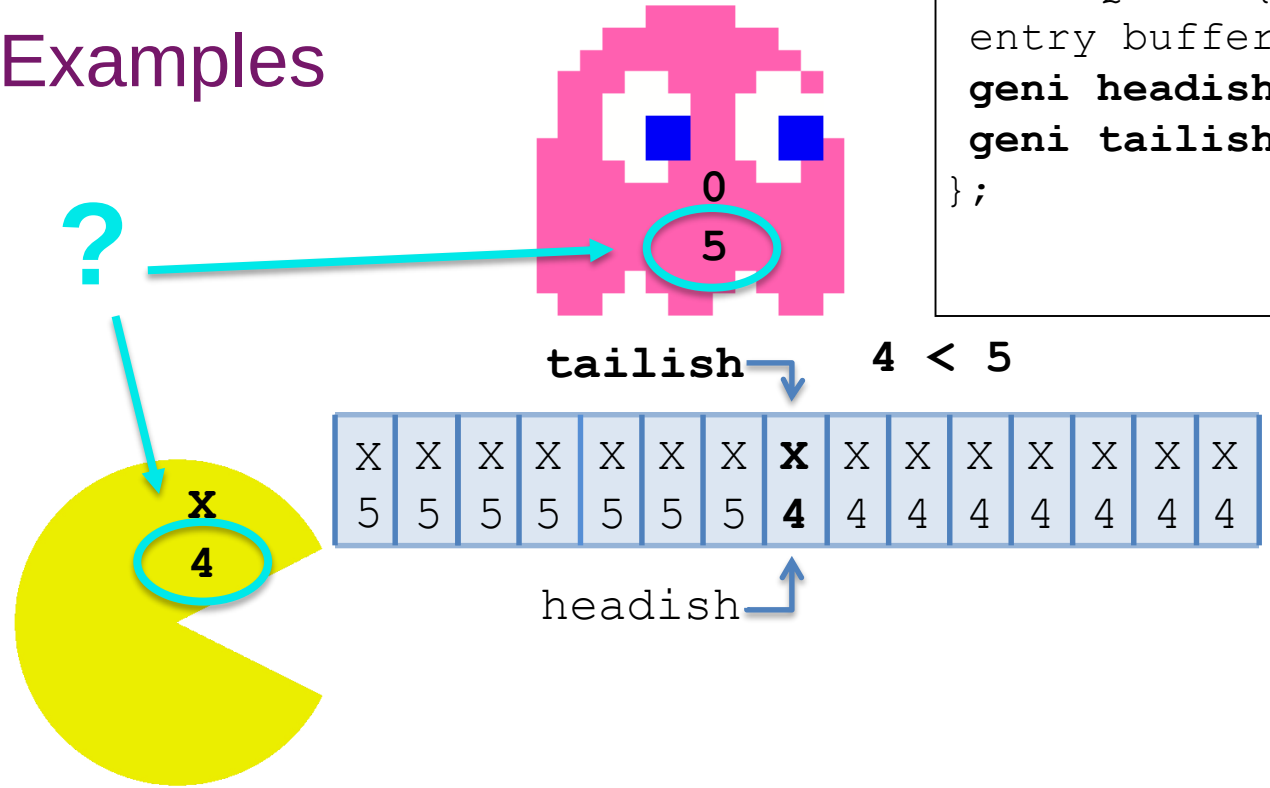
Queue is Full!

Examples




```
class Queue {
 entry buffer[SIZE];
 int headish;
 int h_generation;
 int tailish;
 int t_generation;
};
```

Examples

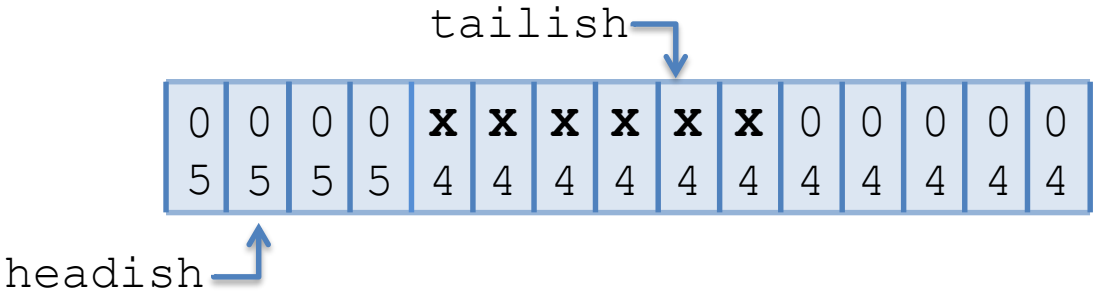



```
class Queue {
 entry buffer[SIZE];
 geni headish;
 geni tailish;
};
```

```
struct geni {
 int val, gen;
 void incr()
 { if (++val%SIZE == 0)
   {   val = 0;
       gen++;
   }
 }
 operator int() {
    return val; }
 operator<() = default;
 bool is_data(int g)
 { return val != 0
       && gen == g; }
 bool is_zero(int g)
 { return val == 0
       && gen == g; }
};
```

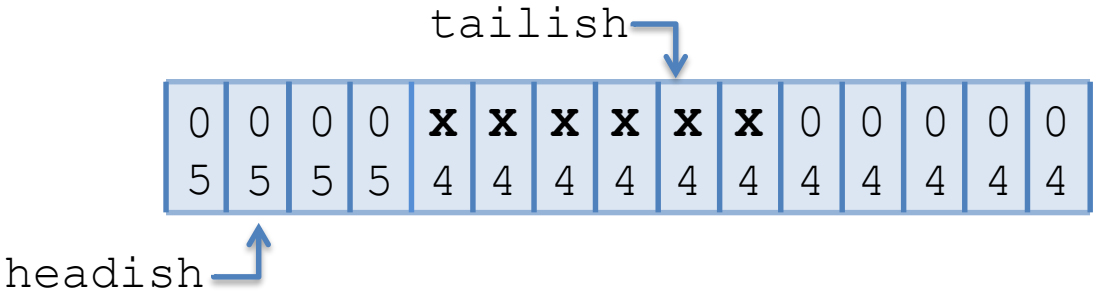
Atomicization!

```
class Queue {
 entry buffer[SIZE];
 geni headish;
 geni tailish;
};
```



Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 geni headish;
 geni tailish;
};
```

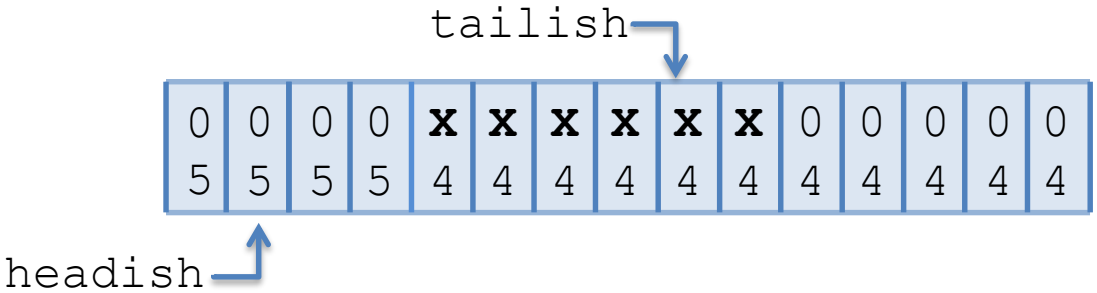


Atomicization

small enough

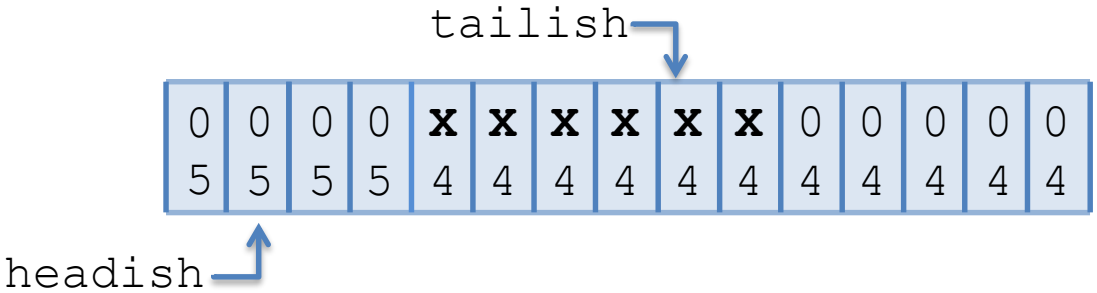
```
struct entry {
 int data;
 int generation;
};
```

```
class Queue {
 atomic<entry> buffer[SIZE];
 geni headish;
 geni tailish;
};
```



Atomicization

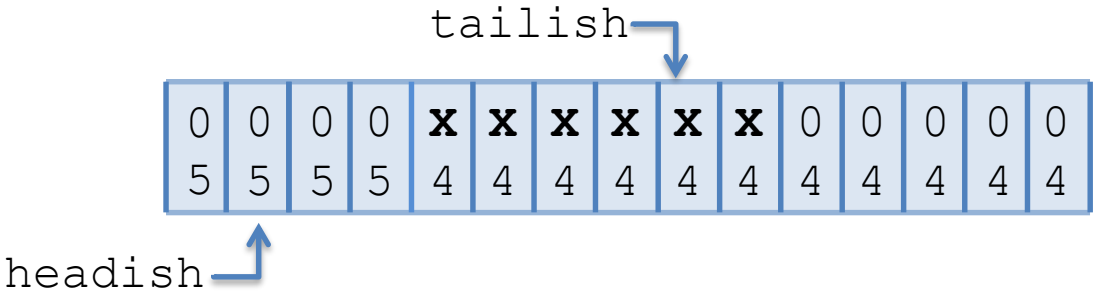
```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 laxtomic<geni> tailish;
};
```



Atomicization

?

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 laxtomic<geni> tailish;
};
```



Atomicization

?

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 laxtomic<geni> tailish;
};
```

Sorry Herb…

0	0	0	0	**X**	**X**	**X**	**X**	**X**	**X**	0	0	0	0	0
5	5	5	5	4	4	4	4	4	4	4	4	4	4	4

headish

Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 laxtomic<geni> tailish;
};
```

```
template <typename T> struct laxtomic : atomic<T> {
   …function name…(…, memory_order = memory_order_relaxed){…}
};
```

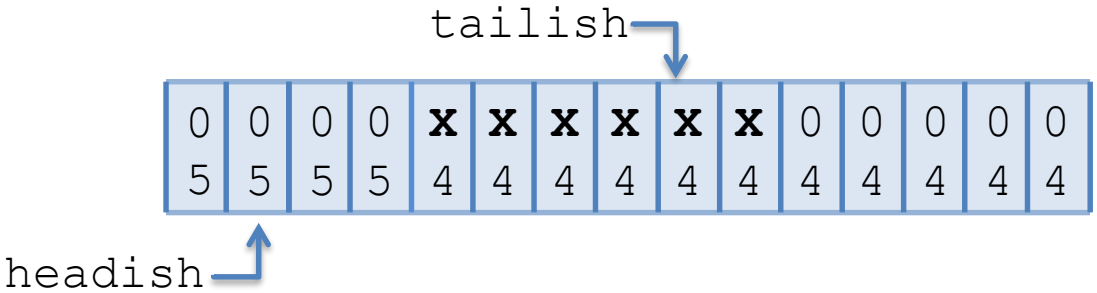
0	0	0	0	**X**	**X**	**X**	**X**	**X**	**X**	0	0	0	0	0
5	5	5	5	4	4	4	4	4	4	4	4	4	4	4

headish

Atomicization

OK?

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 laxtomic<geni> tailish;
};
```



Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 geni> tailish;
```

“normal” lock free code

```
data.x = 10;
data.y = 20;
data.ready.store(true,release);
```

x
4

```
if (data.ready.load(acquire))
{
    x = data.x;
    y = data.y;
    ...
}
```

Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 geni> tailish;
```

“normal” lock free code

```
data.x = 10;
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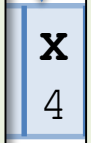



```
if (data.ready.load(acquire))
{
   x = data.x;
   y = data.y;
   ...
}
```

Atomicization

OK?

"normal" lock free code

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 geni> tailish;
```

```
data.x = 10;
data.y = 20;
data.ready.store(true,release);
data.x = 10; // can't happen!
```

x
4

```
   x = data.x; // can't happen!
if (data.ready.load(acquire))
{
   x = data.x;
   y = data.y;
   ...
}
```

Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 geni> tailish;
```

“normal” lock free code

```
data.x = 10;
data.y = 20;
data.ready.store(true,release);
data.x = 10; // can't happen!
```

release:
before means before

x
4

```
   x = data.x; // can't happen!
if (data.ready.load(acquire))
{
   x = data.x;
   y = data.y;
   ...
}
```

acquire:
after means after

Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 geni> tailish;
```

relaxed lock free code

```
data.x = 10;
data.y = 20;
data.ready.store(true,mo_relax);
data.x = 10; // CAN happen!
```

x
4

```
   x = data.x; // CAN happen!
if (data.ready.load(mo_relax))
{
   x = data.x;
   y = data.y;
   ...
}
```

Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 geni> tailish;
```

“normal” lock free code

```
data.x = 10;
data.y = 20;
data.ready.store(true,release);
data.x = 10; // can't happen!
```

x
4

```
x = data.x; // can't happen!
if (data.ready.load(acquire))
{
  x = data.x;
  y = data.y;
  ...
```

there is a *relationship* between `ready` and the other data

Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 geni> tailish;
```

relaxed lock free code

```
data.x = 10;
data.y = 20;
data.ready.store(true,mo_relax);
data.x = 10; // CAN happen!
```

x
4

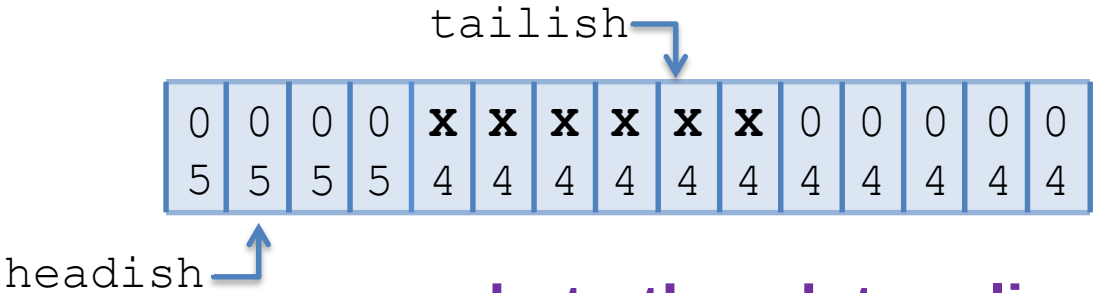
```
x = data.x; // CAN happen!
if (data.ready.load(mo_relax))
{
 x = data.x;
 y = data.y;
 ...
```

there is *no relationship* between `ready` and the other data

Atomicization

OK?

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 laxtomic<geni> tailish;
};
```

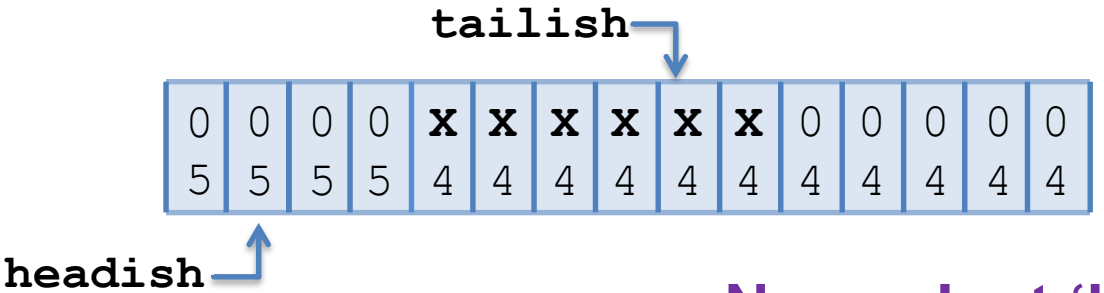


what other data relies on head/tail?

Atomicization

OK

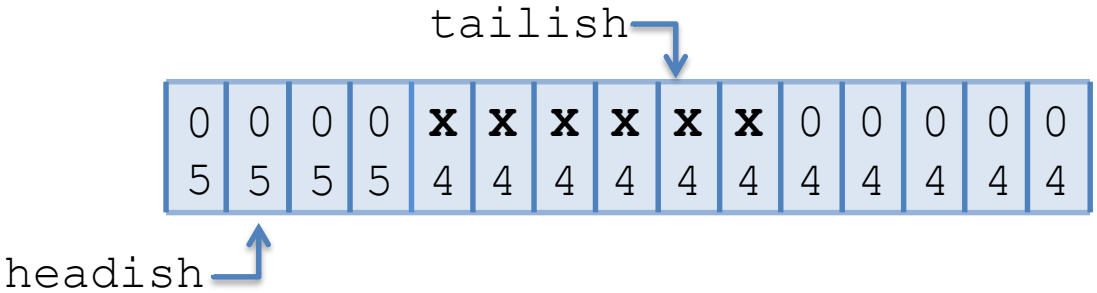
```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 laxtomic<geni> tailish;
};
```



None. Just ‘hints’.

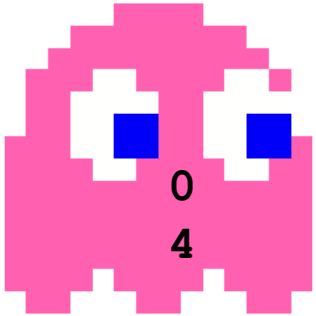
Atomicization

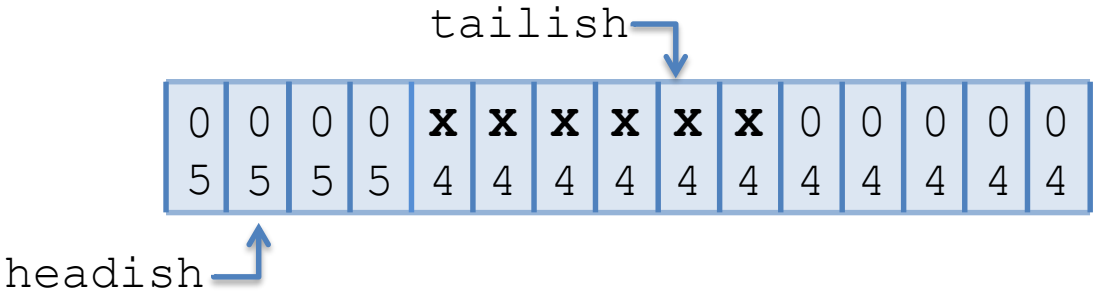
```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 laxtomic<geni> tailish;
};
```



Codization

```
void push(int val) {
  …
}
```





0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

0	0	0	0	0	0	0	0	0	0	**x**	**x**	**x**	**x**	**x**
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

x	**x**	**x**	**0**	0	0	0	0	0	0	0	0	0	0	0
4	4	4	**4**	4	4	4	4	4	4	4	4	4	4	4

x	**x**	**x**	**0**	0	0	0	0	0	0	**x**	**x**	**x**	**x**	**x**
5	5	5	**5**	5	5	5	5	5	5	**4**	4	4	4	4

0	0	0	0	**x**	**x**	**x**	**x**	**x**	**x**	**0**	0	0	0	0
5	5	5	5	**4**	4	4	4	4	4	**4**	4	4	4	4

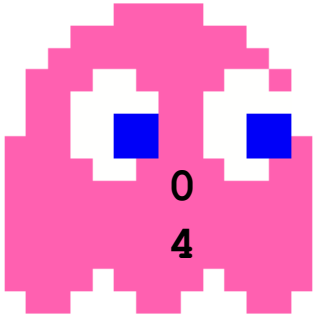
x	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

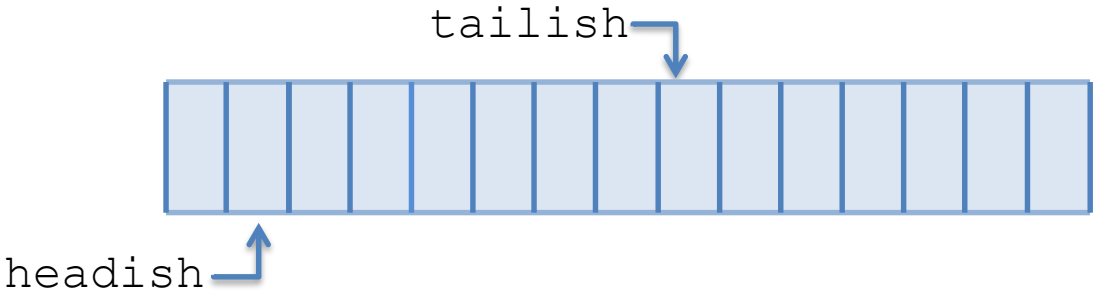
0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

x	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Codization

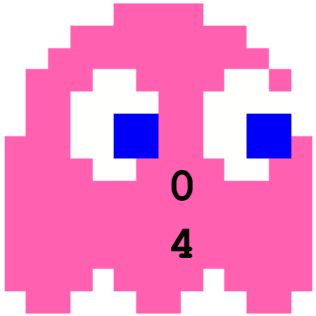
```
void push(int val) {
  …
}
```

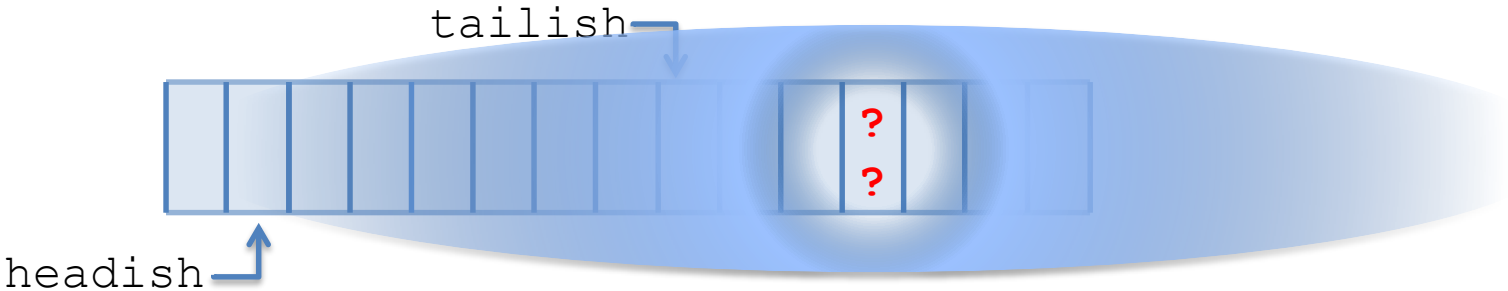




Codization

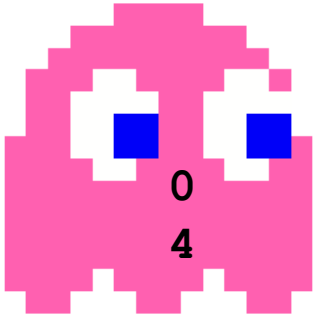
```
void push(int val) {
  …
}
```

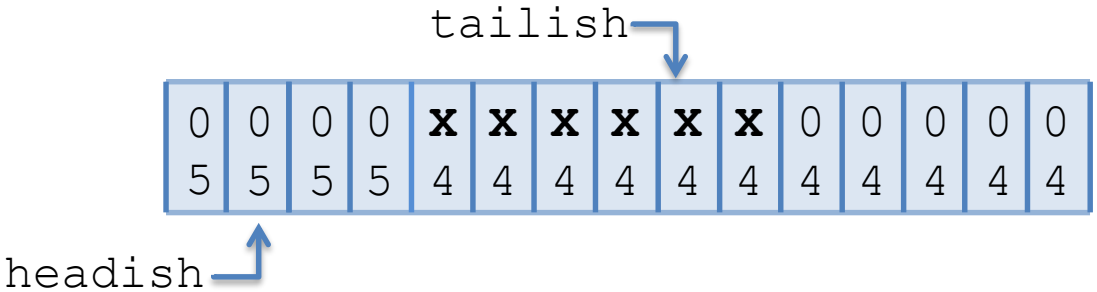




Codization

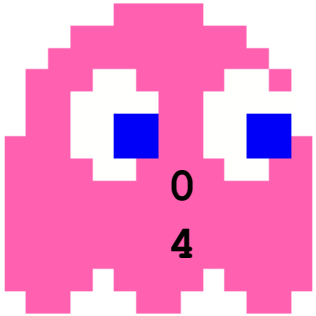
```
void push(int val) {
  …
}
```

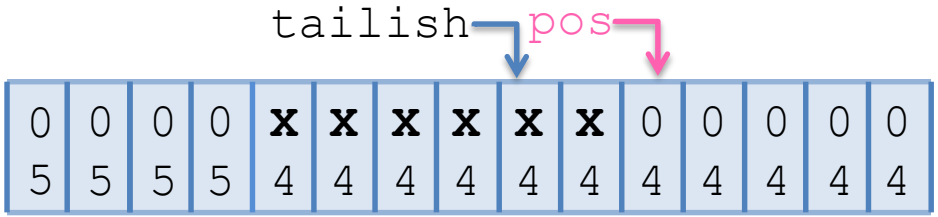




Codization

```
void push(int val) {
  geni pos = find_tail(tailish);
  write_value(pos, val);
}
```





Codization

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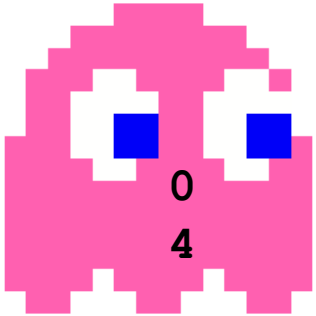

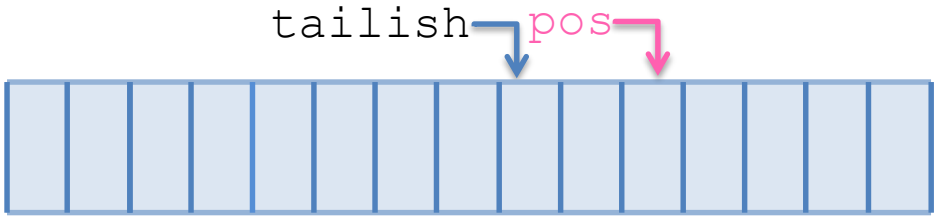

Codization

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void push(int val) {
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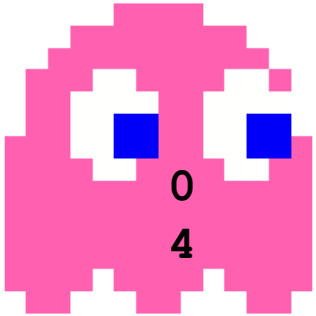
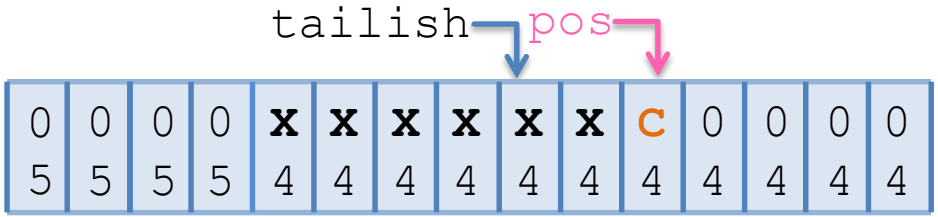
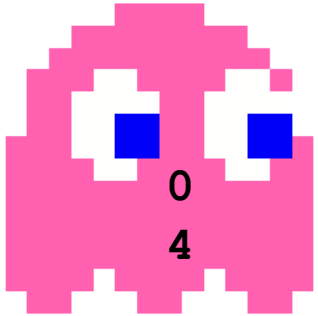
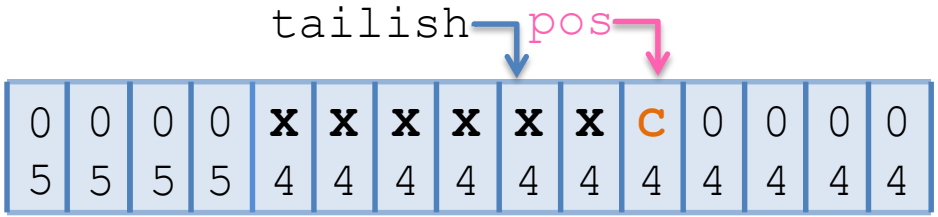
}
```

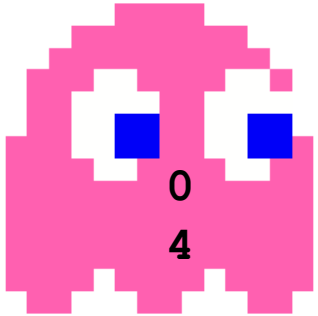







```
void push(int val) {
  do {
    pos = find_tail(tailish);
  } while (!try_write_value(pos, val));
}
```



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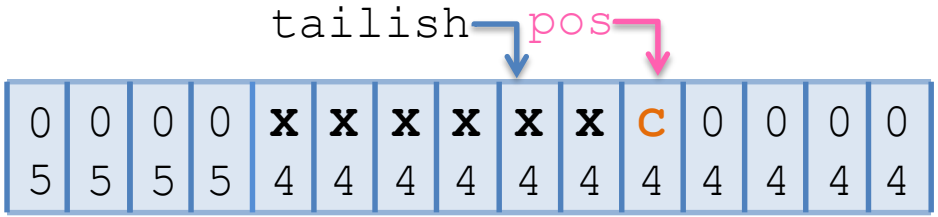
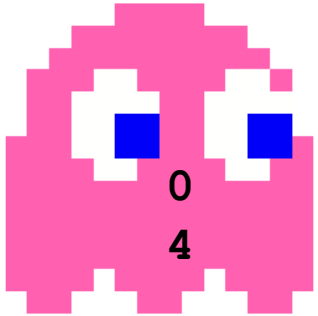


The nature of “lock-free” – you fail ***only*** when someone else makes progress

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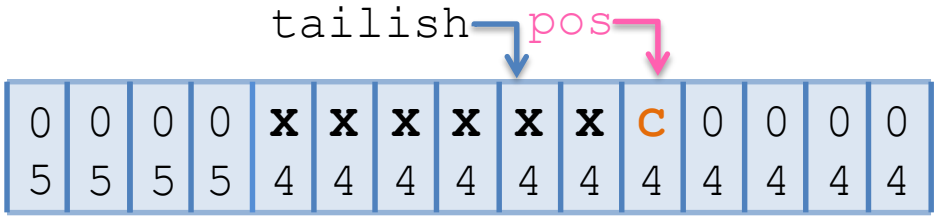
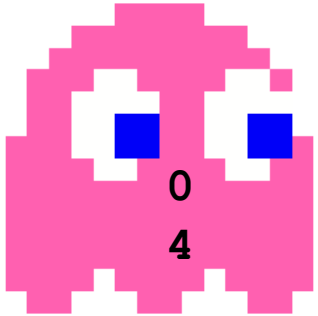
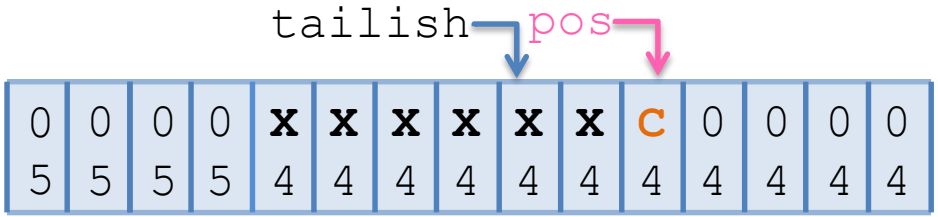
  do {
    pos = find_tail(tailish);
  } while (!try_write_value(pos, val));
}
```

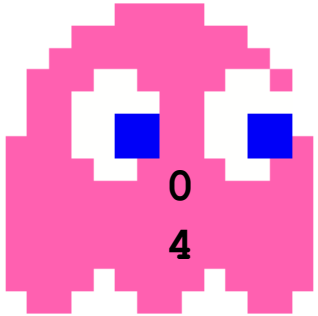


CAS loop: loops on progress
Spin-lock: loops on progress and NON progress




```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
}
```



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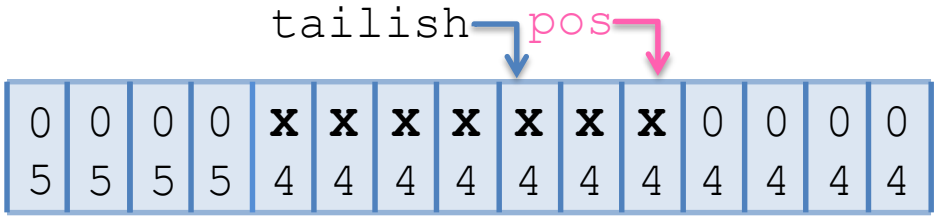
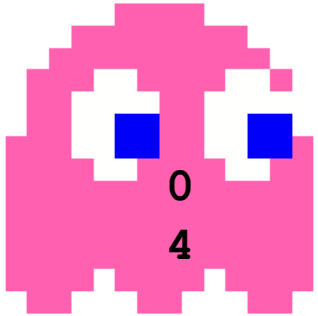



```
bool is_zero(entry e, int gen) {
   return e.data == 0 && e.gen == gen;
}
```

```
geni find_tail(geni pos) {
   while( ! is_zero(buffer[pos.val].load(relaxed), pos.gen) )
       pos++;
   return pos;
}
```

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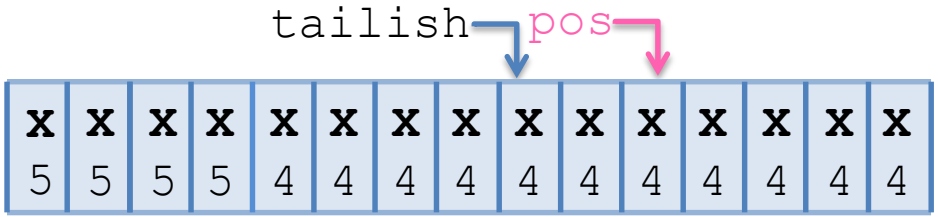
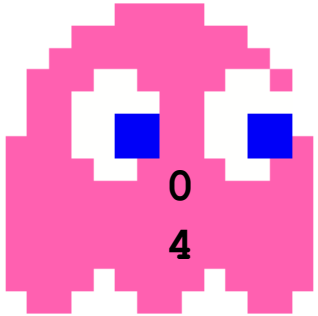


Queue is FULL

```
bool is_zero(entry e, int gen) {
   return e.data == 0 && e.gen == gen;
}
```

```
geni find_tail(geni pos) {
   while( ! is_zero(buffer[pos.val].load(relaxed), pos.gen) )
       pos++;
   return pos;
}
```

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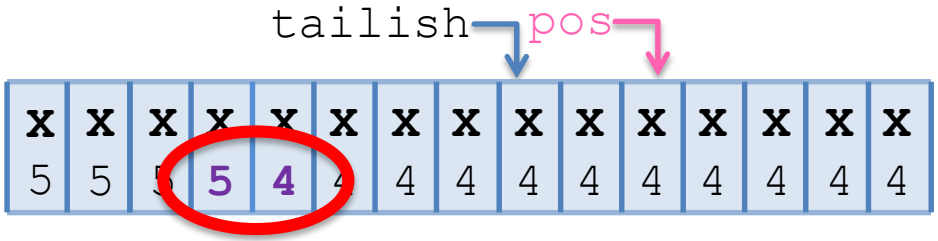

Queue is FULL

```
bool is_tail(entry e, int gen) {
   return e.data == 0 && e.gen == gen
          || e.data  != 0 && e.gen < gen;
}
```

```
geni find_tail(geni pos) {
   while( ! is_tail(buffer[pos.val].load(relaxed), pos.gen) )
       pos++;
   return pos;
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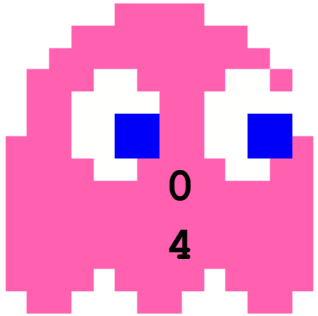
```

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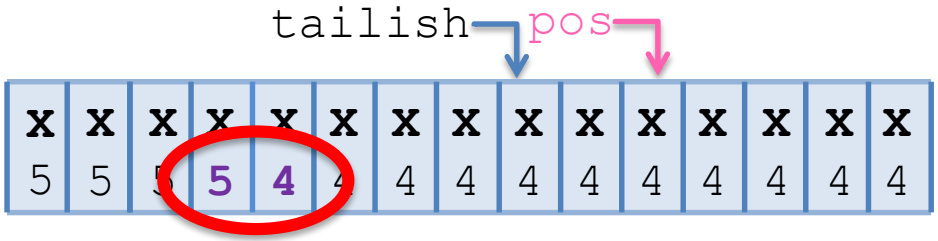

Queue is FULL

```
bool is_tail(entry e, int gen) {
  return e.data == 0  ?
        e.gen == gen  :  e.gen < gen;
}
```

```
geni find_tail(geni pos) {
  while( ! is_tail(buffer[pos.val].load(relaxed), pos.gen) )
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  return pos;
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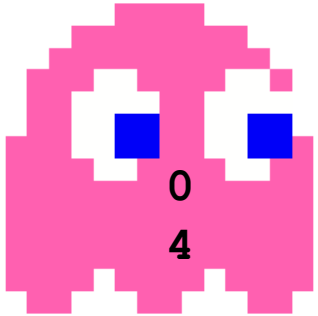


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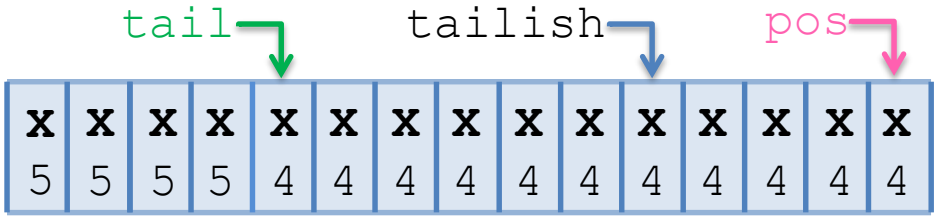

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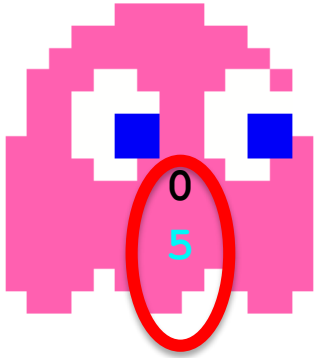


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Queue is FULL

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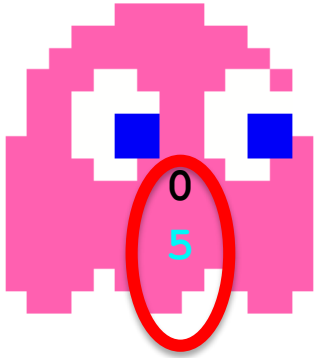


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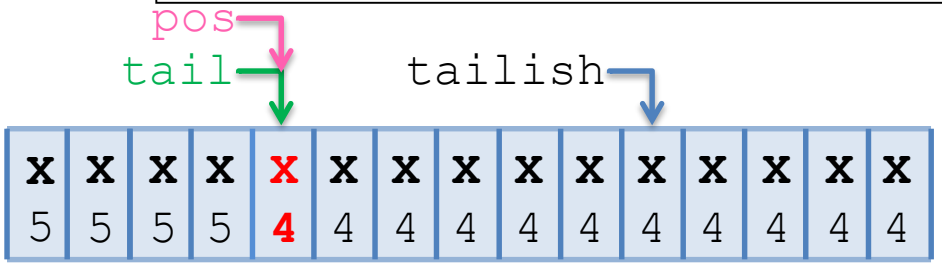

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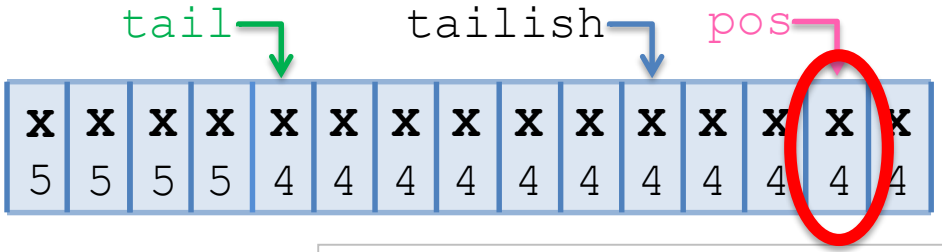

Queue is FULL

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  return e.data == 0 && e.gen == gen
        || e.data  != 0 && e.gen < gen;
}
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geni find_tail(geni pos) {
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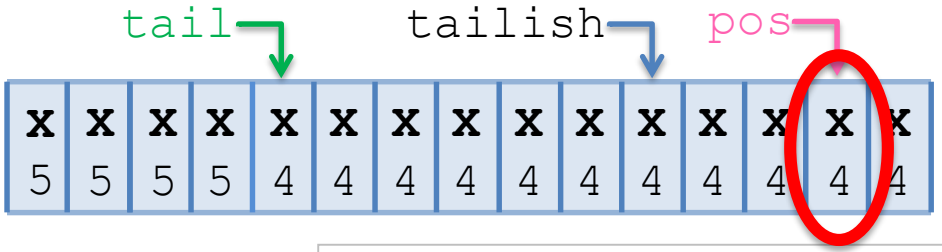
```


```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
}
```



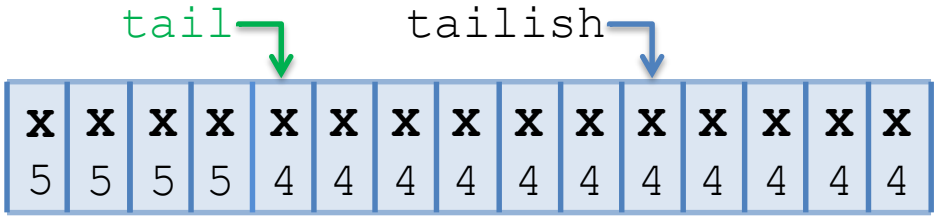
Queue is FULL

```
bool maybe_tail(entry e, int gen) {
  return e.data == 0 && e.gen == gen
         || e.data  != 0 && e.gen < gen;
}
```

```
geni find_tail(geni pos) {
  while(!maybe_tail(buffer[pos.val].load(relaxed), pos.gen))
      pos++;
  return pos;
}
```


```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
}
```

INVARIANT:
tailish <= real tail



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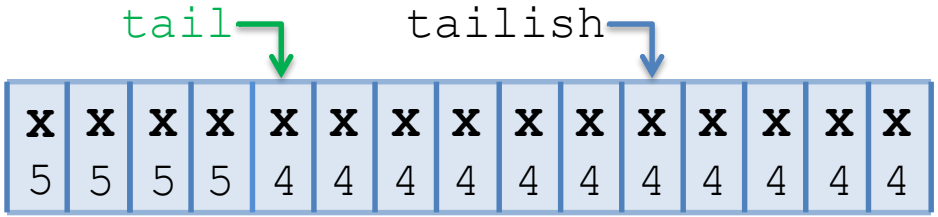
Exercise for the reader:

Don't loop on FULL. Either:
- have push() return false
- *wait* for non full.



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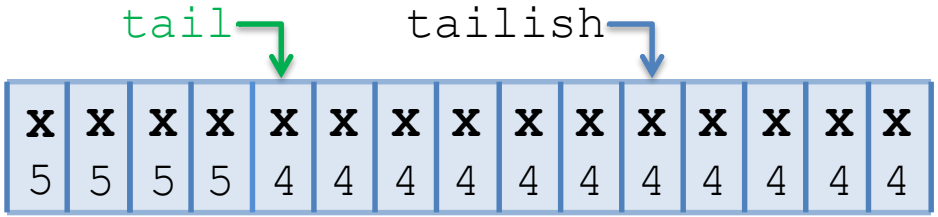
}
```

```
geni find_tail(geni pos) { // precond: pos <= tail
  while(!maybe_tail(buffer[pos.val].load(relaxed), pos.gen)
      pos++;
  return pos;
}
```


```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos, full);
    if (full) …
  } while (!try_write_value(pos, val));
}
```

Exercise for the reader:

Don't loop on FULL. Either:
- have push() return false
- *wait* for non full.



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```
geni find_tail(geni pos) { // precond: pos <= tail
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      pos++;
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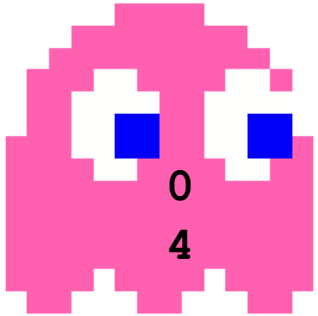
}
```

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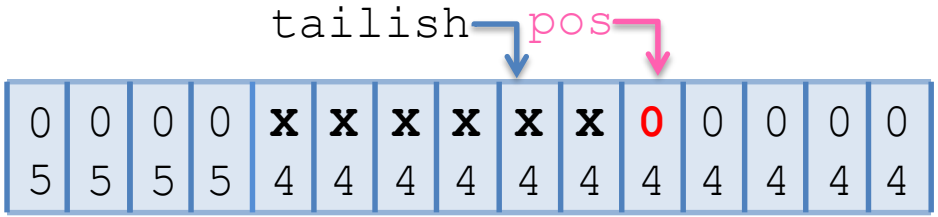
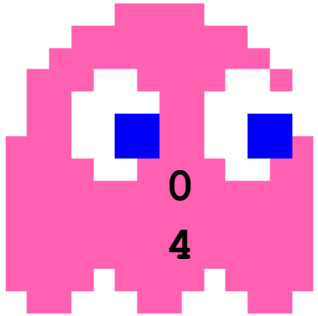



```
bool try_write_value(geni pos, int val) {



}
```

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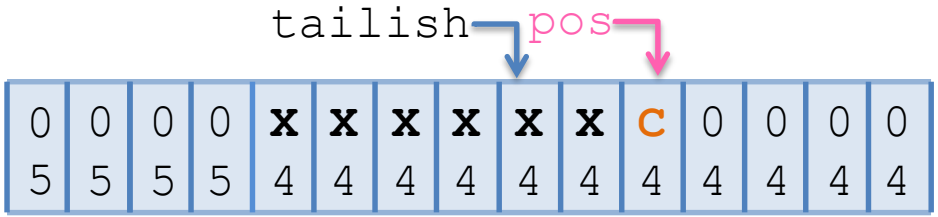
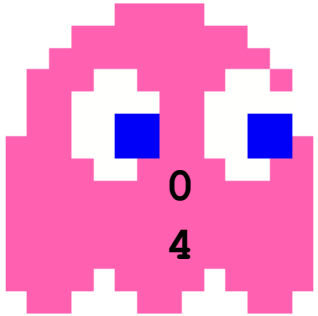


```
bool try_write_value(geni pos, int val) {



}
```

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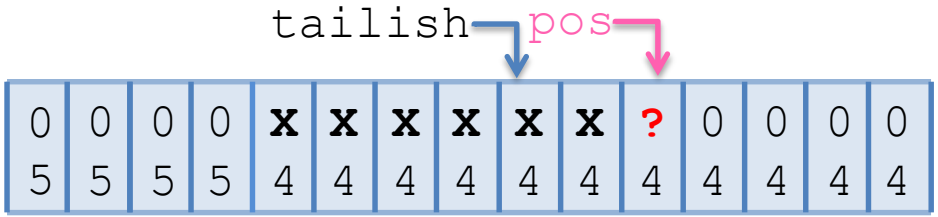
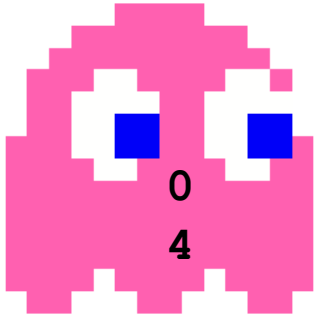
}
```




```
bool try_write_value(geni pos, int val) {
   entry old{0, pos.gen};
   entry nu{val, pos.gen};
   return buffer[pos].compare_exchange_weak(old, nu, release, relaxed);
}
```

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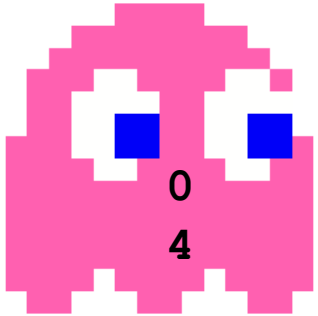
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
}
```

```
bool maybe_tail(entry e, int gen) {
   return e.data == 0 && e.gen == gen
          || e.data  != 0 && e.gen < gen;
}
```

```
geni find_tail(geni pos) { // precond: pos <= tail
   while(!maybe_tail(buffer[pos.val].load(relaxed), pos.gen))
       pos++;
   return pos;
}
```

```
bool try_write_value(geni pos, int val) {
   entry old{0, pos.gen};
   entry nu{val, pos.gen};
   return buffer[pos].compare_exchange_weak(old, nu, release, relaxed);
}
```




```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
  // ???
}
```

```
bool maybe_tail(entry e, int gen) {
   return e.data == 0 && e.gen == gen
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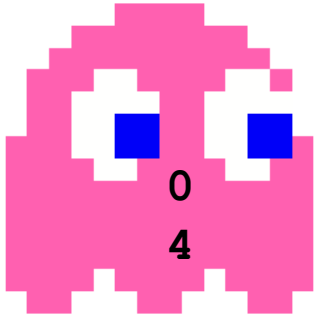
}
```

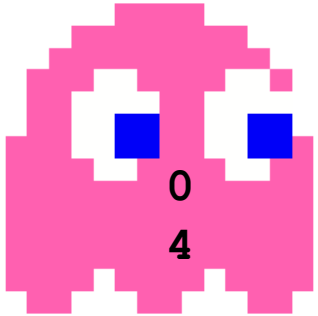



```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
  update_tailish(tailish, pos);
}
```

```
bool maybe_tail(entry e, int gen) {
   return e.data == 0 && e.gen == gen
          || e.data  != 0 && e.gen < gen;
}
```

```
geni find_tail(geni pos) { // precond: pos <= tail
   while(!maybe_tail(buffer[pos.val].load(relaxed), pos.gen))
       pos++;
   return pos;
}
```

```
bool try_write_value(geni pos, int val) {
   entry old{0, pos.gen};
   entry nu{val, pos.gen};
   return buffer[pos].compare_exchange_weak(old, nu, release, relaxed);
}
```




```
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  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
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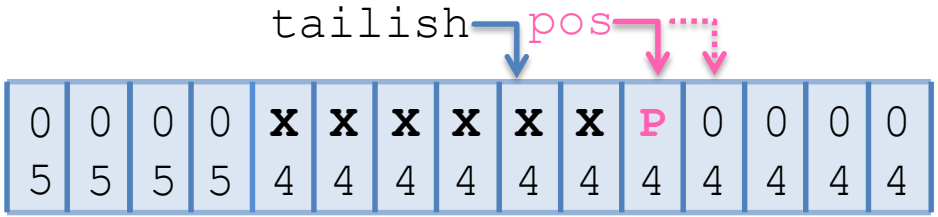
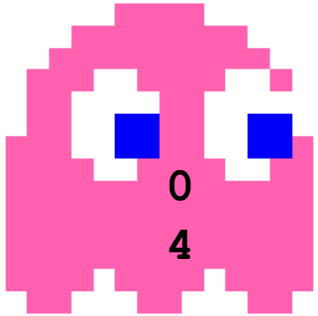
}
```



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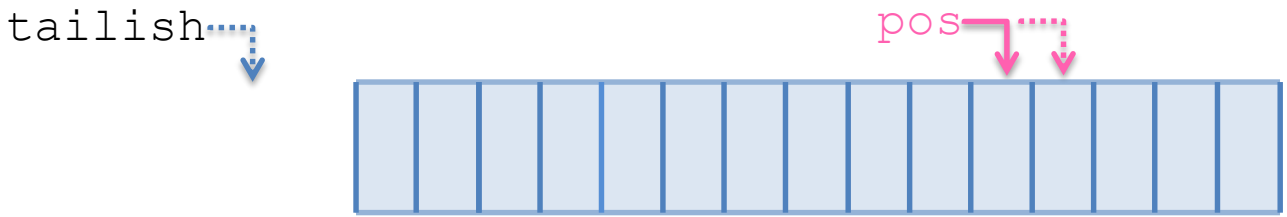
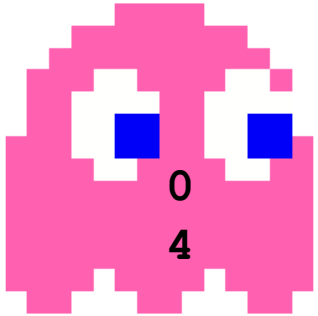
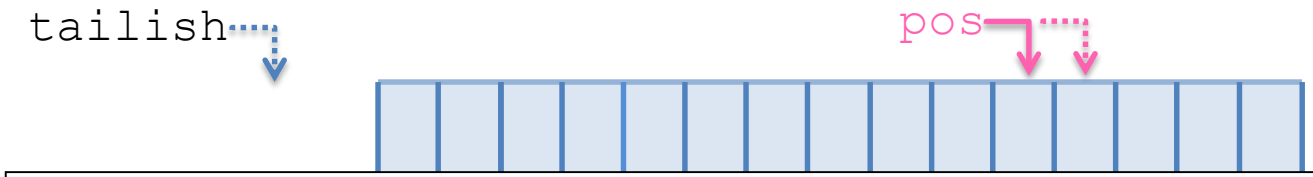
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
  update_tailish(tailish, ++pos);
}
```

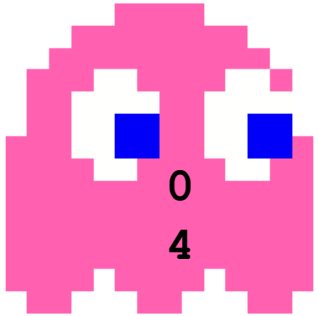




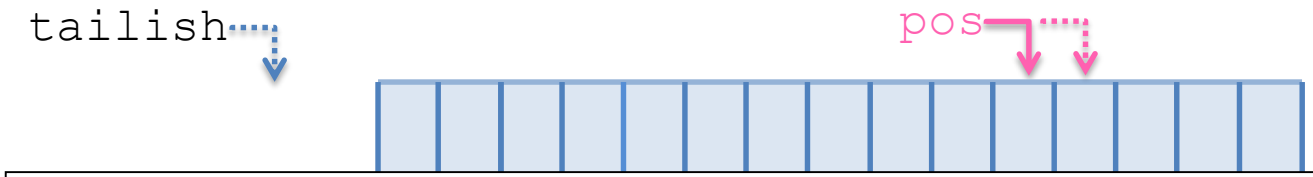

```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
  update_tailish(tailish, ++pos);
}
```



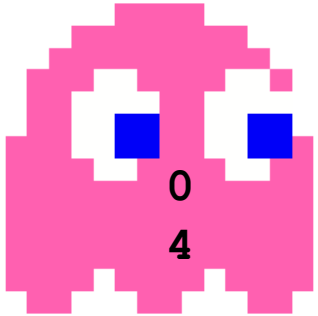

```
tailish.compare_exchange(oldtailish, pos); // relaxed (in theory)
```



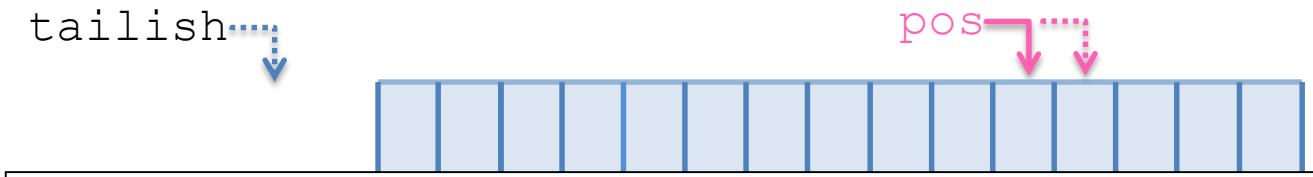

```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
  update_tailish(tailish, ++pos);
}
```



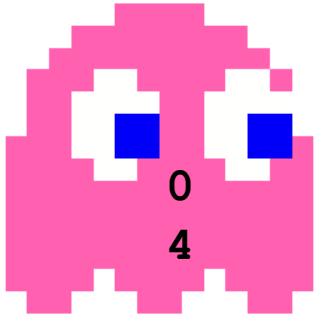

```
tailish.compare_exchange(oldtailish, pos); // relaxed (in theory)
---
geni recent = tailish;
while (recent < pos && !tailish.compare_exchange(recent, pos)) //(recent is updated each loop)
    ;
```



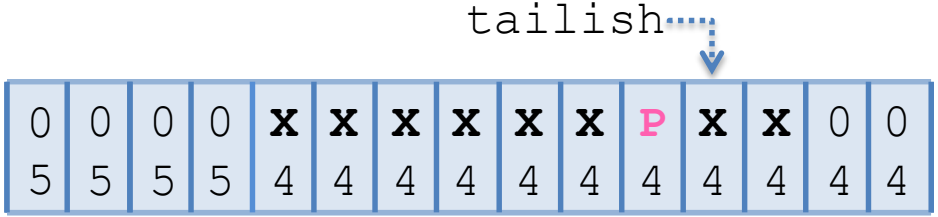

```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
  update_tailish(tailish, ++pos);
}
```

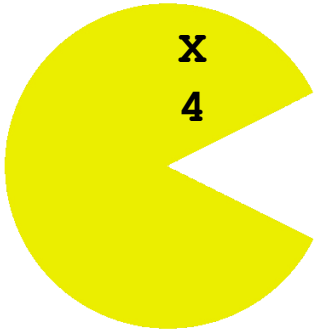



```
tailish.compare_exchange(oldtailish, pos); // relaxed (in theory)
---
geni recent = tailish;
while (recent < pos && !tailish.compare_exchange(recent, pos)) //(recent is updated each loop)
    ;
---
tailish = pos;  // relaxed (from Sebastian Redl)
```




```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
  } while (!try_write_value(pos, val));
  tailish = pos+1;  // thanks Sebastian
}
```

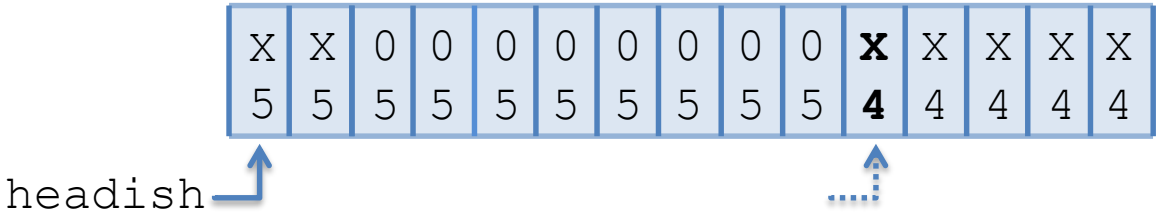




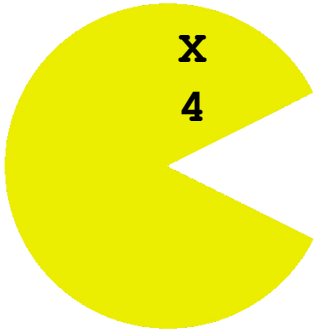

```
int pop() {



}
```



First non-zero data **of correct generation**




```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
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  tailish = pos+1;  // thanks Sebastian
}
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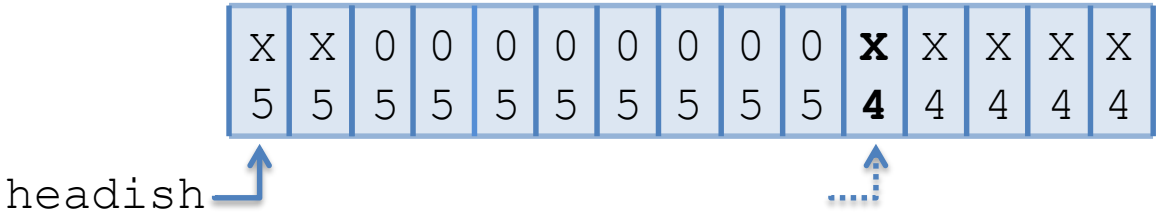

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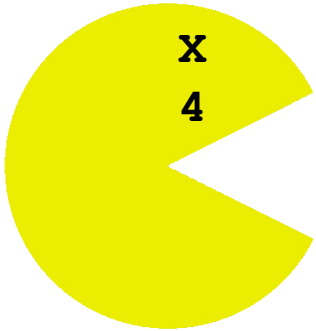
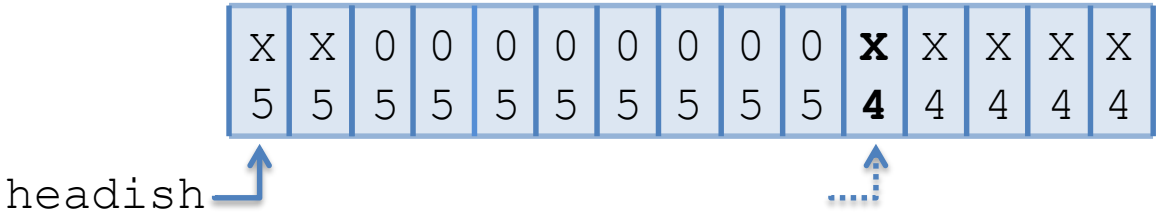



```
int pop() {
  entry ent;
  geni pos = headish; // relaxed load
  do {
    pos = find_head(pos, ent);
  } while (!try_remove_value(pos, ent));
  headish = pos+1;  // thanks Sebastian
  return ent.val;
}
```



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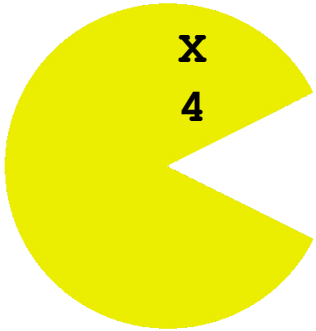


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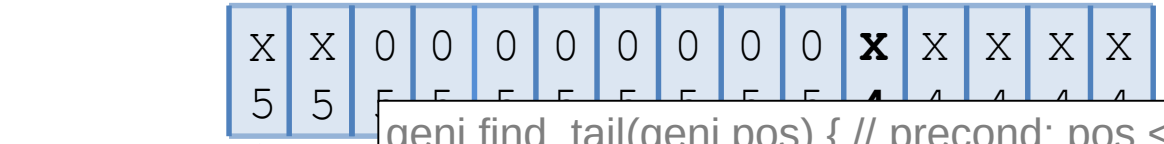
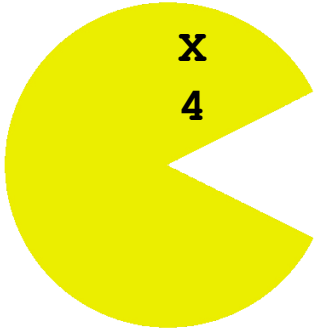


First non-zer

```
geni find_tail(geni pos) { // precond: pos <= tail
  while(!maybe_tail(buffer[pos.val].load(relaxed), pos.gen))
      pos++;
  return pos;
}
```

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int pop() {
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  geni pos = headish; // relaxed load
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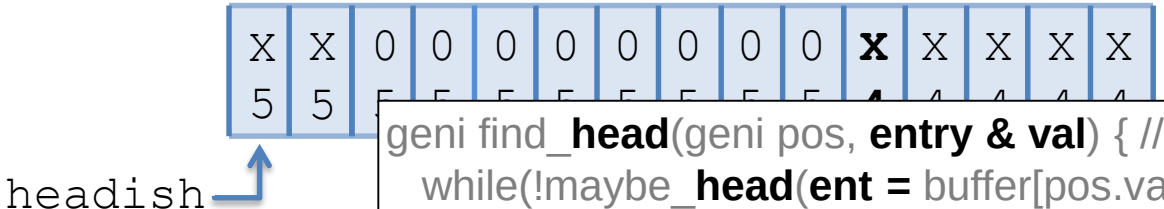
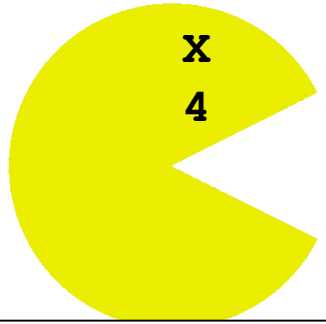



```
geni find_head(geni pos, entry & val) { // precond: pos <= head
  while(!maybe_head(ent = buffer[pos.val].load(relaxed), pos.gen))
      pos++;
  return pos;
}
```

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  adish = pos+1;  // thanks Sebastian
  turn ent.val;
```

```
bool maybe_tail(entry e, int gen) {
  return e.data == 0 && e.gen == gen
       || e.data  != 0 && e.gen < gen;
}
```

X	X	0	0	0	0	0	0	0	0	**X**	X	X	X	X
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

headish

First non-zer

```
geni find_head(geni pos, entry & val) { // precond: pos <= head
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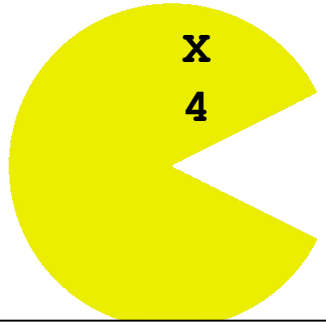
    pos++;
  return pos;
}
```

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  adish = pos+1;  // thanks Sebastian
  turn ent.val;
```

```
bool maybe_head(entry e, int gen) {
  return e.data != 0 && e.gen == gen
       || e.data  == 0 && e.gen < gen;
}
```

X	X	0	0	0	0	0	0	0	0	**X**	X	X	X	X
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

headish

First non-zer

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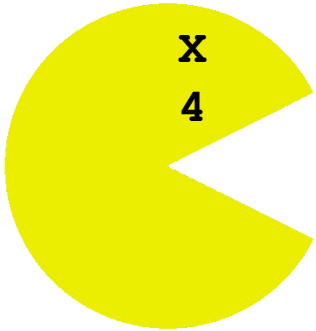


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  return ent.val;
}
```

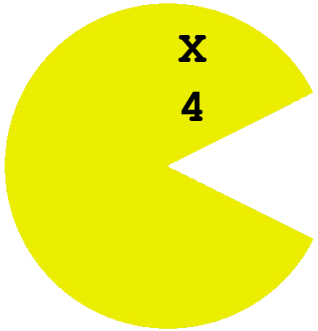
X	X	0	0	0	0	0	0	0	0	**X**	X	X	X	X
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

headish

First

```
bool try_remove_value(geni pos, entry old) {

  entry nu{0, pos.gen};
  return buffer[pos].compare_exchange_weak(old, nu, acquire, relaxed);
}
```

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  } while (!try_remove_value(pos, ent));
  headish = pos+1;  // thanks Sebastian
  return ent.val;
}
```

X	X	0	0	0	0	0	0	0	0	**X**	X	X	X	X
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

headish

First

```
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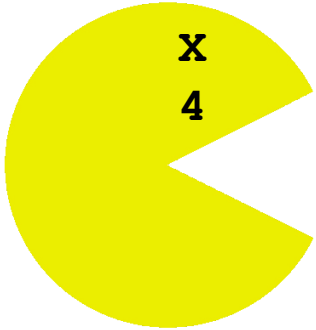
?




```
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  do {
    pos = find_head(pos, ent);
  } while (!try_remove_value(pos, ent));
  headish = pos+1;  // thanks Sebastian
  return ent.val;
}
```

X	X	0	0	0	0	0	0	0	0	**X**	X	X	X	X
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

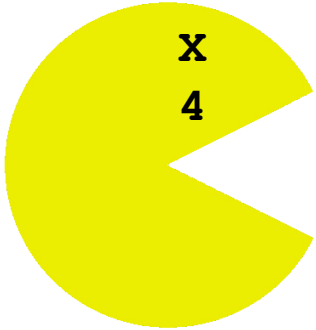
headish

First

```
bool try_remove_value(geni pos, entry old) {

  entry nu{0, pos.gen};
  return buffer[pos].compare_exchange_weak(old, nu, acq_rel, relaxed);
}
```

?

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int pop() {
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  geni pos = headish; // relaxed load
  do {
    pos = find_head(pos, ent);
  } while (!try_remove_value(pos, ent));
  headish = pos+1;  // thanks Sebastian
  return ent.val;
}
```

x	x	0	0	0	0	0	0	0	0	**x**	x	x	x	x
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

headish

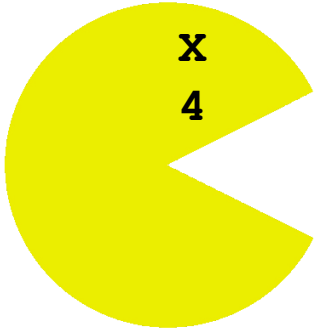
First

Exercise for the reader

```
bool try_remove_value(geni pos, entry old) {

  entry nu{0, pos.gen};
  return buffer[pos].compare_exchange_weak(old, nu, acq_rel, relaxed);
}
```

?




```
int pop() {
  entry ent;
  geni pos = headish; // relaxed lo
  do {
    pos = find_head(pos, ent);
  } while (!try_remove_value(pos,
  headish = pos+1;  // thanks Sebastian
  return ent.val;
}
```

Exercise for the reader:

Don't loop on **EMPTY**. Either:

- have **pop**() return **0**
- *wait* for non **empty**.

X	X	0	0	0	0	0	0	0	0	**X**	X	X	X	X
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

headish

First

Exercise for the reader

```
bool try_remove_value(geni pos, entry old) {

  entry nu{0, pos.gen};
  return buffer[pos].compare_exchange_weak(old, nu, acq_rel, relaxed);
}
```

?

```
void push(int val) {

   geni pos = tailish; // relaxed load
   do {
      pos = find_tail(pos);
      if (FULL) { … }
   } while (!try_write_value(pos, val));
   tailish = pos+1;  // thanks Sebastian

}
geni find_tail(geni pos) { // precond: pos <= tail
  while(!maybe_tail(buff[pos.val].load(relaxed), pos.gen))
      pos++;
  return pos;
}
bool maybe_tail(entry e, int gen) {
   return e.data == 0 && e.gen == gen
         || e.data  != 0 && e.gen < gen;
}
bool try_write_value(geni pos, int val) {
   entry old{0, pos.gen};
   entry nu{val, pos.gen};
   return buffer[pos].c_e_weak(old, nu, release, relaxed);
}
```

```
int pop() {
   entry ent;
   geni pos = headish; // relaxed load
   do {
      pos = find_head(pos, ent);
      if (FULL) { … }
   } while (!try_remove_value(pos, ent));
   headish = pos+1;  // thanks Sebastian
   return ent.val;
}
geni find_head(geni pos, entry & val) { //precond: pos <= head
  while(!maybe_head(ent = buff[pos.val].load(relaxed),pos.gen))
      pos++;
  return pos;
}
bool maybe_head(entry e, int gen) {
   return e.data != 0 && e.gen == gen
         || e.data  == 0 && e.gen < gen;
}
bool try_remove_value(geni pos, entry old) {

   entry nu{0, pos.gen};
   return buffer[pos].c_e_weak(old, nu, acq_rel, relaxed);
}
```

```
void push(int val) {
  geni pos = tailish; // relaxed load
  do {
    pos = find_tail(pos);
    if (FULL) { … }
  } while (!try_write_value(pos, val));
  tailish = pos+1; // thanks Sebastian

}
geni find_tail(geni pos) { // precond: pos <= tail
  while(!maybe_tail(buff[pos.val].load(relaxed), pos.gen))
    pos++;
  return pos;
}
bool maybe_tail(entry e, int gen) {
  return e.data == 0 && e.gen == gen
        || e.data  != 0 && e.gen < gen;
}
bool try_write_value(geni pos, int val) {
  entry old{0, pos.gen};
  entry nu{val, pos.gen};
  return buffer[pos].c_e_weak(old, nu, release, relaxed);
}
```

```
int pop() {
  entry ent;
  geni pos = headish; // relaxed load
  do {
    pos = find_head(pos, ent);
    if (FULL) { … }
  } while (!try_remove_value(pos, ent));
  headish = pos+1;  // thanks Sebastian
  return ent.val;
}
geni find_head(geni pos, entry & val) { //precond: pos <= head
  while(!maybe_head(ent = buff[pos.val].load(relaxed),pos.gen))
    pos++;
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bool maybe_head(entry e, int gen) {
  return e.data != 0 && e.gen == gen
        || e.data  == 0 && e.gen < gen;
}
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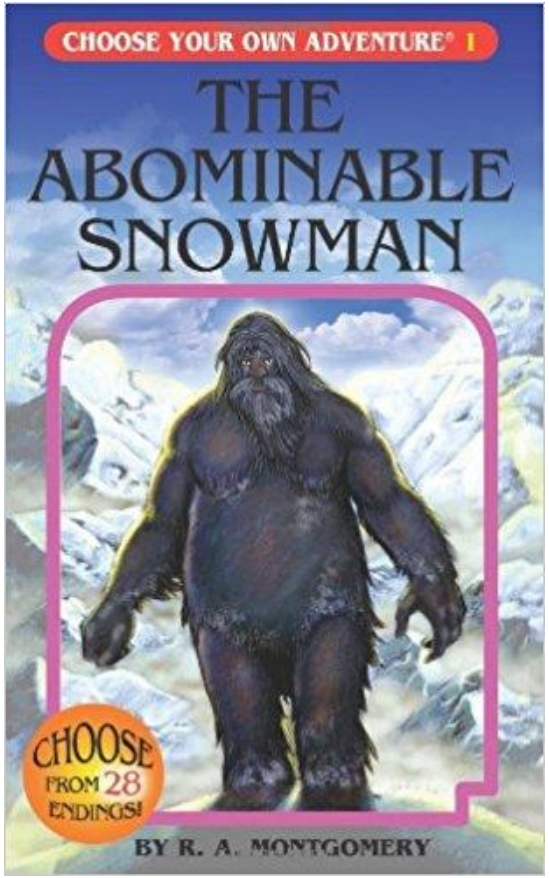
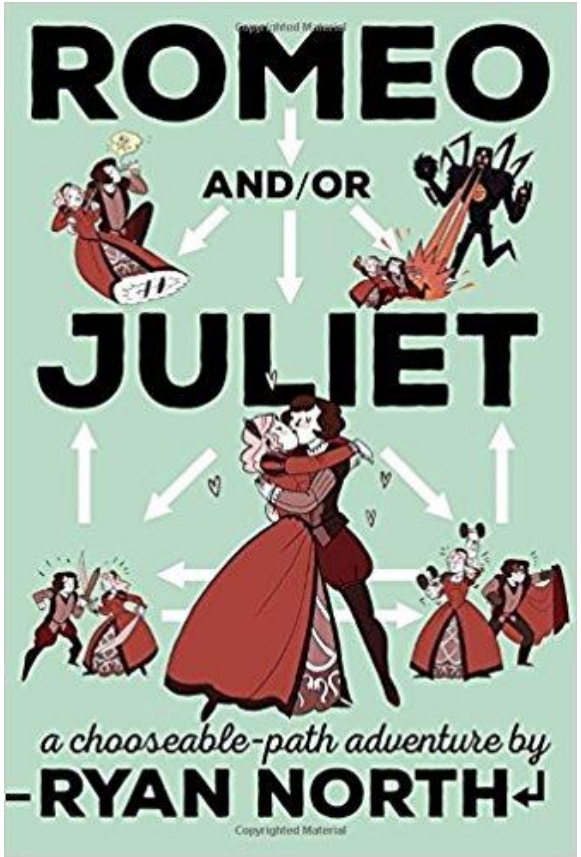
  entry nu{0, pos.gen};
  return buffer[pos].c_e_weak(old, nu, acq_rel, relaxed);
}
```

Choose Your Own Adventure



Chooseable-path Adventure



Choose Your Own Adventure

- Make head/tail *disappear*
- Store non-ints
- Wait on full/empty (with condvar)
- Grow the queue
- Proofs
- *Something else!*

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

0	0	0	0	0	0	0	0	0	0	**x**	**x**	**x**	**x**	**x**
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

x	**x**	**x**	**0**	0	0	0	0	0	0	0	0	0	0	0
4	4	4	**4**	4	4	4	4	4	4	4	4	4	4	4

x	**x**	**x**	**0**	0	0	0	0	0	0	**x**	**x**	**x**	**x**	**x**
5	5	5	**5**	5	5	5	5	5	5	**4**	4	4	4	4

0	0	0	0	**x**	**x**	**x**	**x**	**x**	**x**	**0**	0	0	0	0
5	5	5	5	**4**	4	4	4	4	4	**4**	4	4	4	4

x	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

0	0	0	0	0	0	0	0	0	0	**0**	0	0	0	0
5	5	5	5	5	5	5	5	5	5	**4**	4	4	4	4

x	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

A word about auto

```
auto pos = tailish;
---
geni pos = tailish;
```

A word about auto

```
auto pos = tailish;  // pos is laxtomic<geni>
---
geni pos = tailish;
```

A word about auto

```
auto pos = tailish;  // pos is laxtomic<geni>
---
geni pos = tailish;
---
auto pos = tailish.load();  // pos is geni
```

A word about auto

```
auto pos = tailish;  // pos is laxtomic<geni>
---
geni pos = tailish;
---
auto pos = tailish.load();  // pos is geni

---
Iterator it = v.begin();
```

FCD

FCD

Fear
Certainty
Doubt

Atomicization

```
class Queue {
 atomic<entry> buffer[SIZE];
 laxtomic<geni> headish;
 geni> tailish;
```

“normal” lock free code

```
data.x = 10;
data.y = 20;
data.ready.store(true,release);
```

release:
before means before

x
4

```
if (data.ready.load(acquire))
{
    x = data.x;
    y = data.y;
    ...
}
```

acquire:
after means after

```
int non_atomic_data;
atomic<bool> initialized;


// Thread 1
void init() {
   non_atomic_data = 17;
   initialized.store(true, release);
};
```

```
// User thread
if (initialized.load(acquire)) {
   read(non_atomic_data);
}
```

```
int non_atomic_data;
atomic<bool> initialized;


// Thread 1
void init() {
   non_atomic_data = 17;
   initialized.store(true, release);
};
```

```
// User thread
if (initialized.load(acquire)) {
   read(non_atomic_data);
}
```

```
int non_atomic_data;
atomic<bool> initialized;
atomic<bool> counted; // for accounting

// Thread 1
void init() {
   non_atomic_data = 17;
   initialized.store(true, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (initialized && !counted) {//or acquire/relaxed
      keep_track++;
      counted.store(true, relaxed);
   }
}
```

```
// User thread
if (initialized.load(acquire)) {
   read(non_atomic_data);
}
```

```
int non_atomic_data;
atomic<bool> initialized;
atomic<bool> counted; // for accounting

// Thread 1
void init() {
   non_atomic_data = 17;
   initialized.store(true, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (initialized && !counted) {//or acquire/relaxed
      keep_track++;
      counted.store(true, relaxed);
   }
}
```

```
int non_atomic_data;
enum State { un, initted, counted };
atomic<State> state; // combined!

// Thread 1
void init() {
   non_atomic_data = 17;
   state.store(initted, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

```
int non_atomic_data;
enum State { un, initted, counted };
atomic<State> state; // combined!

// Thread 1
void init() {
   non_atomic_data = 17;
   state.store(initted, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
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```
int non_atomic_data;
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atomic<State> state; // combined!

// Thread 1
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};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

```
// User thread…?
if (initialized.load(acquire)) {
   read(non_atomic_data);
}
```

```
int non_atomic_data;
enum State { un, initted, counted };
atomic<State> state; // combined!

// Thread 1
void init() {
   non_atomic_data = 17;
   state.store(initted, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

```
// User thread
if (state.load(acquire) >= initted) {
   read(non_atomic_data);
}
```

```
int non_atomic_data;
enum State { un, initted =0x1, counted =0x3 };
atomic<State> state; // combined!

// Thread 1
void init() {
   non_atomic_data = 17;
   state.store(initted, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

Equivalently

```
// User thread
if (state.load(acquire) & initted) {
   read(non_atomic_data);
}
```

```
int non_atomic_data;
enum State { un, initted, counted };
atomic<State> state; // combined!

// Thread 1
void init() {
   non_atomic_data = 17;
   state.store(initted, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

```
// User thread
if (state.load(acquire) >= initted) {
   read(non_atomic_data);
}
```

```
int non_atomic_data;
enum State { un, initted, counted };
atomic<State> state; // combined!

// Thread 1
void init() {
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atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

```
// User thread
if (state.load(acquire) >= initted) {
   read(non_atomic_data);
}
```

```
int non_atomic_data;
enum State { un, initted, counted };
atomic<State> state; // combined!

// Thread 1
void init() {
   non_atomic_data = 17;
   state.store(initted, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

```
// User thread
if (state.load(acquire) >= initted) {
   read(non_atomic_data);
}
```

UNDEFINED BEHAVIOUR

```
int non_atomic_data;
enum State { un, initted, counted };
atomic<State> state; // combined!

// Thread 1
void init() {
   non_atomic_data = 17;
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};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

```
// User thread
if (state.load(acquire) >= initted) {
   read(non_atomic_data);
}
```

UNDEFINED BEHAVIOUR

(probably)

```
int non_atomic_data;
enum State { un, initted, counted };
atomic<State> state; // combined!

// Thread 1
void init() {
   non_atomic_data = 17;
   state.store(initted, release);
};

// Thread 2
atomic<int> keep_track;
void accounting() {
   if (state == initted) {
      keep_track++;
      state.store(counted, relaxed);
   }
}
```

```
// User thread
if (state.load(acquire) >= initted) {
   read(non_atomic_data);
}
```

UNDEFINED BEHAVIOUR

(probably)

```
int r1 = *p;
```

This is 2 separate loads, the second depending on the first:

```
int* ptr = read(p);
int r1 = read_at(ptr);
```

“The Problem with Threads”

http://ptolemy.eecs.berkeley.edu/

http://ptolemy.eecs.berkeley.edu/publications/papers/06/problemwithThreads/

“A part of the Ptolemy Project experiment was to see whether **effective software engineering practices** could be developed for an academic research setting. We developed a process that included a code maturity rating system (with four levels, red, yellow, green, and blue), **design reviews**, **code reviews**, **nightly builds**, **regression tests**, and **automated code coverage metrics**. The portion of the kernel that ensured a consistent view of the program structure was written in early 2000, design reviewed to yellow, and code reviewed to green. The **reviewers included concurrency experts**, not just inexperienced graduate students (Christopher Hylands (now Brooks), Bart Kienhuis, John Reekie, and myself were all reviewers). We wrote **regression tests that achieved 100 percent code coverage**. The nightly build and regression tests ran on a two processor SMP machine, which exhibited different thread behavior than the development machines, which all had a single processor. The Ptolemy II **system** itself began to be **widely used**, and every use of the system exercised this code. **No problems were observed until the code deadlocked on April 26, 2004, four years later**.”

The Continuing Saga of the Lock-free Queue
Part 3 of N

Tony Van Eerd C++Now May 2018

CHRISTIE